6. CRITICALITY EVALUATION

The purpose of this Chapter is to identify, describe, discuss, and analyze the principal criticality engineering physics design of the packaging and components important to safety for the Model 2000 Transport Package. This Chapter demonstrates compliance with the criticality safety requirements of 10CFR Part 71 [6.17] and the IAEA regulations [6.18] for the safe transport of MTR type fuel, including the Tower Shielding Reactor (TSR) fuel, and TRIGA fuel elements. The Code of Federal Regulations and the IAEA Safety Standards govern the packaging and transport of radioactive material (within the United States and internationally, respectively).

6.1 DISCUSSION AND RESULTS

The Model 2000 cask is a cylindrical steel case with lead shielding. The cask has a cavity that is 26.5 inches (67.31 cm) inside diameter by 54 inches (137.16 cm) long for holding material, including special nuclear material. The type of fuel proposed for transport is the MTR type fuel, which consists of U_3O_8, U_3Si_2, UAl_x, or U Metal, and aluminum plates surrounded by aluminum cladding and the TRIGA type fuel which consists of $UZrH_x$ surrounded by an aluminum, stainless steel or inconel cladding. TSR fuel is a form of MTR type fuel which consists of highly enriched uranium metal mixed with aluminum. Due to its unique composition, the TSR fuel evaluation is presented in Appendix 6.7.3.

6.1.1 Analysis Scenarios

6.1.1.1 Applicable Regulatory Criteria

In order to demonstrate compliance with 10CFR Part 71 and the IAEA criteria, the following scenarios are considered in the criticality analysis:

1. Normal (Undamaged) Array — At least five times the allowable number of packages (5 X N) in an undamaged condition must remain subcritical in any arrangement and with optimum interspersed hydrogenous moderation. In the case of the Model 2000 cask with contents, this corresponds to an array of two (2) internally dry casks (taken to be no greater than 5.0% of full density pure water[1]) containing fresh fuel.

2. Single Container — A single container demonstration of subcriticality under optimum moderation conditions (both internal and external moderation) is required. In the case of the Model 2000 cask with contents, this corresponds to one (1) cask with fresh fuel elements. To achieve optimum moderation, the fuel element regions are mixed with pure water and the cask is surrounded with a reflector of full density water.

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1 5.0% of full density pure water (i.e., H_2O at 0.05 x 1.0 gm/cm^3) is used to model "dry" conditions to account for humidity/condensation that could be present in the fuel. This treatment is conservative; saturated water vapor at 120°F has a density of about 8 x 10-5 gm/cm^3.

3. Accident Array — Twice the allowable number of packages (2 x N) must remain subcritical if the packages are subjected to hypothetical accident conditions and are stacked together in any arrangement, closely reflected on all sides by water, and with optimum interspersed hydrogenous moderation. In the accident condition, no significant reduction in volume (deformation) of the cask is expected. Also, the contents of the cask are expected to remain dry. For N-1, the accident array demonstration is a subset of the normal condition array.

A conservative demonstration of subcriticality for these three scenarios qualifies the Model 2000 cask (with TRIGA and MTR type fuel) as a Fissile Class III package for transport within the United States. The above criteria are consistent with those stated in Sections 71.55 and 71.61 of 10CFR Part 71.

6.1.1.2 Infinite Cask Scenario

In order to achieve a zero transport index (i.e., an infinite number of cask shipments), a slight modification to the previously approved GEMER methodology is being proposed. This modification is described and validated in Appendix 6.7.4. The application of the Infinite Cask Methodology qualifies the cask loading as an infinite ($N=\infty$) Fissile Class III package with a zero Transport Index under the provisions of 10CFR71.61. This loading also meets the IAEA Safety Standards for an infinite shipment ($N=\infty$) with a zero Transport Index for criticality safety.

6.1.2 Container Description

The Model 2000 cask is shown in Figure 6.1. The MTR type of fuel divider structure is shown in Figure 6.2. The support structure is essentially a solid cylindrical "core" of 304 stainless steel with 3.15 by 3.50 inch slots (8.00 by 8.89 cm) for fuel elements. Single or multiple MTR type fuel elements (stacked end-to-end) fit in each slot in the grid. The divider structure is also used to ship TRIGA fuels. The support assembly fits inside the 26.5 inch (67.31 cm) diameter cavity of the Model 2000 cask.

The Model 2000 MTR type fuel divider design incorporates neutron poison material to ensure criticality safety. Borated aluminum sheets are built into the fuel support structure, providing a "neutron curtain" between fuel elements. The Boron content in the divider is conservatively modeled by reducing the boron atom density to 60% of the minimum specification.

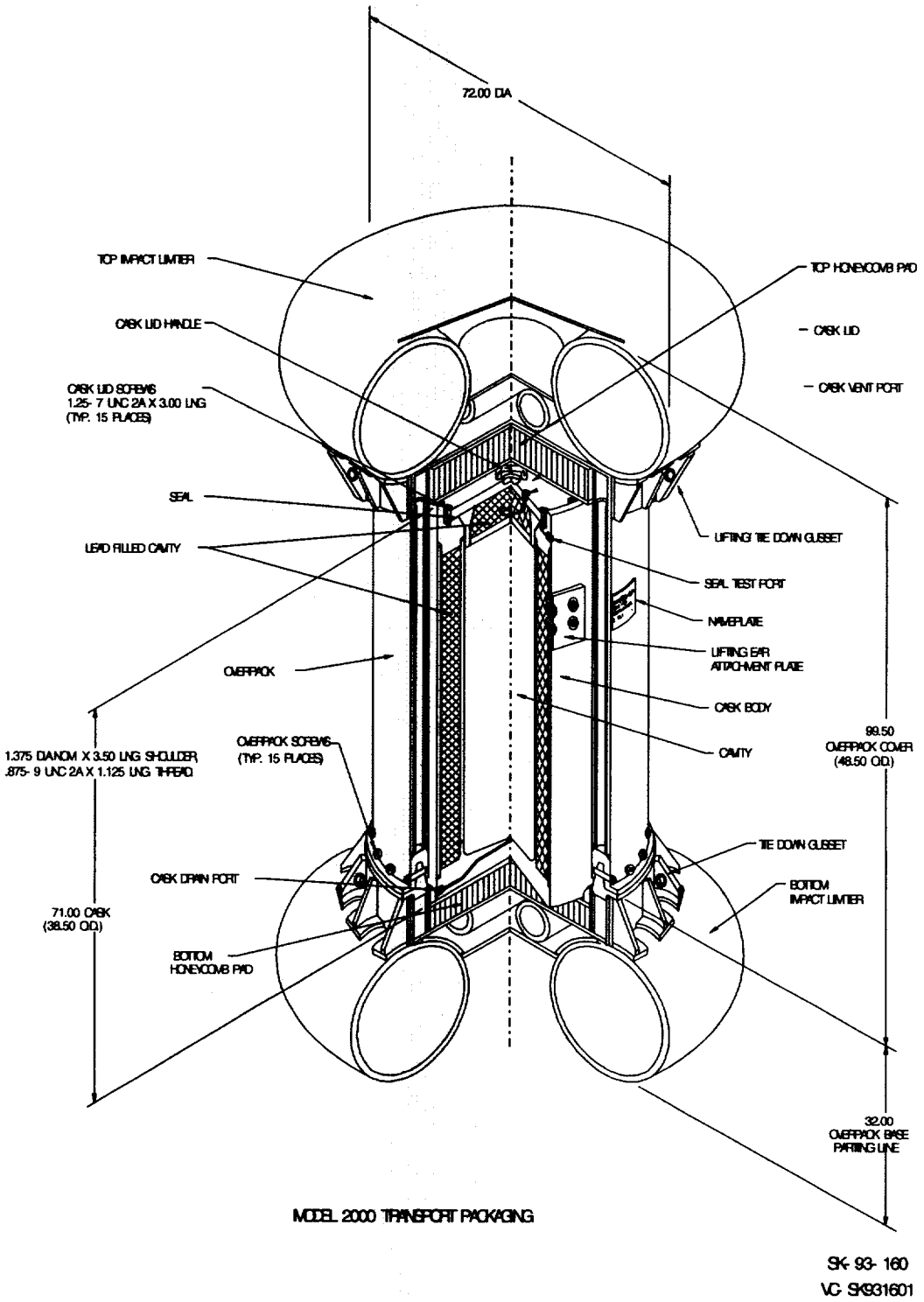


Figure 6.1. Model 2000 Transport Packaging

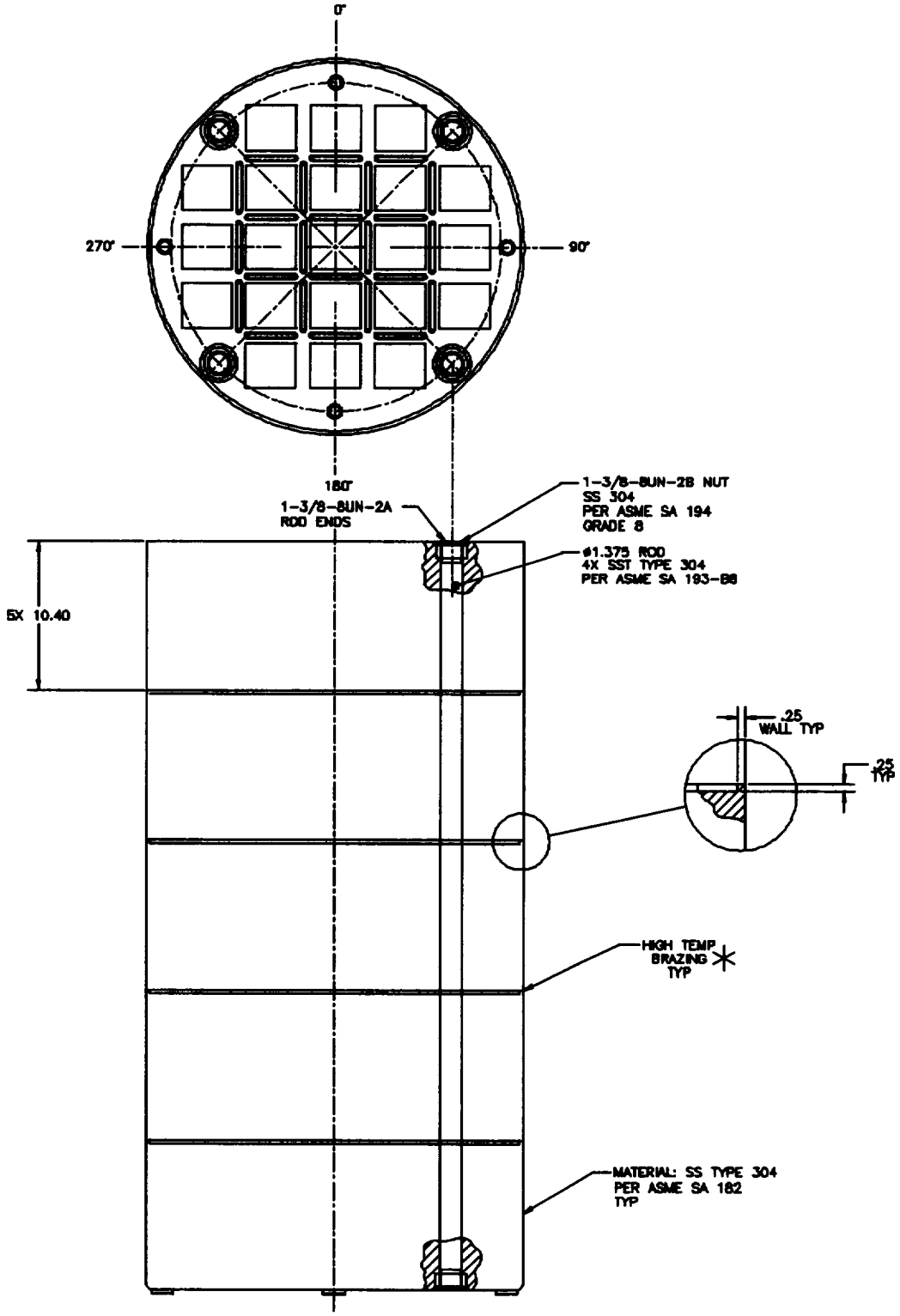


Figure 6.2. MTR Type Fuel Divider for the Model 2000 Shipping Cask

6.1.3 Contents Description

6.1.3.1 MTR Type Fuels

Four generic fuel assembly cases are specifically considered, to bound the analyses for other MTR type fuel designs, where the material and form of the fuel are consistent: Cases I, II, III, and IV cover the U_3O_8, U_3Si_2, UAl_x, and U Metal forms, respectively. Case I is chosen due to having the highest weight fraction of U_3O_8 among the MTR type fuels. Case II is chosen to specifically study the U_3Si_2 type of MTR fuel. Case III is chosen to specifically study the UAl_x type of MTR fuel. Case IV is chosen to specifically study the most limiting type of MTR fuel, where only U Metal is used. **Case IV U Metal fuel is used to envelope any other ^{235}U-based fuels not covered by Cases I, II, and III types of fuels.**

The package under consideration includes MTR type fuel assemblies and a fuel support structure. The Model 2000 overpack is conservatively omitted from consideration.

6.1.3.2 TRIGA Type Fuels

The TRIGA fuel assemblies consist of a solid, cylindrical homogeneous mixture of uranium-zirconium hydride alloy fuel elements within an aluminum, stainless steel, or inconel cladding (Table 6.23). They are transported within the MTR type fuel divider. Multiple TRIGA fuel assemblies may be shipped within each divider.

The TRIGA fuel inventory consists of four basic fuel element types [6.21 through 6.24]. These are aluminum clad elements, stainless steel clad elements, incoloy 800 clad elements and fuel follower control rod elements. All aluminum clad elements and stainless steel clad elements are 1.5-inch-diameter rods by 30 in. long including the end fittings. The Incoloy 800 clad elements are of the same length but with a smaller diameter of 0.54 inches. The fuel follower control rod elements are 1.5 inches in diameter and range from 45.0 inches to 66.5 inches in length.

TRIGA fuels come in several enrichments ranging from 20% to 94%. From a criticality stand point, the highest enrichment case will be the most limiting and the analysis was performed with TRIGA fuel enrichments up to 94%.

TRIGA Case XVII (0) fuel with 70% enrichment envelopes an overwhelming majority of TRIGA type fuels from a criticality standpoint and has been evaluated as the limiting case for all TRIGA fuels of ≤ 70% enrichment. The few TRIGA type fuels with ≥ 70% enrichment have been enveloped by TRIGA Cases V (0) and VIII (0) fuels, both with 94% enrichment, and have been evaluated as the limiting cases for TRIGA fuels of > 70% enrichment.

6.1.3.2.1 TRIGA Case XVII

The Case XVII stainless-steel clad fuel element with 70% ^{235}U enrichment and 8.5 uranium weight percent is the most limiting case for TRIGA type fuels with enrichments ≤ 70%. This fuel element type consisting of 137 grams of U-235 will be analyzed in detail using the Infinite Cask Methodology [Appendix 6.7.4]. This TRIGA fuel type consists of $UZrH_{1.6}$ with a burnable poison of 20 to 36 grams per fuel element. For this analysis, the burnable poison is ignored in all calculations. The fuel element has a 1.435 inch OD with a stainless steel cladding thickness of 0.02 inches and is 15.0 inches in length. The top and bottom graphite reflectors are 3.40 inches in length each, with a density of 1.60 grams/cc. The Case XVII fuel element is shown in Figure 6.3. To facilitate hydriding, a 0.25-in.-diameter hole is drilled through the center of the active fuel section; a zirconium rod (density = 6.5 g/cc) is inserted in this hole after hydriding is complete. Graphite cylinders 3.4 in. long and 1.435 in. in diameter act as top and bottom reflectors (density=1.6 g/cc). The end fittings on both ends of the fuel element are estimated to contain 4.22 cubic in. of stainless steel (density = 7.827 g/cc).

6.1.3.2.2 TRIGA Case V

TRIGA Case V fuel with 94% ^{235}U enrichment and 8.5 uranium weight percent is the limiting case for TRIGA fuels with enrichments > 70% and with end reflectors. This TRIGA fuel type consists of $UZrH_{1.6}$ with no burnable poison [6.22]. The fuel element has a 1.435 inch OD with a cladding thickness of 0.02 inches and 15.0 inches in length. The top and bottom graphite reflectors are 3.40 inches in length each, with a density of 1.60 grams/cc. The TRIGA Case V fuel element is shown in Figure 6.3. The active fuel section contains 174.143 grams of 94% enriched ^{235}U. To facilitate hydriding, a 0.25 in. diameter hole is drilled through the center of the active fuel section; a zirconium rod (density = 6.5 g/cc) is inserted in this hole after hydriding is complete. The end fittings on each end of the fuel element are estimated to contain 4.22 cubic inches of stainless steel.

6.1.3.2.3 TRIGA Case VIII

TRIGA Case VIII fuel with 94% ^{235}U enrichment and 10 uranium weight percent is the limiting case for TRIGA fuels with enrichments > 70% and with no end reflectors. This TRIGA fuel type consists of $UZrH_{1.6}$ with a burnable poison of 2.8 weight percent of natural Erbium [6.21]. For this analysis, the burnable poison is ignored in all calculations. Each fuel element contains approximately 41.16 grams of 94% enriched ^{235}U. The fuel element has a 0.542-inch OD with 25.63 inches clad length, is 30.37 inches long, has 118 grams of inconel end fittings and an internal spring in a 5.00-inch ID x 30.0-inch internal height tube. From Table A.3-2 in Reference [6.21], volume of fuel = 73.64 cm^3 per fuel element. Volume of equivalent cladding is 25 cm^3 per fuel element. The TRIGA Case VIII fuel element has no zirconium rod and is shown in Figure 6.4.

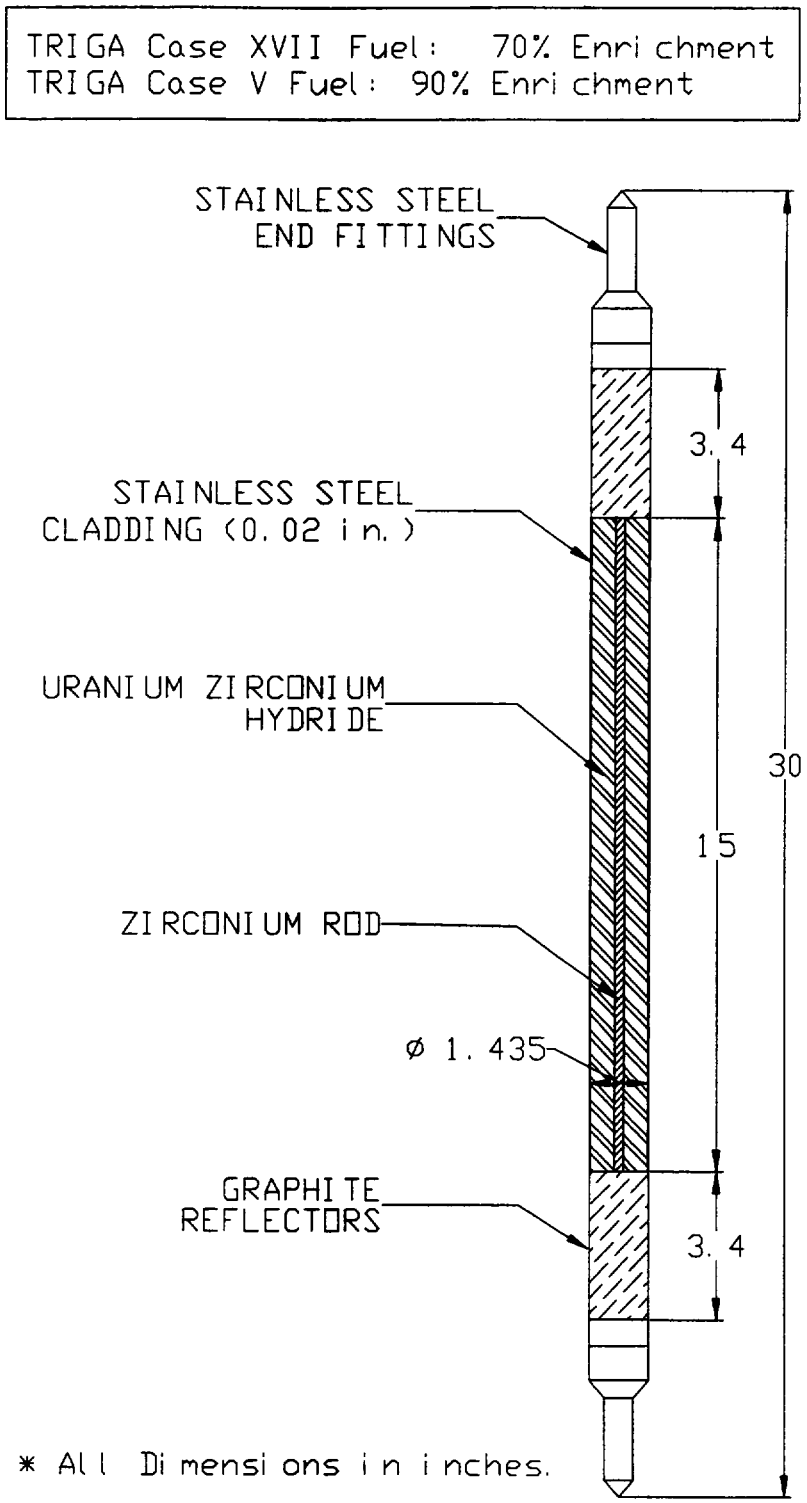


Figure 6.3. Fuel Element Schematic for TRIGA Case XVII and Case V Fuels

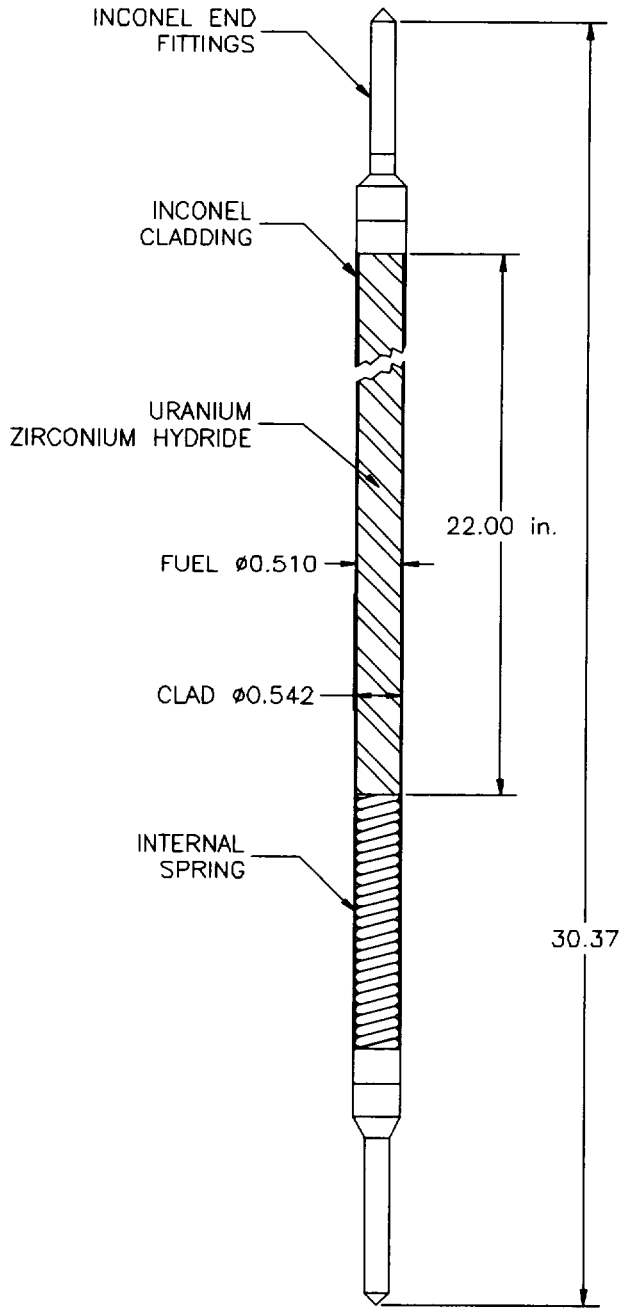


Figure 6.4. TRIGA Case VIII Fuel Element

6.1.4 Calculational Method

The GEMER01V Monte Carlo neutron transport computer program [6.1] is used to demonstrate subcriticality of the Model 2000 cask with contents. GEMER is an enhanced version of the MERIT Monte Carlo code, incorporating the cross-section processing of MERIT and the geometry handling capabilities of KENO-IV [6.2]. Previous analyses of the criticality safety of the Model 2000 cask have been performed using the MERIT computer code and associated ENDF/B library set [6.3]. There are 190 energy groups in the cross-section set. The resolved resonances are treated explicitly in GEMER by keeping track of each neutron's energy and solving the single-level Breit-Wigner equation at each collision in the resonance energy range in regions containing materials whose resolved resonances are explicitly represented. Critical benchmark experiments verify the accuracy of the calculational method chosen for the present analyses and provide the basis for the calculational bias.

6.1.5 Summary of Results

6.1.5.1 MTR Type Fuels

6.1.5.1.1 MTR Cases I and II

Table 6.1 through Table 6.6 summarize the results of the criticality evaluation for MTR Cases I and II. Table 6.1 provides results for the normal conditions of transport (number of undamaged packages > 5 X N) demonstration for Case I fuel.

Table 6.2 and Table 6.3 provide results for the single container and accident array (2 X N) cases, respectively, for Case I fuel. Table 6.4 provides results for the normal conditions of transport (number of undamaged packages > 5 X N) demonstration for Case II fuel. Table 6.5 and Table 6.6 provide results for the single container and accident array (2 X N) cases, respectively, for Case II fuel. The maximum k_{eff} values from the analyses are provided in the last row of each table. The effective multiplication factors (after adjusting for uncertainty and calculational bias) are less than 0.95 for all cases. The bias is a lower 3σ limit determined from critical experiment data relevant to these cases (i.e., Uranium-235 enrichment > 90%). Note that no credit is taken for a positive bias.

Hydrogenous moderation is separately considered in three regions:

a) moderation within the fuel,

b) interspersed moderation within the cask(s), but not within the fuel, and

c) interspersed moderation outside the cask(s).

Moderation outside the casks means between casks, up to the reflector boundary. In the single container case, the region outside the cask consists of a water reflector (there is no outer interspersed region). In the array cases, there are outer regions of interspersed water (e.g., between casks, bounded by planes tangent to the outer cylinders). The reflector is a one foot thick box of water containing the casks.

Structural analysis of the package and fuel basket (Chapter 2) shows that the geometry of the cask and contents remains unchanged throughout the hypothetical accident. No reduction in the effective package volume is assumed for the evaluation of criticality safety. Since the fuel and support structure remain unchanged throughout the hypothetical accident, the geometry parameters for normal conditions of transport, hypothetical accident conditions, and the single container are identical. Only the number of packages under consideration and the degree of moderation are different between cases.

In each case, no credit for fuel burnup is taken in this analysis. The fuel elements are conservatively treated as fresh fuel assemblies with no burnable poisons (e.g., gadolinium, which is used for reactivity suppression in light water reactors). The fuel is analyzed in its most reactive state, since there are no fission products to serve as neutron poisons. No constraint on fuel burnup is necessary to ensure criticality safety.

Table 6.1. Summary of Results — Normal Conditions of Transport for Case I, U_3O_8, Type of Fuel (93.2% Enriched)

Condition/Parameter	Quantity/Comment
Number of Containers in Demonstration	7 (Close packed Triangular Array)
Hydrogenous Moderation (In Fuel)	0.05 Weight Fraction H_2O (Dry)
Optimum Hydrogenous Moderation (Interspersed Moderation)	0.02 Weight Fraction H_2O (Between Casks) 0.0 Weight Fraction H_2O (Inside Casks)
Reflector	30.5 cm (1 ft) Full Density H_2O
Maximum Multiplication Factor $k_{eff} + 2\sigma$ + Bias	0.47154

Table 6.2. Summary of Results — Normal Conditions of Transport for Case II, U_3Si_2, Type of Fuel (20.0% Enriched)

Condition/Parameter	Quantity/Comment
Number of Containers in Demonstration	7 (Close packed Triangular Array)
Hydrogenous Moderation (In Fuel)	0.05 Weight Fraction H_2O (Dry)
Optimum Hydrogenous Moderation (Interspersed Moderation)	0.05 Weight Fraction H_2O (Between Casks) 0.0 Weight Fraction H_2O (Inside Casks)
Reflector	30.5 cm (1 ft) Full Density H_2O
Maximum Multiplication Factor $k_{eff} + 2\sigma$ + Bias	0.48110

Table 6.3. Summary of Results — Single Container for Case I, U_3O_8, Type of Fuel (93.2% Enriched)

Condition/Parameter	Quantity/Comment
Number of Containers in Demonstration	1
Optimum Hydrogenous Moderation (In Fuel)	0.40 Weight Fraction H_2O
Optimum Hydrogenous Moderation (Interspersed Moderation)	1.00 Weight Fraction H_2O
Reflector	30.5 cm (1 ft) Full Density H_2O
Maximum Multiplication Factor $k_{eff} + 2\sigma$ + Bias	0.91682

Table 6.4. Summary of Results — Single Container for Case II, U_3Si_2, Type of Fuel (20.0% Enriched)

Condition/Parameter	Quantity/Comment
Number of Containers in Demonstration	Condition/Parameter
Optimum Hydrogenous Moderation (In Fuel)	0.35 Weight Fraction H_2O
Optimum Hydrogenous Moderation (Interspersed Moderation)	1.00 Weight Fraction H_2O
Reflector	30.5 cm (1 ft) Full Density H_2O
Maximum Multiplication Factor $k_{eff} + 2\sigma$ + Bias	0.82333

Table 6.5. Summary of Results — Accident Condition (Conservatively Treated as Flooded) for Case I, U_3O_8, Type of Fuel (93.2% Enriched)

Condition/Parameter	Quantity/Comment
Number of Containers in Demonstration	2 (Side-By-Side)
Optimum Hydrogenous Moderation (In Fuel)	0.45 Weight Fraction H_2O
Optimum Hydrogenous Moderation (Interspersed Moderation)	0 .02 Weight Fraction H_2O (Between Casks) 0.02 Weight Fraction H_2O (Inside Casks)
Reflector	30.5 cm (1 ft) Full Density H_2O
Maximum Multiplication Factor $k_{eff} + 2\sigma$ + Bias	0.93559

Table 6.6. Summary of Results — Accident Condition (Conservatively Treated as Flooded) for Case II, U_3Si_2, Type of Fuel (20.0% Enriched)

Condition/Parameter	Quantity/Comment
Number of Containers in Demonstration	2 (Side-By-Side)
Optimum Hydrogenous Moderation (In Fuel)	0.40 Weight Fraction H_2O
Optimum Hydrogenous Moderation (Interspersed Moderation)	0.00 Weight Fraction H_2O (Between Casks) 0.00 Weight Fraction H_2O (Inside Casks)
Reflector	30.5 cm (1 ft) Full Density H_2O
Maximum Multiplication Factor $k_{eff} + 2\sigma$ + Bias	0.82671

Table 6.7. Summary of Results — Infinite Cask Scenario for MTR Case I, U_3O_8, Type of Fuel (94.0% Enriched)

Condition/Parameter	Quantity/Comment
Number of Containers in Demonstration	Infinite Array
Optimum Hydrogenous Moderation (In Fuel)	0.440 Weight Fraction H_2O
Maximum Multiplication Factor $k_{eff} + 2\sigma$ + Bias	0.94519

Table 6.8. Summary of Results — Infinite Cask Scenario for MTR Case II, U_3Si_2, Type of Fuel (20.0% Enriched)

Condition/Parameter	Quantity/Comment
Number of Containers in Demonstration	Infinite Array
Optimum Hydrogenous Moderation (In Fuel)	0.350 Weight Fraction H_2O
Maximum Multiplication Factor $k_{eff} + 2\sigma$ + Bias	0.84670

6.1.5.1.2 MTR Cases III and IV

Table 6.9 and Table 6.10 summarize the results of the Infinite Cask scenario for MTR Case III and IV types of fuel.

Table 6.9. Summary of Results — Infinite Cask Scenario for MTR Case III, UAl_x, Type of Fuel (94% Enriched)

Condition/Parameter	Quantity/Comment
Number of Containers in Demonstration	Infinite Array
Optimum Hydrogenous Moderation (In Fuel)	0.225 Weight Fraction H_2O
Maximum Multiplication Factor $k_{eff} + 2\sigma$ + Bias	0.76935

Table 6.10. Summary of Results — Infinite Cask Scenario for MTR Case IV, U Metal Type of Fuel (95% Enriched)

Condition/Parameter	Quantity/Comment
Number of Containers in Demonstration	Infinite Array
Optimum Hydrogenous Moderation (In Fuel)	0.875 Weight Fraction H_2O
Maximum Multiplication Factor $k_{eff} + 2\sigma$ + Bias	0.92003

6.1.5.2 TRIGA-Type Fuels

The key assumptions used in the criticality analysis of TRIGA-type fuels are as follows:

1. The borated aluminum plates used for reactivity control are conservatively modeled. Only 60% of the boron atoms are accounted for in the calculations.
2. The borated aluminum plates, typically 3.25 inches (8.26 cm) by 0.25 inch (0.635 cm), are conservatively treated as 3.25 inches (8.26 cm) by 0.225 inch (0.572 cm).
3. The poison in the TRIGA fuels (Erbium) will be ignored in this analysis. This is a conservative assumption.
4. All TRIGA fuels are analyzed in fresh fuel condition. This is a conservative assumption.

Tables 6.11, 6.12, and 6.13 summarize the results of the Infinite Cask scenario for TRIGA Cases XVII, V, and VIII, respectively.

Table 6.11. Summary of Results — Infinite Cask Scenario for TRIGA Case XVII Type of Fuel (70.0% Enriched)

Condition/Parameter	Quantity/Comment
Number of Containers in Demonstration	Infinite Array
Optimum Hydrogenous Moderation (In Fuel)	0.0875 Weight Fraction H_2O
Maximum Multiplication Factor $k_{eff} + 2\sigma$ + Bias	0.89138

Table 6.12. Summary of Results — Infinite Cask Scenario for TRIGA Case V Type of Fuel (94% Enriched)

Condition/Parameter	Quantity/Comment
Number of Containers in Demonstration	Infinite Array
Optimum Hydrogenous Moderation (In Fuel)	0.125 Weight Fraction H_2O
Maximum Multiplication Factor $k_{eff} + 2\sigma$ + Bias	0.92414

Table 6.13. Summary of Results — Infinite Cask Scenario for TRIGA Case VIII Type of Fuel (94% Enriched)

Condition/Parameter	Quantity/Comment
Number of Containers in Demonstration	Infinite Array
Optimum Hydrogenous Moderation (In Fuel)	0.200 Weight Fraction H_2O
Maximum Multiplication Factor $k_{eff} + 2\sigma$ + Bias	0.92156

6.2 PACKAGE FUEL LOADING

6.2.1 MTR

Table 6.14 and Table 6.15 described herein qualifies as a single (N=1) Fissile Class III package under the provisions of 10CFR71.61. This loading also meets the IAEA Safety Standards for a single shipment (N=1) with a Transport Index of 50 for criticality safety.

Tables 6.16 through 6.19 summarize the maximum fuel load (mass), as well as some significant constraints for MTR fuel cases I, II, III, and IV, respectively, as a result of the infinite cask analysis.

As the Infinite Cask Methodology is applied to the GEMER analyses, the loading specified in Tables 6.16 through 6.19, described herein, qualify as an infinite (N=∞) Fissile Class III package with a zero Transport Index under the provisions of 10CFR71.61. This loading also meets the IAEA Safety Standards for an infinite shipment (N=∞) with a zero Transport Index for criticality safety. The loadings specified in Tables 6.16 through 6.19 envelope those specified in Tables 6.14 and 6.15.

Table 6.14. Model 2000 ^{235}U Mass Limit for a Single (N=1) Shipment for Case I (U_3O_8) Type of Fuel (93.2% Enriched)

Number of Allowable Basket Positions	^{235}U Mass Per Position (gm)	Total ^{235}U Mass (gm)
21	710	14,910

Table 6.15. Model 2000 235U Mass Limit for a Single (N=1) Shipment for Case II (U3Si2) Type of Fuel (93.2% Enriched)

Number of Allowable Basket Positions	^{235}U Mass Per Position (gm)	Total ^{235}U Mass (gm)
21	694	14,570

Table 6.16. Model 2000 ^{235}U Mass Limit for an Infinite (N=∞) Shipment for MTR Case I (U_3O_8) Type of Fuel (94% Enriched)

Number of Allowable Basket Positions	^{235}U Mass Per Position (gm)	Total ^{235}U Mass (gm)
21	710	14,910

Table 6.17. Model 2000 ^{235}U Mass Limit for an Infinite (N=∞) Shipment for MTR Case II (U_3Si_2) Type of Fuel (20% Enriched)

Number of Allowable Basket Positions	^{235}U Mass Per Position (gm)	Total ^{235}U Mass (gm)
21	694	14,570

Table 6.18. Model 2000 ^{235}U Mass Limit for an Infinite (N=∞) Shipment for MTR Case III (UAl_x) Type of Fuel (94% Enriched)

Number of Allowable Basket Positions	^{235}U Mass Per Position (gm)	Total ^{235}U Mass (gm)
21	1112	23,352

Table 6.19. Model 2000 ^{235}U Mass Limit for an Infinite (N=∞) Shipment for MTR Case IV (U Metal) Type of Fuel (95% Enriched)

Number of Allowable Basket Positions	^{235}U Mass Per Position (gm)	Total ^{235}U Mass (gm)
21	220	4,620

The criticality analysis for Case I through IV fuels considers a homogeneous fuel-water mixture that occupies the entire fuel divider slot in the x-y plane. Fuel plates are not discretely modeled. Therefore, this analysis does not impose geometry constraints on the form of the fuel. This analysis can be applied to other fuels of similar material and construction so that the treatment of the fuel number densities is applicable. For example, homogenizing a BSR fuel element should yield nearly the same ^{235}U, ^{238}U and Al number densities as the NBSR element, though the total fissile mass will be less.

Figure 6.5 and Table 6.20 provide dimensions and nuclear data for several MTR type fuels to which this analysis applies. These MTR types of fuel assemblies include those of NBSR, BSR, HFBR, ORR, TSR, SAPHIR and OWR. Fuel assemblies for these reactors are similarly constructed aluminum clad plates with U_3O_8, U_3Si_2, or UAl_x fuel material.

MTR Case III fuel consists of a UAl_x fuel mixture. The criticality analysis for Case III fuel considers a homogeneous fuel-water mixture that occupies the entire fuel divider in the x-y plane. Fuel plates are not discretely modeled; therefore, this analysis does not impose geometry constraints on the form of the fuel. MTR Case IV fuel consists of 94% enriched metallic U-235 mixed with water. The uranium metal density is assumed to be 19.1 g/cc. MTR Case Type IV is used to envelope any other U-235-based fuels not covered by Case I, II, and III types of fuels.

Table 6.21 provides the packaging parameters for the Model 2000 cask with U_3O_8 MTR type of fuel while Table 6.22 provides the packaging parameters for the U_3Si_2 MTR type of fuel.

Of all UAl_x fuels, the BSR reactor is the most limiting. Table 6.23 summarizes the limiting Case III (UAl_x) fuel data. Similarly,

Table 6.24 summarizes the limiting Case IV (U Metal) fuel data.

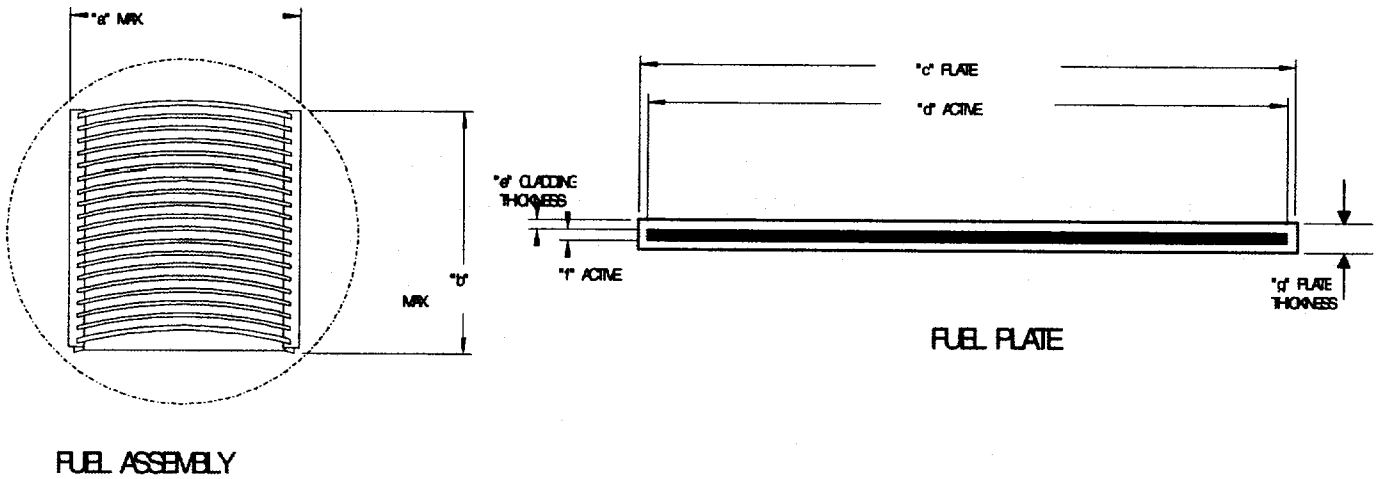


Figure 6.5. MTR Type Fuel Dimensions

Table 6.20. MTR Type of Fuel Data

FUEL TYPE		GEOMETRY											NUCLEAR DATA					
		TRIMMED LENGTH (IN)	FUEL DIMENSION (IN) [See Figure 6.5]										MAX. TOTAL g	MAX. U-235 g	MAX. No. of Fuel	NOMINAL ENRICHMENT	BURNUP	BURNUP
REACTOR	CLASS		a	b	c	d	e	f	g	Lf	La	Le	U-235	per Plate	Plate/Elem	(%)	(MWd)	(%)
BSR	MTR	n/a	2.996	3.313	2.799	2.5	0.015	0.02	0.051	27.125	23.530	37.125	223	11.7	19	93.0	88	40
HFBR	MTR	24.625	2.878	3.218	2.611	2.236	0.014	0.023	0.050	23.750	22.856	57.250	355	19.5+3g	18	93.0		44-48
ORR	MTR	n/a	3.034	3.188	2.800	2.500	0.015	0.020	0.050	24.625	23.625	38.375	344	18.000	19	20.0	20-172	6-50
OWR	MTR	n/a	3.017	3.303	2.796	2.456	0.015	0.020	0.050	24.625	23.538	42.625	235	12.210	19	93.0		50
TSR	MTR												8687				83.300	
NBSR	MTR	13.313	3.000	3.368	2.625	2.415	0.015	0.02	0.050	13.313	11	68.797	350	10.294	17*2	93.0	170-200	65-73
SAPHIR	MTR		2.996	2.968		2.469				24.61	23.61	34.39	280.8+2%		23	90.0	155	71/57
													280.8+2%			93.0	155	71/64
													280.8+2%			45.0	180	70/64

Lf = Length of Fuel Plate

La = Active Fuel Length

Le = Length of Element

Table 6.21. Package Parameters for the Model 2000 Cask with MTR Type Fuel for Case I, U_3O_8, Type of Fuel (94% Enriched)

Parameter	Quantity/Comment
Fuel Construction	MTR Type Fuel Plates
Fuel Material	U_3O_8 (41.6%) + Al (58.4%)
Cladding Material	Al
Maximum Fuel Enrichment	94.0%
Minimum Fuel Burnup	N/A
Burnable Poison Materials (e.g., Gd)	None
Maximum U_3O_8 Density (100% T.D.)	8.39 gm/cm^3
Nominal Al Density	2.699 gm/cm^3

Table 6.22. Package Parameters for the Model 2000 Cask with MTR Type Fuel for Case II, U_3Si_2, Type of Fuel (20% Enriched)

Parameter	Quantity/Comment
Fuel Construction	MTR Type Fuel Plates
Fuel Material	U_3Si_2 (80%) + Al (20%)
Cladding Material	Al
Maximum Fuel Enrichment	20%
Minimum Fuel Burnup	N/A
Burnable Poison Materials (e.g., Gd)	None
Maximum U_3Si_2 Density (100% T.D.)	12.02 gm/cm^3
Nominal Al Density	2.699 gm/cm^3

Table 6.23. Package Parameters for the Model 2000 Cask with MTR Case III Fuel (UAl_x) (94% Enriched)

Parameters	Quantity/Comment
Fuel type	UAl/Al
Fuel/Aluminum ratio	22.5/77.5
^{235}U mass per plate	11.71 grams
Number of plates/fuel element	19
Number of fuel elements per divider position	5
Total ^{235}U mass per divider position	1112.45 grams
^{235}U enrichment	94.0%
^{238}U mass per divider position	71.0 grams
Al mass (fuel + mixture) per divider position	14279.8 grams
UAl_X density	6 g/cc
Al density	2.7 g/cc

Table 6.24. Package Parameters for the Model 2000 Cask with MTR Case IV Fuel (U Metal) (95% Enriched)

Parameters	Quantity/Comment
Fuel type	U Metal
^{235}U mass per divider position	220 grams
^{235}U enrichment	94.0%
^{238}U mass per divider position	11.58 grams
U density	19.1 g/cc

6.2.2 TRIGA

Table 6.26 provides dimensions and nuclear data for several TRIGA type fuels to which this analysis applies.

6.2.2.1 TRIGA Case XVII

The GEMER model for the TRIGA Case XVII fuel consists of 10 fuel elements loaded into each MTR divider position. A total of 1370.0 grams of 70% enriched U-235 per divider position in the MTR type fuel divider is modeled in this criticality analysis. This represents 10 TRIGA fuel elements per divider position. The corresponding masses of U-238, and cladding material can be estimated. The detailed calculations of these number densities are shown in Subsection 6.7.2.1.2.

Table 6.25 summarizes the maximum fuel load (mass), as well as some significant constraints for the TRIGA Case XVII type fuel. As the Infinite Cask Methodology is applied to the GEMER analyses, the loading specified in Table 6.25 described herein qualifies as an infinite (N=∞) Fissile Class III package with a zero Transport Index under the provisions of 10CFR 71.61. This loading also meets the IAEA Safety Standards for an infinite (N=∞) shipment with a zero Transport Index for criticality safety.

Table 6.26 provides the packaging parameters for the Model 2000 cask with TRIGA Case XVII type fuel.

Table 6.25. Model 2000 ^{235}U Mass Limit for an Infinite (N=∞) Shipment for TRIGA Case XVII Type of Fuel (70% Enriched)

Number of Allowable Basket Positions	^{235}U Mass Per Position (gm)	Total ^{235}U Mass (gm)
21	1370.0	28,770

Table 6.26. TRIGA Type Fuel Data

TRIGA Case	Fuel Element	Cladding	Zirconium Rod	U-238 Mass (g)	U-235 Mass (g)	Uranium Weight %	Enrichment (%)	Zirconium Mass (g)	Element Length (in)	Fuel Length (in)	Fuel OD (in)	Cladding Thickness (in)	H/Zr in the Fuel
I		SS	Yes		<137	8.5	20		28.5	15	1.435	0.020	1.6
II		SS	Yes		<137	8.5	20		28.5	15	1.371	0.020	1.6
III		SS	Yes		<137	8.5	70		28.5	15	1.435	0.020	1.6
IV		SS	Yes		<137	8.5	70		28.5	15	1.371	0.020	1.6
V		**SS**	**Yes**	**13.08**	**174.1**	**8.5**	**94**	**1981**	**28.5**	**15**	**1.435**	**0.020**	**1.6**
VI		Al	No		< 174.1	8.5	93		30.0	15	1.415	0.030	1.6
VII		SS	Yes		<137	12.0	20		28.5	15	1.435	0.020	1.6
VIII		**Incoloy**	**No**	**3.10**	**41.16**	**10.0**	**94**	**391**	**30.0**	**22**	**0.510**	**0.016**	**1.6**
IX		SS	Yes		<137	20.0	20		28.5	15	1.435	0.020	1.6
X		SS	Yes		<137	30.0	20		28.5	15	1.435	0.020	1.6
XI		Incoloy	No		<137	30.0	20		30.0	22	0.510	0.016	1.6
XII		Incoloy	No		<137	45.0	20		30.0	22	0.510	0.016	1.6
XIII	14"	Al	No	144	36	8.0	20	2070					1.0
XIV	15"		No	144	36	8.0	20	2070					1.0
XV	Std. (prior 11/64)	SS	Yes	156	39	8.0	20	2088					1.0
XVI	Std. (after 11/64)		Yes	156	39	8.5	20	2088					1.7
XVII	**FLIP**	**SS**	**Yes**	**59**	**137**	**8.5**	**70**	**2070**	**28.5**	**15**	**1.435**	**0.02**	**1.6**
XVIII	FLIP-LEU-I		Yes	403	101	20.0	20	1988					1.6
XIX	FLIP-LEU-II		Yes	659	165	30.0	20	1886					1.6
XX	ACPR		Yes	215	54	12.0	20	1962					1.7
XXI		Incoloy 800	No	219	55	45.0	20	327					1.6
XXII	Fuel Follower Control Rod		Yes	150	38	8.5	20	2004					1.6
XXIII	FLIP-LEU-I		Yes	387	97	8.5	20	1908					1.6

FLIP = Fuel Life Improvement Program

LEU = Low Enriched Uranium

ACPR = Annular Core Pulsed Reactor

Table 6.27. Package Parameters for the Model 2000 Cask with TRIGA Case XVII Type of Fuel (70% Enriched)

Parameter	Quantity/Comment
Fuel Construction	Cylinders
Fuel Material	$UZrH_{1.6}$ (8.5 wt% U)
Cladding Material	Stainless Steel
Maximum Fuel Enrichment	70%
Minimum Fuel Burnup	N/A
Burnable Poison Materials	20 to 36 grams per fuel element
Nominal Stainless Steel Density	7.827 g/cc

6.2.2.2 TRIGA Case V

The GEMER model for the TRIGA fuel consists of 1219.0 grams of 94% enriched U-235 per divider position in the MTR type fuel divider. This represents 7 TRIGA fuel elements loaded into each divider position. Based on the U-235 mass (174.143 grams per fuel element) provided in Table A.1-2 of Reference [6.2], the corresponding masses of U-238, and cladding material can be estimated. The detailed calculations of these number densities are shown in Subsection 6.7.2.2.2.

Table 6.28 summarizes the maximum fuel load (mass), as well as some significant constraints for the TRIGA Case V type fuel. As the Infinite Cask Methodology is applied to the GEMER analyses, the loading specified in Table 6.28 described herein qualifies as an infinite (N=∞) Fissile Class III package with a zero Transport Index under the provisions of 10CFR 71.61. This loading also meets the IAEA Safety Standards for an infinite (N=∞) shipment with a zero Transport Index for criticality safety.

Table 6.29 provides the packaging parameters for the Model 2000 cask with TRIGA Case V type fuel.

Table 6.28. Model 2000 ^{235}U Mass Limit for an Infinite (N=∞) Shipment for TRIGA Case V Type of Fuel (94% Enriched)

Number of Allowable Basket Positions	^{235}U Mass Per Position (gm)	Total ^{235}U Mass (gm)
21	1219.0	25,600

Table 6.29. Package Parameters for the Model 2000 Cask with TRIGA Case V Type of Fuel (94% Enriched)

Parameter	Quantity/Comment
Fuel Construction	Cylinders
Fuel Material	$UZrH_{1.6}$ (8.5 wt% U)
Cladding Material	Stainless Steel
Maximum Fuel Enrichment	94%
Minimum Fuel Burnup	N/A
Burnable Poison Materials	None
Nominal Stainless Steel Density	7.827 g/cc

6.2.2.3 TRIGA Case VIII

The GEMER model for the TRIGA fuel consists of 493.9 grams of 94% enriched U-235 per divider position in the MTR type fuel divider. This represents 12 fuel elements per divider position. Based on the ^{235}U mass (41.16 grams per fuel element) provided in Table A.1-2 of Reference [6.21], the corresponding masses of ^{238}U and cladding material can be estimated. The detailed calculations of these number densities are shown in Subsection 6.7.2.3.2.

Table 6.30 summarizes the maximum fuel load (mass), as well as some significant constraints for the TRIGA Case VIII type fuel. As the Infinite Cask Methodology is applied to the GEMER analyses, the loading specified in Table 6.30 described herein qualifies as an infinite (N=∞) Fissile Class III package with a zero Transport Index under the provisions of 10CFR 71.61. This loading also meets the IAEA Safety Standards for an infinite (N=∞) shipment with a zero Transport Index for criticality safety. Table 6.31 provides the packaging parameters for the Model 2000 cask with TRIGA Case VIII type fuel.

Table 6.30. Model 2000 ^{235}U Mass Limit for an Infinite (N=∞) Shipment for TRIGA Case VIII Type of Fuel (94% Enriched)

Number of Allowable Basket Positions	^{235}U Mass Per Position (gm)	Total ^{235}U Mass (gm)
21	493.9	10,370

Table 6.31. Package Parameters for the Model 2000 Cask with TRIGA Case VIII Type of Fuel (94% Enriched)

Parameter	Quantity/Comment
Fuel Construction	Cylinders
Fuel Material	$UZrH_{1.6}$ (10 wt% U)
Cladding Material	Inconel
Maximum Fuel Enrichment	94%
Minimum Fuel Burnup	N/A
Burnable Poison Materials	2.8 wt% Natural Erbium (Not Modelled)
Nominal Inconel Density	8.01 g/cc

6.3 MODEL SPECIFICATION

6.3.1 Description of Calculational Models

6.3.1.1 MTR

Similar models are used to evaluate the normal condition, single container, and accident array. The models are identical except in their representation of the number of casks and the interspersed moderation. The single container model assumes that there is one (1) cask fully loaded with well-moderated fuel assemblies. The normal condition model assumes that there are seven (7) casks; each cask is fully loaded with dry fuel assemblies and in contact with each other in a triangular array. The accident array assumes there are two casks with well-moderated fuel assemblies, side-by-side and touching. *All models assume fresh, un-depleted fuel in the active fuel region, neglecting any as-built poisons or fission products.* All models omit the overpack from consideration, which brings the water reflector closer to the fissile material and adds an extra degree of conservatism to the analysis.

The model for normal condition consists of seven (7) fully loaded casks, touching in a hexagonal configuration (triangular array). This places the units of fissile material inside each cask nearest the other for the most reactive configuration. Also, in the calculational model the fuel atoms are dispersed over the full volume of each fuel slot/position to maximize the projected target area for neutrons. The hydrogen-to-fissile ratio inside each cask is varied to find the peak k-effective value for the normal condition model. The inside of each cask is dry in the undamaged condition, which is conservatively modeled as having 5 wt% (a specific gravity of 0.05) interspersed water in the fuel region and inside the remainder of container. The array is surrounded by a 12 inch (30.5 cm) thick parallelogram of full density water (reflection on all sides). The cask with fuel is highly under moderated in the normal condition of transport, as will be seen from the results.

The model for the single container case is one (1) cask that is filled with partial density water to achieve optimum moderation. Even though it has been shown that the cask remains water tight under hypothetical accident conditions, Section 71.55 of 10CFR71 and Section V of the IAEA Safety Standards require that a single cask be shown safe under optimum moderation conditions. For a Fissile Class III shipment of one Model 2000 cask, the single container case bounds the hypothetical accident condition array (of one unit). The accident array (according to the 10CFR criteria) would be dry and severely under moderated. In the single container case, the hydrogen-to-fissile ratio within the fissile fuel and the interspersed moderation inside the cask are varied to find the peak k-effective. The outside of the cask is surrounded by a 12 inch (30.5 cm) thick water reflector.

The model for the accident array case is two side-by-side casks, flooded with partial density water to achieve optimum moderation. The cask is treated as flooded even though it has been shown that the Model 2000 remains water tight under hypothetical accident conditions. Neutron multiplication is relatively insensitive to the number of casks in the array; the casks are nearly neutronically de-coupled. The k-effective values for the single container demonstration and the flooded two-cask array are very close. Similar to the single container case, the hydrogen-to-fissile ratio within the fissile fuel and the interspersed moderation are varied to find the peak k-effective. The outside of the cask is surrounded by a 12 inch (30.5 cm) thick water reflector.

All models utilize the same basic interior geometry. The fuel elements inside the cask are constrained by the fuel support structure. The divider does not allow lateral movement of the fuel elements. The separation between the active fuel regions is always maintained by the configuration of the support structure.

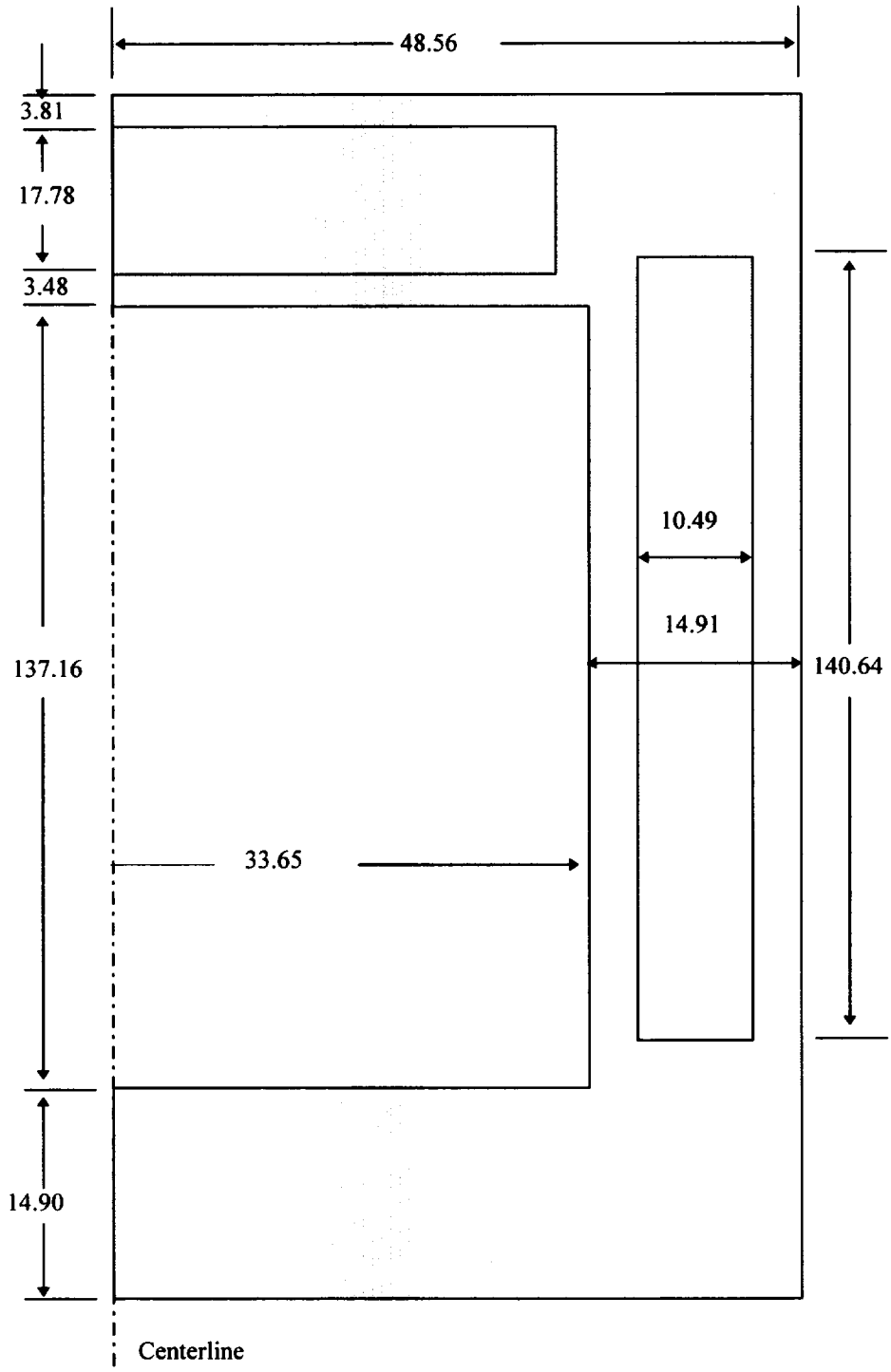
Figure 6.6 provides the side view of the Model 2000 Cask Model. Figure 6.7 provides the top view of the fuel support structure. Figure 6.6 and Figure 6.7 also show the cask geometry and pertinent dimensions used for modeling the cask loaded with fuel. The fuel is homogenized by distributing the maximum mass of ^{235}U throughout the entire active fuel region (individual fuel plates within each assembly are not explicitly modeled). This modeling approach has been shown to be conservative relative to benchmark experiments [6.4].

The borated aluminum plates used for reactivity control are conservatively modeled. Only 60% of the boron atoms are accounted for in the calculations. The plate dimensions are 3.25 inches (8.26 cm) by 0.25 inches (0.635 cm); however, the analysis conservatively treated them as 3.25 inches (8.26 cm) by 0.225 inches (0.572 cm)[2]. This corresponds to a 10% allowance for manufacturing tolerance. Borated aluminum is an alloy composed of B and Al that retains most of the physical attributes of the original aluminum alloy. It

[2] The B-10 atom density is the parameter important to criticality safety. The Borated aluminum thickness and density can be adjusted by the manufacturer to retain the proper B-10 content. The thickness of the Borated plates can be varied as long as the boron content specified in Subsection 6.3.2 is met or exceeded.

consists of AlB_2 salt alloyed with aluminum. The borated aluminum plates must have minimum Boron-10 content of 3.452 weight percent. To meet this requirement, the boron in the salt must have a 95 to 98% Boron-10 enrichment with a corresponding boron weight percent of 3.63 to 3.5%.

The Model 2000 cask is modeled in three dimensions. Only the fuel and the cask (without the overpack) are modeled. The cask is cylindrical with an interior cavity. This cavity is 26.5 inches (67.31 cm) in diameter and 54 inches (137.16 cm) in height. The cask outside diameter is 38.5 inches (97.79 cm). The total cask radial wall and bottom plate thicknesses are 6.0 inches (15.24 cm). The Model 2000 cask consists of a layered radial wall design composed of 1.0 inch (2.54 cm) of 304 stainless steel, 4.0 inches (10.16 cm) of lead, and then another 1.0 inch of 304 stainless steel. The cask bottom consists of 6 inches (15.24 cm) of 304 stainless steel. The top of the cask was modeled as having a 1.5 inch (3.81 cm) thick 304 stainless steel plate inside the cask at the top, then 4.5 inches (11.43 cm) of lead, and then a 1.75 inch (4.45 cm) thick 304 stainless steel plate on the top of the cask. For conservatism, the model reduces the wall thickness of stainless steel portions of the cask in areas where neutron absorption in the stainless steel reduces the neutron multiplication (i.e., cask walls and cask top).



All Dimensions in cm (Not to Scale)

Figure 6.6. Side View of Model 2000 Cask Schematic (Contents and Support Structure Not Shown)

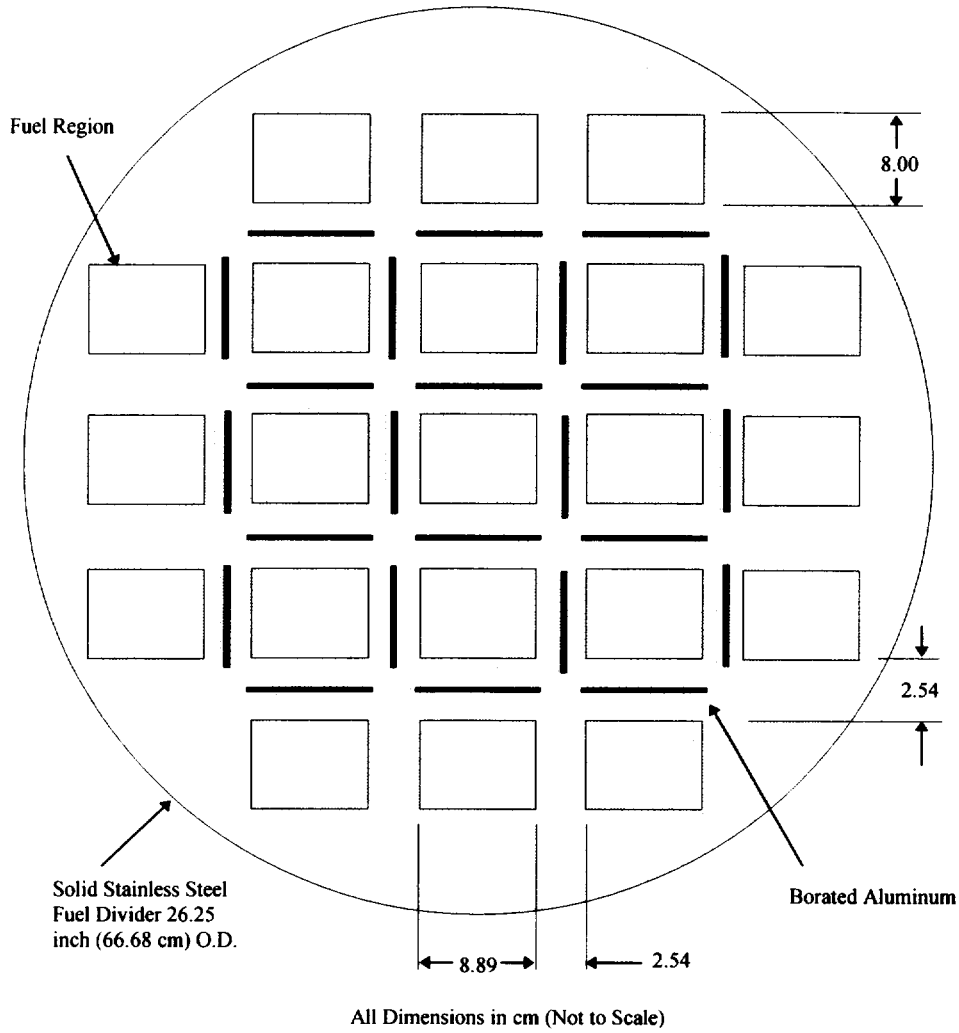


Figure 6.7. Top View of Fuel Support Structure Schematic

6.3.1.2 TRIGA

Similar models are used to evaluate the normal condition, single container and accident array. The models are identical except in their representation of the number of casks and the interspersed moderation. The single container model assumes that there is one (1) cask fully loaded with well moderated fuel assemblies. The normal condition model assumes that there are seven (7) casks; each cask is fully loaded with dry fuel assemblies and in contact with each other in a triangular array. The accident array assumes there are two casks with well moderated fuel assemblies, side-by-side and touching. *All models assume fresh, un-depleted fuel in the active fuel region, neglecting any as-built poisons or fission products.* All models omit the overpack from consideration, which brings the water reflector closer to the fissile material and adds an extra degree of conservatism to the analysis.

The model for normal condition consists of seven (7) fully loaded casks, touching in a hexagonal configuration (triangular array). This places the units of fissile material inside each cask nearest the other for the most reactive configuration. Also, in the calculational model the fuel atoms are dispersed over the full volume of each fuel slot/position to maximize the projected target area for neutrons. The hydrogen-to-fissile ratio inside each cask is varied to find the peak k-effective value for the normal condition model. The inside of each cask is dry in the undamaged condition, which is conservatively modeled as having 5 wt% (a specific gravity of 0.05) interspersed water in the fuel region and inside the remainder of container. The array is surrounded by a 12 inch (30.5 cm) thick parallelogram of full density water (reflection on all sides). The cask with fuel is highly under moderated in the normal condition of transport, as will be seen from the results.

The model for the single container case is one (1) cask that is filled with partial density water to achieve optimum moderation. Even though it has been shown that the cask remains water tight under hypothetical accident conditions, Section 71.55 of 10CFR71 and Section V of the IAEA Safety Standards require that a single cask be shown safe under optimum moderation conditions. For a Fissile Class III shipment of one Model 2000 cask, the single container case bounds the hypothetical accident condition array (of one unit). The accident array (according to the 10CFR criteria) would be dry and severely under moderated. In the single container case, the hydrogen-to-fissile ratio within the fissile fuel and the interspersed moderation inside the cask are varied to find the peak k-effective. The outside of the cask is surrounded by a 12 inch (30.5 cm) thick water reflector.

The model for the accident array case is two (2) casks side-by-side, flooded with partial density water to achieve optimum moderation. The cask is treated as flooded even though it has been shown that the Model 2000 remains water tight under hypothetical accident conditions. Neutron multiplication is relatively insensitive to the number of casks in the array; the casks are nearly neutronically de-coupled. The k-effective values for the single container demonstration and the flooded two cask array are very close. Similar to the single container case, the hydrogen-to-fissile ratio within the fissile fuel and the interspersed moderation are varied to find the peak k-effective. The outside of the cask is surrounded by a 12 inch (30.5 cm) thick water reflector.

All models utilize the same basic interior geometry. The fuel elements inside the cask are constrained by the fuel support structure. The divider does not allow lateral movement of the fuel elements. The separation between the active fuel regions is always maintained by the configuration of the support structure.

6.3.2 Package Regional Densities

6.3.2.1 MTR

In the single container model, the fuel assembly height is allowed to vary as the weight fraction of water varies (Table 6.32). The density of the fuel-water mixture varies as

$$\rho_{mix} = \left[\frac{(1 - WF)}{\rho_{FE}} + \frac{WF}{\rho_{H_2 0}} \right]^{-1} \tag{1}$$

where WF is the weight fraction of water and ρ_{FE} is the density of a homogenized fuel element (41.6% U_3O_8 and 58.4% Al for the Case I Fuel; 80.0% U_3Si_2 and 20.0% Al for the Case II Fuel; 22.5% Ual and 77.5% Al for the Case III Fuel; and 100% U Metal for the Case IV Fuel). In the normal array model, the fuel atoms are spread over the entire fuel region/slot to maximize the projected target area between casks. Table 6.32 shows the variation in mixture height as the water weight fraction in the fuel/water mixture is changed. Please note the maximum fuel column height is 140.64 cm, which is the physical limit.

Table 6.32. Selected Densities as a Function of WF for MTR Type of Fuel

WF H_2O in Fuel	Mixture Height			
	Case I Fuel (cm)	Case II Fuel (cm)	Case III Fuel (cm)	Case IV Fuel (cm)
0.0	22.07	25.89	76.94	0.17
0.05	25.64	31.72	88.38	0.34
0.10	29.61	38.19	101.09	0.53
0.15	34.04	45.42	115.30	0.75
0.20	39.02	53.56	131.29	0.98
0.25	44.68	62.79	149.40	1.26
0.30	51.13	73.33		1.57
0.35	58.59	85.49		1.92
0.40	67.28	99.69		2.34
0.45	77.56	116.46		2.83
0.50	89.89	136.58		3.43
0.55	104.96	161.18		4.58
0.60	123.80			5.05
0.65	148.02			6.22
0.70				7.77
0.75				9.94
0.80				13.19
0.85				18.62
0.90				29.47
0.95				62.03
0.975				127.15
0.980				213.97

Notes: * Maximum Column Height = 140.64 cm

Table 6.33. Material Densities Used in the Model 2000

	Material	Component Density (gm/cm^3)	Number Density (atom/barn-cm)
304 Stainless Steel	SS304	7.800	1.716E-02 (Cr) 1.710E-03 (Mn) 5.846E-02 (Fe) 7.601E-03 (Ni)
Lead Shielding	Pb	11.35	3.299E-02
Water (Reflector)	H_2O	1.00	6.691E-02 (H) 3.345E-02 (O)

Material densities and corresponding number densities are based on standard material specifications. The composition for 304 stainless steel is taken as the minimum alloy content (since these alloys tend to be neutron absorbers) using the specifications provided in Reference [6.5]. Aluminum is modeled as pure aluminum, since alloying agents tend to be neutron absorbers and are conservatively omitted from consideration. Table 6.33 presents the material densities and number densities for substances (materials) in the criticality model. Substances composed of more than one element are broken into their elemental number densities in the number density column.

The material densities for borated aluminum are provided in Table 6.34. The core density of borated aluminum is nominally 2.693 gm/cm^3.

Table 6.34. Material Densities of Borated Aluminum

Nuclide	Number Density (atom/bn-cm) (Used in GEMER Analysis*)	Number Density (atom/bn-cm) (Actual Design Requirement)
B-10*	3.3266E-03	5.5443E-03
B-11*	6.7889E-05	1.1315E-04
Al*	5.8001E-02	5.8001E-02

Notes: *The B-10, B-11 and Al number densities are calculated as follows:

N(B-10) = 98% B-10 * 3.5 weight percent of Boron * 2.693 g/cm^3 in the mixture * Avogardo's number / Boron Atomic Weight * (60% reduction factor)

= 98 * .035 * 2.693 * 6.022E23 *.60 / (.98*10.01294 + .02*11.00931)

= 3.3266×10^{21} number/cm^3

N(B-11) = 02/.98 * N(B-10)

= 6.7889×10^{19} number/cm^3

N(Al) = 0.965 * 2.693 * 6.022E23/26.98153

= 5.8001×10^{22} number/cm^3

6.3.2.2 TRIGA

The same boral plates discussed in the MTR section are used in the TRIGA fuel shipment as neutron poisons. The same assumptions are applied as follows:

1. The borated aluminium plates are conservatively modeled. Only 60% of the boron atoms are accounted for in the criticality calculations.
2. The borated aluminium plates, typically 3.25 inches by 0.25 inches, are conservatively treated as 3.25 inches by 0.225 inches.

Table 6.34 shows the material densities of borated aluminium.

Appendix 6.7.3.2 shows number density calculations used in the TRIGA fuel criticality evaluations. Table 6.35 shows the variation in mixture height as the water weight fraction in the fuel/water mixture is changed for the TRIGA fuels. Table 6.36 shows the materials and number densities of the materials used in the GEMER TRIGA models.

Table 6.35. Mixture Height as a Function of Water Weight Fraction for TRIGA Fuels

WF H_2O in Fuel	Mixture Height		
	Case V Fuel (cm)	Case VIII Fuel (cm)	Case XVII Fuel (cm)
0.0	66.02	17.34	94.32
0.05	83.27	23.30	119.87
0.10	102.43	29.92	148.25
0.15	123.84	37.32	
0.20	147.93	45.65	
0.25	175.24	55.09	
0.30		65.87	
0.35		78.32	
0.40		92.84	
0.45		109.99	
0.50		130.58	
0.55		155.75	

Notes: * Maximum Column Height = 140.64 cm.

Table 6.36. Material Densities Used in GEMER TRIGA Model

	Material	Component Density (gm/cm^3)	Number Density (atom/barn-cm)
304 Stainless Steel	SS304	7.800	1.716E-02 (Cr) 1.710E-03 (Mn) 5.846E-02 (Fe) 7.601E-03 (Ni)
Lead Shielding	Pb	11.35	3.2989E-02
Water (Reflector)	H_2O	1.00	6.691E-02 (H) 3.345E-02 (O)
Graphite (Reflector)	C	1.60	2.076E-02 (C)
Zirconium	Zr	6.50	1.913E-2 (Zr)
Incoloy	In	8.01	1.126E-2 (Fe) 7.454E-3 (Ni) 5.522E-3 (Cr) 2.489E-4 (Mn)

6.4 CRITICALITY CALCULATION

The fuel elements are represented in the calculation by multi-group and resonance parameter cross sections for fuel/cladding/moderator and are spatially homogenized. The neutron statistics for determining the multiplication factor k_{eff} with the GEMER01V program are based on 65 or more iterations of 1000 neutrons each, in which the first five iterations are not counted. Flux-weighted estimates of k_{eff} are provided for each iteration. Final k_{eff} values are based on fission particle flux weighting.

The calculational method used to determine the nuclear reactivity for this package is described below. This is followed by a presentation of the k_{eff} results obtained using these methods and a discussion of these results.

6.4.1 Calculational Method

The computational tool used in this evaluation is the GE MERit code (GEMER). A brief description of this computational tool is provided below.

The GEMER program is a Monte Carlo program for solving the linear neutron transport equation as a fixed source or an eigenvalue problem in three space dimensions. The cross sections in GEMER are processed from the ENDF/B-IV library in the multi-group and resonance parameter formats. Thermal scattering in water is represented by the Haywood Kernel obtained from the ENDF/B library. The GEMER program utilizes 190 full spectrum cross section energy groups. The types of reactions considered in GEMER are

fission, elastic, inelastic and (n,2n) reactions. Absorptions are implicitly treated by applying the non-absorption probability to neutron weights on each collision.

The geometry treatments available in GEMER include the specialized (regular) and generalized geometry options (from the KENO-IV code) and a complex embedded option.

In the specialized (regular) geometry treatment, a spatial description is generated by defining boxes each of which contains an increment of the desired system. With each box, the description consists of a nested series of shapes such as CYLINDERS, SPHERES, and CUBOIDS. Within each box, each region defined must completely enclose all previously defined regions. Arrays of the boxes can be put together to describe the entire system and surrounded by reflecting materials or boundaries 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. This geometry option allows one to describe very complicated systems, but it becomes inefficient when used to describe a system in which small units are repeated a large number of times, as in a rod lattice.

In the complex embedded geometry treatment, boxes, as defined in the specialized (regular) geometry treatment, may be placed inside one or more other boxes. For example, if Box Type 1 describes a homogenized fuel element, Box Type 2 describes a borated aluminum plate and Box Type 3 describes the shipping cask, then Box Types 1 and 2 can be embedded into Box Type 3 to represent a loaded shipping cask. The boxes which result from the embedding operation may be assembled into arrays as described in the specialized (regular) geometry treatment to form complex systems.

The three geometry options described above may be used in any combination to describe a system. In the present analysis, the specialized (regular) geometry treatment is used to describe the cask, and separately to describe the fuel elements, cask top, as well as the outer model boundaries (full density water reflector). The complex embedded option is used to assemble the components of the model into the proper geometric relationships.

6.4.2 Fuel Loading Optimization

Fuel assemblies are held within the divider structure during both normal conditions of transport and during hypothetical accident, so the geometry to be analyzed is well defined. Like other light water reactor fuels, the fuels considered here are substantially subcritical when placed in air due to a lack of neutron moderation. Increasing the moderation within an assembly by adding water to it results in an increase in k_{eff}. During the hypothetical accident conditions in the Model 2000 cask, the fuel is calculated to be confined in each fuel element and located in the positions defined by the support grid geometry as shown in Figure 6.7, as it is under normal shipping conditions.

6.4.3 Criticality Results

6.4.3.1 MTR

Table 6.37 and Table 6.38 provide GEMER01V results for the normal condition array for MTR Case I and Case II Fuels, respectively. The k_{eff} values are substantially subcritical; dry fuel (0.05 WF H_2O) is severely under-moderated. The effect of varying the interspersed water density is shown. No correction for calculational bias is provided because GEMER over-predicts k_{eff} for this system. In these cases the fuel is considered to occupy the maximum possible space within each slot of the support structure, increasing the effective fuel target area between the 7 casks. This effect is relatively unimportant compared with the impact of under-moderation in the system.

Table 6.37. GEMER Results for the Normal Condition Array for Case I (93.2% Enriched U_3O_8)

Interspersed Water Density Outside Cask (gm/cm^3)	$H/^{235}U$ Ratio (in Fuel)	k_{eff}	$\pm\sigma$	Bias	$k_{eff} + 2\sigma +$ Bias
0.00	9	0.46649	0.00236	.00000	0.47121
0.02	**9**	**0.46772**	**0.00191**	**.00000**	**0.47154**
0.05	9	0.46027	0.00198	.00000	0.46423
0.10	9	0.46587	0.00205	.00000	0.46997
0.50	9	0.46303	0.00206	.00000	0.46715
1.00	9	0.45459	0.00210	.00000	0.45879

Table 6.38. GEMER Results for the Normal Condition Array for Case II (20.0% Enriched U_3Si_2)

Interspersed Water Density Outside Cask (gm/cm^3)	$H/^{235}U$ Ratio (in Fuel)	k_{eff}	$\pm\sigma$	Bias	$k_{eff} + 2\sigma +$ Bias
0.00	16	0.47524	0.00191	0.0000	0.47906
0.02	16	0.47588	0.00187	0.0000	0.47962
0.05	**16**	**0.47738**	**0.00186**	**0.0000**	**0.48110**
0.10	16	0.47305	0.00200	0.0000	0.47705
0.50	16	0.46827	0.00226	0.0000	0.47279
1.00	16	0.46965	0.00221	0.0000	0.47407

Table 6.39 and Table 6.40 show results for the single container MTR Case I and Case II Fuels, respectively. These tables provide $k_{eff} + 2\sigma + Bias$ for a variety of water weight fractions within the fuel. The maximum k_{eff}, accounting for uncertainty and bias, are 0.91682 for Case I fuel and 0.82333 for Case II fuel. The single container is closely reflected by full density water. Also, empty spaces within the cask, but not occupied by the fuel-water mixture, are filled with full density water (i.e., in the gap between the cask inner wall and in the support structure and above the fuel-water mixture in the slots).

Table 6.39. GEMER Results for a Single Container for Case I (93.2% Enriched U3O8)

WF H_2O (in Fuel)	$H/^{235}U$ Ratio (in Fuel)	k_{eff}	$\pm\sigma$	Bias	$k_{eff} + 2\sigma +$ Bias
0.05	9	0.47429	0.00227	0.0000	0.47883
0.10	20	0.59499	0.00269	0.0000	0.60037
0.15	31	0.69974	0.00350	0.0000	0.70675
0.20	45	0.77266	0.00305	0.0003	0.77904
025	59	0.82551	0.00272	0.0006	0.83150
0.30	76	0.87577	0.00260	0.0009	0.88183
0.35	96	0.89519	0.00316	0.0012	0.90274
0.40	**119**	**0.90934**	**0.00292**	**0.0016**	**0.91682**
0.45	146	0.90879	0.00295	0.0021	0.91680
0.50	178	0.90548	0.00331	0.0026	0.91474
0.55	218	0.88840	0.00273	0.0033	0.89714

Table 6.40. GEMER Results for a Single Container for Case II (20.0% Enriched U_3Si_2)

WF H_2O (in Fuel)	$H/^{235}U$ Ratio (in Fuel)	k_{eff}	$\pm\sigma$	Bias	$k_{eff} + 2\sigma +$ Bias
0.05	16	0.47538	0.00218	0.0000	0.47974
0.10	33	0.59025	0.00248	0.0000	0.59521
0.15	52	0.68806	0.00317	0.0004	0.69481
0.20	74	0.75134	0.00319	0.0008	0.75855
025	99	0.78708	0.00302	0.0013	0.79440
0.30	127	0.80595	0.00284	0.0018	0.81341
0.35	**160**	**0.81443**	**0.00328**	**0.0023**	**0.82333**
0.40	198	0.80336	0.00294	0.0030	0.81221
0.45	243	0.79462	0.00279	0.0037	0.80387
0.50	296	0.77489	0.00249	0.0044	0.78431

Table 6.41 and Table 6.42 provide the results for the accident array for MTR Case I and Case II Fuels, respectively. The accident array is treated as flooded, despite test results which indicate that the Model 2000 Cask will not leak. These tables provide $k_{eff} + 2\sigma + Bias$ for a variety of weight fractions of water within the fuel as well as within the interspersed regions (i.e., between the casks, in the gap between the cask inner wall, and in the support structure and above the fuel-water mixture, in the slots). The maximum k_{eff} for Case I fuel, accounting for uncertainty and bias, is 0.93559, which is below the subcriticality limit of 0.95. Similarly, the maximum k_{eff} for Case II fuel, accounting for uncertainty and bias, is 0.82672, which is also below the subcriticality limit of 0.95. For Case I fuel, the interspersed water density is varied from 0.00 to 1.00 at the .45 weight fraction case. The change in k_{eff} is small: from 0.92915 to 0.92615, showing the negligible effect of interspersed moderation. The two containers are closely reflected by a 1 ft (30.5 cm) thick parallelogram of full density water.

In the cases shown in Table 6.32 and Table 6.33, the fuel-water mixture height is allowed to vary with the weight fraction of water, as in the single container case. Increasing the fuel-water volume to occupy the entire fuel slot (maximizing the effective target area of the fuel between the casks) decreases neutron multiplication.

Table 6.41. GEMER Results for the Accident Array (Conservatively Treated as Flooded) for Case I (93.2% Enriched U_3O_8)

WF H_2O (in Fuel)	$H/^{235}U$ Ratio (in Fuel)	H_2O Density (Interspersed)	k_{eff}	$\pm\sigma$	Bias	$k_{eff} + 2\sigma$ +Bias
0.25	59	0.00	0.83878	0.00333	0.0005	0.84599
0.30	76	0.00	0.87553	0.00278	0.0009	0.88195
0.35	96	0.00	0.90358	0.00270	0.0012	0.91021
0.40	119	0.00	0.92091	0.00292	0.0016	0.92839
0.45	146	0.00	0.92044	0.00330	0.0021	0.92915
0.45	**146**	**0.02**	**0.92772**	**0.00288**	**0.0021**	**0.93559**
0.45	146	0.05	0.92423	0.00289	0.0021	0.93212
0.45	146	0.10	0.92323	0.00302	0.0021	0.93138
0.45	146	1.00	0.91386	0.00284	0.0021	0.92615
0.50	178	0.00	0.91733	0.00320	0.0026	0.92637

Table 6.42. GEMER Results for the Accident Array (Conservatively Treated as Flooded) for Case II (20% Enriched U_3Si_2)

WF H_2O (in Fuel)	$H/^{235}U$ Ratio (in Fuel)	H_2O Density (Interspersed)	k_{eff}	$\pm\sigma$	Bias	$k_{eff} + 2\sigma$ +Bias
0.25	99	0.00	0.78603	0.00282	0.0013	0.79295
0.30	127	0.00	0.81260	0.00289	0.0018	0.82016
0.35	160	0.00	0.81811	0.00300	0.0023	0.82645
0.40	**198**	**0.00**	**0.81838**	**0.00268**	**0.0030**	**0.82671**
0.45	243	0.00	0.80459	0.00261	0.0037	0.81348
0.50	296	0.00	0.78931	0.00282	0.0044	0.79939

Tables 6.43 through 6.46 provide the GEMER results for MTR cases I, II, III, and IV, respectively, for the infinite cask scenario. This data provides $k_{eff} + 2\sigma$ + Bias for a variety of weight fractions of water within the fuel. Figures 6.8 through 6.11 show the GEMER results for MTR Case I, II, III, and IV fuels, respectively, for the infinite cask scenario. The k-effectives in Case I, II, III, and IV fuels increase as the water weight fraction (hence, neutron moderation) is increased. As more and more water is added, neutron absorption becomes dominant and the k-effective curves around for the Case I, II, and IV fuels. The Case III fuel never curves around as the fuel divider is completely filled with water before the neutron absorption effect is dominant.

The maximum k_{eff} for MTR Cases I, II, III, and IV is 0.94519, 0.84670 and 0.76935, 0.92003, respectively, accounting for uncertainty and bias. These values are all below the subcriticality limit of 0.95.

Table 6.43. GEMER Results — Infinite Cask Scenario for MTR Case I (94% Enriched U3O8)

WF H_2O (in Fuel)	$H/^{235}U$ Ratio (in Fuel)	H_2O Density (Interspersed)	K_{eff}	$\pm\sigma$	Bias	$K_{eff} + 2\sigma +$ Bias
0.00	0	0	0.33753	0.00070	0.00000	0.33893
0.05	9.34	0	0.51799	0.00082	0.00000	0.51963
0.10	19.71	0	0.64409	0.00096	0.00000	0.64601
0.15	31.31	0	0.73928	0.00099	0.00002	0.74128
0.20	44.34	0	0.81160	0.00102	0.00027	0.81391
0.25	59.13	0	0.86669	0.00106	0.00055	0.86936
0.30	76.03	0	0.90023	0.00107	0.00086	0.90323
0.35	95.52	0	0.92480	0.00106	0.00122	0.92814
0.40	118.27	0	0.93775	0.00100	0.00163	0.94138
0.41	123.28	0	0.93913	0.00099	0.00171	0.94282
0.42	128.46	0	0.94087	0.00098	0.00180	0.94463
0.43	133.83	0	0.94109	0.00100	0.00190	0.94499
0.44	**139.39**	**0**	**0.94118**	**0.00101**	**0.00199**	**0.94519**
0.45	145.15	0	0.93829	0.00095	0.00209	0.94228
0.50	177.40	0	0.93318	0.00095	0.00263	0.93771
0.55	216.82	0	0.91707	0.00094	0.00327	0.92222
0.60	266.10	0	0.89201	0.00089	0.00401	0.89780

Table 6.44. GEMER Results — Infinite Cask Scenario for MTR Case II (20% Enriched U3Si2)

WF H_2O (in Fuel)	$H/^{235}U$ Ratio (in Fuel)	H_2O Density (Interspersed)	K_{eff}	$\pm\sigma$	Bias	$K_{eff} + 2\sigma +$ Bias
0.00	0	0%	0.31839	0.00169	0.000000	0.32177
0.05	16	0%	0.50961	0.00227	0.000000	0.51415
0.10	33	0%	0.49046	0.00208	0.000049	0.49467
0.15	52	0%	0.71850	0.00304	0.000413	0.72499
0.20	74	0%	0.77423	0.00300	0.000825	0.78106
0.25	99	0%	0.81146	0.00271	0.001282	0.81816
0.30	127	0%	0.83106	0.00251	0.001779	0.83786
0.35	**160**	**0%**	**0.83800**	**0.00318**	**0.002344**	**0.84670**
0.40	198	0%	0.83152	0.00326	0.002968	0.84101
0.45	243	0%	0.82026	0.0027	0.003670	0.82933
0.50	296	0%	0.80792	0.00257	0.004444	0.81750

Table 6.45. GEMER Results — Infinite Cask Scenario for MTR Case III (94% Enriched UAlx)

WF H_2O (in Fuel)	$H/^{235}U$ Ratio (in Fuel)	H_2O Density (Interspersed)	K_{eff}	$\pm\sigma$	Bias	$K_{eff} + 2\sigma +$ Bias
0.000	0	0	0.29762	0.00096	0.00000	0.29954
0.025	9.31	0	0.42323	0.00139	0.00000	0.42601
0.050	19.10	0	0.49769	0.00143	0.00000	0.50055
0.075	29.43	0	0.56063	0.00155	0.00000	0.56373
0.100	40.33	0	0.61495	0.00175	0.00019	0.61864
0.125	51.85	0	0.65770	0.00151	0.00041	0.66113
0.150	64.05	0	0.69221	0.00199	0.00064	0.69683
0.175	76.99	0	0.72176	0.00170	0.00088	0.72604
0.200	90.74	0	0.74168	0.00187	0.00113	0.74655
0.225	**105.37**	**0**	**0.76397**	**0.00199**	**0.00140**	**0.76935**

Table 6.46. GEMER Results — Infinite Cask Scenario for MTR Case IV (95% Enriched U Metal)

WF H_2O (in Fuel)	$H/^{235}U$ Ratio (in Fuel)	H_2O Density (Interspersed)	K_{eff}	$\pm\sigma$	Bias	$K_{eff} + 2\sigma +$ Bias
0.000	0.00	0	0.34099	0.00076	0.00000	0.34251
0.100	3.05	0	0.36888	0.00086	0.00000	0.37060
0.200	6.87	0	0.40609	0.00083	0.00000	0.40775
0.300	11.78	0	0.45285	0.00085	0.00000	0.45455
0.400	18.33	0	0.51216	0.00096	0.00000	0.51408
0.500	27.49	0	0.58686	0.00108	0.00000	0.58902
0.600	41.24	0	0.67568	0.00106	0.00021	0.67801
0.700	64.14	0	0.77638	0.00112	0.00064	0.77926
0.800	109.96	0	0.87788	0.00107	0.00148	0.88150
0.825	129.60	0	0.89525	0.00108	0.00182	0.89923
0.850	155.78	0	0.91089	0.00108	0.00227	0.91532
0.875	**192.43**	**0**	**0.91507**	**0.00104**	**0.00288**	**0.92003**
0.900	247.41	0	0.90415	0.00102	0.00374	0.90993
0.950	522.32	0	0.77136	0.00088	0.00712	0.78024

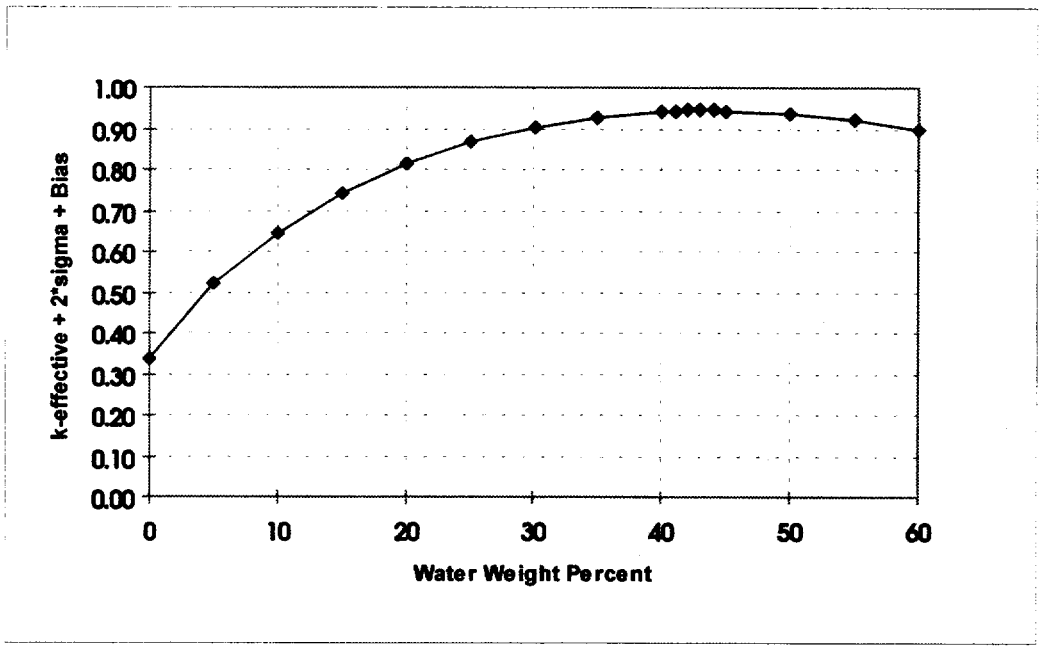


Figure 6.8. MTR Case I Fuel (94% Enriched U3O8), Infinite Cask Array

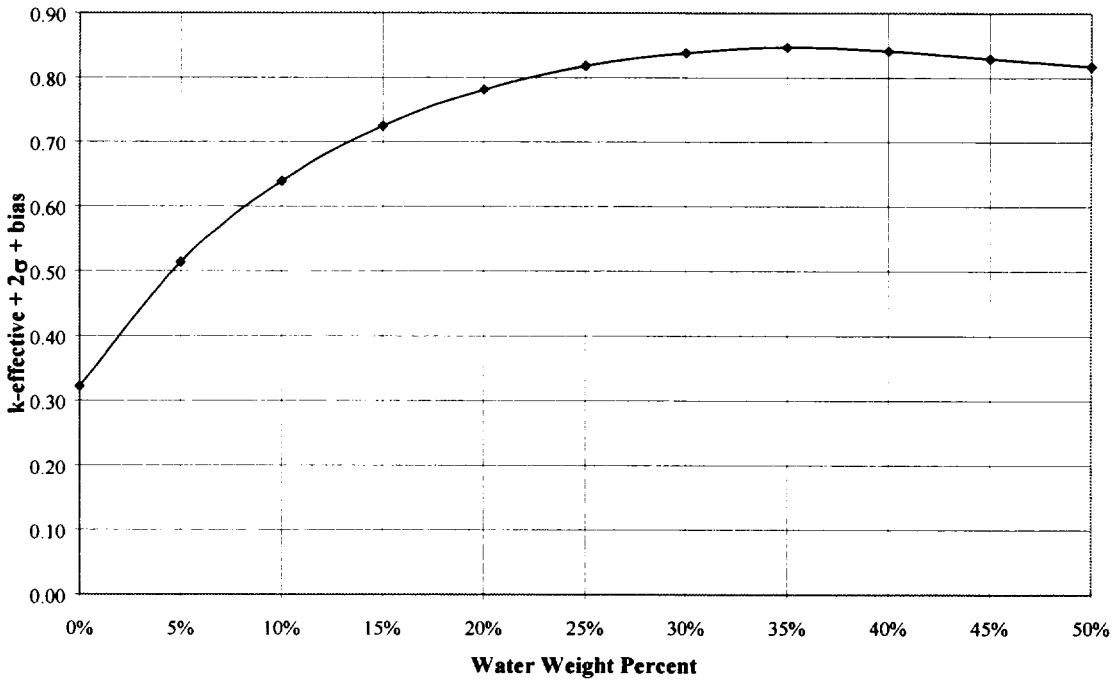


Figure 6.9. MTR Case II Fuel (20% Enriched U3Si2), Infinite Cask Array

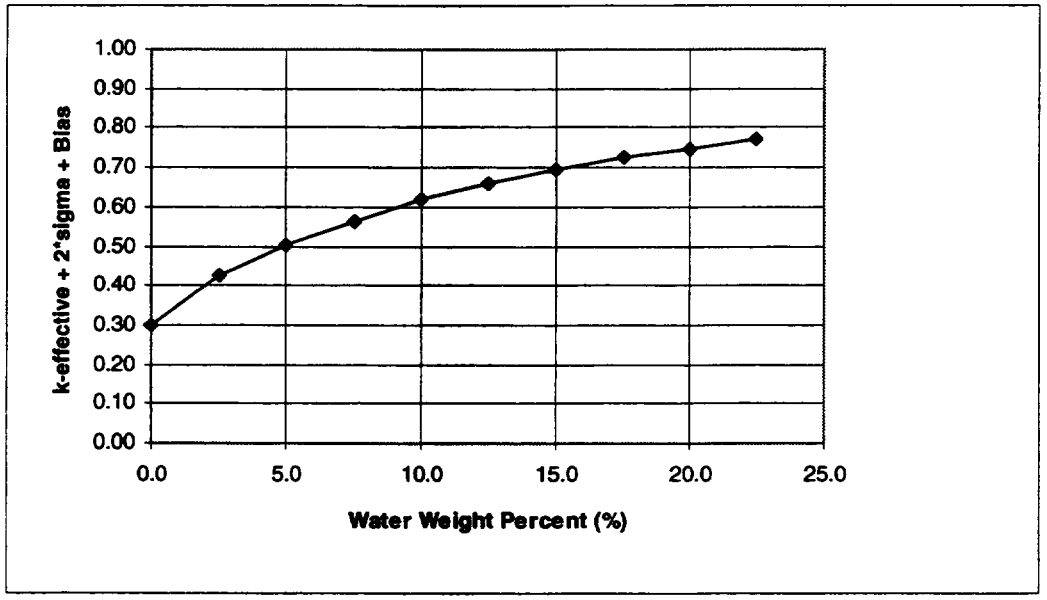


Figure 6.10. MTR Case III Fuel (94% UAlx), Infinite Cask Array

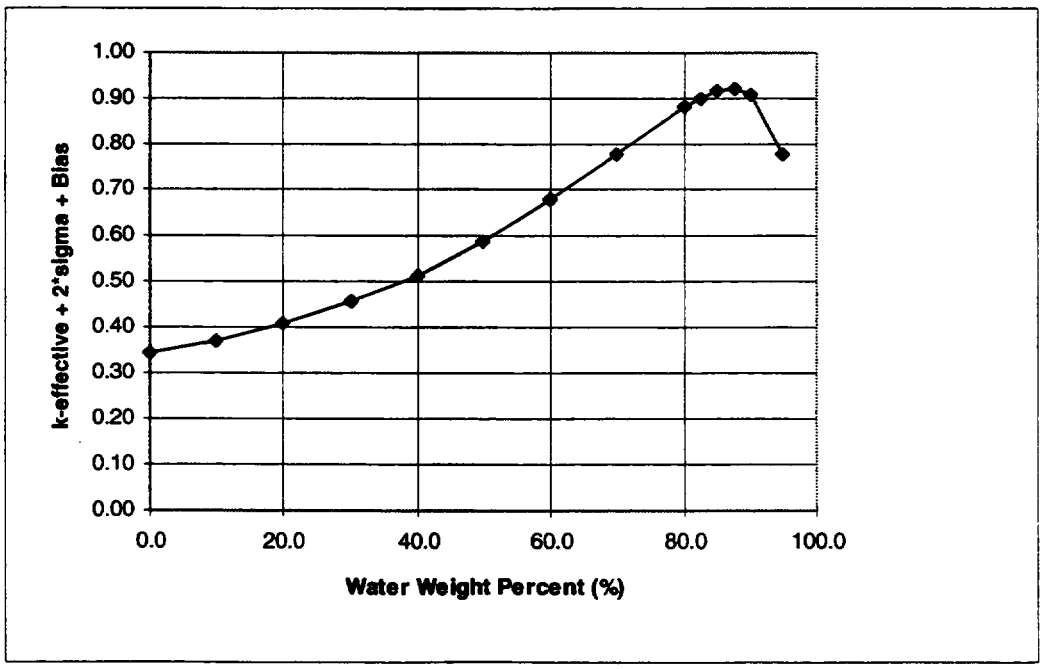


Figure 6.11. MTR Case IV Fuel (95% U Metal), Infinite Cask Array

6.4.3.2 TRIGA

The GEMER results for the TRIGA Case VIII fuels for Single, Normal, and Accident arrays are tabulated in Tables 6.47 through 6.49, respectively.

Tables 6.50 through 6.52 display the GEMER results for the infinite cask scenario for TRIGA cases XVII, V, and VIII, respectively. The worst k_{eff} for cases XVII, V, and VIII are 0.89138, 0.92414, and 0.92156, respectively. These values all account for bias plus two standard deviations. The k-effectives in Case XVII, V and VIII fuels increase as the water weight fraction (hence, neutron moderation) is increased. As more and more water is added, neutron absorption becomes dominant and the k-effective curves around for the Case V and VIII fuels. The Case XVII fuel never curves around as the fuel divider is completely filled with water before the neutron absorption effect is dominant.In all cases, all k-effective values are less than 0.95. The system will be subcritical under all conceivable and realistic accident scenarios.

Table 6.47. GEMER Results — Single Container for TRIGA Case VIII Fuel (93% Enriched)

WF H_2O (in Fuel)	H/U^{235} Ratio (in Fuel)	k_{eff}	$\pm\sigma$	Bias	$k_{eff} + 2\sigma +$ Bias
0.05	61.775	0.82726	0.00329	0.000597	0.834437
0.10	86.856	0.87371	0.00308	0.001062	0.880932
0.15	114.888	0.88934	0.00306	0.001566	0.897026
0.20	**146.424**	**0.89613**	**0.00317**	**0.002114**	**0.904584**
0.25	182.164	0.88303	0.00272	0.002711	0.891181
0.30	223.011	0.87095	0.00268	0.003363	0.879673
0.35	270.141	0.84733	0.00264	0.004073	0.856683
0.40	325.127	0.81358	0.00240	0.004845	0.823225
0.45	390.110	0.77661	0.00273	0.005680	0.78775
0.50	468.089	0.74225	0.00206	0.006571	0.752941

Table 6.48. GEMER Results — Normal Condition Array for TRIGA Case VIII Fuel (93% Enriched)

Interspersed Water Density Outside Cask (in gm/cm^3)	H/U^{235} Ratio (in Fuel)	k_{eff}	$\pm\sigma$	Bias	$k_{eff} + 2\sigma +$ Bias
0.00	61.775	0.84010	0.00300	0.002114	0.848214
0.02	61.775	0.84226	0.00334	0.002114	0.851054
0.05	61.775	0.83872	0.00263	0.002114	0.846094
0.10	**61.775**	**0.84010**	**0.00300**	**0.002114**	**0.848214**
0.50	61.775	0.83694	0.00370	0.002114	0.846454
1.00	61.775	0.82778	0.00327	0.002114	0.836434

Table 6.49. GEMER Results — Accident Array (Conservatively Treated as Flooded) for TRIGA Case VIII Fuel (93% Enriched)

WF H_2O (in Fuel)	$H/^{235}U$ Ratio (in Fuel)	H_2O Density (Interspersed)	k_{eff}	$\pm\sigma$	Bias	$k_{eff} + 2\sigma +$ bias
0.00	39.202	0.00	0.74099	0.00299	0.00169	0.74866
0.05	61.775	0.00	0.83037	0.00319	0.000597	0.837347
0.10	86.856	0.00	0.87696	0.00286	0.001062	0.883742
0.15	114.888	0.00	0.90126	0.00253	0.001566	0.907886
0.20	146.424	0.00	0.90713	0.00299	0.002114	0.915224
0.20	**146.424**	**0.02**	**0.90761**	**0.00311**	**0.002114**	**0.915944**
0.20	146.424	0.05	0.90542	0.00299	0.002114	0.913514
0.20	146.424	0.10	0.90351	0.00265	0.002114	0.910924
0.20	146.424	0.50	0.89694	0.00267	0.002114	0.904394
0.20	146.424	1.00	0.89520	0.00344	0.002114	0.904194
0.25	182.164	0.00	0.89085	0.00275	0.002711	0.899061
0.30	223.011	0.00	0.87423	0.00274	0.003363	0.883073
0.35	270.141	0.00	0.84991	0.00259	0.004073	0.859163
0.40	325.127	0.00	0.82410	0.00250	0.004845	0.833945
0.45	390.110	0.00	0.78794	0.00266	0.005680	0.79894
0.50	468.089	0.00	0.74311	0.00307	0.006571	0.755821

Table 6.50. GEMER Results — Infinite Cask Scenario for TRIGA Case XVII (70% Enriched)

WF H_2O (in Fuel)	$H/^{235}U$ Ratio (in Fuel)	H_2O Density (Interspersed)	K_{eff}	$\pm\sigma$	Bias	$K_{eff} + 2\sigma +$ Bias
0.000	62.30	0%	0.83826	0.00179	0.000607	0.84245
0.025	79.17	0%	0.86056	0.00195	0.000921	0.86538
0.050	96.93	0%	0.87156	0.00181	0.001245	0.87642
0.075	115.65	0%	0.87992	0.00195	0.001579	0.88540
0.087	**125.00**	**0%**	**0.88612**	**0.00176**	**0.00174**	**0.89138**

Table 6.51. GEMER Results — Infinite Cask Scenario for TRIGA Case V (94% Enriched)

WF H_2O (in Fuel)	$H/^{235}U$ Ratio (in Fuel)	H_2O Density (Interspersed)	K_{eff}	$\pm\sigma$	Bias	$K_{eff} + 2\sigma +$ Bias
0.000	46.39	0	0.84995	0.00219	0.00031	0.85464
0.025	56.19	0	0.88094	0.00196	0.00049	0.88535
0.050	72.67	0	0.90394	0.00193	0.00080	0.90860
0.075	86.87	0	0.91133	0.00188	0.00106	0.91615
0.100	101.87	0	0.91728	0.00198	0.00133	0.92257
0.125	**117.72**	**0**	**0.91822**	**0.00215**	**0.00162**	**0.92414**
0.150	134.50	0	0.91479	0.00185	0.00191	0.92040
0.175	152.30	0	0.90653	0.00206	0.00221	0.91286

Table 6.52. GEMER Results — Infinite Cask Scenario for TRIGA Case VIII (94% Enriched)

WF H_2O (in Fuel)	$H/^{235}U$ Ratio (in Fuel)	H_2O Density (Interspersed)	K_{eff}	$\pm\sigma$	Bias	$K_{eff} + 2\sigma +$ Bias
0.000	38.79	0	0.77538	0.00216	0.00016	0.77986
0.050	61.20	0	0.85648	0.00191	0.00059	0.86089
0.100	86.11	0	0.90243	0.00208	0.00105	0.90764
0.150	113.94	0	0.91330	0.00220	0.00155	0.91925
0.200	**145.26**	**0**	**0.91563**	**0.00192**	**0.00209**	**0.92156**
0.250	180.75	0	0.91048	0.00210	0.00269	0.91737
0.300	221.31	0	0.88951	0.00191	0.00334	0.89667
0.350	268.12	0	0.86393	0.00177	0.00404	0.87151
0.400	322.72	0	0.83409	0.00167	0.00481	0.84224
0.450	387.25	0	0.80078	0.00178	0.00565	0.80999
0.500	464.68	0	0.76113	0.00220	0.00653	0.77206

Figure 6.12 shows $k_{eff} + 2\sigma + bias$ for varying water weight percentages with TRIGA Case VIII fuel in the single container scenario. Figure 6.13 shows $k_{eff} + 2\sigma + bias$ for varying interspersed water densities with TRIGA Case VIII fuel in the normal array. Figure 6.14 shows $k_{eff} + 2\sigma + bias$ for varying water weight percentages with TRIGA Case VIII fuel in the accident array. Figure 6.15 shows $k_{eff} + 2\sigma + bias$ for varying moderator density with TRIGA Case VIII fuel in the accident array.

Figures 6.16 through 6.18 show $k_{eff} + 2\sigma + bias$ for varying water weight percentages with TRIGA Case XVII, V, and VIII fuels, respectively, for the infinite cask scenario.

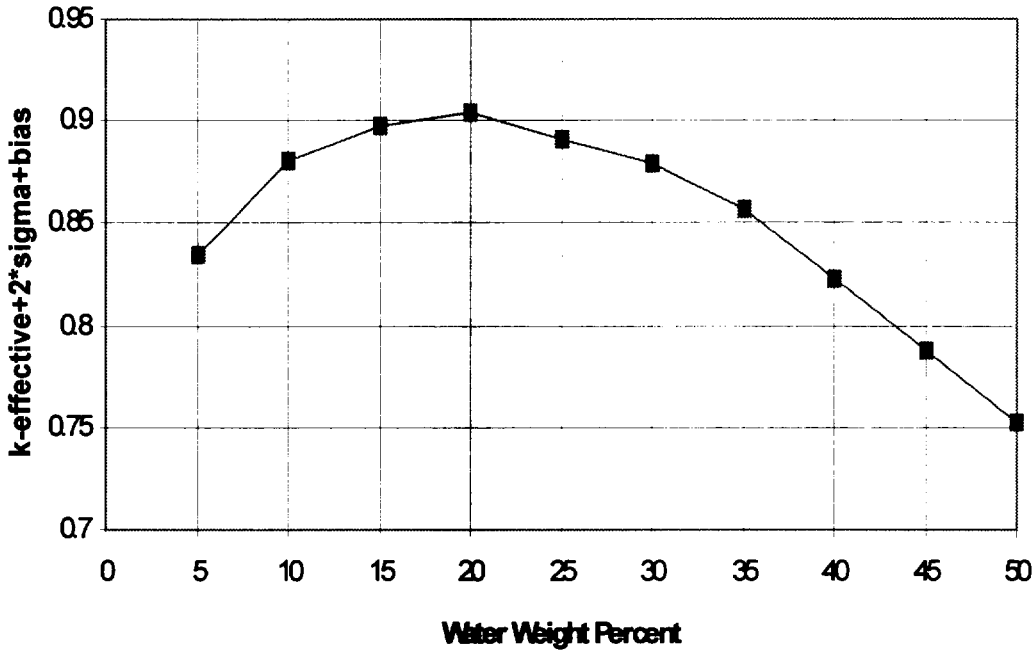


Figure 6.12. TRIGA Case VIII Fuel, 93% Enrichment, Single Container Case, 493.9g

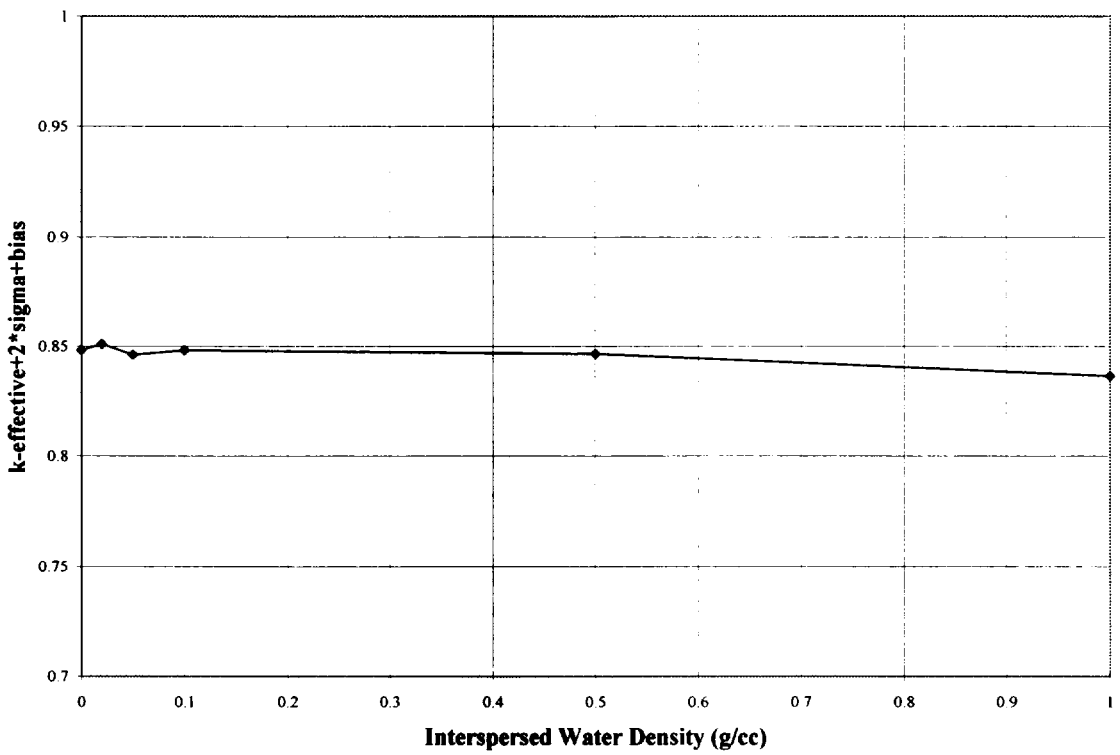


Figure 6.13. TRIGA Case VIII Fuel, 93% Enrichment, Normal Array Case, 493.9g of U-235

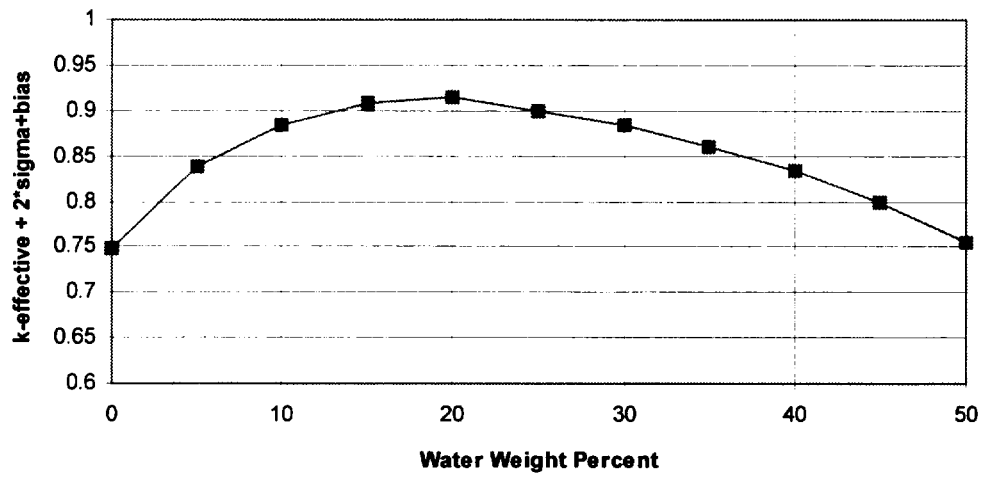


Figure 6.14. TRIGA Case VIII Fuel, 93% Enrichment, Accident Array, 493.9g of U-235

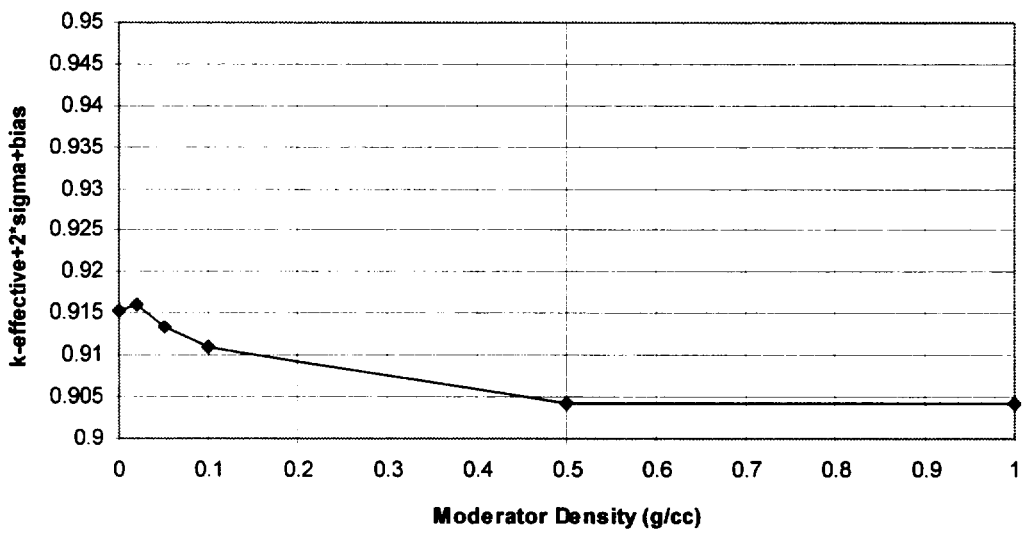


Figure 6.15. TRIGA Case VIII Fuel, 93% Enrichment, 493.9g of U-235, Accident Array, 20% Water Weight

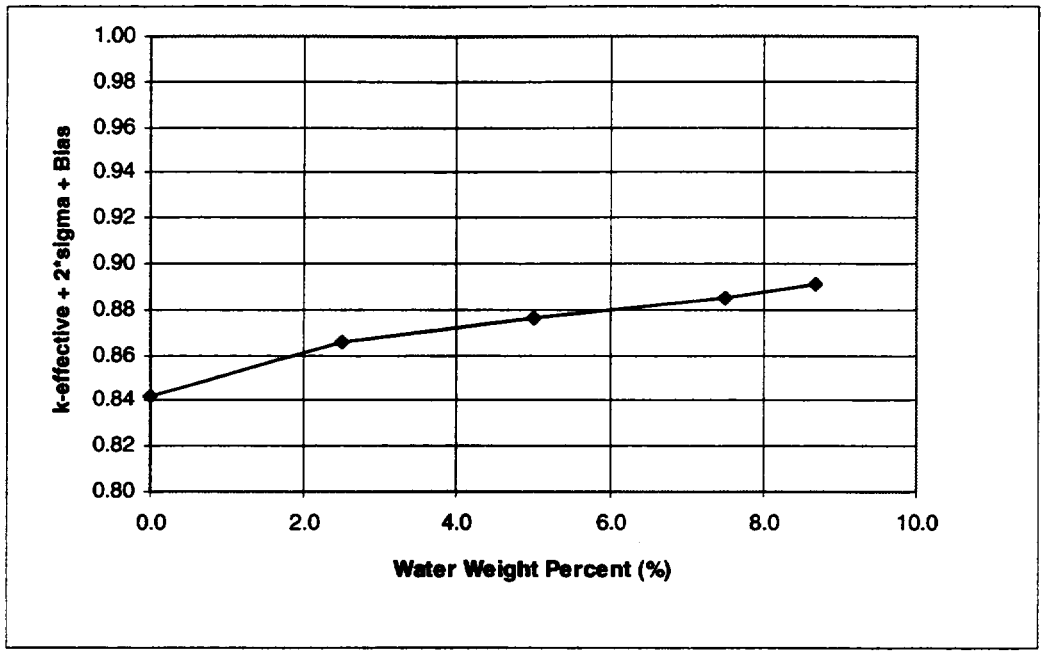


Figure 6.16. TRIGA Case XVII Fuel, 70% Enrichment, Infinite Cask Array

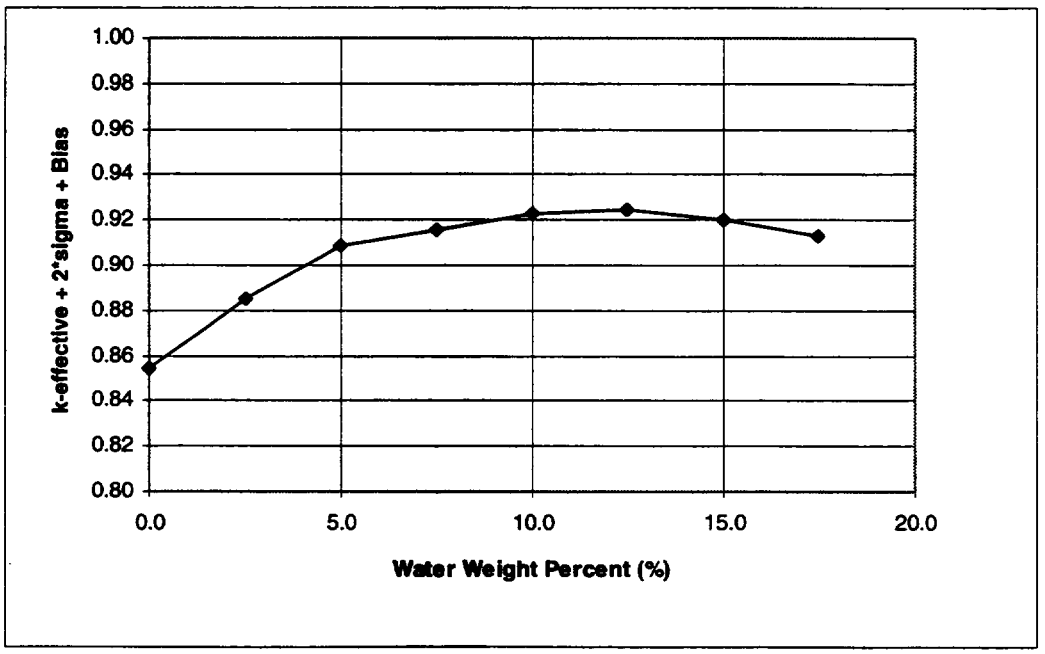


Figure 6.17. TRIGA Case V Fuel, 94% Enrichment, Infinite Cask Array

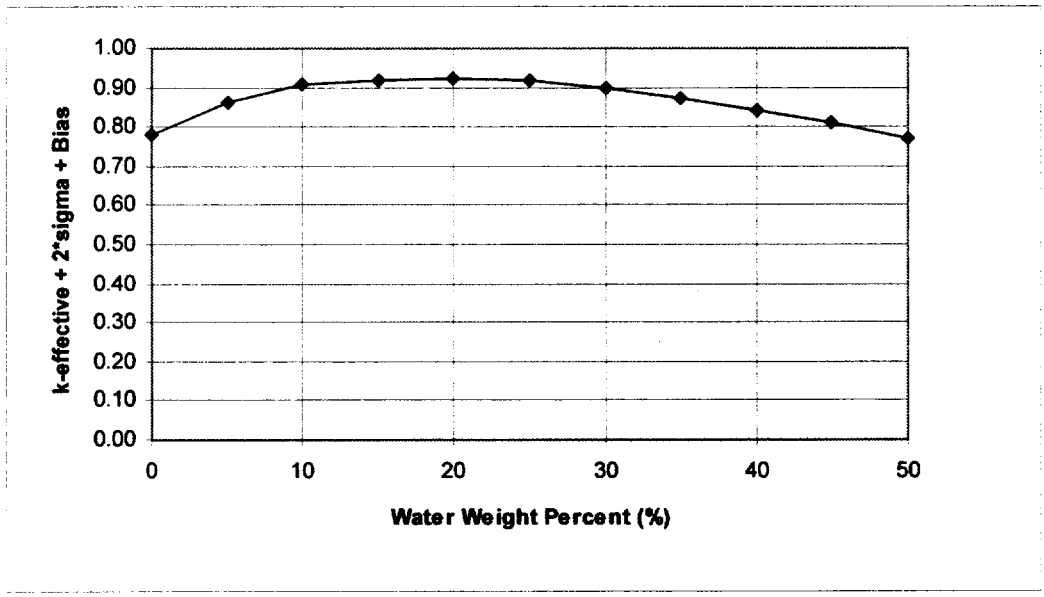


Figure 6.18. TRIGA Case VIII Fuel, 94% Enrichment, Infinite Cask Array

6.4.4 Conclusions

6.4.4.1 MTR

All MTR type fuel results, including the conservative accident condition cases, are subcritical. Accounting for bias and uncertainty, the effective multiplication factors are all less than 0.95. The maximum k-effective for the worst case, after accounting for uncertainty and bias, is 0.94519 (Table 6.43). This conclusion is reached based on the requirement that the structural integrity of the fuel support and borated aluminum poison structure is maintained under all credible accident conditions. This meets all NRC requirements for the subcriticality safety analysis and the MTR type Cases I, II, and III fuels can be safely transported using the Model 2000 cask.

6.4.4.2 TRIGA

All TRIGA type fuel results, including the conservative accident condition cases, are subcritical. Accounting for bias and uncertainty, the effective multiplication factors are all less than 0.95. The maximum k-effective for the worst case, after accounting for uncertainty and bias, is 0.92414 (Table 6.52). This conclusion is reached based on the requirement that the structural integrity of the fuel support and borated aluminum poison structure is maintained under all credible accident conditions. This meets all NRC requirements for the subcriticality safety analysis and the TRIGA type cases XVII, V, and VIII fuels can be safely transported using the Model 2000 cask.

6.5 CRITICAL BENCHMARK EXPERIMENTS

6.5.1 Benchmark Experiments and Applicability

6.5.1.1 Bias Development

The GEMER01V code has been validated by comparison against 123 critical experiments [6.1]. These experiments form the database from which the GEMER bias is calculated.

Validation of GEMER01V against experimental data was performed using the same cases which were developed for benchmarking the original version of GEMER. The validation consisted of performing a set of 123 calculations that were taken from the following experiments, as shown in Table 6.53.

Table 6.53. Summary of GEMER01V Validation Cases

Name of Experiment	Reference Document No.	No. used in Benchmark
Handley-Hopper (Y-1948)	6.9	40
Handley-Hopper (Y-1858 Set A)	6.8	21
Handley-Hopper (Y-1858 Set B)	6.8	22
Bierman (NUREG/CR-0796)	6.13	19
Rocky Flats (NUREG/CR-0674)	6.12	10
RSIC	6.10	9
TRX (WAPD-TM-931)	6.11	2

Because calculational biases are normally due to the cross-section treatment rather than the geometry treatment, good agreement with the original validation and critical experiment is expected. The experimental parameters are described very briefly below. Consult the appropriate Reference Document for further information on the experiments themselves.

Handley-Hopper Critical Experiments

- Fuel forms of UF_4, UO_2F_2, U-metal or UNH
- Enrichments ranging from 1.4 wt% to 93.8 wt%
- Moderators of water, paraffin or none
- Reflectors of water, graphite, oil, or bare

Bierman et. al. Critical Experiments

- Fuel form is UO_2
- Enrichments of 2.35 wt% to 4.29 wt%
- Moderator and reflectors of water

Rocky Flats Critical Experiments

- Uranium form of U_3O_8
- Enrichment is 4.46 wt%
- Moderator is water
- Reflectors of concrete, plastic, or steel

RSIC Critical Experiments

- Fuel form is UO_2
- Enrichment of 2.35 wt%
- Moderator and reflectors of water

TRX Critical Experiments

- Fuel form is U-metal
- Enrichment of 1.3 wt%
- Moderator and reflectors of water

Detailed results of the benchmark calculations for the GEMER criticality code are provided in Reference [6.1].

The results of the validation cases are compared to experiment and a calculational bias is determined from this comparison. Validation cases have been developed previously and were not newly created for this analysis. Obviously, for critical experiments, the value of k-effective is 1.000. No attempt has been made to include the experimental uncertainties into the models or the development of the calculated bias.

K-effectives for these cases have been selected based on the following selection technique. A Monte Carlo code begins with a source distribution and generates a new source distribution from each subsequent batch of neutrons. This allows the solution to converge to a correct distribution at a rate which is dependent upon the neutronic coupling of the model. K-effective is determined by discarding an appropriate number of initial batches so that the remaining batches are all representative subsets of the converged source distribution. The user generally specifies the number of initial batches to be skipped. However, since models do not converge at the same rate, the user is responsible for ensuring that the k-effective selected is a conservative one for criticality analyses. An approach to ensure this is to choose k-effective such that

$$k_{eff} = \max\left[\sum_{i=n}^{m} \frac{(k_i - 3\sigma_i)}{(m-n)}\right] \tag{2}$$

providing that $\sigma_i > 0$ and $\sigma_i < \sigma_{i+1}$, where m is the number of the last batch and n is the number of batches skipped.

Since the validation cases fit into the category of criticality calculation, and the models were developed with such guidelines as are used in criticality analyses, this selection technique was used to develop the bias. It is not necessary to further include uncertainty into the bias, since it is already included in the bias correlation.

The bias calculated for GEMER01V is identical to the bias developed for the PRIME version of GEMER. The differences in k-effective calculated by skipping the first two batches between the two codes are calculated and an average value and spread of this difference is found. The differences in k-effectives selected as described above are also found and the average of these is calculated.

The GEMER critical benchmark bias, which is known as a function of hydrogen-to-^{235}U ratio, was used to determine from the critical experiments. When the bias is positive (i.e., neutron multiplication is over-predicted), it is conservative to omit this positive bias as a reduction in k_{eff}.

K-effective results for the cross-section set used by GEMER have also been benchmarked using the original MERIT code for the ORNL, PNL, TRX, and B&W critical experiments. In the TRX cases, MERIT and the associated ENDF/B-IV cross-section set was used to compute k_∞. This k_∞ together with the leakage corrections from Reference [6.15] were applied to obtain k_{eff}. For all other calculations, the MERIT models used full three-dimensional geometric representations.

For the Cross Section Evaluation Working Group (CSEWG) problems [6.16], the cross section processing is generally in agreement (within statistics) with the other calculations; agreeing especially well with the detailed BAPL (Bettis Atomic Power Laboratories) Monte Carlo calculations. For the two B&W critical experiments with boron curtains and gadolinia rods, the cross sections under-predict the eigenvalue by approximately 0.3 to 0.5 percent. The previous CSEWG evaluations of the ENDF/B-IV files [6.16] concluded that the experimental k_{eff} is generally over-predicted by 1–2% for plutonium nitrate systems and under-predicted by approximately 0.5 percent for high moderator-to-fuel ratios, to approximately 1.5 percent for low moderator-to-fuel ratios in water moderated uranium lattices. The MERIT results confirm these biases, thus supporting the CSEWG conclusions. More details on these results are found in Reference [6.3].

For this specific study, a new bias equation based solely on the high enrichment criticals (Uranium-235 enrichment > 90%) would be developed here. The data set used are the Handley-Hopper Y-1858 Criticals [6.1], Oak Ridge Critical [6.19], and Gwin Criticals [6.20]. The Handley-Hopper Y-1858 Criticals had been provided to the NRC earlier in the GEMER topical submittal [6.1] and would not be elaborated here. The selected Oak Ridge Critical consists of a single 93% enriched uranyl fluoride sphere. The sphere is unreflected and has a diameter of 32.0 cm. This critical was chosen for its H/U ratio of 203. The Gwin Criticals consist of a set of criticals using aqueous uranyl nitrate solution with and without boric acid in a unreflected bare sphere. These criticals are useful for the verification of boron poisons used in the MTR-type of fuel. Table 6.54 tabulates the predictions by GEMER runs.

Figure 6.19 shows the critical data points used to develop the bias equation below. The bias equation developed is highly conservative as we used the k-effective with 3 standard deviations deducted from it (i.e., k-effective - 3.0*sigma).

From the GWIN critical results in Table 6.54, the average k-effective for the non-boron cases (GWIN-1, 5, 10, and 11) is 0.99529. The average k-effective for the boron cases (GWIN-2, 3, 4, 6, 7, 8, and 9) is 0.994487. It is noted that the difference between the non-boron and boron cases is very small, showing negligible bias uncertainty caused by the boron.

The bias equation as a function of H/U-235 ratio in the fuel (defined as the x variable) is as follows:

$$\boldsymbol{Bias = (1.0*10^{-8} *x^2 - 2.0*10^{-5} *x + 1.0006) - 1.0000} \qquad (3)$$

where

$Bias = 0$ if positive

$= -Bias$ if negative.

Table 6.54. Criticals Used in Bias Determination

File	Refer-ence	Fuel	Enrich-ment	Moderator	Reflector	H/U^{235}	k_{eff}	sigma
HH-A1	1	U	93.8	None	bare	0	1.01571	0.00277
HH-A2	1	Alloy	93.2	None	bare	0	1.02836	0.00385
HH-A3	1	Alloy	93.2	None	bare	0	1.01769	0.00284
HH-A4	1	UO2F2	93.2	None	bare	1393	0.99600	0.00292
HH-A5	1	UNH	93.2	None	bare	1378	0.98933	0.00283
HH-A6	1	U	93.5	None	water	0	1.01076	0.00385
HH-A7	1	U	93.2	None	graphite	0	1.01843	0.00409
HH-A8	1	U	93.2	None	graphite	0	1.01669	0.00368
HH-A9	1	U	94.0	None	U-natural	0	1.00847	0.00600
HH-A10	1	U	93.1	None	oil	0	0.99622	0.00834
HH-A11	1	U	93.1	None	oil	0	1.02162	0.00488
HH-A12	1	U	93.1	None	oil	0	1.00934	0.00354
HH-A13	1	U	93.1	None	oil	0	1.00842	0.00428
HH-A14	1	Alloy	93.3	None	bare	0	1.02222	0.00354
HH-A18	1	U	93.3	None	bare	0	1.00843	0.00363
HH-A19	1	U	93.3	None	bare	0	1.02152	0.00255
HH-A20	1	U	97.7	None	water	0	1.01032	0.00351
HH-A21	1	UNH	93.2	Water	bare	71	1.00185	0.00483
HH-B1	1	U	93.2	None	bare	0	1.01572	0.00355
HH-B2	1	U	93.2	None	bare	0	1.02861	0.00397
HH-B3	1	U	93.2	None	bare	0	1.00044	0.00278
HH-B4	1	U	93.2	None	bare	0	1.00894	0.00292
HH-B5	1	U	93.2	None	bare	0	1.00724	0.00361
HH-B6	1	U	93.2	None	bare	0	1.00797	0.00280
HH-B7	1	U	93.2	None	bare	0	1.00530	0.00261
HH-B8	1	U	93.2	None	bare	0	1.01989	0.00292

Table 6.54. Criticals Used in Bias Determination (Continued)

File	Refer-ence	Fuel	Enrich-ment	Moderator	Reflector	H/U^{235}	k_{eff}	sigma
HH-B9	1	U	93.2	None	paraffin	0	1.00538	0.00388
HH-B10	1	U	93.2	None	paraffin	0	1.00693	0.00367
HH-B11	1	U	93.2	Plexi	bare	0	1.01440	0.00337
HH-B12	1	U	93.2	Plexi	paraffin	0	1.00969	0.00417
HH-B13	1	UNH	92.6	Water	bare	59	1.01503	0.00483
HH-B14	1	UNH	92.6	Water	bare	440	1.00001	0.00392
HH-B15	1	UNH	93.2	Water	plex	45	1.03203	0.00481
HH-B16	1	U	93.2	Graphite	poly	0	1.02205	0.00408
HH-B17	1	UNH	92.6	Water	bare	59	0.97689	0.00330
HH-B18	1	UNH	92.6	Water	paraffin	59	1.00803	0.00422
HH-B19	1	UNH	92.6	Water	plexi	59	0.99710	0.00456
HH-B20	1	UNH	93.0	Water	bare	51	1.02239	0.00669
HH-B21	1	UNH	93.2	Water	plexi	69	1.02162	0.00502
HH-B22	1	UNH	93.2	Water	concrete	69	1.02006	0.00436
ORNL-17	19	UO2F2	93.0	Water	None	203	0.99373	0.00087
GWIN-1	20	U Nitrate no boron	93.0	Water	None	1378	0.99308	0.00050
GWIN-2	20	U Nitrate boron	93.0	Water	None	1177	0.99206	0.00050
GWIN-3	20	U Nitrate boron	93.0	Water	None	1033	0.98844	0.00049
GWIN-4	20	U Nitrate boron	93.0	Water	None	972	0.98943	0.00050
GWIN-5	20	U Nitrate no boron	93.0	Water	None	1533	1.00029	0.00085
GWIN-6	20	U Nitrate boron	93.0	Water	None	1470	0.99977	0.00084
GWIN-7	20	U Nitrate boron	93.0	Water	None	1417	0.99664	0.00088

Table 6.54. Criticals Used in Bias Determination (Continued)

File	Refer-ence	Fuel	Enrich-ment	Moderator	Reflector	H/U^{235}	k_{eff}	sigma
GWIN-8	20	U Nitrate boron	93.0	Water	None	1368	0.99857	0.00091
GWIN-9	20	U Nitrate boron	93.0	Water	None	1324	0.99650	0.00049
GWIN-10	20	U Nitrate no boron	93.0	Water	None	1835	0.99244	0.00032
GWIN-11	20	U Nitrate no boron	93.0	Water	None	1986	0.99535	0.00030

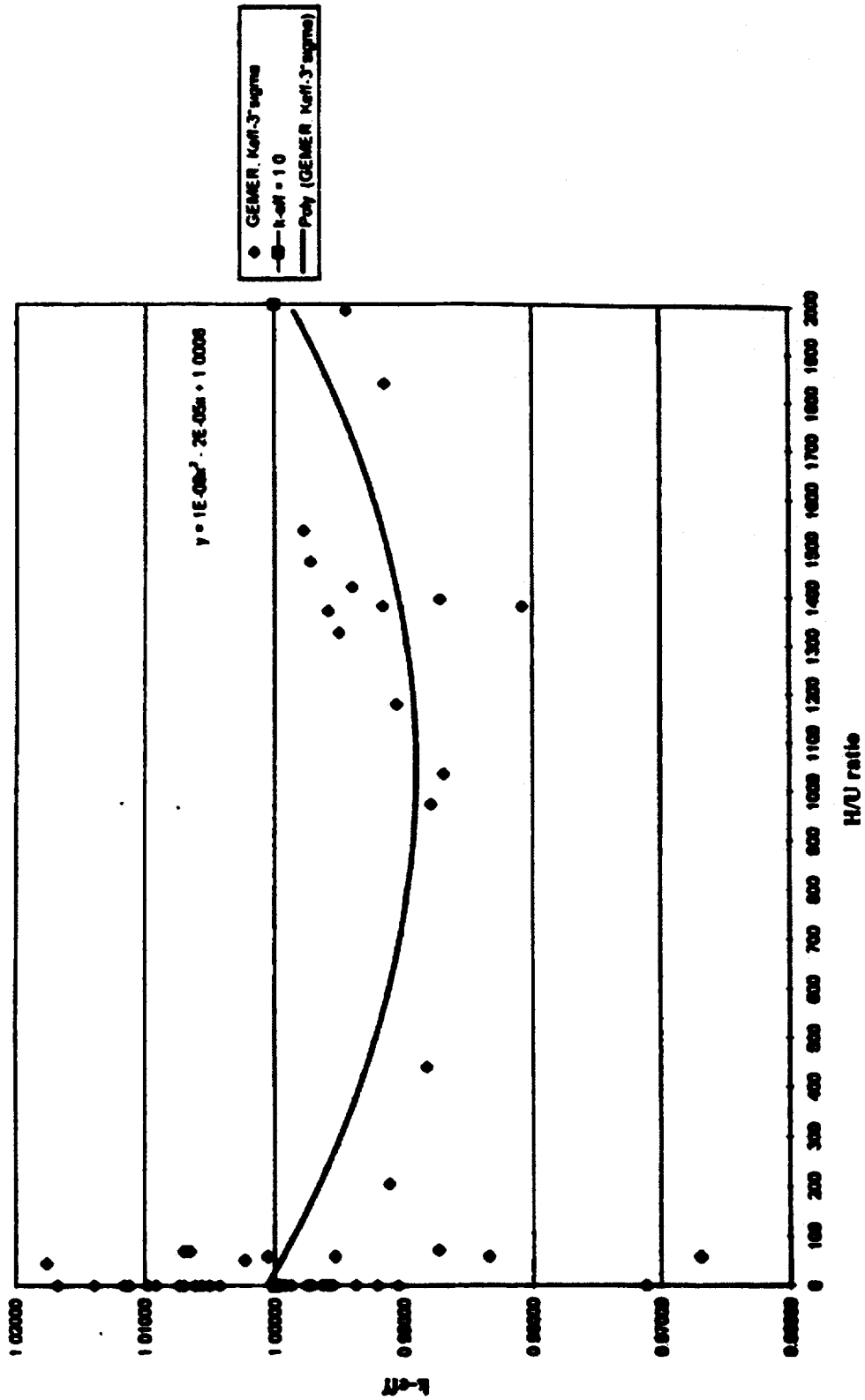


Figure 6.19. Flux-Weighted Bias Curve

6.5.1.2 Other Critical Experiments

GEMER has been benchmarked against critical experiments conducted with HFIR fuel [6.4]. These experiments are relevant in that HFIR fuel shares some important characteristics with the MTR type fuel considered here (i.e., HFIR fuel is constructed of U_3O_8 and aluminum plates, though the configuration of the fuel elements is somewhat unique). In the comparisons, GEMER overestimated the reactivity of the HFIR fuel. This overestimation, at least in part, can be attributed to the treatment (homogenization) of the HFIR fuel plates. As mentioned previously, this implies that the treatment of the fuel region in this analysis (for MTR-type fuel) is conservative.

6.6 REFERENCES

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6.7 APPENDIX

6.7.1 Input/Output — MTR-Type Fuels

6.7.1.1 Case I Fuel (U_3O_8)

6.7.1.1.1 GEMER Input Decks

This Appendix includes GEMER geometrical plots and input listings for the single container, normal array, accident array, and infinite array for MTR Case I fuel. Each basedeck contains a "header" with fuel material and geometry information. Since the program input is similar to the popular KENO program (and deviations from this were discussed previously) no further explanation of the inputs is provided.

6.7.1.1.1.1 Normal (93.2% Enriched U3O8)

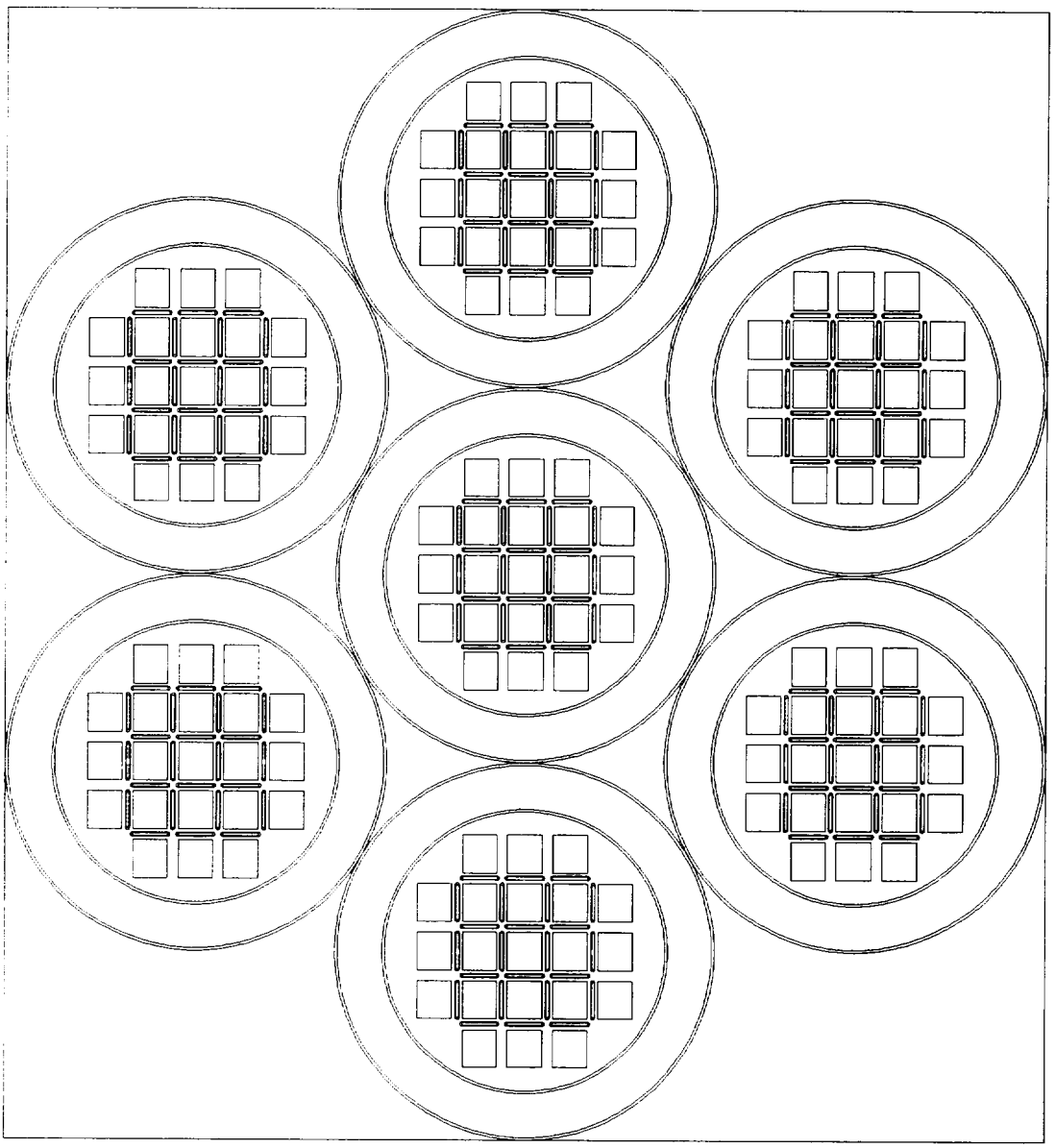

Figure 6.20. Normal Container for MTR Case I Fuel — Top View

```
CASE I FUEL/ IF2000/21 ELEMENTS, SS+Pb SHIELDING. WFH2O IN FUEL=0.05
MASS U235 IN EACH ELEM=710G
    65 /* # BATCHES
  1000  /* # NEUTRONS PER BATCH
    5  /* # BATCHES TO SKIP
 2123469/* INITIAL "SEED" (IF NON-ZERO)
     0  /* "IDUMP"
     0  /* "NRSTRT"
     0  /* "NBTED" (NON-ZERO IS PRINT EDITS)
     0  /* "KRED" (NUMBER OF COMBINED REGIONS IN EDITS)
     0  293   14  7
      5  293 0  0 U(93.2)3O8+0.05 WF -H2O RHOMIX=2.79340 g/cc     MAT 1
       1  9.3454784E-03
      16  7.5232312E-03
     131  4.8222743E-02
    2381  7.1818627E-05
    2351  9.9711574E-04
      4  293 0 0 Boral 0.25" Plate +/- 10% (60% Boron Loading)  MAT 2
    10    3.32658E-03
    11    6.7889E-05
   131   5.8001E-02
      2  293 0 0  MODERATOR IN CASK (5.00%)                    MAT 3
     1   3.34555656E-03
    16   1.67277878E-03
      2  293 0 0  INTERSPERSED MODERATOR (0.00%)            MAT4
     1   1.00000000E-09
    16   1.00000000E-09
      2  293 0 0 FULL DENSITY WATER                     MAT 5
     1    6.69111121E-02

  16    3.34555566E-02
      1  293 0 0 LEAD SHIELDING                         MAT 6
    82   3.29890E-02
      7  293 0 0 304 STAINLESS STEEL                    MAT 7
    12   6.82690E-05
    14   8.53360E-04
    24   1.53600E-02
    26   6.04950E-02
    28   6.82690E-03
    55   1.70670E-03
  1316   2.56010E-05
KENO GEOM
    14  /* "KREFM"
     6  /* "NBOX"
     1  /* "NBXMAX"
     1  /* "NBYMAX"
     1  /* "NBZMAX"
     0  /* "NXX"
     0  /* "NTYPST"
     1  /* "NEMBRG"
     0  /* "NGMCHK"
BOX TYPE      1 /*MODEL 2000 CASK & STAINLESS SUPPORT STRUCTURE
CYLINDER      7  33.34     140.64      0.0     16*0.5
CYLINDER      3  33.65     140.64      0.0     16*0.5
CYLINDER      7  35.85     140.64      0.0     16*0.5
CYLINDER      6  46.34     140.64      0.0     16*0.5
CYLINDER      7  48.56     140.64   -14.90     16*0.5
BOX TYPE      2 /* CASK TOP
CYLINDER      6  30.96     158.42    140.64   16*0.5
CYLINDER      7  48.56     162.23    140.64   16*0.5
BOX TYPE      3 /* NBSR FUEL ASSEMBLY-COLLAPSED
```

```
 CUBOID        1  4.4450 -4.4450  4.0005  -4.0005  25.65309  0.0   16*0.5
CUBOID        3  4.4450 -4.4450  4.0005  -4.0005  140.64  0.0   16*0.5
BOX TYPE      4 /* BORAL PLATE (VERT)
CUBOID        2  0.286  -0.286  4.12  -4.12  138.64  2.0   16*0.5
BOX TYPE      5 /* BORAL PLATE (HORIZ)
CUBOID        2  4.12  -4.12  0.286  -0.286  138.64  2.0   16*0.5
BOX TYPE      6  /* OVERALL BOX FOR THE PROBLEM
CUBOID        4  146.80  -146.80  133.70  -133.70  162.30  -15.24  16*0.5
CORE          0  146.80  -146.80  133.70  -133.70  162.30  -15.24  16*0.5
CUBOID        5  177.30  -177.30  164.20  -164.20  192.80  -45.74  16*0.5
6  1 1 1  1 1 1  1 1 1  1
BEGIN COMPLEX
/* PLACE FUEL ASSEMBLIES INTO CASK
COMPLEX  1  3   -22.860  -10.540  0.0  5  3  1  11.430  10.540  0.0
/*MIDDLE ROWS
COMPLEX  1  3   -11.430  -21.080  0.0  3  2  1  11.430  42.160  0.0
/*OUTER ROWS
/* PLACE BORAL PLATES INTO CASK
COMPLEX  1  4   -17.145  -10.540  0.0  4  3  1  11.430  10.540  0.0
/*VERT PLATES
COMPLEX  1  5   -11.430  -15.810  0.0  3  4  1  11.430  10.540  0.0
/*HORIZ PLATES
/* PLACE 7 LOADED CASKS INTO OVERALL PROBLEM BOX
COMPLEX  6  1    -97.5    0.0    0.0   3 1 1   97.5    0.0   0.0
/*MIDDLE ROW
COMPLEX  6  1    -48.8  -84.4    0.0   2 2 1   97.5  168.9   0.0 /*OUTER
ROW
/* PLACE TOPS INTO OVERALL PROBLEM BOX
COMPLEX  6  2    -97.5    0.0    0.0   3 1 1   97.5    0.0   0.0
/*MIDDLE ROW
COMPLEX  6  2    -48.8  -84.4    0.0   2 2 1   97.5  168.9   0.0 /*OUTER
ROW
END GEOM
*END GEMER*
```

6.7.1.1.1.2 Single (93.2% Enriched U3O8)

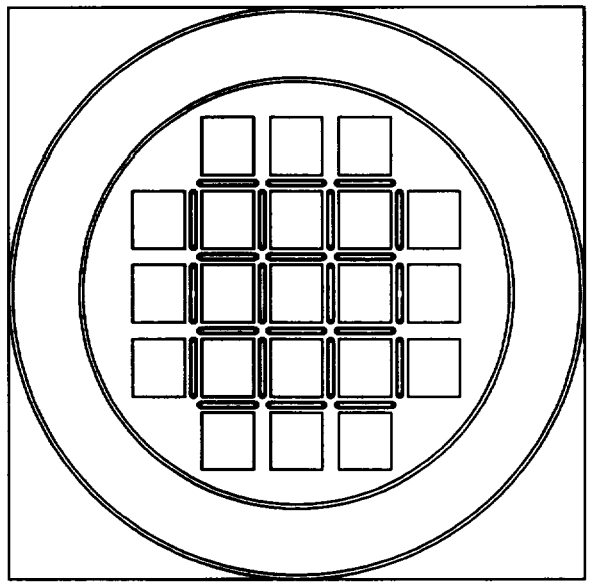

Figure 6.21. Single Container for MTR Case I Fuel — Top View

```
CASE I FUEL/ IF2000/21 ELEMENTS, SS+Pb SHIELDING. WFH2O IN FUEL=0.45
MASS U235 IN EACH ELEM=710G
    65 /* # BATCHES
  1000  /* # NEUTRONS PER BATCH
    5  /* # BATCHES TO SKIP
 2123469/* INITIAL "SEED" (IF NON-ZERO)
     0  /* "IDUMP"
     0  /* "NRSTRT"
     0  /* "NBTED" (NON-ZERO IS PRINT EDITS)
     0  /* "KRED" (NUMBER OF COMBINED REGIONS IN EDITS)
     0  293   14  7
      5  293 0  0 U(93.2)3O8+0.45 WF -H2O RHOMIX=1.591576 g/cc     MAT 1
      1  4.7922347E-02
     16  2.4901444E-02
    131  1.5906887E-02
   2381  2.3690292E-05
   2351  3.2891135E-04
      4  293 0 0 Boral 0.25" Plate +/- 10% (60% Boron Loading)  MAT 2
     10   3.32658E-03
     11   6.7889E-05
    131  5.8001E-02
      2  293 0 0  MODERATOR IN CASK (100.00%)                    MAT 3
      1  6.69111121E-02
     16  3.34555566E-02
      2  293 0 0  INTERSPERSED MODERATOR (100.00%)            MAT4
      1  6.69111121E-02
     16  3.34555566E-02
      2  293 0 0 FULL DENSITY WATER                     MAT 5
```

```
     1    6.69111121E-02
  16    3.34555566E-02
     1  293 0 0 LEAD SHIELDING                          MAT 6
    82   3.29890E-02
     7  293 0 0 304 STAINLESS STEEL                     MAT 7
    12   6.82690E-05
    14   8.53360E-04
    24   1.53600E-02
    26   6.04950E-02
    28   6.82690E-03
    55   1.70670E-03
  1316   2.56010E-05
KENO GEOM
    14  /* "KREFM"
     6  /* "NBOX"
     1  /* "NBXMAX"
     1  /* "NBYMAX"
     1  /* "NBZMAX"
     0  /* "NXX"
     0  /* "NTYPST"
     1  /* "NEMBRG"
     0  /* "NGMCHK"
BOX TYPE      1 /*MODEL 2000 CASK & STAINLESS SUPPORT STRUCTURE
CYLINDER      7  33.34     140.64     0.0    16*0.5
CYLINDER      3  33.65     140.64     0.0    16*0.5
CYLINDER      7  35.85     140.64     0.0    16*0.5
CYLINDER      6  46.34     140.64     0.0    16*0.5
CYLINDER      7  48.56     140.64   -14.90   16*0.5
BOX TYPE      2 /* CASK TOP
CYLINDER      6  30.96     158.42    140.64  16*0.5
CYLINDER      7  48.56     162.23    140.64  16*0.5
BOX TYPE      3 /* NBSR FUEL ASSEMBLY-COLLAPSED
 CUBOID        1  4.4450 -4.4450  4.0005  -4.0005  77.76897  0.0   16*0.5
CUBOID        3  4.4450 -4.4450  4.0005  -4.0005  140.64  0.0   16*0.5
BOX TYPE      4 /* BORAL PLATE (VERT)
CUBOID        2  0.286  -0.286  4.12  -4.12  138.64  2.0   16*0.5
BOX TYPE      5 /* BORAL PLATE (HORIZ)
CUBOID        2  4.12  -4.12  0.286  -0.286  138.64  2.0   16*0.5
BOX TYPE      6  /* OVERALL BOX FOR THE PROBLEM
CUBOID        4  48.60    -48.60   48.60 -48.60 162.23 -15.24 16*0.5
CORE          0  48.60    -48.60   48.60 -48.60 162.23 -15.24 16*0.5
CUBOID        5  79.10    -79.10   79.10 -79.10 192.71 -45.72 16*0.5
6  1 1 1  1 1 1  1 1 1  1
BEGIN COMPLEX
/* PLACE FUEL ASSEMBLIES INTO CASK
COMPLEX  1  3   -22.860  -10.540  0.0  5  3  1  11.430  10.540  0.0
/*MIDDLE ROWS
COMPLEX  1  3   -11.430  -21.080  0.0  3  2  1  11.430  42.160  0.0
/*OUTER ROWS
/* PLACE BORAL PLATES INTO CASK
COMPLEX  1  4   -17.145  -10.540  0.0  4  3  1  11.430  10.540  0.0
/*VERT PLATES
COMPLEX  1  5   -11.430  -15.810  0.0  3  4  1  11.430  10.540  0.0
/*HORIZ PLATES
/* PLACE LOADED CASK INTO OVERALL PROBLEM BOX
COMPLEX  6  1  0.0     0.0    0.0   1 1 1   0.0    0.0    0.0
/* PLACE TOP INTO OVERALL PROBLEM BOX
COMPLEX  6  2  0.0     0.0    0.0   1 1 1   0.0    0.0    0.0
END GEOM
*END GEMER*
```

6.7.1.1.1.3 Accident (93.2% Enriched U3O8)

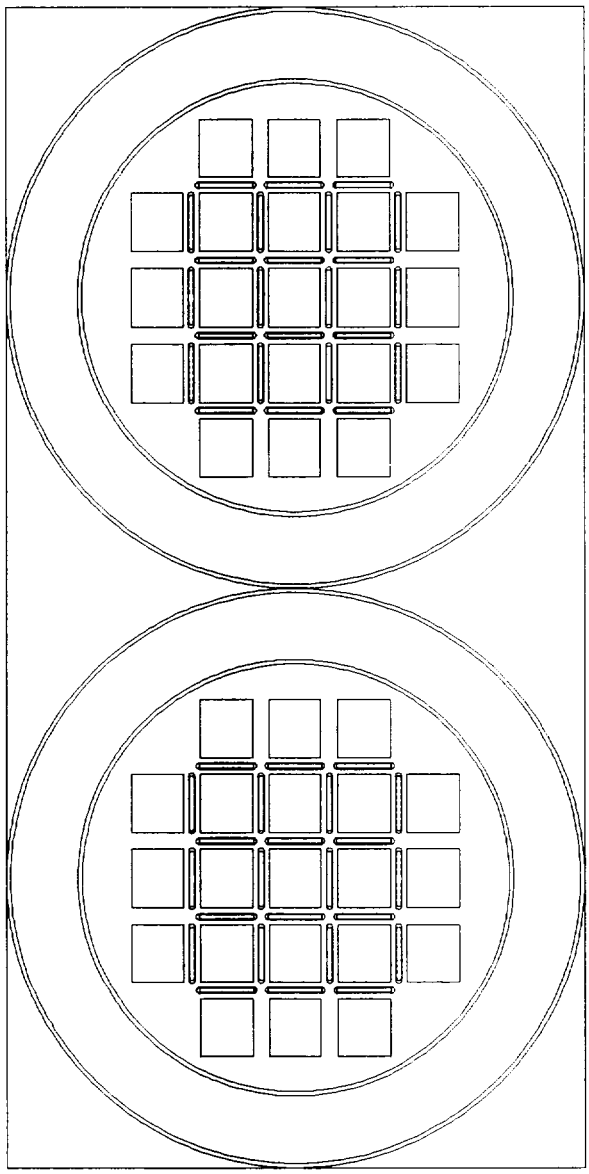

Figure 6.22. Accident Array for MTR Case I Fuel — Top View

```
CASE I FUEL/ IF2000/21 ELEMENTS, SS+Pb SHIELDING. WFH2O IN FUEL=0.45
MASS U235 IN EACH ELEM=710G
    65 /* # BATCHES
  1000  /* # NEUTRONS PER BATCH
    5  /* # BATCHES TO SKIP
 2123469/* INITIAL "SEED" (IF NON-ZERO)
     0  /* "IDUMP"
     0  /* "NRSTRT"
     0  /* "NBTED" (NON-ZERO IS PRINT EDITS)
     0  /* "KRED" (NUMBER OF COMBINED REGIONS IN EDITS)
     0  293   14  7
      5  293 0  0 U(93.2)3O8+0.45 WF -H2O RHOMIX=1.591576 g/cc     MAT 1
       1  4.7922347E-02
      16  2.4901444E-02
     131  1.5906887E-02
    2381  2.3690292E-05
    2351  3.2891135E-04
      4  293 0 0 Boral 0.25" Plate +/- 10% (60% Boron Loading)  MAT 2
    10    3.32658E-03
    11    6.7889E-05
   131   5.8001E-02
      2  293 0 0  MODERATOR IN CASK (100.0%)                    MAT 3
     1    6.69111121E-02
    16    3.34555566E-02
      2  293 0 0  INTERSPERSED MODERATOR (100.0%)            MAT4
     1    6.69111121E-02
    16    3.34555566E-02
      2  293 0 0 FULL DENSITY WATER                    MAT 5
     1    6.69111121E-02

  16    3.34555566E-02
      1  293 0 0 LEAD SHIELDING                        MAT 6
    82   3.29890E-02
      7  293 0 0 304 STAINLESS STEEL                   MAT 7
    12   6.82690E-05
    14   8.53360E-04
    24   1.53600E-02
    26   6.04950E-02
    28   6.82690E-03
    55   1.70670E-03
  1316   2.56010E-05
KENO GEOM
    14  /* "KREFM"
     6  /* "NBOX"
     1  /* "NBXMAX"
     1  /* "NBYMAX"
     1  /* "NBZMAX"
     0  /* "NXX"
     0  /* "NTYPST"
     1  /* "NEMBRG"
     0  /* "NGMCHK"
BOX TYPE     1 /*MODEL 2000 CASK & STAINLESS SUPPORT STRUCTURE
CYLINDER     7  33.34     140.64     0.0    16*0.5
CYLINDER     3  33.65     140.64     0.0    16*0.5
CYLINDER     7  35.85     140.64     0.0    16*0.5
CYLINDER     6  46.34     140.64     0.0    16*0.5
CYLINDER     7  48.56     140.64   -14.90   16*0.5
BOX TYPE     2 /* CASK TOP
CYLINDER     6  30.96     158.42    140.64  16*0.5
CYLINDER     7  48.56     162.23    140.64  16*0.5
BOX TYPE     3 /* NBSR FUEL ASSEMBLY-COLLAPSED
```

```
 CUBOID        1  4.4450 -4.4450  4.0005  -4.0005  77.76897  0.0   16*0.5
CUBOID        3  4.4450 -4.4450  4.0005  -4.0005  140.64  0.0   16*0.5
BOX TYPE      4 /* BORAL PLATE (VERT)
CUBOID        2  0.286  -0.286  4.12  -4.12  138.64  2.0   16*0.5
BOX TYPE      5 /* BORAL PLATE (HORIZ)
CUBOID        2  4.12  -4.12  0.286  -0.286  138.64  2.0   16*0.5
BOX TYPE      6  /* OVERALL BOX FOR THE PROBLEM
CUBOID        4  97.20    -97.20   48.60 -48.60 162.23 -15.24 16*0.5
CORE          0  97.20    -97.20   48.60 -48.60 162.23 -15.24 16*0.5
CUBOID        5  127.70  -127.70   79.10 -79.10 192.73 -45.74 16*0.5
6  1 1 1  1 1 1  1 1 1  1
BEGIN COMPLEX
/* PLACE FUEL ASSEMBLIES INTO CASK
COMPLEX  1  3   -22.860  -10.540  0.0  5  3  1  11.430  10.540  0.0
/*MIDDLE ROWS
COMPLEX  1  3   -11.430  -21.080  0.0  3  2  1  11.430  42.160  0.0
/*OUTER ROWS
/* PLACE BORAL PLATES INTO CASK
COMPLEX  1  4   -17.145  -10.540  0.0  4  3  1  11.430  10.540  0.0
/*VERT PLATES
COMPLEX  1  5   -11.430  -15.810  0.0  3  4  1  11.430  10.540  0.0
/*HORIZ PLATES
/* PLACE 2 LOADED CASKS INTO OVERALL PROBLEM BOX
COMPLEX  6  1  -48.6     0.0    0.0   2 1 1   97.2    0.0    0.0
/* PLACE TOPS INTO OVERALL PROBLEM BOX
COMPLEX  6  2  -48.6     0.0    0.0   2 1 1   97.2    0.0    0.0
END GEOM
*END GEMER*
```

6.7.1.1.1.4 Infinite (94% Enriched U3O8)

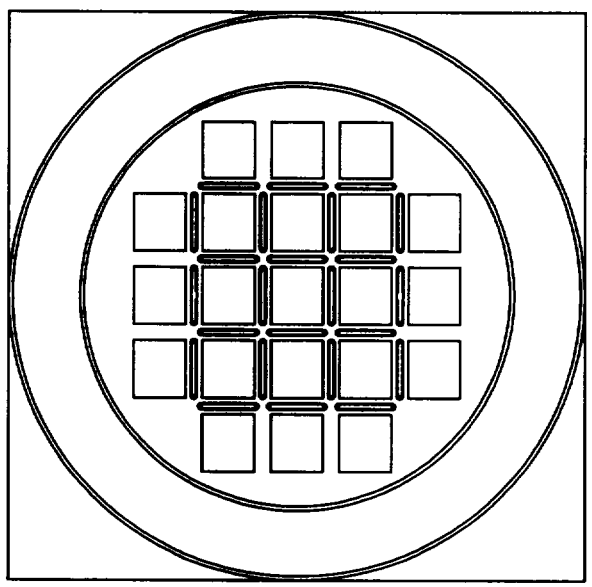

Figure 6.23. Unit Array for MTR Case I Fuel — Top View

```
NBSR FUEL/ IF2000/21 ELEMENTS, SS+Pb SHIELDING. WFH2O IN FUEL=0.45 MASS
U235 IN EACH ELEM=710G
   605 /* # BATCHES
  1000  /* # NEUTRONS PER BATCH
     5  /* # BATCHES TO SKIP
 2123469/* INITIAL "SEED" (IF NON-ZERO)
     0  /* "IDUMP"
     0  /* "NRSTRT"
     0  /* "NBTED" (NON-ZERO IS PRINT EDITS)
     0  /* "KRED" (NUMBER OF COMBINED REGIONS IN EDITS)
     0  293   14  8
      5  293 0  0 U(94.0)3O8+0.45 WF -H2O RHOMIX=1.589857 g/cc     MAT 1
      1  4.7870591E-02
     16  2.4870202E-02
    131  1.5906820E-02
   2381  2.0781777E-05
   2351  3.2980787E-04
      3  293 0 0 Boral 0.25" Plate (60% Boron Loading)  MAT 2
     10    3.32658E-03
     11    6.7889E-05
    131    5.8001E-02
      2  293 0 0  MODERATOR IN CASK (100.00%)                    MAT 3
      1   6.69111121E-02
     16   3.34555566E-02
      2  293 0 0  INTERSPERSED MODERATOR (100.00%)            MAT4
      1   6.69111121E-02
     16   3.34555566E-02
      2  293 0 0 FULL DENSITY WATER                     MAT 5
      1    6.69111121E-02
     16    3.34555566E-02
      1  293 0 0 LEAD SHIELDING                         MAT 6
     82   3.29890E-02
      7  293 0 0 304 STAINLESS STEEL                    MAT 7
     12   6.82690E-05
     14   8.53360E-04
     24   1.53600E-02
     26   6.04950E-02
     28   6.82690E-03
     55   1.70670E-03
   1316   2.56010E-05
      2  293 0 0 FULL DENSITY WATER (VOID)              MAT 8
      1    6.69111121E-09
     16    3.34555566E-09
KENO GEOM
     14  /* "KREFM"
      6  /* "NBOX"
      1  /* "NBXMAX"
      1  /* "NBYMAX"
      1  /* "NBZMAX"
      1  /* "NXX"
      0  /* "NTYPST"
      1  /* "NEMBRG"
      0  /* "NGMCHK"
 -1.0  -1.0  -1.0  -1.0  -1.0  -1.0
BOX TYPE      1 /*MODEL 2000 CASK & STAINLESS SUPPORT STRUCTURE
CYLINDER      7  33.34      140.64      0.0     16*0.5
CYLINDER      3  33.65      140.64      0.0     16*0.5
CYLINDER      7  35.85      140.64      0.0     16*0.5
CYLINDER      6  46.34      140.64      0.0     16*0.5
CYLINDER      7  48.56      140.64    -14.90    16*0.5
```

```
BOX TYPE      2 /* CASK TOP
CYLINDER      6  30.96     158.42    140.64  16*0.5
CYLINDER      7  48.56     162.23    140.64  16*0.5
BOX TYPE      3 /* NBSR FUEL ASSEMBLY-COLLAPSED
CUBOID        1  4.4450 -4.4450  4.0005  -4.0005  77.55756  0.0   16*0.5
CUBOID        3  4.4450 -4.4450  4.0005  -4.0005  140.64  0.0   16*0.5
BOX TYPE      4 /* BORAL PLATE (VERT)
CUBOID        2  0.286  -0.286  4.12  -4.12  138.64  2.0   16*0.5
BOX TYPE      5 /* BORAL PLATE (HORIZ)
CUBOID        2  4.12  -4.12  0.286  -0.286  138.64  2.0   16*0.5
BOX TYPE      6  /* OVERALL BOX FOR THE PROBLEM
CUBOID        8  48.60    -48.60   48.60 -48.60 162.23 -14.91 16*0.5
CORE          0  48.60    -48.60   48.60 -48.60 162.23 -14.91 16*0.5
CUBOID        8  48.70    -48.70   48.70 -48.70 162.33 -15.01 16*0.5
6  1 1 1  1 1 1  1 1 1  1
BEGIN COMPLEX
/* PLACE FUEL ASSEMBLIES INTO CASK
COMPLEX  1  3   -22.860  -10.540  0.0  5  3  1  11.430  10.540  0.0
/*MIDDLE ROWS
COMPLEX  1  3   -11.430  -21.080  0.0  3  2  1  11.430  42.160  0.0
/*OUTER ROWS
/* PLACE BORAL PLATES INTO CASK
COMPLEX  1  4   -17.145  -10.540  0.0  4  3  1  11.430  10.540  0.0
/*VERT PLATES
COMPLEX  1  5   -11.430  -15.810  0.0  3  4  1  11.430  10.540  0.0
/*HORIZ PLATES
/* PLACE LOADED CASK INTO OVERALL PROBLEM BOX
COMPLEX  6  1  0.0     0.0    0.0   1 1 1   0.0    0.0    0.0
/* PLACE TOP INTO OVERALL PROBLEM BOX
COMPLEX  6  2  0.0     0.0    0.0   1 1 1   0.0    0.0    0.0
END GEOM
*END GEMER*
```

6.7.1.1.2 Number Density Calculations

6.7.1.1.2.1 FORTRAN Program (MTR Case I Fuel)

```
PROGRAM NUMBER
C
C   ASSUMPTIONS:
C   1. THE FUEL AND WATER ARE IN A HOMOGENOUS MIXTURE.
C
C
C
       REAL NAL_CLAD,MAL
       REAL MU235,M238,MO16,MH2O,MH
       REAL MU,MUOLD
       REAL MU3O8
       REAL NELEMTOT,NELEMACT
       REAL N235,N238,N16,N131,N1
       OPEN(6,FILE='NBSR_E94.OUT',STATUS='UNKNOWN')
C
C    FOR U3O8 FUEL
C
C    NUMBER DENSITY PROGRAM FOR HFBR/NBSR
C    SEE VARIABLE ICASE
C
C      10/14/94
C      AV = AVOGADRO'S NUMBER
```

```
C
       AV=0.6022
      M235 =235.0439
      M238 =238.0508
      MAL = 26.98
      MO16 = 16.000
      MH2O=18.0
      MH=1.0
C
C   ITER VARIABLE FOR VARYING THE WATER WEIGHT FRACTION
C
C      DO 100 ITER=0,28
C      DO 100 ITER=0,70
      DO 100 ITER=0,14
      DO 200 II=1,1
      WRITE(6,*) ' ************************************'
C
C    D  = ACTIVE FUEL LENGTH (IN)
C    E  = CLADDING THICKNESS (IN)
C    C  = PLATE LENGTH (IN)
C    G  = PLATE THICKNESS (IN)
C    F  = ACTIVE FUEL THICKNESS (IN)
C    RHOU3O8 = DENSITY OF U3O8 (G/CC)
C    RHOCLAD = DENISTY OF AL CLAD (G/CC)
C     WF= WEIGHT % OF U3O8  IN THE U3O8/AL MIXTURE
C     WFWATER = WEIGHT FRACTION OF WATER
C      ENRICH = FUEL ENRICHMENT
C     ELEMH = ELEMENT HEIGHT IN INCHES
C    NELEMACT = NUMBER OF ACTIVE FUEL ELEMENTS
C    NELEMTOT = TOTAL NUMBER OF ELEMENTS
C-----------------------------------------------------
C
C     ICASE=1    HFBR
C          =2    NBSR
C-----------------------------------------------------
       ICASE=2
C*****************************************************
C      HFBR
C
       IF (ICASE.EQ.1) THEN
       D=2.236
       E=0.014
       C=2.611
       G=0.050
       F=0.023
       RHOU3O8 = 8.20
C       ENRICH = 0.932
       ENRICH = 0.940
       WF=0.368
       WFWATER=0.025*FLOAT(ITER)
C
C      (ORIGINAL LICENSED LIMIT)
       U235MAS=710.0
C
C       U235MAS=690.0
C       ELEMH=22.50
       ELEMH=22.0-0.10*FLOAT(II)
       NELEMTOT=19.0
       NELEMACT=19.0
       END IF
C
```

```
C ----------------------------------------------------
C       NBSR
        IF (ICASE.EQ.2) THEN
        D=2.415
        E=0.015
        C=2.625
        G=0.050
        F=0.020
        RHOU3O8 = 8.20
C        ENRICH = 0.932
C        ENRICH = U-235 ENRICHMENT
C
C     94 % ENRICHMENT
C
        ENRICH = 0.940
        WF=0.416
        WFWATER=0.050*FLOAT(ITER)
C        WFWATER=0.025*FLOAT(ITER)
C        WFWATER=0.010*FLOAT(ITER)
C
C        ELEMH=21.46+0.001*FLOAT(II)
C
        ELEMH=21.467
C    NBSR CASE
C     ORIGINAL LICENSED CASE
C
        U235MAS=710.0
C        U235MAS=680.0
        NELEMTOT=17.0
        NELEMACT=17.0
        END IF
C----------------------------------------------------
C    AREASLOT = SLOT AREA PER ELEMENT (cm^2)
C
        RHOWATER=1.0
        RHOH2O = 1.0
        RHOCLAD=2.7
        AREASLOT=71.12889
C
C
        WRITE(6,*) ' ICASE =',ICASE
       IF (ICASE.EQ.1) WRITE(6,*) '  HFBR CASE'
       IF (ICASE.EQ.2) WRITE(6,*) '  NBSR CASE'
       WRITE(6,*) ' ELEMENT HEIGHT=',ELEMH
       WRITE(6,*) ' RHOH2O =',RHOH2O
       WRITE(6,*) ' ENRICH =',ENRICH
       WRITE(6,*) ' WF     =',WF
       WRITE(6,*) ' WFWATER=',WFWATER
       WRITE(6,*) ' RHOU3O8=',RHOU3O8
       WRITE(6,*) ' RHOCLAD=',RHOCLAD
C
C       HFBR
C
        IF(ICASE.EQ.1) THEN
        AELEMENT=C*G*2.54*2.54
        AMEAT=D*F*2.54*2.54
        ACLAD=AELEMENT-AMEAT
        END IF
C
C       NBSR
C
```

```
      IF(ICASE.EQ.2) THEN
      AELEMENT=C*G*2.54*2.54
      AMEAT=D*F*2.54*2.54
      ACLAD=AELEMENT-AMEAT
      END IF
C
      WRITE(6,*) ' '
      WRITE(6,*) '  FOR EACH UNIT ELEMENT'
      WRITE(6,*) '   ACLAD   AMEAT AELEMENT (CM2)'
      WRITE(6,*) ACLAD,AMEAT,AELEMENT
C
C-----------------------------------------------
      U238MAS=U235MAS/ENRICH - U235MAS
C
      MU= 1.0/(ENRICH/M235 + (1.0-ENRICH)/M238)
      F2=3.0*MU/(3.0*MU + 8.0*MO16)
      U3O8MAS=(U235MAS+U238MAS)/F2
      O16MAS=U3O8MAS-(U235MAS+U238MAS)
      WRITE(6,*) ' O16(FUEL) MASS =',O16MAS
      WRITE(6,*) ' U238      MASS =',U238MAS
      WRITE(6,*) ' U235      MASS =',U235MAS
      WRITE(6,*) ' U3O8      MASS =',U3O8MAS
C
      ALFUEL=U3O8MAS/WF*(1.0-WF)
      ALCLAD=ACLAD*(ELEMH*2.0*2.54)*NELEMTOT*RHOCLAD
      ALTOTAL=ALCLAD+ALFUEL
      WRITE(6,*) ' AL MASS IN FUEL =',ALFUEL
      WRITE(6,*) ' AL MASS IN CLAD =',ALCLAD
      WRITE(6,*) ' AL MASS (TOTAL) =',ALTOTAL
C
      TOTAL1 = ALTOTAL + U3O8MAS
      TOTAL2 = TOTAL1/(1.0-WFWATER) - TOTAL1
      TOTAL = TOTAL1 +TOTAL2
      WRITE(6,*) 'TOTAL MASS (NO WATER) =',TOTAL1
      WRITE(6,*) 'TOTAL MASS (WATER ONLY) =',TOTAL2
      WRITE(6,*) 'TOTAL MASS (WATER +FUEL +CLAD) =',TOTAL
C
      FCVOLUME=AELEMENT*NELEMACT*(2.0*ELEMH*2.54)
      WRITE(6,*) '   TOTAL FUEL + CLAD VOLUME =',FCVOLUME,' CM^3'
      RHOFC = TOTAL1/FCVOLUME
      WRITE(6,*) ' FUEL+CLAD MIXTURE DENSITY =',RHOFC
C
C     F4 = FRACTION OF AL OVER AL + U3O8
C
      F4=ALTOTAL/(U3O8MAS+ALTOTAL)
C
      RHOU3O8C = (1.0-F4)/(1.0/RHOFC - F4/RHOCLAD)
      WRITE(6,*) ' F4 =',F4
      WRITE(6,*) ' RHOU3O8 CALCULATED =',RHOU3O8C
      WATERVOL=TOTAL2/RHOWATER
      VOLTOT=WATERVOL + FCVOLUME
C
      WRITE(6,*) ' TOTAL WATER VOLUME =',WATERVOL
      WRITE(6,*) ' TOTAL WATER + FUEL + CLAD VOLUMES=',VOLTOT
      RHOMIX = TOTAL/VOLTOT
      WRITE(6,*) ' MIXTURE DENSITY =',RHOMIX,' G/CC'
      COLHEIGHT=VOLTOT/AREASLOT
      WRITE(6,*) ' COLHEIGHT=',COLHEIGHT,' CM'
      WRITE(6,*) ' '
C
     N235 = U235MAS*AV/M235/VOLTOT
```

```
      N238 = U238MAS*AV/M238/VOLTOT
      N16 = O16MAS*AV/MO16/VOLTOT + TOTAL2*AV/VOLTOT/MH2O
      N131= ALTOTAL*AV/MAL/VOLTOT
      N1= TOTAL2*AV/MH/VOLTOT *(2.0*MH/MH2O)
      HURATIO=N1/N235
C
C
C
C
      WRITE(6,*) '  '
      WRITE(6,*) '  '
      WRITE(6,*) ' N1  N16  N131  N238  N235'
      WRITE(6,*) '      1',N1
      WRITE(6,*) '     16',N16
      WRITE(6,*) '    131',N131
      WRITE(6,*) '   2381',N238
      WRITE(6,*) '   2351',N235
      WRITE(6,*) 'TOTAL',N1+N16+N131+N238+N235
      WRITE(6,*) ' H/U-235 RATIO =',HURATIO
C ************************************************************
C
C    CHECKING THE NUMBER DENSITIES
C
C ************************************************************
       F3=1.0-F4
       U235CHECK=RHOMIX*(1.0-WFWATER)*F3*F2*ENRICH*VOLTOT
       U238CHECK=RHOMIX*(1.0-WFWATER)*F3*F2*(1.0-ENRICH)*VOLTOT
       ALCHECK=RHOMIX*(1.0-WFWATER)*(1.0-F3)*VOLTOT
       WATERCHECK=RHOMIX*WFWATER*VOLTOT
       O16FCHECK=RHOMIX*(1.0-WFWATER)*F3*(1.0-F2)*VOLTOT
       WRITE(6,*) ' U235 (CHECK)= ',U235CHECK
       WRITE(6,*) ' U238 (CHECK)= ',U238CHECK
       WRITE(6,*) ' AL (CHECK)= ',ALCHECK
       WRITE(6,*) ' WATER (CHECK)= ',WATERCHECK
       WRITE(6,*) ' O-16 FUEL (CHECK)= ',O16FCHECK

C-----------------------------------------------------------
C-----------------------------------------------------------
C
C
 200   CONTINUE
 100   CONTINUE
C
       END
```

6.7.1.1.2.2 FORTRAN Output (MTR Case I Fuel)

```
************************************
 ICASE =           2
  NBSR CASE
 ELEMENT HEIGHT=   21.46700
 RHOH2O =   1.000000
 ENRICH =  0.9400000
 WF     =  0.4160000
 WFWATER=  0.0000000E+00
 RHOU3O8=   8.200000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELEMENT
   ACLAD   AMEAT AELEMENT (CM2)
```

```
 0.5351602      0.3116122      0.8467725
 O16(FUEL) MASS =   137.0305
 U238      MASS =   45.31915
 U235      MASS =   710.0000
 U3O8      MASS =   892.3497
 AL MASS IN FUEL =   1252.722
 AL MASS IN CLAD =   2678.746
 AL MASS (TOTAL) =   3931.468
TOTAL MASS (NO WATER) =   4823.818
TOTAL MASS (WATER ONLY) =  0.0000000E+00
TOTAL MASS (WATER +FUEL +CLAD) =   4823.818
   TOTAL FUEL + CLAD VOLUME =   1569.823     CM^3
 FUEL+CLAD MIXTURE DENSITY =   3.072842
 F4 =  0.8150117
 RHOU3O8 CALCULATED =   7.846639
 TOTAL WATER VOLUME =  0.0000000E+00
 TOTAL WATER + FUEL + CLAD VOLUMES=   1569.823
 MIXTURE DENSITY =   3.072842     G/CC
 COLHEIGHT=   22.07012     CM


 N1  N16  N131  N238  N235
      1  0.0000000E+00
     16  3.2853934E-03
    131  5.5898849E-02
   2381  7.3030147E-05
   2351  1.1589923E-03
TOTAL  6.0416266E-02
 H/U-235 RATIO =  0.0000000E+00
 U235 (CHECK)=    710.0002
 U238 (CHECK)=    45.31916
 AL (CHECK)=    3931.468
 WATER (CHECK)=   0.0000000E+00
 O-16 FUEL (CHECK)=    137.0306
 ************************************
 ICASE =           2
  NBSR CASE
 ELEMENT HEIGHT=   21.46700
 RHOH2O =   1.000000
 ENRICH =  0.9400000
 WF     =  0.4160000
 WFWATER=  5.0000001E-02
 RHOU3O8=   8.200000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELEMENT
   ACLAD   AMEAT AELEMENT (CM2)
 0.5351602      0.3116122      0.8467725
 O16(FUEL) MASS =   137.0305
 U238      MASS =   45.31915
 U235      MASS =   710.0000
 U3O8      MASS =   892.3497
 AL MASS IN FUEL =   1252.722
 AL MASS IN CLAD =   2678.746
 AL MASS (TOTAL) =   3931.468
TOTAL MASS (NO WATER) =   4823.818
TOTAL MASS (WATER ONLY) =   253.8853
TOTAL MASS (WATER +FUEL +CLAD) =   5077.703
   TOTAL FUEL + CLAD VOLUME =   1569.823     CM^3
 FUEL+CLAD MIXTURE DENSITY =   3.072842
```

```
 F4 =  0.8150117
 RHOU3O8 CALCULATED =   7.846639
 TOTAL WATER VOLUME =   253.8853
 TOTAL WATER + FUEL + CLAD VOLUMES=   1823.708
 MIXTURE DENSITY =   2.784274     G/CC
 COLHEIGHT=   25.63949     CM


 N1  N16  N131  N238  N235
      1  9.3149459E-03
     16  7.4854945E-03
    131  4.8116960E-02
   2381  6.2863350E-05
   2351  9.9764462E-04
TOTAL  6.5977909E-02
 H/U-235 RATIO =   9.336938
 U235 (CHECK)=    710.0002
 U238 (CHECK)=    45.31917
 AL (CHECK)=    3931.468
 WATER (CHECK)=    253.8852
 O-16 FUEL (CHECK)=    137.0306
 ************************************
 ICASE =           2
  NBSR CASE
 ELEMENT HEIGHT=   21.46700
 RHOH2O =   1.000000
 ENRICH =  0.9400000
 WF     =  0.4160000
 WFWATER=  0.1000000
 RHOU3O8=   8.200000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELEMENT
   ACLAD   AMEAT AELEMENT (CM2)
 0.5351602      0.3116122      0.8467725
 O16(FUEL) MASS =   137.0305
 U238      MASS =   45.31915
 U235      MASS =   710.0000
 U3O8      MASS =   892.3497
 AL MASS IN FUEL =   1252.722
 AL MASS IN CLAD =   2678.746
 AL MASS (TOTAL) =   3931.468
TOTAL MASS (NO WATER) =   4823.818
TOTAL MASS (WATER ONLY) =   535.9800
TOTAL MASS (WATER +FUEL +CLAD) =   5359.798
   TOTAL FUEL + CLAD VOLUME =   1569.823     CM^3
 FUEL+CLAD MIXTURE DENSITY =   3.072842
 F4 =  0.8150117
 RHOU3O8 CALCULATED =   7.846639
 TOTAL WATER VOLUME =   535.9800
 TOTAL WATER + FUEL + CLAD VOLUMES=   2105.803
 MIXTURE DENSITY =   2.545251     G/CC
 COLHEIGHT=   29.60545     CM


 N1  N16  N131  N238  N235
      1  1.7030565E-02
     16  1.0964461E-02
    131  4.1671179E-02
```

```
   2381  5.4442135E-05
   2351  8.6399948E-04
TOTAL  7.0584647E-02
 H/U-235 RATIO =   19.71131
 U235 (CHECK)=    710.0002
 U238 (CHECK)=    45.31917
 AL (CHECK)=    3931.468
 WATER (CHECK)=    535.9799
 O-16 FUEL (CHECK)=    137.0306
 ************************************
 ICASE =           2
  NBSR CASE
 ELEMENT HEIGHT=   21.46700
 RHOH2O =   1.000000
 ENRICH =  0.9400000
 WF     =  0.4160000
 WFWATER=  0.1500000
 RHOU3O8=   8.200000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELEMENT
   ACLAD   AMEAT AELEMENT (CM2)
 0.5351602      0.3116122      0.8467725
 O16(FUEL) MASS =   137.0305
 U238      MASS =   45.31915
 U235      MASS =   710.0000
 U3O8      MASS =   892.3497
 AL MASS IN FUEL =   1252.722
 AL MASS IN CLAD =   2678.746
 AL MASS (TOTAL) =   3931.468
TOTAL MASS (NO WATER) =   4823.818
TOTAL MASS (WATER ONLY) =   851.2617
TOTAL MASS (WATER +FUEL +CLAD) =   5675.080
   TOTAL FUEL + CLAD VOLUME =   1569.823     CM^3
 FUEL+CLAD MIXTURE DENSITY =   3.072842
 F4 =  0.8150117
 RHOU3O8 CALCULATED =   7.846639
 TOTAL WATER VOLUME =   851.2617
 TOTAL WATER + FUEL + CLAD VOLUMES=   2421.085
 MIXTURE DENSITY =   2.344023     G/CC
 COLHEIGHT=   34.03799     CM


 N1  N16  N131  N238  N235
      1  2.3526175E-02
     16  1.3893325E-02
    131  3.6244620E-02
   2381  4.7352496E-05
   2351  7.5148657E-04
TOTAL  7.4462965E-02
 H/U-235 RATIO =   31.30618
 U235 (CHECK)=    710.0001
 U238 (CHECK)=    45.31916
 AL (CHECK)=    3931.468
 WATER (CHECK)=    851.2620
 O-16 FUEL (CHECK)=    137.0306
 ************************************
 ICASE =           2
  NBSR CASE
 ELEMENT HEIGHT=   21.46700
```

```
 RHOH2O =   1.000000
 ENRICH =  0.9400000
 WF     =  0.4160000
 WFWATER=  0.2000000
 RHOU3O8=   8.200000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELEMENT
   ACLAD   AMEAT AELEMENT (CM2)
 0.5351602      0.3116122      0.8467725
 O16(FUEL) MASS =   137.0305
 U238      MASS =   45.31915
 U235      MASS =   710.0000
 U3O8      MASS =   892.3497
 AL MASS IN FUEL =   1252.722
 AL MASS IN CLAD =   2678.746
 AL MASS (TOTAL) =   3931.468
TOTAL MASS (NO WATER) =   4823.818
TOTAL MASS (WATER ONLY) =   1205.955
TOTAL MASS (WATER +FUEL +CLAD) =   6029.772
   TOTAL FUEL + CLAD VOLUME =   1569.823     CM^3
 FUEL+CLAD MIXTURE DENSITY =   3.072842
 F4 =  0.8150117
 RHOU3O8 CALCULATED =   7.846639
 TOTAL WATER VOLUME =   1205.955
 TOTAL WATER + FUEL + CLAD VOLUMES=   2775.778
 MIXTURE DENSITY =   2.172282     G/CC
 COLHEIGHT=   39.02462     CM


 N1  N16  N131  N238  N235
      1  2.9069968E-02
     16  1.6393017E-02
    131  3.1613231E-02
   2381  4.1301726E-05
   2351  6.5546058E-04
TOTAL  7.7772975E-02
 H/U-235 RATIO =   44.35044
 U235 (CHECK)=    710.0002
 U238 (CHECK)=    45.31916
 AL (CHECK)=    3931.468
 WATER (CHECK)=    1205.954
 O-16 FUEL (CHECK)=    137.0306
 ************************************
 ICASE =           2
  NBSR CASE
 ELEMENT HEIGHT=   21.46700
 RHOH2O =   1.000000
 ENRICH =  0.9400000
 WF     =  0.4160000
 WFWATER=  0.2500000
 RHOU3O8=   8.200000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELEMENT
   ACLAD   AMEAT AELEMENT (CM2)
 0.5351602      0.3116122      0.8467725
 O16(FUEL) MASS =   137.0305
 U238      MASS =   45.31915
 U235      MASS =   710.0000
```

```
 U3O8       MASS =   892.3497
 AL MASS IN FUEL =   1252.722
 AL MASS IN CLAD =   2678.746
 AL MASS (TOTAL) =   3931.468
TOTAL MASS (NO WATER) =   4823.818
TOTAL MASS (WATER ONLY) =   1607.939
TOTAL MASS (WATER +FUEL +CLAD) =   6431.757
   TOTAL FUEL + CLAD VOLUME =   1569.823     CM^3
 FUEL+CLAD MIXTURE DENSITY =   3.072842
 F4 =  0.8150117
 RHOU3O8 CALCULATED =   7.846639
 TOTAL WATER VOLUME =   1607.939
 TOTAL WATER + FUEL + CLAD VOLUMES=   3177.762
 MIXTURE DENSITY =   2.023989     G/CC
 COLHEIGHT=   44.67611     CM



 N1  N16  N131  N238  N235
      1  3.3856846E-02
     16  1.8551417E-02
    131  2.7614178E-02
   2381  3.6077086E-05
   2351  5.7254522E-04
TOTAL  8.0631062E-02
 H/U-235 RATIO =   59.13393
 U235 (CHECK)=    710.0002
 U238 (CHECK)=    45.31917
 AL (CHECK)=    3931.468
 WATER (CHECK)=    1607.939
 O-16 FUEL (CHECK)=    137.0306
 ************************************
 ICASE =           2
  NBSR CASE
 ELEMENT HEIGHT=   21.46700
 RHOH2O =   1.000000
 ENRICH =  0.9400000
 WF     =  0.4160000
 WFWATER=  0.3000000
 RHOU3O8=   8.200000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELEMENT
   ACLAD   AMEAT AELEMENT (CM2)
 0.5351602      0.3116122      0.8467725
 O16(FUEL) MASS =   137.0305
 U238      MASS =   45.31915
 U235      MASS =   710.0000
 U3O8      MASS =   892.3497
 AL MASS IN FUEL =   1252.722
 AL MASS IN CLAD =   2678.746
 AL MASS (TOTAL) =   3931.468
TOTAL MASS (NO WATER) =   4823.818
TOTAL MASS (WATER ONLY) =   2067.351
TOTAL MASS (WATER +FUEL +CLAD) =   6891.168
   TOTAL FUEL + CLAD VOLUME =   1569.823     CM^3
 FUEL+CLAD MIXTURE DENSITY =   3.072842
 F4 =  0.8150117
 RHOU3O8 CALCULATED =   7.846639
 TOTAL WATER VOLUME =   2067.351
 TOTAL WATER + FUEL + CLAD VOLUMES=   3637.174
```

```
 MIXTURE DENSITY =   1.894649     G/CC
 COLHEIGHT=   51.13497     CM


 N1  N16  N131  N238  N235
      1  3.8031928E-02
     16  2.0433957E-02
    131  2.4126234E-02
   2381  3.1520191E-05
   2351  5.0022709E-04
TOTAL  8.3123870E-02
 H/U-235 RATIO =   76.02933
 U235 (CHECK)=    710.0002
 U238 (CHECK)=    45.31916
 AL (CHECK)=    3931.468
 WATER (CHECK)=    2067.351
 O-16 FUEL (CHECK)=    137.0306
 ************************************
 ICASE =           2
  NBSR CASE
 ELEMENT HEIGHT=   21.46700
 RHOH2O =   1.000000
 ENRICH =  0.9400000
 WF     =  0.4160000
 WFWATER=  0.3500000
 RHOU3O8=   8.200000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELEMENT
   ACLAD   AMEAT AELEMENT (CM2)
 0.5351602      0.3116122      0.8467725
 O16(FUEL) MASS =   137.0305
 U238      MASS =   45.31915
 U235      MASS =   710.0000
 U3O8      MASS =   892.3497
 AL MASS IN FUEL =   1252.722
 AL MASS IN CLAD =   2678.746
 AL MASS (TOTAL) =   3931.468
TOTAL MASS (NO WATER) =   4823.818
TOTAL MASS (WATER ONLY) =   2597.440
TOTAL MASS (WATER +FUEL +CLAD) =   7421.258
   TOTAL FUEL + CLAD VOLUME =   1569.823     CM^3
 FUEL+CLAD MIXTURE DENSITY =   3.072842
 F4 =  0.8150117
 RHOU3O8 CALCULATED =   7.846639
 TOTAL WATER VOLUME =   2597.440
 TOTAL WATER + FUEL + CLAD VOLUMES=   4167.263
 MIXTURE DENSITY =   1.780847     G/CC
 COLHEIGHT=   58.58749     CM


 N1  N16  N131  N238  N235
      1  4.1705448E-02
     16  2.2090344E-02
    131  2.1057297E-02
   2381  2.7510720E-05
   2351  4.3659654E-04
TOTAL  8.5317194E-02
 H/U-235 RATIO =   95.52400
```

```
 U235 (CHECK)=    710.0002
 U238 (CHECK)=    45.31916
 AL (CHECK)=    3931.468
 WATER (CHECK)=    2597.440
 O-16 FUEL (CHECK)=    137.0306
 ************************************
 ICASE =           2
  NBSR CASE
 ELEMENT HEIGHT=   21.46700
 RHOH2O =   1.000000
 ENRICH =  0.9400000
 WF     =  0.4160000
 WFWATER=  0.4000000
 RHOU3O8=   8.200000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELEMENT
   ACLAD   AMEAT AELEMENT (CM2)
 0.5351602      0.3116122      0.8467725
 O16(FUEL) MASS =   137.0305
 U238      MASS =   45.31915
 U235      MASS =   710.0000
 U3O8      MASS =   892.3497
 AL MASS IN FUEL =   1252.722
 AL MASS IN CLAD =   2678.746
 AL MASS (TOTAL) =   3931.468
TOTAL MASS (NO WATER) =   4823.818
TOTAL MASS (WATER ONLY) =   3215.878
TOTAL MASS (WATER +FUEL +CLAD) =   8039.696
   TOTAL FUEL + CLAD VOLUME =   1569.823     CM^3
 FUEL+CLAD MIXTURE DENSITY =   3.072842
 F4 =  0.8150117
 RHOU3O8 CALCULATED =   7.846639
 TOTAL WATER VOLUME =   3215.878
 TOTAL WATER + FUEL + CLAD VOLUMES=   4785.702
 MIXTURE DENSITY =   1.679941     G/CC
 COLHEIGHT=   67.28210     CM


 N1  N16  N131  N238  N235
      1  4.4962686E-02
     16  2.3559030E-02
    131  1.8336140E-02
   2381  2.3955612E-05
   2351  3.8017679E-04
TOTAL  8.7261982E-02
 H/U-235 RATIO =   118.2678
 U235 (CHECK)=    710.0003
 U238 (CHECK)=    45.31917
 AL (CHECK)=    3931.468
 WATER (CHECK)=    3215.878
 O-16 FUEL (CHECK)=    137.0306
 ************************************
 ICASE =           2
  NBSR CASE
 ELEMENT HEIGHT=   21.46700
 RHOH2O =   1.000000
 ENRICH =  0.9400000
 WF     =  0.4160000
 WFWATER=  0.4500000
```

```
 RHOU3O8=   8.200000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELEMENT
   ACLAD   AMEAT AELEMENT (CM2)
 0.5351602      0.3116122      0.8467725
 O16(FUEL) MASS =   137.0305
 U238      MASS =   45.31915
 U235      MASS =   710.0000
 U3O8      MASS =   892.3497
 AL MASS IN FUEL =   1252.722
 AL MASS IN CLAD =   2678.746
 AL MASS (TOTAL) =   3931.468
TOTAL MASS (NO WATER) =   4823.818
TOTAL MASS (WATER ONLY) =   3946.760
TOTAL MASS (WATER +FUEL +CLAD) =   8770.578
   TOTAL FUEL + CLAD VOLUME =   1569.823     CM^3
 FUEL+CLAD MIXTURE DENSITY =   3.072842
 F4 =  0.8150117
 RHOU3O8 CALCULATED =   7.846639
 TOTAL WATER VOLUME =   3946.760
 TOTAL WATER + FUEL + CLAD VOLUMES=   5516.583
 MIXTURE DENSITY =   1.589857     G/CC
 COLHEIGHT=   77.55756     CM


 N1  N16  N131  N238  N235
      1  4.7870591E-02
     16  2.4870202E-02
    131  1.5906820E-02
   2381  2.0781777E-05
   2351  3.2980787E-04
TOTAL  8.8998199E-02
 H/U-235 RATIO =   145.1469
 U235 (CHECK)=    710.0002
 U238 (CHECK)=    45.31916
 AL (CHECK)=    3931.468
 WATER (CHECK)=    3946.760
 O-16 FUEL (CHECK)=    137.0306
 ************************************
 ICASE =           2
  NBSR CASE
 ELEMENT HEIGHT=   21.46700
 RHOH2O =   1.000000
 ENRICH =  0.9400000
 WF     =  0.4160000
 WFWATER=  0.5000000
 RHOU3O8=   8.200000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELEMENT
   ACLAD   AMEAT AELEMENT (CM2)
 0.5351602      0.3116122      0.8467725
 O16(FUEL) MASS =   137.0305
 U238      MASS =   45.31915
 U235      MASS =   710.0000
 U3O8      MASS =   892.3497
 AL MASS IN FUEL =   1252.722
 AL MASS IN CLAD =   2678.746
 AL MASS (TOTAL) =   3931.468
```

```
TOTAL MASS (NO WATER) =   4823.818
TOTAL MASS (WATER ONLY) =   4823.818
TOTAL MASS (WATER +FUEL +CLAD) =   9647.636
   TOTAL FUEL + CLAD VOLUME =   1569.823     CM^3
 FUEL+CLAD MIXTURE DENSITY =   3.072842
 F4 =  0.8150117
 RHOU3O8 CALCULATED =   7.846639
 TOTAL WATER VOLUME =   4823.818
 TOTAL WATER + FUEL + CLAD VOLUMES=   6393.641
 MIXTURE DENSITY =   1.508942     G/CC
 COLHEIGHT=   89.88810     CM


 N1  N16  N131  N238  N235
      1  5.0482504E-02
     16  2.6047911E-02
    131  1.3724777E-02
   2381  1.7931005E-05
   2351  2.8456596E-04
TOTAL  9.0557694E-02
 H/U-235 RATIO =   177.4018
 U235 (CHECK)=    710.0002
 U238 (CHECK)=    45.31917
 AL (CHECK)=    3931.468
 WATER (CHECK)=    4823.818
 O-16 FUEL (CHECK)=    137.0306
 ************************************
 ICASE =           2
  NBSR CASE
 ELEMENT HEIGHT=   21.46700
 RHOH2O =   1.000000
 ENRICH =  0.9400000
 WF     =  0.4160000
 WFWATER=  0.5500000
 RHOU3O8=   8.200000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELEMENT
   ACLAD   AMEAT AELEMENT (CM2)
 0.5351602      0.3116122      0.8467725
 O16(FUEL) MASS =   137.0305
 U238      MASS =   45.31915
 U235      MASS =   710.0000
 U3O8      MASS =   892.3497
 AL MASS IN FUEL =   1252.722
 AL MASS IN CLAD =   2678.746
 AL MASS (TOTAL) =   3931.468
TOTAL MASS (NO WATER) =   4823.818
TOTAL MASS (WATER ONLY) =   5895.778
TOTAL MASS (WATER +FUEL +CLAD) =   10719.60
   TOTAL FUEL + CLAD VOLUME =   1569.823     CM^3
 FUEL+CLAD MIXTURE DENSITY =   3.072842
 F4 =  0.8150117
 RHOU3O8 CALCULATED =   7.846639
 TOTAL WATER VOLUME =   5895.778
 TOTAL WATER + FUEL + CLAD VOLUMES=   7465.601
 MIXTURE DENSITY =   1.435865     G/CC
 COLHEIGHT=   104.9588     CM
```

```
 N1  N16  N131  N238  N235
      1  5.2841429E-02
     16  2.7111547E-02
    131  1.1754083E-02
   2381  1.5356354E-05
   2351  2.4370612E-04
TOTAL  9.1966122E-02
 H/U-235 RATIO =   216.8244
 U235 (CHECK)=    710.0002
 U238 (CHECK)=    45.31917
 AL (CHECK)=    3931.468
 WATER (CHECK)=    5895.778
 O-16 FUEL (CHECK)=    137.0306
 ************************************
 ICASE =           2
  NBSR CASE
 ELEMENT HEIGHT=   21.46700
 RHOH2O =   1.000000
 ENRICH =  0.9400000
 WF     =  0.4160000
 WFWATER=  0.6000000
 RHOU3O8=   8.200000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELEMENT
   ACLAD   AMEAT AELEMENT (CM2)
 0.5351602      0.3116122      0.8467725
 O16(FUEL) MASS =   137.0305
 U238      MASS =   45.31915
 U235      MASS =   710.0000
 U3O8      MASS =   892.3497
 AL MASS IN FUEL =   1252.722
 AL MASS IN CLAD =   2678.746
 AL MASS (TOTAL) =   3931.468
TOTAL MASS (NO WATER) =   4823.818
TOTAL MASS (WATER ONLY) =   7235.727
TOTAL MASS (WATER +FUEL +CLAD) =   12059.54
   TOTAL FUEL + CLAD VOLUME =   1569.823     CM^3
 FUEL+CLAD MIXTURE DENSITY =   3.072842
 F4 =  0.8150117
 RHOU3O8 CALCULATED =   7.846639
 TOTAL WATER VOLUME =   7235.727
 TOTAL WATER + FUEL + CLAD VOLUMES=   8805.550
 MIXTURE DENSITY =   1.369539     G/CC
 COLHEIGHT=   123.7971     CM


 N1  N16  N131  N238  N235
      1  5.4982428E-02
     16  2.8076923E-02
    131  9.9654533E-03
   2381  1.3019563E-05
   2351  2.0662113E-04
TOTAL  9.3244441E-02
 H/U-235 RATIO =   266.1026
 U235 (CHECK)=    710.0002
 U238 (CHECK)=    45.31916
 AL (CHECK)=    3931.468
 WATER (CHECK)=    7235.728
```

```
 O-16 FUEL (CHECK)=    137.0306
 ************************************
 ICASE =           2
  NBSR CASE
 ELEMENT HEIGHT=   21.46700
 RHOH2O =   1.000000
 ENRICH =  0.9400000
 WF     =  0.4160000
 WFWATER=  0.6500000
 RHOU3O8=   8.200000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELEMENT
   ACLAD   AMEAT AELEMENT (CM2)
 0.5351602      0.3116122      0.8467725
 O16(FUEL) MASS =   137.0305
 U238      MASS =   45.31915
 U235      MASS =   710.0000
 U3O8      MASS =   892.3497
 AL MASS IN FUEL =   1252.722
 AL MASS IN CLAD =   2678.746
 AL MASS (TOTAL) =   3931.468
TOTAL MASS (NO WATER) =   4823.818
TOTAL MASS (WATER ONLY) =   8958.521
TOTAL MASS (WATER +FUEL +CLAD) =   13782.34
   TOTAL FUEL + CLAD VOLUME =   1569.823     CM^3
 FUEL+CLAD MIXTURE DENSITY =   3.072842
 F4 =  0.8150117
 RHOU3O8 CALCULATED =   7.846639
 TOTAL WATER VOLUME =   8958.521
 TOTAL WATER + FUEL + CLAD VOLUMES=   10528.34
 MIXTURE DENSITY =   1.309070     G/CC
 COLHEIGHT=   148.0178     CM


 N1  N16  N131  N238  N235
      1  5.6934364E-02
     16  2.8957048E-02
    131  8.3347671E-03
   2381  1.0889121E-05
   2351  1.7281092E-04
TOTAL  9.4409883E-02
 H/U-235 RATIO =   329.4604
 U235 (CHECK)=    710.0002
 U238 (CHECK)=    45.31916
 AL (CHECK)=    3931.468
 WATER (CHECK)=    8958.521
 O-16 FUEL (CHECK)=    137.0306
 ************************************
 ICASE =           2
  NBSR CASE
 ELEMENT HEIGHT=   21.46700
 RHOH2O =   1.000000
 ENRICH =  0.9400000
 WF     =  0.4160000
 WFWATER=  0.7000000
 RHOU3O8=   8.200000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELEMENT
```

```
   ACLAD    AMEAT AELEMENT (CM2)
 0.5351602       0.3116122       0.8467725
 O16(FUEL) MASS =   137.0305
 U238      MASS =   45.31915
 U235      MASS =   710.0000
 U3O8      MASS =   892.3497
 AL MASS IN FUEL =   1252.722
 AL MASS IN CLAD =   2678.746
 AL MASS (TOTAL) =   3931.468
TOTAL MASS (NO WATER) =   4823.818
TOTAL MASS (WATER ONLY) =   11255.58
TOTAL MASS (WATER +FUEL +CLAD) =   16079.39
   TOTAL FUEL + CLAD VOLUME =   1569.823     CM^3
 FUEL+CLAD MIXTURE DENSITY =   3.072842
 F4 =  0.8150117
 RHOU3O8 CALCULATED =   7.846639
 TOTAL WATER VOLUME =   11255.58
 TOTAL WATER + FUEL + CLAD VOLUMES=   12825.40
 MIXTURE DENSITY =   1.253715     G/CC
 COLHEIGHT=   180.3121     CM


 N1  N16  N131  N238  N235
      1  5.8721218E-02
     16  2.9762739E-02
    131  6.8419939E-03
   2381  8.9388577E-06
   2351  1.4186013E-04
TOTAL  9.5476754E-02
 H/U-235 RATIO =   413.9374
 U235 (CHECK)=    710.0002
 U238 (CHECK)=    45.31917
 AL (CHECK)=    3931.468
 WATER (CHECK)=    11255.58
 O-16 FUEL (CHECK)=    137.0306
```

6.7.1.2 Case II Fuel (U_3Si_2)

6.7.1.2.1 GEMER Input Decks

This Appendix includes GEMER geometrical plots and input listings for the single container, normal array, accident array, and infinite array for MTR Case II fuel. Each basedeck contains a "header" with fuel material and geometry information.

6.7.1.2.1.1 Normal (20% Enriched)

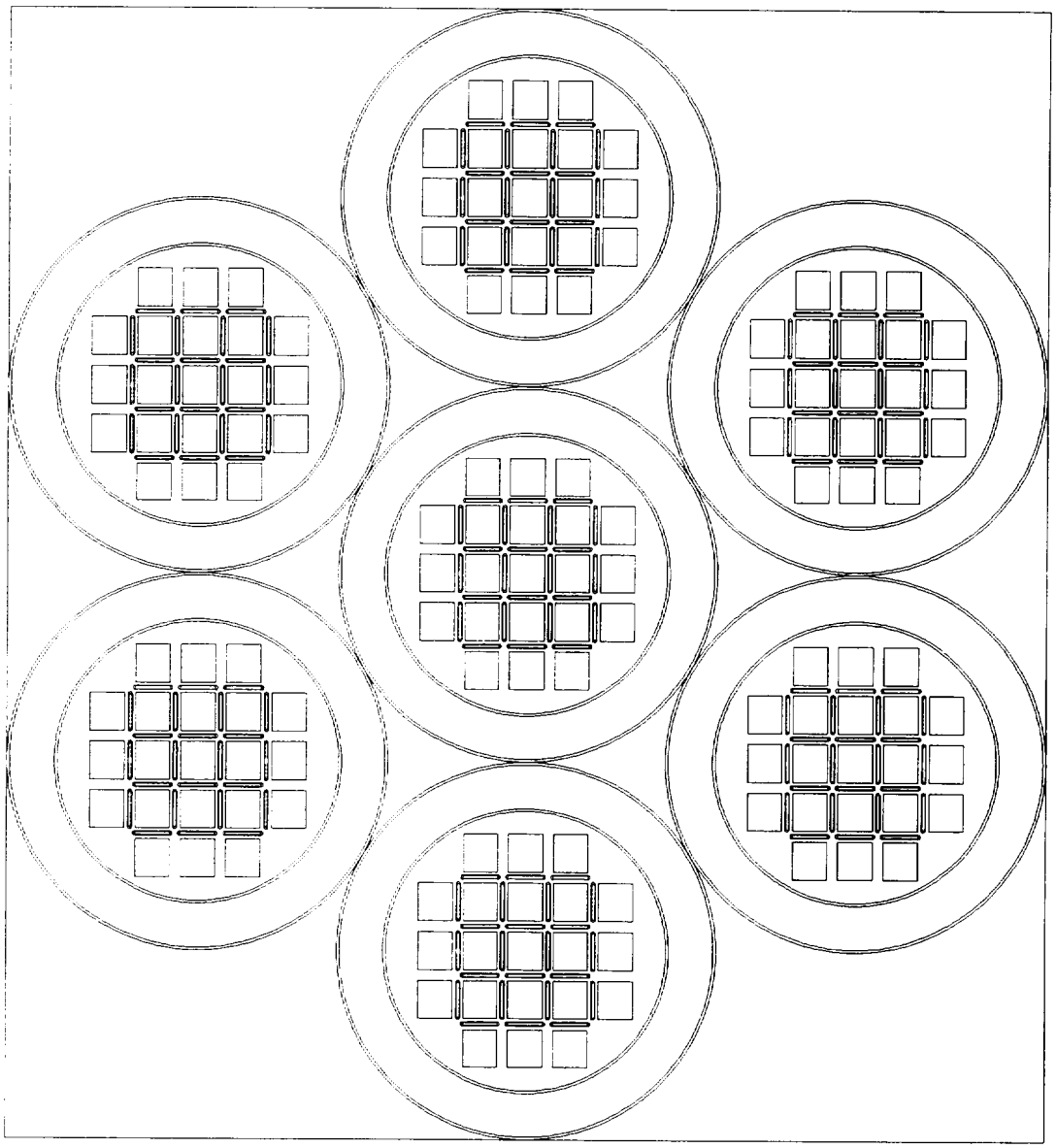

Figure 6.24. Normal Container for MTR Case II Fuel — Top View

```
CASE II FUEL/ IF2000/21 ELEMENTS, SS+Pb SHIELDING. WFH2O IN FUEL=0.05
MASS U235 IN EACH ELEM=694G
    65 /* # BATCHES
  1000  /* # NEUTRONS PER BATCH
    5  /* # BATCHES TO SKIP
 2123469/* INITIAL "SEED" (IF NON-ZERO)
     0  /* "IDUMP"
     0  /* "NRSTRT"
     0  /* "NBTED" (NON-ZERO IS PRINT EDITS)
     0  /* "KRED" (NUMBER OF COMBINED REGIONS IN EDITS)
     0  293   14  7
      6  293 0  0 U(20.0)3SI2+0.05 WF -H2O RHOMIX=3.673662 g/cc     MAT
1
       1  1.2290440E-02
      14  2.5992552E-03
      16  6.1452198E-03
     131  4.0879738E-02
    2381  3.1110286E-03
    2351  7.8785414E-04
      4  293 0 0 Boral 0.25" Plate +/- 10% (60% Boron Loading)  MAT 2
    10    3.32658E-03
    11    6.7889E-05
   131   5.8001E-02
      2  293 0 0  MODERATOR IN CASK (5.00%)                    MAT 3
     1   3.34555656E-03
    16   1.67277878E-03
      2  293 0 0  INTERSPERSED MODERATOR (0.00%)            MAT4
     1   1.00000000E-09
    16   1.00000000E-09
      2  293 0 0 FULL DENSITY WATER                     MAT 5
     1    6.69111121E-02
    16    3.34555566E-02
      1  293 0 0 LEAD SHIELDING                         MAT 6
    82   3.29890E-02
      7  293 0 0 304 STAINLESS STEEL                    MAT 7
    12   6.82690E-05
    14   8.53360E-04
    24   1.53600E-02
    26   6.04950E-02
    28   6.82690E-03
    55   1.70670E-03
  1316   2.56010E-05
KENO GEOM
    14  /* "KREFM"
     6  /* "NBOX"
     1  /* "NBXMAX"
     1  /* "NBYMAX"
     1  /* "NBZMAX"
     0  /* "NXX"
     0  /* "NTYPST"
     1  /* "NEMBRG"
     0  /* "NGMCHK"
BOX TYPE      1 /*MODEL 2000 CASK & STAINLESS SUPPORT STRUCTURE
CYLINDER      7  33.34      140.64      0.0     16*0.5
CYLINDER      3  33.65      140.64      0.0     16*0.5
CYLINDER      7  35.85      140.64      0.0     16*0.5
CYLINDER      6  46.34      140.64      0.0     16*0.5
CYLINDER      7  48.56      140.64    -14.90    16*0.5
BOX TYPE      2 /* CASK TOP
CYLINDER      6  30.96      158.42     140.64   16*0.5
CYLINDER      7  48.56      162.23     140.64   16*0.5
```

```
BOX TYPE      3 /* ORR FUEL ASSEMBLY-COLLAPSED
CUBOID        1  4.4450 -4.4450  4.0005  -4.0005  31.71685  0.0   16*0.5
CUBOID        3  4.4450 -4.4450  4.0005  -4.0005  140.64  0.0   16*0.5
BOX TYPE      4 /* BORAL PLATE (VERT)
CUBOID        2  0.286  -0.286  4.12  -4.12  138.64  2.0   16*0.5
BOX TYPE      5 /* BORAL PLATE (HORIZ)
CUBOID        2  4.12  -4.12  0.286  -0.286  138.64  2.0   16*0.5
BOX TYPE      6  /* OVERALL BOX FOR THE PROBLEM
CUBOID        4  146.80  -146.80  133.70  -133.70  162.30  -15.24  16*0.5
CORE          0  146.80  -146.80  133.70  -133.70  162.30  -15.24  16*0.5
CUBOID        5  177.30  -177.30  164.20  -164.20  192.80  -45.74  16*0.5
6  1 1 1  1 1 1  1 1 1  1
BEGIN COMPLEX
/* PLACE FUEL ASSEMBLIES INTO CASK
COMPLEX  1  3   -22.860  -10.540  0.0  5  3  1  11.430  10.540  0.0
/*MIDDLE ROWS
COMPLEX  1  3   -11.430  -21.080  0.0  3  2  1  11.430  42.160  0.0
/*OUTER ROWS
/* PLACE BORAL PLATES INTO CASK
COMPLEX  1  4   -17.145  -10.540  0.0  4  3  1  11.430  10.540  0.0
/*VERT PLATES
COMPLEX  1  5   -11.430  -15.810  0.0  3  4  1  11.430  10.540  0.0
/*HORIZ PLATES
/* PLACE 7 LOADED CASKS INTO OVERALL PROBLEM BOX
COMPLEX  6  1    -97.5    0.0    0.0   3 1 1   97.5    0.0   0.0
/*MIDDLE ROW
COMPLEX  6  1    -48.8  -84.4    0.0   2 2 1   97.5  168.9   0.0 /*OUTER
ROW
/* PLACE TOPS INTO OVERALL PROBLEM BOX
COMPLEX  6  2    -97.5    0.0    0.0   3 1 1   97.5    0.0   0.0
/*MIDDLE ROW
COMPLEX  6  2    -48.8  -84.4    0.0   2 2 1   97.5  168.9   0.0 /*OUTER
ROW
END GEOM
*END GEMER*
```

6.7.1.2.1.2 Single (20% Enriched)

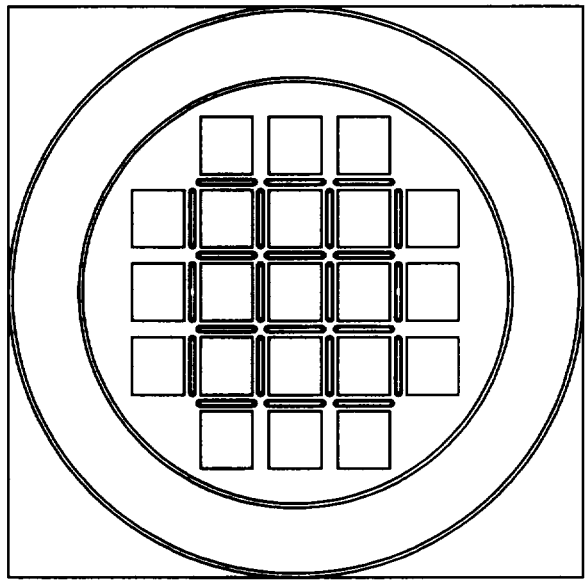

Figure 6.25. Single Container for MTR Case II Fuel — Top View

```
CASE II FUEL/ IF2000/21 ELEMENTS, SS+Pb SHIELDING. WFH2O IN FUEL=0.35
MASS U235 IN EACH ELEM=694G
    65 /* # BATCHES
  1000  /* # NEUTRONS PER BATCH
    5  /* # BATCHES TO SKIP
 2123469/* INITIAL "SEED" (IF NON-ZERO)
     0  /* "IDUMP"
     0  /* "NRSTRT"
     0  /* "NBTED" (NON-ZERO IS PRINT EDITS)
     0  /* "KRED" (NUMBER OF COMBINED REGIONS IN EDITS)
     0  293   14  7
      6  293 0  0 U(20.0)3SI2 +0.35 WF -H2O RHOMIX=1.991885 g/cc     MAT
1
      1  4.6647731E-02
     14  9.6428132E-04
     16  2.3323866E-02
    131  1.5165717E-02
   2381  1.1541409E-03
   2351  2.9228107E-04
      4  293 0 0 Boral 0.25" Plate +/- 10% (60% Boron Loading)  MAT 2
   10    3.32658E-03
   11    6.7889E-05
  131   5.8001E-02
    2  293 0 0  MODERATOR IN CASK (100.00%)                    MAT 3
    1   6.69111121E-02
   16   3.34555566E-02
      2  293 0 0  INTERSPERSED MODERATOR (100.00%)            MAT4
    1   6.69111121E-02
   16   3.34555566E-02
      2  293 0 0 FULL DENSITY WATER                    MAT 5
```

```
     1    6.69111121E-02
    16    3.34555566E-02
     1  293 0 0 LEAD SHIELDING                          MAT 6
    82   3.29890E-02
     7  293 0 0 304 STAINLESS STEEL                     MAT 7
    12   6.82690E-05
    14   8.53360E-04
    24   1.53600E-02
    26   6.04950E-02
    28   6.82690E-03
    55   1.70670E-03
  1316   2.56010E-05
KENO GEOM
    14  /* "KREFM"
     6  /* "NBOX"
     1  /* "NBXMAX"
     1  /* "NBYMAX"
     1  /* "NBZMAX"
     0  /* "NXX"
     0  /* "NTYPST"
     1  /* "NEMBRG"
     0  /* "NGMCHK"
BOX TYPE     1 /*MODEL 2000 CASK & STAINLESS SUPPORT STRUCTURE
CYLINDER     7  33.34     140.64     0.0    16*0.5
CYLINDER     3  33.65     140.64     0.0    16*0.5
CYLINDER     7  35.85     140.64     0.0    16*0.5
CYLINDER     6  46.34     140.64     0.0    16*0.5
CYLINDER     7  48.56     140.64   -14.90   16*0.5
BOX TYPE     2 /* CASK TOP
CYLINDER     6  30.96     158.42    140.64  16*0.5
CYLINDER     7  48.56     162.23    140.64  16*0.5
BOX TYPE     3 /* ORR FUEL ASSEMBLY-COLLAPSED
CUBOID       1  4.4450 -4.4450  4.0005  -4.0005  85.49392  0.0   16*0.5
CUBOID       3  4.4450 -4.4450  4.0005  -4.0005  140.64  0.0   16*0.5
BOX TYPE     4 /* BORAL PLATE (VERT)
CUBOID       2  0.286  -0.286  4.12  -4.12  138.64  2.0   16*0.5
BOX TYPE     5 /* BORAL PLATE (HORIZ)
CUBOID       2  4.12  -4.12  0.286  -0.286  138.64  2.0   16*0.5
BOX TYPE     6  /* OVERALL BOX FOR THE PROBLEM
CUBOID       4  48.60    -48.60   48.60 -48.60 162.23 -15.24 16*0.5
CORE         0  48.60    -48.60   48.60 -48.60 162.23 -15.24 16*0.5
CUBOID       5  79.10    -79.10   79.10 -79.10 192.71 -45.72 16*0.5
6  1 1 1  1 1 1  1 1 1  1
BEGIN COMPLEX
/* PLACE FUEL ASSEMBLIES INTO CASK
COMPLEX  1  3   -22.860  -10.540  0.0  5  3  1  11.430  10.540  0.0
/*MIDDLE ROWS
COMPLEX  1  3   -11.430  -21.080  0.0  3  2  1  11.430  42.160  0.0
/*OUTER ROWS
/* PLACE BORAL PLATES INTO CASK
COMPLEX  1  4   -17.145  -10.540  0.0  4  3  1  11.430  10.540  0.0
/*VERT PLATES
COMPLEX  1  5   -11.430  -15.810  0.0  3  4  1  11.430  10.540  0.0
/*HORIZ PLATES
/* PLACE LOADED CASK INTO OVERALL PROBLEM BOX
COMPLEX  6  1  0.0     0.0    0.0   1 1 1   0.0    0.0    0.0
/* PLACE TOP INTO OVERALL PROBLEM BOX
COMPLEX  6  2  0.0     0.0    0.0   1 1 1   0.0    0.0    0.0
END GEOM
*END GEMER*
```

6.7.1.2.1.3 Accident (20% Enriched)

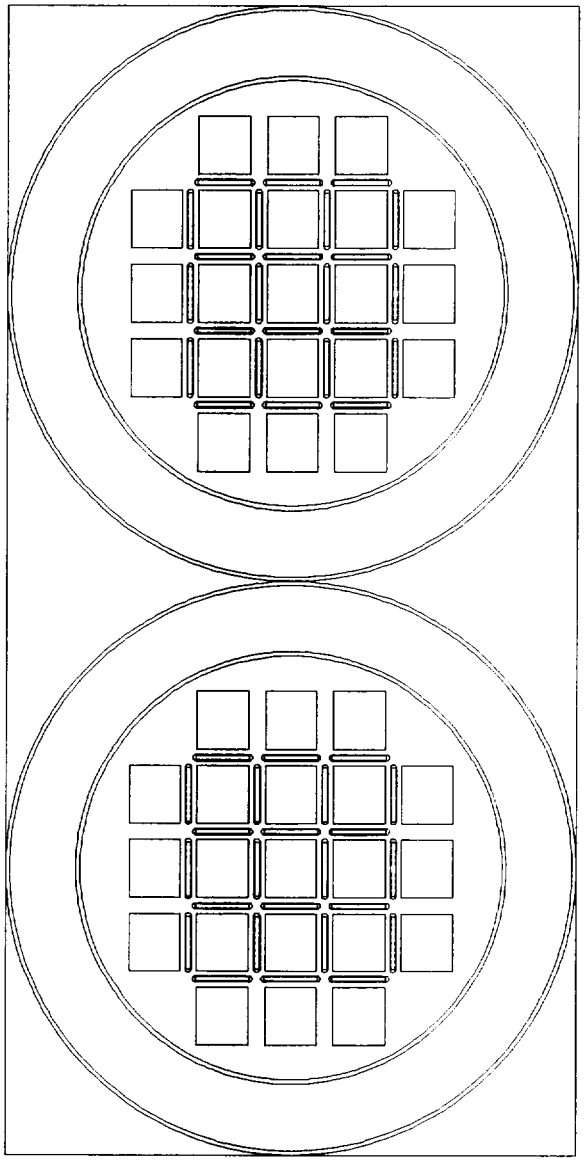

Figure 6.26. Accident Array for MTR Case II Fuel — Top View

```
CASE II  FUEL/ IF2000/21 ELEMS, SS+Pb SHLD.WF=.8,WFH2O IN FUEL=0.35 MASS
U235 IN EACH ELEM=693.6
    65 /* # BATCHES
  1000  /* # NEUTRONS PER BATCH
     5  /* # BATCHES TO SKIP
 2123469/* INITIAL "SEED" (IF NON-ZERO)
     0  /* "IDUMP"
     0  /* "NRSTRT"
     0  /* "NBTED" (NON-ZERO IS PRINT EDITS)
     0  /* "KRED" (NUMBER OF COMBINED REGIONS IN EDITS)
     0  293   14  7
      6  293 0 0 U(20.0)3SI2+0.35 WF -H2O RHOMIX=1.991885 g/cc  MAT 1
      1  4.6647731E-02
     14  9.6428132E-04
     16  2.3323866E-02
    131  1.5165717E-02
   2381  1.1541409E-03
   2351  2.9228107E-04
      4  293 0 0 Boral 0.25" Plate +/- 10% (60% Boron Loading)  MAT 2
     10    3.32658E-03
     11    6.7889E-05
    131   5.8001E-02
      2  293 0 0  MODERATOR IN CASK (100.0%)                    MAT 3
      1    6.69111121E-02
     16    3.34555566E-02
      2  293 0 0  INTERSPERSED MODERATOR (100.0%)            MAT4
      1    6.69111121E-02
     16    3.34555566E-02
      2  293 0 0 FULL DENSITY WATER                     MAT 5
      1    6.69111121E-02
     16    3.34555566E-02
      1  293 0 0 LEAD SHIELDING                         MAT 6
     82   3.29890E-02
      7  293 0 0 304 STAINLESS STEEL                    MAT 7
     12   6.82690E-05
     14   8.53360E-04
     24   1.53600E-02
     26   6.04950E-02
     28   6.82690E-03
     55   1.70670E-03
   1316   2.56010E-05
KENO GEOM
     14  /* "KREFM"
      6  /* "NBOX"
      1  /* "NBXMAX"
      1  /* "NBYMAX"
      1  /* "NBZMAX"
      0  /* "NXX"
      0  /* "NTYPST"
      1  /* "NEMBRG"
      0  /* "NGMCHK"
BOX TYPE      1 /*MODEL 2000 CASK & STAINLESS SUPPORT STRUCTURE
CYLINDER      7  33.34      140.64      0.0     16*0.5
CYLINDER      3  33.65      140.64      0.0     16*0.5
CYLINDER      7  35.85      140.64      0.0     16*0.5
CYLINDER      6  46.34      140.64      0.0     16*0.5
CYLINDER      7  48.56      140.64    -14.90    16*0.5
BOX TYPE      2 /* CASK TOP
CYLINDER      6  30.96      158.42     140.64   16*0.5
CYLINDER      7  48.56      162.23     140.64   16*0.5
BOX TYPE      3 /* NBSR FUEL ASSEMBLY-COLLAPSED
```

```
CUBOID        1  4.4450 -4.4450  4.0005  -4.0005  85.49392  0.0   16*0.5
CUBOID        3  4.4450 -4.4450  4.0005  -4.0005  140.64  0.0   16*0.5
BOX TYPE      4 /* BORAL PLATE (VERT)
CUBOID        2  0.286  -0.286  4.12  -4.12  138.64  2.0   16*0.5
BOX TYPE      5 /* BORAL PLATE (HORIZ)
CUBOID        2  4.12  -4.12  0.286  -0.286  138.64  2.0   16*0.5
BOX TYPE      6  /* OVERALL BOX FOR THE PROBLEM
CUBOID        4  97.20    -97.20   48.60 -48.60 162.23 -15.24 16*0.5
CORE          0  97.20    -97.20   48.60 -48.60 162.23 -15.24 16*0.5
CUBOID        5  127.70  -127.70   79.10 -79.10 192.73 -45.74 16*0.5
6  1 1 1  1 1 1  1 1 1  1
BEGIN COMPLEX
/* PLACE FUEL ASSEMBLIES INTO CASK
COMPLEX  1  3   -22.860  -10.540  0.0  5  3  1  11.430  10.540  0.0
/*MIDDLE ROWS
COMPLEX  1  3   -11.430  -21.080  0.0  3  2  1  11.430  42.160  0.0
/*OUTER ROWS
/* PLACE BORAL PLATES INTO CASK
COMPLEX  1  4   -17.145  -10.540  0.0  4  3  1  11.430  10.540  0.0
/*VERT PLATES
COMPLEX  1  5   -11.430  -15.810  0.0  3  4  1  11.430  10.540  0.0
/*HORIZ PLATES
/* PLACE 2 LOADED CASKS INTO OVERALL PROBLEM BOX
COMPLEX  6  1  -48.6     0.0    0.0   2 1 1   97.2    0.0    0.0
/* PLACE TOPS INTO OVERALL PROBLEM BOX
COMPLEX  6  2  -48.6     0.0    0.0   2 1 1   97.2    0.0    0.0
END GEOM
*END GEMER*
```

6.7.1.2.1.4 Infinite (20% Enriched)

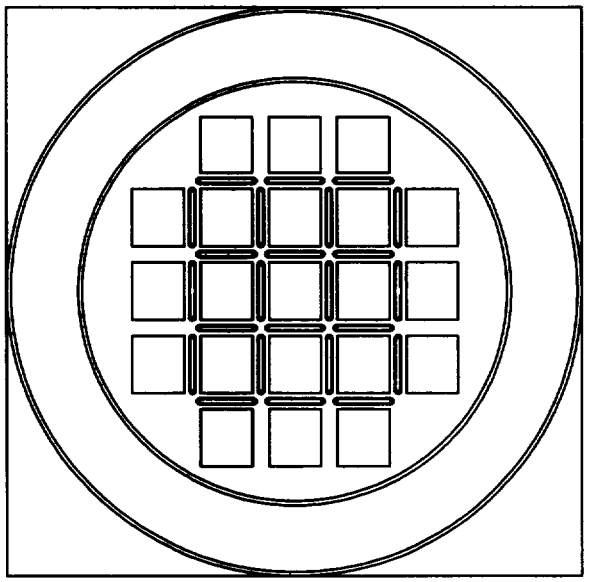

Figure 6.27. Unit Array for MTR Case II Fuel — Top View

```
ORR FUEL/ IF2000/21 ELEMENTS, SS+Pb SHIELDING. WFH2O IN FUEL=0.35 MASS
U235 IN EACH ELEM=694G
    65 /* # BATCHES
  1000  /* # NEUTRONS PER BATCH
    5  /* # BATCHES TO SKIP
 2123469/* INITIAL "SEED" (IF NON-ZERO)
     0  /* "IDUMP"
     0  /* "NRSTRT"
     0  /* "NBTED" (NON-ZERO IS PRINT EDITS)
     0  /* "KRED" (NUMBER OF COMBINED REGIONS IN EDITS)
     0  293   14  8
      6  293 0  0 U(20.0)3SI2 +0.35 WF -H2O RHOMIX=1.991885 g/cc     MAT
1
       1  4.6647731E-02
      14  9.6428132E-04
      16  2.3323866E-02
     131  1.5165717E-02
    2381  1.1541409E-03
    2351  2.9228107E-04
      3  293 0 0 Boral 0.25" Plate (60% Boron Loading)  MAT 2
    10    3.32658E-03
    11    6.7889E-05
   131    5.8001E-02
      2  293 0 0  MODERATOR IN CASK (100.00%)                    MAT 3
     1   6.69111121E-02
    16   3.34555566E-02
      2  293 0 0  INTERSPERSED MODERATOR (100.00%)            MAT4
     1   6.69111121E-02
    16   3.34555566E-02
      2  293 0 0 FULL DENSITY WATER                     MAT 5
     1    6.69111121E-02
    16    3.34555566E-02
      1  293 0 0 LEAD SHIELDING                         MAT 6
    82   3.29890E-02
      7  293 0 0 304 STAINLESS STEEL                    MAT 7
    12   6.82690E-05
    14   8.53360E-04
    24   1.53600E-02
    26   6.04950E-02
    28   6.82690E-03
    55   1.70670E-03
  1316   2.56010E-05
     2  293 0 0 FULL DENSITY WATER (VOID)             MAT 8
     1    6.69111121E-09
    16    3.34555566E-09
KENO GEOM
    14  /* "KREFM"
     6  /* "NBOX"
     1  /* "NBXMAX"
     1  /* "NBYMAX"
     1  /* "NBZMAX"
     1  /* "NXX"
     0  /* "NTYPST"
     1  /* "NEMBRG"
     0  /* "NGMCHK"
  -1.0  -1.0  -1.0  -1.0  -1.0  -1.0
BOX TYPE     1 /*MODEL 2000 CASK & STAINLESS SUPPORT STRUCTURE
CYLINDER     7  33.34     140.64     0.0    16*0.5
CYLINDER     3  33.65     140.64     0.0    16*0.5
CYLINDER     7  35.85     140.64     0.0    16*0.5
CYLINDER     6  46.34     140.64     0.0    16*0.5
```

```
CYLINDER     7  48.56     140.64   -14.90   16*0.5
BOX TYPE     2 /* CASK TOP
CYLINDER     6  30.96     158.42    140.64  16*0.5
CYLINDER     7  48.56     162.23    140.64  16*0.5
BOX TYPE     3 /* ORR FUEL ASSEMBLY-COLLAPSED
CUBOID       1  4.4450 -4.4450  4.0005  -4.0005  85.49392  0.0   16*0.5
CUBOID       3  4.4450 -4.4450  4.0005  -4.0005  140.64  0.0   16*0.5
BOX TYPE     4 /* BORAL PLATE (VERT)
CUBOID       2  0.286  -0.286  4.12  -4.12  138.64  2.0   16*0.5
BOX TYPE     5 /* BORAL PLATE (HORIZ)
CUBOID       2  4.12  -4.12  0.286  -0.286  138.64  2.0   16*0.5
BOX TYPE     6  /* OVERALL BOX FOR THE PROBLEM
CUBOID       8  48.60    -48.60   48.60 -48.60 162.23 -14.91 16*0.5
CORE         0  48.60    -48.60   48.60 -48.60 162.23 -14.91 16*0.5
CUBOID       8  48.70    -48.70   48.70 -48.70 162.33 -15.01 16*0.5
6  1 1 1  1 1 1  1 1 1  1
BEGIN COMPLEX
/* PLACE FUEL ASSEMBLIES INTO CASK
COMPLEX  1  3   -22.860  -10.540  0.0  5  3  1  11.430  10.540  0.0
/*MIDDLE ROWS
COMPLEX  1  3   -11.430  -21.080  0.0  3  2  1  11.430  42.160  0.0
/*OUTER ROWS
/* PLACE BORAL PLATES INTO CASK
COMPLEX  1  4   -17.145  -10.540  0.0  4  3  1  11.430  10.540  0.0
/*VERT PLATES
COMPLEX  1  5   -11.430  -15.810  0.0  3  4  1  11.430  10.540  0.0
/*HORIZ PLATES
/* PLACE LOADED CASK INTO OVERALL PROBLEM BOX
COMPLEX  6  1  0.0     0.0    0.0   1 1 1   0.0    0.0    0.0
/* PLACE TOP INTO OVERALL PROBLEM BOX
COMPLEX  6  2  0.0     0.0    0.0   1 1 1   0.0    0.0    0.0
END GEOM
*END GEMER*
```

6.7.1.2.2 Number Density Calculations

6.7.1.2.2.1 FORTRAN Program (Case II Fuel)

```
PROGRAM NUMBER
       REAL NAL_CLAD,MAL
       REAL MU235,M238,MO16,MH2O,MH,MSI
       REAL MU,MUOLD
       REAL MU3SI2
       REAL NELEMTOT,NELEMACT
       REAL N235,N238,N16,N131,N1,N14
       OPEN(6,FILE='P1.OUT',STATUS='UNKNOWN')
C
C    FOR U3SI2 FUEL
C
C    NUMBER DENSITY PROGRAM FOR HFBR
C
C      10/14/94
C      AV = AVOGADRO'S NUMBER
C
       AV=0.6022
      M235 =235.0439
      M238 =238.0508
      MAL = 26.98
      MO16 = 16.000
```

```
      MH2O=18.0
      MSI=28.0855
      MAL=26.98
      MH=1.0

      DO 100 ITER=1,12
      DO 200 II=1,1
      WRITE(6,*) ' ************************************'
C
C    D  = ACTIVE FUEL LENGTH (IN)
C    E  = CLADDING THICKNESS (IN)
C    C  = PLATE LENGTH (IN)
C    G  = PLATE THICKNESS (IN)
C    F  = ACTIVE FUEL THICKNESS (IN)
C    RHOU3SI2 = DENSITY OF U3SI2 (G/CC)
C    RHOCLAD = DENISTY OF AL CLAD (G/CC)
C     WF= WEIGHT % OF U3SI2  IN THE U3SI2/AL MIXTURE
C     WFWATER = WEIGHT FRACTION OF WATER
C      ENRICH = FUEL ENRICHMENT
C     ELEMH = ELEMENT HEIGHT IN INCHES
C    NELEMACT = NUMBER OF ACTIVE FUEL ELEMENTS
C    NELEMTOT = TOTAL NUMBER OF ELEMENTS
C
C ------------------------------------------------
C
C      U3SI2 FOR ORR ONLY
       D=2.500
       E=0.015
       C=2.800
       G=0.050
       F=0.020
       WRITE(6,*) ' ********************************'
       RHOU3SI2 = 12.02
       RHOCLAD=2.7
       WF=0.80
       RHOH2O = 1.0
       WFWATER = 0.05*FLOAT(ITER)
       ENRICH = 0.20
C
C       U235MAS=710.0
       U235MAS=693.6
C
C       ELEMH=23.600+0.001*FLOAT(II)
       ELEMH=23.6095
       NELEMTOT=17.0
       NELEMACT=17.0
C
C ---------------------------------------------------
C
       RHOWATER=1.0
       RHOH2O = 1.0
       RHOCLAD=2.7
       AREASLOT=71.12889
C
C
      WRITE(6,*) '  ORR CASE'
      WRITE(6,*) ' ELEMENT HEIGHT=',ELEMH
      WRITE(6,*) ' RHOH2O =',RHOH2O
      WRITE(6,*) ' ENRICH =',ENRICH
      WRITE(6,*) ' WF     =',WF
      WRITE(6,*) ' WFWATER=',WFWATER
```

```
      WRITE(6,*)  ' RHOU3SI2=',RHOU3SI2
      WRITE(6,*)  ' RHOCLAD=',RHOCLAD
C
C
C
       AELEMENT=C*G*2.54*2.54
       AMEAT=D*F*2.54*2.54
       ACLAD=AELEMENT-AMEAT
C
C
       WRITE(6,*)  ' '
       WRITE(6,*)  '  FOR EACH UNIT ELEMENT'
       WRITE(6,*)  '   ACLAD   AMEAT AELEMENT (CM2)'
       WRITE(6,*) ACLAD,AMEAT,AELEMENT
C
C-------------------------------------------------
       U238MAS=U235MAS/ENRICH - U235MAS
C   F2 TO BE RECALCULATED
       MU= 1.0/(ENRICH/M235 + (1.0-ENRICH)/M238)
       F2=3.0*MU/(3.0*MU + 2.0*MSI)
       U3SI2MAS=(U235MAS+U238MAS)/F2
       SIMAS=U3SI2MAS-(U235MAS+U238MAS)
       WRITE(6,*)  ' SI        MASS =',SIMAS
       WRITE(6,*)  ' U238      MASS =',U238MAS
       WRITE(6,*)  ' U235      MASS =',U235MAS
       WRITE(6,*)  ' U3SI2      MASS =',U3SI2MAS
C
       ALFUEL=U3SI2MAS/WF*(1.0-WF)
       ALCLAD=ACLAD*(ELEMH*2.0*2.54)*NELEMTOT*RHOCLAD
       ALTOTAL=ALCLAD+ALFUEL
       WRITE(6,*)  ' AL MASS IN FUEL =',ALFUEL
       WRITE(6,*)  ' AL MASS IN CLAD =',ALCLAD
       WRITE(6,*)  ' AL MASS (TOTAL) =',ALTOTAL
C
       TOTAL1 = ALTOTAL + U3SI2MAS
       TOTAL2 = TOTAL1/(1.0-WFWATER) - TOTAL1
       TOTAL = TOTAL1 +TOTAL2
       WRITE(6,*)  'TOTAL MASS (NO WATER) =',TOTAL1
       WRITE(6,*)  'TOTAL MASS (WATER ONLY) =',TOTAL2
       WRITE(6,*)  'TOTAL MASS (WATER +FUEL +CLAD) =',TOTAL
C
       FCVOLUME=AELEMENT*NELEMACT*(2.0*ELEMH*2.54)
       WRITE(6,*)  '   TOTAL FUEL + CLAD VOLUME =',FCVOLUME,' CM^3'
       RHOFC = TOTAL1/FCVOLUME
       WRITE(6,*)  ' FUEL+CLAD MIXTURE DENSITY =',RHOFC
C
       F4=ALTOTAL/(U3SI2MAS+ALTOTAL)
C
       RHOU3SI2C = (1.0-F4)/(1.0/RHOFC - F4/RHOCLAD)
       WRITE(6,*)  ' F4 =',F4
       WRITE(6,*)  ' RHOU3SI2 CALCULATED =',RHOU3SI2C
C
       WATERVOL=TOTAL2/RHOWATER
       VOLTOT=WATERVOL + FCVOLUME
C
       WRITE(6,*)  ' TOTAL WATER VOLUME =',WATERVOL
       WRITE(6,*)  ' TOTAL WATER + FUEL + CLAD VOLUMES=',VOLTOT
       RHOMIX = TOTAL/VOLTOT
       WRITE(6,*)  ' MIXTURE DENSITY =',RHOMIX,' G/CC'
       COLHEIGHT=VOLTOT/AREASLOT
       WRITE(6,*)  ' COLHEIGHT=',COLHEIGHT,' CM'
```

```
      WRITE(6,*) ' '
C
      N235 = U235MAS*AV/M235/VOLTOT
      N238 = U238MAS*AV/M238/VOLTOT
      N14=2.0/3.0*(N235+N238)
      N16 = TOTAL2*AV/VOLTOT/MH2O
      N131= ALTOTAL*AV/MAL/VOLTOT
      N1= TOTAL2*AV/VOLTOT *(2.0/MH2O)
C
C
      WRITE(6,*) '  '
      WRITE(6,*) '  '
      WRITE(6,*) ' N1  N14  N16  N131  N238  N235'
      WRITE(6,*) '      1',N1
      WRITE(6,*) '     14',N14
      WRITE(6,*) '     16',N16
      WRITE(6,*) '    131',N131
      WRITE(6,*) '   2381',N238
      WRITE(6,*) '   2351',N235
      WRITE(6,*) 'TOTAL',N1+N14+N16+N131+N238+N235
C
      F3=U3SI2MAS/(U3SI2MAS+ALTOTAL)
      U235CHECK=RHOMIX*(1.0-WFWATER)*F3*F2*ENRICH*VOLTOT
      WRITE(6,*) ' U235 (CHECK)= ',U235CHECK
      WRITE(6,*) ' H/U235 RATIO=',N1/N235
      RATIO=N1/N235
      BIAS1=BIASPART(RATIO)
      BIAS2=BIASFLUX(RATIO)
      WRITE(6,*) ' H/U RATIO =',RATIO,'BIAS PARTICLE =',BIAS1
      WRITE(6,*) ' H/U RATIO =',RATIO,'BIAS FLUX =',BIAS2
C-------------------------------------------------------------
C
C
 200  CONTINUE
 100  CONTINUE

      END
      FUNCTION BIASFLUX(X)
      BIASFLUX=.0098 - .63771E-4*X + .38611E-7*X*X - .66215E-11*X*X*X
      RETURN
      END
      FUNCTION BIASPART(X)
      BIASPART=.0073 - .60275E-4*X + .36218E-7*X*X - .65666E-11*X*X*X
      RETURN
      END
```

6.7.1.2.2.2 FORTRAN Output (Case II Fuel)

```
*************************************
  ********************************
   ORR CASE
  ELEMENT HEIGHT=   23.60950
  RHOH2O =   1.000000
  ENRICH =  0.2000000
  WF     =  0.8000000
  WFWATER=  5.0000001E-02
  RHOU3SI2=   12.02000
  RHOCLAD=   2.700000

   FOR EACH UNIT ELEMENT
    ACLAD   AMEAT AELEMENT (CM2)
  0.5806440      0.3225800      0.9032240
  SI        MASS =   273.4807
  U238      MASS =   2774.400
  U235      MASS =   693.6000
  U3SI2      MASS =   3741.481
  AL MASS IN FUEL =   935.3701
  AL MASS IN CLAD =   3196.489
  AL MASS (TOTAL) =   4131.858
 TOTAL MASS (NO WATER) =   7873.339
 TOTAL MASS (WATER ONLY) =   414.3862
 TOTAL MASS (WATER +FUEL +CLAD) =   8287.726
    TOTAL FUEL + CLAD VOLUME =   1841.598     CM^3
  FUEL+CLAD MIXTURE DENSITY =   4.275275
  F4 =  0.5247911
  RHOU3SI2 CALCULATED =   12.01965
  TOTAL WATER VOLUME =   414.3862
  TOTAL WATER + FUEL + CLAD VOLUMES=   2255.985
  MIXTURE DENSITY =   3.673662     G/CC
  COLHEIGHT=   31.71685     CM


  N1  N14  N16  N131  N238  N235
       1  1.2290440E-02
      14  2.5992552E-03
      16  6.1452198E-03
     131  4.0879738E-02
    2381  3.1110286E-03
    2351  7.8785414E-04
 TOTAL  6.5813534E-02
  U235 (CHECK)=    693.6000
  H/U235 RATIO=   15.59989
  H/U RATIO =   15.59989    BIAS PARTICLE =  6.3685058E-03
  H/U RATIO =   15.59989    BIAS FLUX =  8.8145500E-03
  *************************************
  ********************************
   ORR CASE
  ELEMENT HEIGHT=   23.60950
  RHOH2O =   1.000000
  ENRICH =  0.2000000
  WF     =  0.8000000
  WFWATER=  0.1000000
  RHOU3SI2=   12.02000
  RHOCLAD=   2.700000
```

```
  FOR EACH UNIT ELEMENT
   ACLAD   AMEAT AELEMENT (CM2)
 0.5806440      0.3225800      0.9032240
 SI        MASS =   273.4807
 U238      MASS =   2774.400
 U235      MASS =   693.6000
 U3SI2      MASS =   3741.481
 AL MASS IN FUEL =   935.3701
 AL MASS IN CLAD =   3196.489
 AL MASS (TOTAL) =   4131.858
TOTAL MASS (NO WATER) =   7873.339
TOTAL MASS (WATER ONLY) =   874.8159
TOTAL MASS (WATER +FUEL +CLAD) =   8748.155
   TOTAL FUEL + CLAD VOLUME =   1841.598     CM^3
 FUEL+CLAD MIXTURE DENSITY =   4.275275
 F4 =  0.5247911
 RHOU3SI2 CALCULATED =   12.01965
 TOTAL WATER VOLUME =   874.8159
 TOTAL WATER + FUEL + CLAD VOLUMES=   2716.414
 MIXTURE DENSITY =   3.220479     G/CC
 COLHEIGHT=   38.19003     CM


 N1  N14  N16  N131  N238  N235
      1  2.1548593E-02
     14  2.1586840E-03
     16  1.0774296E-02
    131  3.3950660E-02
   2381  2.5837121E-03
   2351  6.5431360E-04
TOTAL  7.1670257E-02
 U235 (CHECK)=    693.6000
 H/U235 RATIO=   32.93313
 H/U RATIO =   32.93313    BIAS PARTICLE =  5.3540030E-03
 H/U RATIO =   32.93313    BIAS FLUX =  7.7414620E-03
 ************************************
 *********************************
  ORR CASE
 ELEMENT HEIGHT=   23.60950
 RHOH2O =   1.000000
 ENRICH =  0.2000000
 WF     =  0.8000000
 WFWATER=  0.1500000
 RHOU3SI2=   12.02000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELEMENT
   ACLAD   AMEAT AELEMENT (CM2)
 0.5806440      0.3225800      0.9032240
 SI        MASS =   273.4807
 U238      MASS =   2774.400
 U235      MASS =   693.6000
 U3SI2      MASS =   3741.481
 AL MASS IN FUEL =   935.3701
 AL MASS IN CLAD =   3196.489
 AL MASS (TOTAL) =   4131.858
TOTAL MASS (NO WATER) =   7873.339
TOTAL MASS (WATER ONLY) =   1389.413
TOTAL MASS (WATER +FUEL +CLAD) =   9262.752
```

```
  TOTAL FUEL + CLAD VOLUME =   1841.598     CM^3
 FUEL+CLAD MIXTURE DENSITY =   4.275275
 F4 =  0.5247911
 RHOU3SI2 CALCULATED =   12.01965
 TOTAL WATER VOLUME =   1389.413
 TOTAL WATER + FUEL + CLAD VOLUMES=   3231.011
 MIXTURE DENSITY =   2.866828     G/CC
 COLHEIGHT=   45.42474     CM


 N1  N14  N16  N131  N238  N235
      1  2.8773392E-02
     14  1.8148747E-03
     16  1.4386695E-02
    131  2.8543407E-02
   2381  2.1722096E-03
   2351  5.5010238E-04
TOTAL  7.6240674E-02
 U235 (CHECK)=    693.6000
 H/U235 RATIO=   52.30552
 H/U RATIO =   52.30552    BIAS PARTICLE =  4.2454330E-03
 H/U RATIO =   52.30552    BIAS FLUX =  6.5691122E-03
 ************************************
 *********************************
  ORR CASE
 ELEMENT HEIGHT=   23.60950
 RHOH2O =   1.000000
 ENRICH =  0.2000000
 WF     =  0.8000000
 WFWATER=  0.2000000
 RHOU3SI2=   12.02000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELEMENT
   ACLAD   AMEAT AELEMENT (CM2)
 0.5806440      0.3225800      0.9032240
 SI        MASS =   273.4807
 U238      MASS =   2774.400
 U235      MASS =   693.6000
 U3SI2      MASS =   3741.481
 AL MASS IN FUEL =   935.3701
 AL MASS IN CLAD =   3196.489
 AL MASS (TOTAL) =   4131.858
TOTAL MASS (NO WATER) =   7873.339
TOTAL MASS (WATER ONLY) =   1968.334
TOTAL MASS (WATER +FUEL +CLAD) =   9841.674
  TOTAL FUEL + CLAD VOLUME =   1841.598     CM^3
 FUEL+CLAD MIXTURE DENSITY =   4.275275
 F4 =  0.5247911
 RHOU3SI2 CALCULATED =   12.01965
 TOTAL WATER VOLUME =   1968.334
 TOTAL WATER + FUEL + CLAD VOLUMES=   3809.933
 MIXTURE DENSITY =   2.583162     G/CC
 COLHEIGHT=   53.56379     CM


 N1  N14  N16  N131  N238  N235
      1  3.4568440E-02
     14  1.5391032E-03
```

```
     16  1.7284220E-02
    131  2.4206217E-02
   2381  1.8421408E-03
   2351  4.6651394E-04
TOTAL  7.9906635E-02
 U235 (CHECK)=    693.6000
 H/U235 RATIO=   74.09948
 H/U RATIO =   74.09948    BIAS PARTICLE =  3.0298459E-03
 H/U RATIO =   74.09948    BIAS FLUX =  5.2839108E-03
 ************************************
 *********************************
  ORR CASE
 ELEMENT HEIGHT=   23.60950
 RHOH2O =   1.000000
 ENRICH =  0.2000000
 WF     =  0.8000000
 WFWATER=  0.2500000
 RHOU3SI2=   12.02000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELEMENT
   ACLAD   AMEAT AELEMENT (CM2)
 0.5806440      0.3225800      0.9032240
 SI        MASS =   273.4807
 U238      MASS =   2774.400
 U235      MASS =   693.6000
 U3SI2      MASS =   3741.481
 AL MASS IN FUEL =   935.3701
 AL MASS IN CLAD =   3196.489
 AL MASS (TOTAL) =   4131.858
TOTAL MASS (NO WATER) =   7873.339
TOTAL MASS (WATER ONLY) =   2624.447
TOTAL MASS (WATER +FUEL +CLAD) =   10497.79
   TOTAL FUEL + CLAD VOLUME =   1841.598     CM^3
 FUEL+CLAD MIXTURE DENSITY =   4.275275
 F4 =  0.5247911
 RHOU3SI2 CALCULATED =   12.01965
 TOTAL WATER VOLUME =   2624.447
 TOTAL WATER + FUEL + CLAD VOLUMES=   4466.045
 MIXTURE DENSITY =   2.350578     G/CC
 COLHEIGHT=   62.78806     CM


 N1  N14  N16  N131  N238  N235
      1  3.9319947E-02
     14  1.3129916E-03
     16  1.9659974E-02
    131  2.0650052E-02
   2381  1.5715096E-03
   2351  3.9797780E-04
TOTAL  8.2912453E-02
 U235 (CHECK)=    693.6000
 H/U235 RATIO=   98.79935
 H/U RATIO =   98.79935    BIAS PARTICLE =  1.6920717E-03
 H/U RATIO =   98.79935    BIAS FLUX =  3.8699745E-03
 ************************************
 *********************************
  ORR CASE
 ELEMENT HEIGHT=   23.60950
 RHOH2O =   1.000000
```

```
 ENRICH =  0.2000000
 WF     =  0.8000000
 WFWATER=  0.3000000
 RHOU3SI2=   12.02000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELEMENT
   ACLAD   AMEAT AELEMENT (CM2)
 0.5806440      0.3225800      0.9032240
 SI        MASS =   273.4807
 U238      MASS =   2774.400
 U235      MASS =   693.6000
 U3SI2      MASS =   3741.481
 AL MASS IN FUEL =   935.3701
 AL MASS IN CLAD =   3196.489
 AL MASS (TOTAL) =   4131.858
TOTAL MASS (NO WATER) =   7873.339
TOTAL MASS (WATER ONLY) =   3374.289
TOTAL MASS (WATER +FUEL +CLAD) =   11247.63
   TOTAL FUEL + CLAD VOLUME =   1841.598     CM^3
 FUEL+CLAD MIXTURE DENSITY =   4.275275
 F4 =  0.5247911
 RHOU3SI2 CALCULATED =   12.01965
 TOTAL WATER VOLUME =   3374.289
 TOTAL WATER + FUEL + CLAD VOLUMES=   5215.887
 MIXTURE DENSITY =   2.156417     G/CC
 COLHEIGHT=   73.33007     CM


 N1  N14  N16  N131  N238  N235
      1  4.3286484E-02
     14  1.1242345E-03
     16  2.1643242E-02
    131  1.7681377E-02
   2381  1.3455877E-03
   2351  3.4076406E-04
TOTAL  8.5421689E-02
 U235 (CHECK)=    693.6000
 H/U235 RATIO=   127.0277
 H/U RATIO =   127.0277    BIAS PARTICLE =  2.1435953E-04
 H/U RATIO =   127.0277    BIAS FLUX =  2.3087710E-03
 ************************************
 *********************************
  ORR CASE
 ELEMENT HEIGHT=   23.60950
 RHOH2O =   1.000000
 ENRICH =  0.2000000
 WF     =  0.8000000
 WFWATER=  0.3500000
 RHOU3SI2=   12.02000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELEMENT
   ACLAD   AMEAT AELEMENT (CM2)
 0.5806440      0.3225800      0.9032240
 SI        MASS =   273.4807
 U238      MASS =   2774.400
 U235      MASS =   693.6000
 U3SI2      MASS =   3741.481
 AL MASS IN FUEL =   935.3701
```

```
 AL MASS IN CLAD =   3196.489
 AL MASS (TOTAL) =   4131.858
TOTAL MASS (NO WATER) =   7873.339
TOTAL MASS (WATER ONLY) =   4239.490
TOTAL MASS (WATER +FUEL +CLAD) =   12112.83
   TOTAL FUEL + CLAD VOLUME =   1841.598     CM^3
 FUEL+CLAD MIXTURE DENSITY =   4.275275
 F4 =  0.5247911
 RHOU3SI2 CALCULATED =   12.01965
 TOTAL WATER VOLUME =   4239.490
 TOTAL WATER + FUEL + CLAD VOLUMES=   6081.088
 MIXTURE DENSITY =   1.991885     G/CC
 COLHEIGHT=   85.49392     CM


 N1  N14  N16  N131  N238  N235
      1  4.6647731E-02
     14  9.6428132E-04
     16  2.3323866E-02
    131  1.5165717E-02
   2381  1.1541409E-03
   2351  2.9228107E-04
TOTAL  8.7548010E-02
 U235 (CHECK)=    693.6000
 H/U235 RATIO=   159.5989
 H/U RATIO =   159.5989    BIAS PARTICLE = -1.4239799E-03
 H/U RATIO =   159.5989    BIAS FLUX =  5.7879282E-04
 ************************************
 *********************************
  ORR CASE
 ELEMENT HEIGHT=   23.60950
 RHOH2O =   1.000000
 ENRICH =  0.2000000
 WF     =  0.8000000
 WFWATER=  0.4000000
 RHOU3SI2=   12.02000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELEMENT
   ACLAD   AMEAT AELEMENT (CM2)
 0.5806440      0.3225800      0.9032240
 SI        MASS =   273.4807
 U238      MASS =   2774.400
 U235      MASS =   693.6000
 U3SI2      MASS =   3741.481
 AL MASS IN FUEL =   935.3701
 AL MASS IN CLAD =   3196.489
 AL MASS (TOTAL) =   4131.858
TOTAL MASS (NO WATER) =   7873.339
TOTAL MASS (WATER ONLY) =   5248.892
TOTAL MASS (WATER +FUEL +CLAD) =   13122.23
   TOTAL FUEL + CLAD VOLUME =   1841.598     CM^3
 FUEL+CLAD MIXTURE DENSITY =   4.275275
 F4 =  0.5247911
 RHOU3SI2 CALCULATED =   12.01965
 TOTAL WATER VOLUME =   5248.892
 TOTAL WATER + FUEL + CLAD VOLUMES=   7090.490
 MIXTURE DENSITY =   1.850680     G/CC
 COLHEIGHT=   99.68510     CM
 N1  N14  N16  N131  N238  N235
```

```
      1  4.9532425E-02
     14  8.2700630E-04
     16  2.4766212E-02
    131  1.3006725E-02
   2381  9.8983746E-04
   2351  2.5067193E-04
TOTAL  8.9372881E-02
 U235 (CHECK)=    693.6000
 H/U235 RATIO=   197.5986
 H/U RATIO =   197.5986    BIAS PARTICLE = -3.2467798E-03
 H/U RATIO =   197.5986    BIAS FLUX = -1.3445730E-03
 ************************************
 *********************************
  ORR CASE
 ELEMENT HEIGHT=   23.60950
 RHOH2O =   1.000000
 ENRICH =  0.2000000
 WF     =  0.8000000
 WFWATER=  0.4500000
 RHOU3SI2=   12.02000
 RHOCLAD=   2.700000
  FOR EACH UNIT ELEMENT
   ACLAD   AMEAT AELEMENT (CM2)
 0.5806440      0.3225800      0.9032240
 SI        MASS =   273.4807
 U238      MASS =   2774.400
 U235      MASS =   693.6000
 U3SI2      MASS =   3741.481
 AL MASS IN FUEL =   935.3701
 AL MASS IN CLAD =   3196.489
 AL MASS (TOTAL) =   4131.858
TOTAL MASS (NO WATER) =   7873.339
TOTAL MASS (WATER ONLY) =   6441.823
TOTAL MASS (WATER +FUEL +CLAD) =   14315.16
   TOTAL FUEL + CLAD VOLUME =   1841.598     CM^3
 FUEL+CLAD MIXTURE DENSITY =   4.275275
 F4 =  0.5247911
 RHOU3SI2 CALCULATED =   12.01965
 TOTAL WATER VOLUME =   6441.823
 TOTAL WATER + FUEL + CLAD VOLUMES=   8283.421
 MIXTURE DENSITY =   1.728170     G/CC
 COLHEIGHT=   116.4565     CM
 N1  N14  N16  N131  N238  N235
      1  5.2035201E-02
     14  7.0790551E-04
     16  2.6017601E-02
    131  1.1133572E-02
   2381  8.4728672E-04
   2351  2.1457158E-04
TOTAL  9.0956137E-02
 U235 (CHECK)=    693.6000
 H/U235 RATIO=   242.5074
 H/U RATIO =   242.5074    BIAS PARTICLE = -5.2808109E-03
 H/U RATIO =   242.5074    BIAS FLUX = -3.4886687E-03
 ************************************
 *********************************
  ORR CASE
 ELEMENT HEIGHT=   23.60950
 RHOH2O =   1.000000
 ENRICH =  0.2000000
 WF     =  0.8000000
```

```
 WFWATER=  0.5000000
 RHOU3SI2=   12.02000
 RHOCLAD=   2.700000
  FOR EACH UNIT ELEMENT
   ACLAD   AMEAT AELEMENT (CM2)
 0.5806440      0.3225800      0.9032240
 SI        MASS =   273.4807
 U238      MASS =   2774.400
 U235      MASS =   693.6000
 U3SI2      MASS =   3741.481
 AL MASS IN FUEL =   935.3701
 AL MASS IN CLAD =   3196.489
 AL MASS (TOTAL) =   4131.858
TOTAL MASS (NO WATER) =   7873.339
TOTAL MASS (WATER ONLY) =   7873.339
TOTAL MASS (WATER +FUEL +CLAD) =   15746.68
   TOTAL FUEL + CLAD VOLUME =   1841.598     CM^3
 FUEL+CLAD MIXTURE DENSITY =   4.275275
 F4 =  0.5247911
 RHOU3SI2 CALCULATED =   12.01965
 TOTAL WATER VOLUME =   7873.339
 TOTAL WATER + FUEL + CLAD VOLUMES=   9714.938
 MIXTURE DENSITY =   1.620873     G/CC
 COLHEIGHT=   136.5822     CM
 N1  N14  N16  N131  N238  N235
      1  5.4227199E-02
     14  6.0359418E-04
     16  2.7113600E-02
    131  9.4930166E-03
   2381  7.2243722E-04
   2351  1.8295401E-04
TOTAL  9.2342801E-02
 U235 (CHECK)=    693.6000
 H/U235 RATIO=   296.3980
 H/U RATIO =   296.3980    BIAS PARTICLE = -7.5545614E-03
 H/U RATIO =   296.3980    BIAS FLUX = -5.8819694E-03
 ************************************
 *********************************
  ORR CASE
 ELEMENT HEIGHT=   23.60950
 RHOH2O =   1.000000
 ENRICH =  0.2000000
 WF     =  0.8000000
 WFWATER=  0.5500000
 RHOU3SI2=   12.02000
 RHOCLAD=   2.700000
 FOR EACH UNIT ELEMENT
   ACLAD   AMEAT AELEMENT (CM2)
 0.5806440      0.3225800      0.9032240
 SI        MASS =   273.4807
 U238      MASS =   2774.400
 U235      MASS =   693.6000
 U3SI2      MASS =   3741.481
 AL MASS IN FUEL =   935.3701
 AL MASS IN CLAD =   3196.489
 AL MASS (TOTAL) =   4131.858
TOTAL MASS (NO WATER) =   7873.339
TOTAL MASS (WATER ONLY) =   9622.972
TOTAL MASS (WATER +FUEL +CLAD) =   17496.31
   TOTAL FUEL + CLAD VOLUME =   1841.598     CM^3
 FUEL+CLAD MIXTURE DENSITY =   4.275275
```

```
 F4 =  0.5247911
 RHOU3SI2 CALCULATED =   12.01965
 TOTAL WATER VOLUME =   9622.972
 TOTAL WATER + FUEL + CLAD VOLUMES=   11464.57
 MIXTURE DENSITY =   1.526120     G/CC
 COLHEIGHT=   161.1802     CM
 N1  N14  N16  N131  N238  N235
      1  5.6162912E-02
     14  5.1147840E-04
     16  2.8081456E-02
    131  8.0442661E-03
   2381  6.1218452E-04
   2351  1.5503301E-04
TOTAL  9.3567327E-02
 U235 (CHECK)=    693.6000
 H/U235 RATIO=   362.2642
 H/U RATIO =   362.2642    BIAS PARTICLE = -1.0094583E-02
 H/U RATIO =   362.2642    BIAS FLUX = -8.5496232E-03
 ************************************
```

6.7.1.3 Case III Fuel (UAl_x)

6.7.1.3.1 GEMER Input Decks

This Appendix includes GEMER geometrical plots and input listings for the infinite cask array for MTR Case III fuel. Each basedeck contains a "header" with fuel material and geometry information. Since the program input is similar to the popular KENO program (and deviations from this were discussed previously). No further explanation of the inputs is provided.

6.7.1.3.1.1 Infinite (94% Enriched)

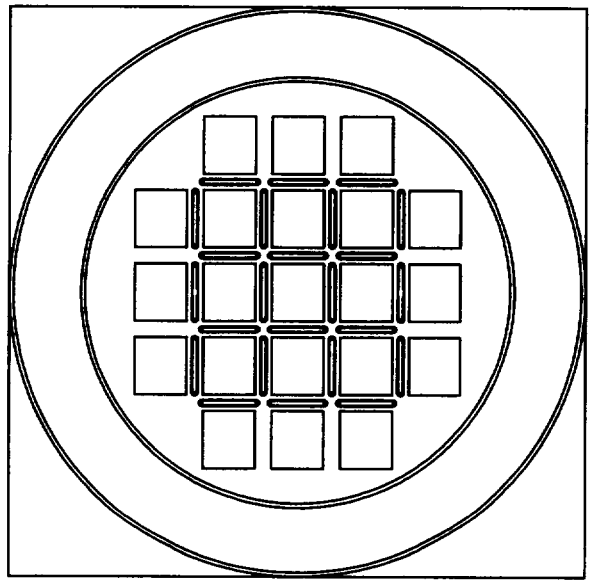

Figure 6.28. Unit Array for MTR Case III Fuel — Top View

```
BSR FUEL/ IF2000/21 ELEMENTS, SS+Pb SHIELDING. MASS U235=1112.45 GRAMS
   125 /* # BATCHES
  1000  /* # NEUTRONS PER BATCH
     5  /* # BATCHES TO SKIP
 2123469/* INITIAL "SEED" (IF NON-ZERO)
     0  /* "IDUMP"
     0  /* "NRSTRT"
     0  /* "NBTED" (NON-ZERO IS PRINT EDITS)
     0  /* "KRED" (NUMBER OF COMBINED REGIONS IN EDITS)
     0  293   14  8
      5  293 0  0 U(94.0)AL+0.225 WF -H2O RHOMIX=2.002935 g/cc     MAT 1
      1  3.0154189E-02
     16  1.5077095E-02
    131  3.1995464E-02
   2381  1.8031913E-05
   2351  2.8616746E-04
      3  293 0 0 Boral 0.25" Plate (60% Boron Loading)  MAT 2
   10     3.32658E-03
   11     6.7889E-05
  131     5.8001E-02
      2  293 0 0  MODERATOR IN CASK (100.00%)                    MAT 3
     1   6.69111121E-02
    16   3.34555566E-02
      2  293 0 0  INTERSPERSED MODERATOR (100.00%)            MAT4
     1   6.69111121E-02
    16   3.34555566E-02
      2  293 0 0 FULL DENSITY WATER                    MAT 5
     1    6.69111121E-02
    16    3.34555566E-02
      1  293 0 0 LEAD SHIELDING                        MAT 6
```

```
    82   3.29890E-02
     7   293 0 0 304 STAINLESS STEEL                    MAT 7
    12   6.82690E-05
    14   8.53360E-04
    24   1.53600E-02
    26   6.04950E-02
    28   6.82690E-03
    55   1.70670E-03
  1316   2.56010E-05
     2   293 0 0 FULL DENSITY WATER (VOID)              MAT 8
     1    6.69111121E-09
    16    3.34555566E-09
KENO GEOM
    14  /* "KREFM"
     6  /* "NBOX"
     1  /* "NBXMAX"
     1  /* "NBYMAX"
     1  /* "NBZMAX"
     1  /* "NXX"
     0  /* "NTYPST"
     1  /* "NEMBRG"
     0  /* "NGMCHK"
 -1.0  -1.0  -1.0  -1.0  -1.0  -1.0
BOX TYPE     1 /*MODEL 2000 CASK & STAINLESS SUPPORT STRUCTURE
CYLINDER     7  33.34     140.64     0.0    16*0.5
CYLINDER     3  33.65     140.64     0.0    16*0.5
CYLINDER     7  35.85     140.64     0.0    16*0.5
CYLINDER     6  46.34     140.64     0.0    16*0.5
CYLINDER     7  48.56     140.64   -14.90   16*0.5
BOX TYPE     2 /* CASK TOP
CYLINDER     6  30.96     158.42    140.64  16*0.5
CYLINDER     7  48.56     162.23    140.64  16*0.5
BOX TYPE     3 /* BSR FUEL ASSEMBLY-COLLAPSED
CUBOID       1  4.4450 -4.4450  4.0005  -4.0005  140.0513  0.0   16*0.5
CUBOID       3  4.4450 -4.4450  4.0005  -4.0005  140.64  0.0   16*0.5
BOX TYPE     4 /* BORAL PLATE (VERT)
CUBOID       2  0.286  -0.286  4.12  -4.12  138.64  2.0   16*0.5
BOX TYPE     5 /* BORAL PLATE (HORIZ)
CUBOID       2  4.12  -4.12  0.286  -0.286  138.64  2.0   16*0.5
BOX TYPE     6  /* OVERALL BOX FOR THE PROBLEM
CUBOID       8  48.60    -48.60   48.60 -48.60 162.23 -14.91 16*0.5
CORE         0  48.60    -48.60   48.60 -48.60 162.23 -14.91 16*0.5
CUBOID       8  48.70    -48.70   48.70 -48.70 162.33 -15.01 16*0.5
6  1 1 1  1 1 1  1 1 1  1
BEGIN COMPLEX
/* PLACE FUEL ASSEMBLIES INTO CASK
COMPLEX  1  3   -22.860  -10.540  0.0  5  3  1  11.430  10.540  0.0
/*MIDDLE ROWS
COMPLEX  1  3   -11.430  -21.080  0.0  3  2  1  11.430  42.160  0.0
/*OUTER ROWS
/* PLACE BORAL PLATES INTO CASK
COMPLEX  1  4   -17.145  -10.540  0.0  4  3  1  11.430  10.540  0.0
/*VERT PLATES
COMPLEX  1  5   -11.430  -15.810  0.0  3  4  1  11.430  10.540  0.0
/*HORIZ PLATES
/* PLACE LOADED CASK INTO OVERALL PROBLEM BOX
COMPLEX  6  1  0.0     0.0    0.0   1 1 1   0.0    0.0    0.0
/* PLACE TOP INTO OVERALL PROBLEM BOX
COMPLEX  6  2  0.0     0.0    0.0   1 1 1   0.0    0.0    0.0
END GEOM
*END GEMER*
```

6.7.1.3.2 Number Density Calculations

6.7.1.3.2.1 FORTRAN Program (MTR Case III Fuel)

```
PROGRAM NUMBER
C
C   ASSUMPTIONS:
C   1. THE FUEL AND WATER ARE IN A HOMOGENOUS MIXTURE.
C
       REAL NELEMENT,NPLATE
       REAL NAL_CLAD,MAL
       REAL MU,MUAL,MU235,M238,MO16,MH2O,MH
       REAL N235,N238,N16,N131,N1
       OPEN(6,FILE='BSR_94.OUT',STATUS='UNKNOWN')
C
C    FOR UAL FUEL
C
C    NUMBER DENSITY PROGRAM FOR BSR
C
C      9/16/96
C      AV = AVOGADRO'S NUMBER
C
      AV=0.6022
      M235 =235.0439
      M238 =238.0508
      MAL = 26.98
      MO16 = 16.000
      MH2O=18.0
      MH=1.0
C
C   ITER VARIABLE FOR VARYING THE WATER WEIGHT FRACTION
C
      DO 100 ITER=0,10,1
      WRITE(6,*) ' ************************************'
C
C    D  = ACTIVE FUEL WIDTH (IN)
C    E  = CLADDING THICKNESS (IN)
C    C  = FUEL PLATE WIDTH (IN)
C    G  = PLATE THICKNESS (IN)
C    F  = ACTIVE FUEL THICKNESS (IN)
C    RHOUAL = DENSITY OF UAL (G/CC)
C    RHOCLAD = DENISTY OF AL CLAD (G/CC)
C     WF= WEIGHT % OF UAL  IN THE UAL/AL MIXTURE
C     WFWATER = WEIGHT FRACTION OF WATER
C      ENRICH = FUEL ENRICHMENT
C      WF= WEIGHT FRACTION OF FUEL (UAL) IN THE FUEL MIXTURE
C     PLATELEN = FUEL PLATE LENGTH IN INCHES
C     U235PLATE= U235 MASS PER PLATE (G)
C     NELEMENT = NUMBER OF FUEL ELEMENTS SQUEEZED INTO ONE CASK SLOT
POSITIOIN
C*****************************************************
C      BSR
C
       D=2.500
       E=0.015
       C=2.799
       G=0.051
       F=0.020
       RHOUAL = 6.00
```

```
C        ENRICH = 0.932
C      CHANGED TO 94% ENRICHMENT
        ENRICH = 0.940
        WF=0.225
        WFWATER=0.025*FLOAT(ITER)
C
        U235PLATE=11.71
        NPLATE=19.0
        NELEMENT=5.0
        U235MAS=U235PLATE*NPLATE*NELEMENT
        PLATELEN= 24.625
C ---------------------------------------------------
C   AREASLOT = SLOT AREA PER ELEMENT (cm^2)
C
        RHOWATER=1.0
        RHOH2O = 1.0
        RHOCLAD=2.7
        AREASLOT=71.12889
C
C
       WRITE(6,*) '  BSR CASE'
       WRITE(6,*) ' ELEMENT HEIGHT=',PLATELEN,' INCHES'
       WRITE(6,*) ' RHOH2O =',RHOH2O,' G/CC'
       WRITE(6,*) ' ENRICH =',ENRICH*100,' %'
       WRITE(6,*) ' WEIGHT FRACTION OF FUEL, WF  =',WF
       WRITE(6,*) ' WEIGHT FRACTION OF WATER WFWATER=',WFWATER
       WRITE(6,*) ' DENSITY OF UAL (RHOUAL)=',RHOUAL,' G/CC'
       WRITE(6,*) ' CLAD DENSITY (RHOCLAD)=',RHOCLAD,' G/CC'
C
C
C---------------------------------------------------
C        ACLAD = AREA OF CLAD PER PLATE
C        AMEAT = FUEL MEAT AREA PER PLATE
C
        APLATE=C*G*2.54*2.54
        AMEAT=D*F*2.54*2.54
        ACLAD=APLATE-AMEAT
C
        WRITE(6,*) ' '
        WRITE(6,*) '  FOR EACH UNIT PLATE'
        WRITE(6,*) '   ACLAD   AMEAT   APLATE (CM2)'
        WRITE(6,*) ACLAD,AMEAT,APLATE
C
C-------------------------------------------------
C      U235MAS = TOTAL U235 MASS IN ALL PLATES AND ALL FUEL ELEMENTS
CONSIDERED
        U238MAS=U235MAS/ENRICH - U235MAS
C
        MU= 1.0/(ENRICH/M235 + (1.0-ENRICH)/M238)
        F2=MU/(MU+MAL)
        UALMAS=(U235MAS+U238MAS)/F2
        ALMAS=UALMAS-(U235MAS+U238MAS)
        WRITE(6,*) ' FOR ALL PLATES AND FUEL ELEMENTS CONSIDERED:'
        WRITE(6,*) ' AL (FUEL) MASS =',ALMAS
        WRITE(6,*) ' U238      MASS =',U238MAS
        WRITE(6,*) ' U235      MASS =',U235MAS
        WRITE(6,*) ' UAL      MASS =',UALMAS
C
C       ALPLATE = ALUMINIUM IN THE PLATE (NON-FUEL SECTION)
C       THE FUEL CONSISTS OF UAL AND AL MIXTURE
C
```

```
      ALPLATE=UALMAS/WF*(1.0-WF)
C
C     ALCLAD = AL IN THE FUELED CLAD
      ALCLAD=ACLAD*(PLATELEN*2.54)*NELEMENT*NPLATE*RHOCLAD
      ALTOTAL=ALCLAD+ALPLATE+ALMAS
      WRITE(6,*) ' AL MASS (NON-FUEL) =',ALPLATE
      WRITE(6,*) ' AL MASS (UAL FUEL) =',ALMAS
      WRITE(6,*) ' AL MASS IN CLAD =',ALCLAD
      WRITE(6,*) ' AL MASS (TOTAL) =',ALTOTAL
C
C    TOTAL1 = TOTAL FUEL ELEMENT MASS
C    TOTAL2 = WATER MASS
      TOTAL1 = ALTOTAL + U235MAS + U238MAS
      TOTAL2 = TOTAL1/(1.0-WFWATER) - TOTAL1
      TOTAL = TOTAL1 +TOTAL2
      WRITE(6,*) 'TOTAL MASS (NO WATER) =',TOTAL1
      WRITE(6,*) 'TOTAL MASS (WATER ONLY) =',TOTAL2
      WRITE(6,*) 'TOTAL MASS (WATER +FUEL +CLAD) =',TOTAL
C
      FCVOLUME=APLATE*NPLATE*NELEMENT*(PLATELEN*2.54)
      WRITE(6,*) '   TOTAL FUEL + CLAD VOLUME =',FCVOLUME,' CM^3'
      RHOFC = TOTAL1/FCVOLUME
      WRITE(6,*) ' FUEL+CLAD MIXTURE DENSITY =',RHOFC
C
C     F4 = FRACTION OF AL OVER AL + UAL
C
      F4=ALTOTAL/(UALMAS+ALTOTAL)
C
      RHOUALC = (1.0-F4)/(1.0/RHOFC - F4/RHOCLAD)
      WRITE(6,*) ' F4 =',F4
      WRITE(6,*) ' RHOUAL CALCULATED =',RHOUALC
      WATERVOL=TOTAL2/RHOWATER
      VOLTOT=WATERVOL + FCVOLUME
C
      WRITE(6,*) ' TOTAL WATER VOLUME =',WATERVOL
      WRITE(6,*) ' TOTAL WATER + FUEL + CLAD VOLUMES=',VOLTOT
      RHOMIX = TOTAL/VOLTOT
      WRITE(6,*) ' MIXTURE DENSITY =',RHOMIX,' G/CC'
      COLHEIGHT=VOLTOT/AREASLOT
      WRITE(6,*) ' COLHEIGHT=',COLHEIGHT,' CM'
      WRITE(6,*) ' '
C
     N235 = U235MAS*AV/M235/VOLTOT
     N238 = U238MAS*AV/M238/VOLTOT
     N16 = TOTAL2*AV/VOLTOT/MH2O
     N131= ALTOTAL*AV/MAL/VOLTOT
     N1= TOTAL2*AV/MH/VOLTOT *(2.0*MH/MH2O)
     HURATIO=N1/N235
C
     WRITE(6,*) '  '
     WRITE(6,*) '  '
     WRITE(6,*) ' N1  N16  N131  N238  N235'
     WRITE(6,*) '      1',N1
     WRITE(6,*) '     16',N16
     WRITE(6,*) '    131',N131
     WRITE(6,*) '   2381',N238
     WRITE(6,*) '   2351',N235
     WRITE(6,*) 'TOTAL =',N1+N16+N131+N238+N235
     WRITE(6,*) ' H/U-235 RATIO =',HURATIO
C ************************************************************
C
```

```
C     CHECKING THE NUMBER DENSITIES
C
C ************************************************************
        F3=1.0-F4
        U235CHECK=RHOMIX*(1.0-WFWATER)*F3*F2*ENRICH*VOLTOT
        U238CHECK=RHOMIX*(1.0-WFWATER)*F3*F2*(1.0-ENRICH)*VOLTOT
        ALCHECK=RHOMIX*(1.0-WFWATER)*(1.0-F3)*VOLTOT
        WATERCHECK=RHOMIX*WFWATER*VOLTOT
        WRITE(6,*) ' U235 (CHECK)= ',U235CHECK
        WRITE(6,*) ' U238 (CHECK)= ',U238CHECK
        WRITE(6,*) ' AL (CHECK)= ',ALCHECK
        WRITE(6,*) ' WATER (CHECK)= ',WATERCHECK

C------------------------------------------------------------
C
 100    CONTINUE
C
        END
```

6.7.1.3.2.2 FORTRAN Output (MTR Case III Fuel)

```
 ************************************
  BSR CASE
 ELEMENT HEIGHT=   24.62500     INCHES
 RHOH2O =   1.000000     G/CC
 ENRICH =   94.00000     %
 WEIGHT FRACTION OF FUEL, WF  =  0.2250000
 WEIGHT FRACTION OF WATER WFWATER=  0.0000000E+00
 DENSITY OF UAL (RHOUAL)=   6.000000     G/CC
 CLAD DENSITY (RHOCLAD)=   2.700000     G/CC

  FOR EACH UNIT PLATE
   ACLAD   AMEAT   APLATE (CM2)
 0.5983794      0.3225800      0.9209594
 FOR ALL PLATES AND FUEL ELEMENTS CONSIDERED:
 AL (FUEL) MASS =   135.7665
 U238      MASS =   71.00745
 U235      MASS =   1112.450
 UAL      MASS =   1319.224
 AL MASS (NON-FUEL) =   4543.994
 AL MASS (UAL FUEL) =   135.7665
 AL MASS IN CLAD =   9600.062
 AL MASS (TOTAL) =   14279.82
TOTAL MASS (NO WATER) =   15463.28
TOTAL MASS (WATER ONLY) =  0.0000000E+00
TOTAL MASS (WATER +FUEL +CLAD) =   15463.28
   TOTAL FUEL + CLAD VOLUME =   5472.352     CM^3
 FUEL+CLAD MIXTURE DENSITY =   2.825710
 F4 =  0.9154292
 RHOUAL CALCULATED =   5.696731
 TOTAL WATER VOLUME =  0.0000000E+00
 TOTAL WATER + FUEL + CLAD VOLUMES=   5472.352
 MIXTURE DENSITY =   2.825710     G/CC
 COLHEIGHT=   76.93571     CM


 N1  N16  N131  N238  N235
      1  0.0000000E+00
     16  0.0000000E+00
```

```
    131  5.8243513E-02
   2381  3.2824712E-05
   2351  5.2093004E-04
TOTAL =  5.8797266E-02
 H/U-235 RATIO =  0.0000000E+00
 U235 (CHECK)=    1102.767
 U238 (CHECK)=    70.38940
 AL (CHECK)=    14155.54
 WATER (CHECK)=   0.0000000E+00
 ************************************
  BSR CASE
 ELEMENT HEIGHT=   24.62500     INCHES
 RHOH2O =   1.000000     G/CC
 ENRICH =   94.00000     %
 WEIGHT FRACTION OF FUEL, WF  =  0.2250000
 WEIGHT FRACTION OF WATER WFWATER=  2.5000000E-02
 DENSITY OF UAL (RHOUAL)=   6.000000     G/CC
 CLAD DENSITY (RHOCLAD)=   2.700000     G/CC

  FOR EACH UNIT PLATE
   ACLAD   AMEAT   APLATE (CM2)
 0.5983794      0.3225800      0.9209594
 FOR ALL PLATES AND FUEL ELEMENTS CONSIDERED:
 AL (FUEL) MASS =   135.7665
 U238      MASS =   71.00745
 U235      MASS =   1112.450
 UAL      MASS =   1319.224
 AL MASS (NON-FUEL) =   4543.994
 AL MASS (UAL FUEL) =   135.7665
 AL MASS IN CLAD =   9600.062
 AL MASS (TOTAL) =   14279.82
TOTAL MASS (NO WATER) =   15463.28
TOTAL MASS (WATER ONLY) =   396.4941
TOTAL MASS (WATER +FUEL +CLAD) =   15859.77
   TOTAL FUEL + CLAD VOLUME =   5472.352     CM^3
 FUEL+CLAD MIXTURE DENSITY =   2.825710
 F4 =  0.9154292
 RHOUAL CALCULATED =   5.696731
 TOTAL WATER VOLUME =   396.4941
 TOTAL WATER + FUEL + CLAD VOLUMES=   5868.846
 MIXTURE DENSITY =   2.702367     G/CC
 COLHEIGHT=   82.51002     CM


 N1  N16  N131  N238  N235
      1  4.5204558E-03
     16  2.2602279E-03
    131  5.4308631E-02
   2381  3.0607105E-05
   2351  4.8573644E-04
TOTAL =  6.1605658E-02
 H/U-235 RATIO =   9.306396
 U235 (CHECK)=    1102.767
 U238 (CHECK)=    70.38940
 AL (CHECK)=    14155.54
 WATER (CHECK)=    396.4944
 ************************************
  BSR CASE
 ELEMENT HEIGHT=   24.62500     INCHES
 RHOH2O =   1.000000     G/CC
```

```
 ENRICH =   94.00000     %
 WEIGHT FRACTION OF FUEL, WF  =  0.2250000
 WEIGHT FRACTION OF WATER WFWATER=  5.0000001E-02
 DENSITY OF UAL (RHOUAL)=   6.000000     G/CC
 CLAD DENSITY (RHOCLAD)=   2.700000     G/CC

  FOR EACH UNIT PLATE
   ACLAD   AMEAT   APLATE (CM2)
 0.5983794      0.3225800      0.9209594
 FOR ALL PLATES AND FUEL ELEMENTS CONSIDERED:
 AL (FUEL) MASS =   135.7665
 U238      MASS =   71.00745
 U235      MASS =   1112.450
 UAL      MASS =   1319.224
 AL MASS (NON-FUEL) =   4543.994
 AL MASS (UAL FUEL) =   135.7665
 AL MASS IN CLAD =   9600.062
 AL MASS (TOTAL) =   14279.82
TOTAL MASS (NO WATER) =   15463.28
TOTAL MASS (WATER ONLY) =   813.8574
TOTAL MASS (WATER +FUEL +CLAD) =   16277.14
   TOTAL FUEL + CLAD VOLUME =   5472.352     CM^3
 FUEL+CLAD MIXTURE DENSITY =   2.825710
 F4 =  0.9154292
 RHOUAL CALCULATED =   5.696731
 TOTAL WATER VOLUME =   813.8574
 TOTAL WATER + FUEL + CLAD VOLUMES=   6286.209
 MIXTURE DENSITY =   2.589341     G/CC
 COLHEIGHT=   88.37772     CM


 N1  N16  N131  N238  N235
      1  8.6627882E-03
     16  4.3313941E-03
    131  5.0702892E-02
   2381  2.8574992E-05
   2351  4.5348672E-04
TOTAL =  6.4179137E-02
 H/U-235 RATIO =   19.10263
 U235 (CHECK)=    1102.767
 U238 (CHECK)=    70.38941
 AL (CHECK)=    14155.54
 WATER (CHECK)=    813.8569
 ************************************
  BSR CASE
 ELEMENT HEIGHT=   24.62500     INCHES
 RHOH2O =   1.000000     G/CC
 ENRICH =   94.00000     %
 WEIGHT FRACTION OF FUEL, WF  =  0.2250000
 WEIGHT FRACTION OF WATER WFWATER=  7.5000003E-02
 DENSITY OF UAL (RHOUAL)=   6.000000     G/CC
 CLAD DENSITY (RHOCLAD)=   2.700000     G/CC

  FOR EACH UNIT PLATE
   ACLAD   AMEAT   APLATE (CM2)
 0.5983794      0.3225800      0.9209594
 FOR ALL PLATES AND FUEL ELEMENTS CONSIDERED:
 AL (FUEL) MASS =   135.7665
 U238      MASS =   71.00745
 U235      MASS =   1112.450
```

```
 UAL       MASS =   1319.224
 AL MASS (NON-FUEL) =   4543.994
 AL MASS (UAL FUEL) =   135.7665
 AL MASS IN CLAD =   9600.062
 AL MASS (TOTAL) =   14279.82
TOTAL MASS (NO WATER) =   15463.28
TOTAL MASS (WATER ONLY) =   1253.778
TOTAL MASS (WATER +FUEL +CLAD) =   16717.06
   TOTAL FUEL + CLAD VOLUME =   5472.352     CM^3
 FUEL+CLAD MIXTURE DENSITY =   2.825710
 F4 =  0.9154292
 RHOUAL CALCULATED =   5.696731
 TOTAL WATER VOLUME =   1253.778
 TOTAL WATER + FUEL + CLAD VOLUMES=   6726.130
 MIXTURE DENSITY =   2.485390     G/CC
 COLHEIGHT=   94.56257     CM


 N1  N16  N131  N238  N235
      1  1.2472506E-02
     16  6.2362528E-03
    131  4.7386684E-02
   2381  2.6706051E-05
   2351  4.2382654E-04
TOTAL =  6.6545971E-02
 H/U-235 RATIO =   29.42833
 U235 (CHECK)=    1102.767
 U238 (CHECK)=    70.38939
 AL (CHECK)=    14155.54
 WATER (CHECK)=    1253.779
 ************************************
  BSR CASE
 ELEMENT HEIGHT=   24.62500     INCHES
 RHOH2O =   1.000000     G/CC
 ENRICH =   94.00000     %
 WEIGHT FRACTION OF FUEL, WF  =  0.2250000
 WEIGHT FRACTION OF WATER WFWATER=  0.1000000
 DENSITY OF UAL (RHOUAL)=   6.000000     G/CC
 CLAD DENSITY (RHOCLAD)=   2.700000     G/CC

  FOR EACH UNIT PLATE
   ACLAD   AMEAT   APLATE (CM2)
 0.5983794      0.3225800      0.9209594
 FOR ALL PLATES AND FUEL ELEMENTS CONSIDERED:
 AL (FUEL) MASS =   135.7665
 U238      MASS =   71.00745
 U235      MASS =   1112.450
 UAL      MASS =   1319.224
 AL MASS (NON-FUEL) =   4543.994
 AL MASS (UAL FUEL) =   135.7665
 AL MASS IN CLAD =   9600.062
 AL MASS (TOTAL) =   14279.82
TOTAL MASS (NO WATER) =   15463.28
TOTAL MASS (WATER ONLY) =   1718.144
TOTAL MASS (WATER +FUEL +CLAD) =   17181.42
   TOTAL FUEL + CLAD VOLUME =   5472.352     CM^3
 FUEL+CLAD MIXTURE DENSITY =   2.825710
 F4 =  0.9154292
 RHOUAL CALCULATED =   5.696731
 TOTAL WATER VOLUME =   1718.144
```

```
 TOTAL WATER + FUEL + CLAD VOLUMES=   7190.496
 MIXTURE DENSITY =   2.389463     G/CC
 COLHEIGHT=   101.0911     CM


 N1  N16  N131  N238  N235
      1  1.5988173E-02
     16  7.9940865E-03
    131  4.4326432E-02
   2381  2.4981364E-05
   2351  3.9645564E-04
TOTAL =  6.8730131E-02
 H/U-235 RATIO =   40.32777
 U235 (CHECK)=    1102.767
 U238 (CHECK)=    70.38941
 AL (CHECK)=    14155.54
 WATER (CHECK)=    1718.142
 ************************************
  BSR CASE
 ELEMENT HEIGHT=   24.62500     INCHES
 RHOH2O =   1.000000     G/CC
 ENRICH =   94.00000     %
 WEIGHT FRACTION OF FUEL, WF  =  0.2250000
 WEIGHT FRACTION OF WATER WFWATER=  0.1250000
 DENSITY OF UAL (RHOUAL)=   6.000000     G/CC
 CLAD DENSITY (RHOCLAD)=   2.700000     G/CC

  FOR EACH UNIT PLATE
   ACLAD   AMEAT   APLATE (CM2)
 0.5983794      0.3225800      0.9209594
 FOR ALL PLATES AND FUEL ELEMENTS CONSIDERED:
 AL (FUEL) MASS =   135.7665
 U238      MASS =   71.00745
 U235      MASS =   1112.450
 UAL      MASS =   1319.224
 AL MASS (NON-FUEL) =   4543.994
 AL MASS (UAL FUEL) =   135.7665
 AL MASS IN CLAD =   9600.062
 AL MASS (TOTAL) =   14279.82
TOTAL MASS (NO WATER) =   15463.28
TOTAL MASS (WATER ONLY) =   2209.040
TOTAL MASS (WATER +FUEL +CLAD) =   17672.32
   TOTAL FUEL + CLAD VOLUME =   5472.352     CM^3
 FUEL+CLAD MIXTURE DENSITY =   2.825710
 F4 =  0.9154292
 RHOUAL CALCULATED =   5.696731
 TOTAL WATER VOLUME =   2209.040
 TOTAL WATER + FUEL + CLAD VOLUMES=   7681.392
 MIXTURE DENSITY =   2.300666     G/CC
 COLHEIGHT=   107.9926     CM


 N1  N16  N131  N238  N235
      1  1.9242518E-02
     16  9.6212588E-03
    131  4.1493651E-02
   2381  2.3384875E-05
   2351  3.7111927E-04
TOTAL =  7.0751935E-02
```

```
 H/U-235 RATIO =   51.84996
 U235 (CHECK)=    1102.767
 U238 (CHECK)=    70.38940
 AL (CHECK)=    14155.54
 WATER (CHECK)=    2209.040
 ************************************
  BSR CASE
 ELEMENT HEIGHT=   24.62500     INCHES
 RHOH2O =   1.000000     G/CC
 ENRICH =   94.00000     %
 WEIGHT FRACTION OF FUEL, WF  =  0.2250000
 WEIGHT FRACTION OF WATER WFWATER=  0.1500000
 DENSITY OF UAL (RHOUAL)=   6.000000     G/CC
 CLAD DENSITY (RHOCLAD)=   2.700000     G/CC

  FOR EACH UNIT PLATE
   ACLAD   AMEAT   APLATE (CM2)
 0.5983794      0.3225800      0.9209594
 FOR ALL PLATES AND FUEL ELEMENTS CONSIDERED:
 AL (FUEL) MASS =   135.7665
 U238      MASS =   71.00745
 U235      MASS =   1112.450
 UAL      MASS =   1319.224
 AL MASS (NON-FUEL) =   4543.994
 AL MASS (UAL FUEL) =   135.7665
 AL MASS IN CLAD =   9600.062
 AL MASS (TOTAL) =   14279.82
TOTAL MASS (NO WATER) =   15463.28
TOTAL MASS (WATER ONLY) =   2728.813
TOTAL MASS (WATER +FUEL +CLAD) =   18192.09
   TOTAL FUEL + CLAD VOLUME =   5472.352     CM^3
 FUEL+CLAD MIXTURE DENSITY =   2.825710
 F4 =  0.9154292
 RHOUAL CALCULATED =   5.696731
 TOTAL WATER VOLUME =   2728.813
 TOTAL WATER + FUEL + CLAD VOLUMES=   8201.166
 MIXTURE DENSITY =   2.218233     G/CC
 COLHEIGHT=   115.3001     CM


 N1  N16  N131  N238  N235
      1  2.2263655E-02
     16  1.1131827E-02
    131  3.8863864E-02
   2381  2.1902786E-05
   2351  3.4759846E-04
TOTAL =  7.2628856E-02
 H/U-235 RATIO =   64.04993
 U235 (CHECK)=    1102.767
 U238 (CHECK)=    70.38941
 AL (CHECK)=    14155.54
 WATER (CHECK)=    2728.814
 ************************************
  BSR CASE
 ELEMENT HEIGHT=   24.62500     INCHES
 RHOH2O =   1.000000     G/CC
 ENRICH =   94.00000     %
 WEIGHT FRACTION OF FUEL, WF  =  0.2250000
 WEIGHT FRACTION OF WATER WFWATER=  0.1750000
 DENSITY OF UAL (RHOUAL)=   6.000000     G/CC
```

```
 CLAD DENSITY (RHOCLAD)=   2.700000     G/CC

  FOR EACH UNIT PLATE
   ACLAD   AMEAT   APLATE (CM2)
 0.5983794      0.3225800      0.9209594
 FOR ALL PLATES AND FUEL ELEMENTS CONSIDERED:
 AL (FUEL) MASS =   135.7665
 U238      MASS =   71.00745
 U235      MASS =   1112.450
 UAL      MASS =   1319.224
 AL MASS (NON-FUEL) =   4543.994
 AL MASS (UAL FUEL) =   135.7665
 AL MASS IN CLAD =   9600.062
 AL MASS (TOTAL) =   14279.82
TOTAL MASS (NO WATER) =   15463.28
TOTAL MASS (WATER ONLY) =   3280.091
TOTAL MASS (WATER +FUEL +CLAD) =   18743.37
   TOTAL FUEL + CLAD VOLUME =   5472.352     CM^3
 FUEL+CLAD MIXTURE DENSITY =   2.825710
 F4 =  0.9154292
 RHOUAL CALCULATED =   5.696731
 TOTAL WATER VOLUME =   3280.091
 TOTAL WATER + FUEL + CLAD VOLUMES=   8752.443
 MIXTURE DENSITY =   2.141502     G/CC
 COLHEIGHT=   123.0505     CM


 N1  N16  N131  N238  N235
      1  2.5075801E-02
     16  1.2537900E-02
    131  3.6416002E-02
   2381  2.0523228E-05
   2351  3.2570478E-04
TOTAL =  7.4375935E-02
 H/U-235 RATIO =   76.98936
 U235 (CHECK)=    1102.767
 U238 (CHECK)=    70.38942
 AL (CHECK)=    14155.54
 WATER (CHECK)=    3280.090
 ************************************
  BSR CASE
 ELEMENT HEIGHT=   24.62500     INCHES
 RHOH2O =   1.000000     G/CC
 ENRICH =   94.00000     %
 WEIGHT FRACTION OF FUEL, WF  =  0.2250000
 WEIGHT FRACTION OF WATER WFWATER=  0.2000000
 DENSITY OF UAL (RHOUAL)=   6.000000     G/CC
 CLAD DENSITY (RHOCLAD)=   2.700000     G/CC

  FOR EACH UNIT PLATE
   ACLAD   AMEAT   APLATE (CM2)
 0.5983794      0.3225800      0.9209594
 FOR ALL PLATES AND FUEL ELEMENTS CONSIDERED:
 AL (FUEL) MASS =   135.7665
 U238      MASS =   71.00745
 U235      MASS =   1112.450
 UAL      MASS =   1319.224
 AL MASS (NON-FUEL) =   4543.994
 AL MASS (UAL FUEL) =   135.7665
 AL MASS IN CLAD =   9600.062
```

```
 AL MASS (TOTAL) =   14279.82
TOTAL MASS (NO WATER) =   15463.28
TOTAL MASS (WATER ONLY) =   3865.819
TOTAL MASS (WATER +FUEL +CLAD) =   19329.10
   TOTAL FUEL + CLAD VOLUME =   5472.352     CM^3
 FUEL+CLAD MIXTURE DENSITY =   2.825710
 F4 =  0.9154292
 RHOUAL CALCULATED =   5.696731
 TOTAL WATER VOLUME =   3865.819
 TOTAL WATER + FUEL + CLAD VOLUMES=   9338.172
 MIXTURE DENSITY =   2.069902     G/CC
 COLHEIGHT=   131.2852     CM


 N1  N16  N131  N238  N235
      1  2.7699882E-02
     16  1.3849941E-02
    131  3.4131840E-02
   2381  1.9235926E-05
   2351  3.0527523E-04
TOTAL =  7.6006174E-02
 H/U-235 RATIO =   90.73740
 U235 (CHECK)=    1102.767
 U238 (CHECK)=    70.38940
 AL (CHECK)=    14155.54
 WATER (CHECK)=    3865.820
 ************************************
  BSR CASE
 ELEMENT HEIGHT=   24.62500     INCHES
 RHOH2O =   1.000000     G/CC
 ENRICH =   94.00000     %
 WEIGHT FRACTION OF FUEL, WF  =  0.2250000
 WEIGHT FRACTION OF WATER WFWATER=  0.2250000
 DENSITY OF UAL (RHOUAL)=   6.000000     G/CC
 CLAD DENSITY (RHOCLAD)=   2.700000     G/CC

  FOR EACH UNIT PLATE
   ACLAD   AMEAT   APLATE (CM2)
 0.5983794      0.3225800      0.9209594
 FOR ALL PLATES AND FUEL ELEMENTS CONSIDERED:
 AL (FUEL) MASS =   135.7665
 U238      MASS =   71.00745
 U235      MASS =   1112.450
 UAL      MASS =   1319.224
 AL MASS (NON-FUEL) =   4543.994
 AL MASS (UAL FUEL) =   135.7665
 AL MASS IN CLAD =   9600.062
 AL MASS (TOTAL) =   14279.82
TOTAL MASS (NO WATER) =   15463.28
TOTAL MASS (WATER ONLY) =   4489.341
TOTAL MASS (WATER +FUEL +CLAD) =   19952.62
   TOTAL FUEL + CLAD VOLUME =   5472.352     CM^3
 FUEL+CLAD MIXTURE DENSITY =   2.825710
 F4 =  0.9154292
 RHOUAL CALCULATED =   5.696731
 TOTAL WATER VOLUME =   4489.341
 TOTAL WATER + FUEL + CLAD VOLUMES=   9961.693
 MIXTURE DENSITY =   2.002935     G/CC
 COLHEIGHT=   140.0513     CM
```

```
 N1  N16  N131  N238  N235
      1  3.0154189E-02
     16  1.5077095E-02
    131  3.1995464E-02
   2381  1.8031913E-05
   2351  2.8616746E-04
TOTAL =  7.7530950E-02
 H/U-235 RATIO =   105.3725
 U235 (CHECK)=    1102.767
 U238 (CHECK)=    70.38940
 AL (CHECK)=    14155.54
 WATER (CHECK)=    4489.340
 ************************************
  BSR CASE
 ELEMENT HEIGHT=   24.62500     INCHES
 RHOH2O =   1.000000     G/CC
 ENRICH =   94.00000     %
 WEIGHT FRACTION OF FUEL, WF  =  0.2250000
 WEIGHT FRACTION OF WATER WFWATER=  0.2500000
 DENSITY OF UAL (RHOUAL)=   6.000000     G/CC
 CLAD DENSITY (RHOCLAD)=   2.700000     G/CC

  FOR EACH UNIT PLATE
   ACLAD   AMEAT   APLATE (CM2)
 0.5983794      0.3225800      0.9209594
 FOR ALL PLATES AND FUEL ELEMENTS CONSIDERED:
 AL (FUEL) MASS =   135.7665
 U238      MASS =   71.00745
 U235      MASS =   1112.450
 UAL      MASS =   1319.224
 AL MASS (NON-FUEL) =   4543.994
 AL MASS (UAL FUEL) =   135.7665
 AL MASS IN CLAD =   9600.062
 AL MASS (TOTAL) =   14279.82
TOTAL MASS (NO WATER) =   15463.28
TOTAL MASS (WATER ONLY) =   5154.427
TOTAL MASS (WATER +FUEL +CLAD) =   20617.71
   TOTAL FUEL + CLAD VOLUME =   5472.352     CM^3
 FUEL+CLAD MIXTURE DENSITY =   2.825710
 F4 =  0.9154292
 RHOUAL CALCULATED =   5.696731
 TOTAL WATER VOLUME =   5154.427
 TOTAL WATER + FUEL + CLAD VOLUMES=   10626.78
 MIXTURE DENSITY =   1.940165     G/CC
 COLHEIGHT=   149.4017     CM


 N1  N16  N131  N238  N235
      1  3.2454651E-02
     16  1.6227325E-02
    131  2.9993001E-02
   2381  1.6903370E-05
   2351  2.6825743E-04
TOTAL =  7.8960143E-02
 H/U-235 RATIO =   120.9832
 U235 (CHECK)=    1102.767
 U238 (CHECK)=    70.38940
 AL (CHECK)=    14155.54
 WATER (CHECK)=    5154.427
```

6.7.1.4 Case IV Fuel (U Metal)

6.7.1.4.1 GEMER Input Decks

This Appendix includes GEMER geometrical plots and input listings for the infinite cask array for MTR Case IV fuel. Each basedeck contains a "header" with fuel material and geometry information. Since the program input is similar to the popular KENO program (and deviations from this were discussed previously). No further explanation of the inputs is provided.

6.7.1.4.1.1 Infinite (95% Enriched U Metal)

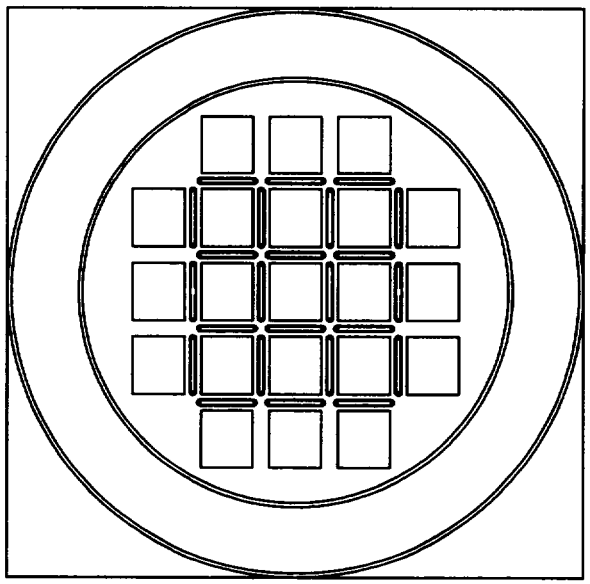

Figure 6.29. Unit Array for MTR Case IV Fuel — Top View

```
MTR FUEL/ IF2000/SS+Pb SHIELDING.  U235 CASE
   605 /* # BATCHES
  1000  /* # NEUTRONS PER BATCH
     5  /* # BATCHES TO SKIP
 2123469/* INITIAL "SEED" (IF NON-ZERO)
     0  /* "IDUMP"
     0  /* "NRSTRT"
     0  /* "NBTED" (NON-ZERO IS PRINT EDITS)
     0  /* "KRED" (NUMBER OF COMBINED REGIONS IN EDITS)
     0  293   14  8
      4  293 0  0 U(95.0)+0.875 WF -H2O RHOMIX= 1.134373 g/cc     MAT 1
        1  6.6414371E-02
       16  3.3207186E-02
      2351  3.4512876E-04
      2381  1.7935230E-05
      3  293 0 0 Boral 0.25" Plate (60% Boron Loading)  MAT 2
    10    3.32658E-03
    11    6.7889E-05
   131    5.8001E-02
      2  293 0 0  MODERATOR IN CASK (100.00%)                    MAT 3
     1   6.69111121E-02
    16   3.34555566E-02
      2  293 0 0  INTERSPERSED MODERATOR (100.00%)            MAT4
     1   6.69111121E-02
    16   3.34555566E-02
      2  293 0 0 FULL DENSITY WATER                    MAT 5
     1    6.69111121E-02
    16    3.34555566E-02
      1  293 0 0 LEAD SHIELDING                        MAT 6
    82   3.29890E-02
      7  293 0 0 304 STAINLESS STEEL                   MAT 7
    12   6.82690E-05
    14   8.53360E-04
    24   1.53600E-02
    26   6.04950E-02
    28   6.82690E-03
    55   1.70670E-03
  1316   2.56010E-05
      2  293 0 0 FULL DENSITY WATER (VOID)             MAT 8
     1    6.69111121E-09
    16    3.34555566E-09
KENO GEOM
    14  /* "KREFM"
     6  /* "NBOX"
     1  /* "NBXMAX"
     1  /* "NBYMAX"
     1  /* "NBZMAX"
     1  /* "NXX"
     0  /* "NTYPST"
     1  /* "NEMBRG"
     0  /* "NGMCHK"
 -1.0  -1.0  -1.0  -1.0  -1.0  -1.0
BOX TYPE     1 /*MODEL 2000 CASK & STAINLESS SUPPORT STRUCTURE
CYLINDER     7  33.34     140.64     0.0    16*0.5
CYLINDER     3  33.65     140.64     0.0    16*0.5
CYLINDER     7  35.85     140.64     0.0    16*0.5
CYLINDER     6  46.34     140.64     0.0    16*0.5
CYLINDER     7  48.56     140.64   -14.90   16*0.5
BOX TYPE     2 /* CASK TOP
CYLINDER     6  30.96     158.42    140.64  16*0.5
CYLINDER     7  48.56     162.23    140.64  16*0.5
```

```
BOX TYPE      3 /* NBSR FUEL ASSEMBLY-COLLAPSED
CUBOID        1  4.4450 -4.4450  4.0005  -4.0005  22.96081  0.0   16*0.5
CUBOID        3  4.4450 -4.4450  4.0005  -4.0005  140.64  0.0   16*0.5
BOX TYPE      4 /* BORAL PLATE (VERT)
CUBOID        2  0.286  -0.286  4.12  -4.12  138.64  2.0   16*0.5
BOX TYPE      5 /* BORAL PLATE (HORIZ)
CUBOID        2  4.12  -4.12  0.286  -0.286  138.64  2.0   16*0.5
BOX TYPE      6  /* OVERALL BOX FOR THE PROBLEM
CUBOID        8  48.60    -48.60   48.60 -48.60 162.23 -14.91 16*0.5
CORE          0  48.60    -48.60   48.60 -48.60 162.23 -14.91 16*0.5
CUBOID        8  48.70    -48.70   48.70 -48.70 162.33 -15.01 16*0.5
6  1 1 1  1 1 1  1 1 1  1
BEGIN COMPLEX
/* PLACE FUEL ASSEMBLIES INTO CASK
COMPLEX  1  3   -22.860  -10.540  0.0  5  3  1  11.430  10.540  0.0
/*MIDDLE ROWS
COMPLEX  1  3   -11.430  -21.080  0.0  3  2  1  11.430  42.160  0.0
/*OUTER ROWS
/* PLACE BORAL PLATES INTO CASK
COMPLEX  1  4   -17.145  -10.540  0.0  4  3  1  11.430  10.540  0.0
/*VERT PLATES
COMPLEX  1  5   -11.430  -15.810  0.0  3  4  1  11.430  10.540  0.0
/*HORIZ PLATES
/* PLACE LOADED CASK INTO OVERALL PROBLEM BOX
COMPLEX  6  1  0.0     0.0    0.0   1 1 1   0.0    0.0    0.0
/* PLACE TOP INTO OVERALL PROBLEM BOX
COMPLEX  6  2  0.0     0.0    0.0   1 1 1   0.0    0.0    0.0
END GEOM
*END GEMER*
```

6.7.1.4.2 Number Density Calculations

6.7.1.4.2.1 FORTRAN Program (MTR Case IV Fuel)

```
PROGRAM NUMBER
        REAL M238,M235,MU
        REAL MH,MH2O
        REAL N235,N238,N1,N16
        OPEN(6,FILE='E.OUT',STATUS='UNKNOWN')
C
C       U METAL CASE
C
C-----------------------------------------------------
C   AREASLOT = SLOT AREA PER ELEMENT (cm^2)
C
C    ENRICHMENT = FUEL ENRICHMENT
C
        AREASLOT=71.12889
        AV=0.6022
      M235=235.0439
        M238=238.0508
        MH=1.0
        MH2O=18.0
        RHOFUEL=19.1
        RHOWATER=1.0
        ENRICH=0.95
C
C
C
```

```
      DO 100 ITER=0,38
      WFWATER=0.025*FLOAT(ITER)
      WRITE(6,*) '    '
      WRITE(6,*) ' CASE =',ITER
      WRITE(6,*) ' ENRICHMENT =',ENRICH
      WRITE(6,*) ' WFWATER =',WFWATER
C
C      U235MAS=300.0
C      U235MAS=200.0
    U235MAS=220.0
      U238MAS=U235MAS/ENRICH - U235MAS
      WRITE(6,*) ' U235 MASS =',U235MAS,' GRAMS'
      WRITE(6,*) ' U238 MASS =',U238MAS,' GRAMS '
      MU = 1.0/(ENRICH/M235 + (1.0-ENRICH)/M238)
      TOTAL1=U235MAS + U238MAS
      TOTAL2=TOTAL1/(1.0-WFWATER) - TOTAL1
      WRITE(6,*) ' TOTAL FUEL MASS =',TOTAL1,' GRAMS'
      WRITE(6,*) ' TOTAL WATER MASS =',TOTAL2,' GRAMS'
C
C    ON A SLOT BASIS  (TOTAL OF 21 SLOTS)
C
      WATERVOL=TOTAL2/RHOWATER
      F_VOLUME=TOTAL1/RHOFUEL
      VOLTOT=WATERVOL + F_VOLUME
      RHOMIX = (TOTAL1 + TOTAL2)/VOLTOT
      WRITE(6,*) ' MIXTURE DENSITY =',RHOMIX,' G/CC'
      COLHEIGHT=VOLTOT/AREASLOT
      WRITE(6,*) ' COLHEIGHT =',COLHEIGHT,' CM'
      WRITE(6,*) ' '
      N235=U235MAS*AV/M235/VOLTOT
      N238=U238MAS*AV/M238/VOLTOT
      N1=TOTAL2*AV/MH/VOLTOT*(2.0*MH/MH2O)
      N16=N1/2.0
    WRITE(6,*) '       1',N1
      WRITE(6,*) '      16',N16
      WRITE(6,*) '    2351',N235
      WRITE(6,*) '    2381',N238
      HURAT = N1/N235
      WRITE(6,*) ' H/U235 = ',HURAT
      WRITE(6,*) '    '
 100  CONTINUE
END
```

6.7.1.4.2.2 FORTRAN Output (MTR Case IV Fuel)

```
CASE =            0
 ENRICHMENT =  0.9500000
 WFWATER =  0.0000000E+00
 U235 MASS =   220.0000     GRAMS
 U238 MASS =   11.57895     GRAMS
 TOTAL FUEL MASS =   231.5789     GRAMS
 TOTAL WATER MASS =  0.0000000E+00 GRAMS
 MIXTURE DENSITY =   19.10000     G/CC
 COLHEIGHT =  0.1704589     CM

       1  0.0000000E+00
      16  0.0000000E+00
    2351  4.6488844E-02
    2381  2.4158754E-03
 H/U235 =   0.0000000E+00


 CASE =            1
 ENRICHMENT =  0.9500000
 WFWATER =  2.5000000E-02
 U235 MASS =   220.0000     GRAMS
 U238 MASS =   11.57895     GRAMS
 TOTAL FUEL MASS =   231.5789     GRAMS
 TOTAL WATER MASS =   5.937912     GRAMS
 MIXTURE DENSITY =   13.14975     G/CC
 COLHEIGHT =  0.2539399     CM

       1  2.1996571E-02
      16  1.0998285E-02
    2351  3.1205952E-02
    2381  1.6216728E-03
 H/U235 =   0.7048838


 CASE =            2
 ENRICHMENT =  0.9500000
 WFWATER =  5.0000001E-02
 U235 MASS =   220.0000     GRAMS
 U238 MASS =   11.57895     GRAMS
 TOTAL FUEL MASS =   231.5789     GRAMS
 TOTAL WATER MASS =   12.18837     GRAMS
 MIXTURE DENSITY =   10.02625     G/CC
 COLHEIGHT =  0.3418150     CM

       1  3.3543371E-02
      16  1.6771685E-02
    2351  2.3183409E-02
    2381  1.2047670E-03
 H/U235 =    1.446870


 CASE =            3
 ENRICHMENT =  0.9500000
 WFWATER =  7.5000003E-02
 U235 MASS =   220.0000     GRAMS
 U238 MASS =   11.57895     GRAMS
 TOTAL FUEL MASS =   231.5789     GRAMS
```

```
TOTAL WATER MASS =   18.77667     GRAMS
MIXTURE DENSITY =   8.101803     G/CC
COLHEIGHT =  0.4344398     CM

      1  4.0657546E-02
     16  2.0328773E-02
   2351  1.8240584E-02
   2381  9.4790442E-04
H/U235 =    2.228961


CASE =           4
ENRICHMENT =  0.9500000
WFWATER =  0.1000000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   25.73099     GRAMS
MIXTURE DENSITY =   6.797154     G/CC
COLHEIGHT =  0.5322105     CM

      1  4.5480501E-02
     16  2.2740250E-02
   2351  1.4889667E-02
   2381  7.7376800E-04
H/U235 =    3.054501


CASE =           5
ENRICHMENT =  0.9500000
WFWATER =  0.1250000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   33.08270     GRAMS
MIXTURE DENSITY =   5.854406     G/CC
COLHEIGHT =  0.6355681     CM

      1  4.8965599E-02
     16  2.4482800E-02
   2351  1.2468273E-02
   2381  6.4793596E-04
H/U235 =    3.927216


CASE =           6
ENRICHMENT =  0.9500000
WFWATER =  0.1500000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   40.86685     GRAMS
MIXTURE DENSITY =   5.141321     G/CC
COLHEIGHT =  0.7450054     CM

      1  5.1601697E-02
     16  2.5800848E-02
   2351  1.0636752E-02
   2381  5.5275770E-04
H/U235 =    4.851264
```

```
CASE =            7
ENRICHMENT =  0.9500000
WFWATER =  0.1750000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   49.12280     GRAMS
MIXTURE DENSITY =   4.583084     G/CC
COLHEIGHT =  0.8610756     CM

      1  5.3665359E-02
     16  2.6832679E-02
   2351  9.2029506E-03
   2381  4.7824768E-04
H/U235 =    5.831321


CASE =            8
ENRICHMENT =  0.9500000
WFWATER =  0.2000000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   57.89474     GRAMS
MIXTURE DENSITY =   4.134199     G/CC
COLHEIGHT =  0.9844002     CM

      1  5.5324771E-02
     16  2.7662385E-02
   2351  8.0500152E-03
   2381  4.1833337E-04
H/U235 =    6.872629


CASE =            9
ENRICHMENT =  0.9500000
WFWATER =  0.2250000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   67.23260     GRAMS
MIXTURE DENSITY =   3.765402     G/CC
COLHEIGHT =   1.115681     CM

      1  5.6688122E-02
     16  2.8344061E-02
   2351  7.1027796E-03
   2381  3.6910857E-04
H/U235 =    7.981118


CASE =           10
ENRICHMENT =  0.9500000
WFWATER =  0.2500000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   77.19299     GRAMS
MIXTURE DENSITY =   3.457013     G/CC
COLHEIGHT =   1.255714     CM
```

```
      1  5.7828154E-02
     16  2.8914077E-02
   2351  6.3107018E-03
   2381  3.2794685E-04
H/U235 =    9.163507


CASE =          11
ENRICHMENT =  0.9500000
WFWATER =  0.2750000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   87.84027     GRAMS
MIXTURE DENSITY =   3.195316     G/CC
COLHEIGHT =   1.405404     CM

      1  5.8795579E-02
     16  2.9397789E-02
   2351  5.6385477E-03
   2381  2.9301713E-04
H/U235 =    10.42743


CASE =          12
ENRICHMENT =  0.9500000
WFWATER =  0.3000000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   99.24814     GRAMS
MIXTURE DENSITY =   2.970451     G/CC
COLHEIGHT =   1.565787     CM

      1  5.9626851E-02
     16  2.9813426E-02
   2351  5.0609931E-03
   2381  2.6300349E-04
H/U235 =    11.78165


CASE =          13
ENRICHMENT =  0.9500000
WFWATER =  0.3250000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   111.5010     GRAMS
MIXTURE DENSITY =   2.775154     G/CC
COLHEIGHT =   1.738049     CM

      1  6.0348809E-02
     16  3.0174404E-02
   2351  4.5593851E-03
   2381  2.3693655E-04
H/U235 =    13.23617


CASE =          14
ENRICHMENT =  0.9500000
```

```
WFWATER =  0.3500000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   124.6964     GRAMS
MIXTURE DENSITY =   2.603954     G/CC
COLHEIGHT =   1.923563     CM

      1  6.0981698E-02
     16  3.0490849E-02
   2351  4.1196658E-03
   2381  2.1408575E-04
H/U235 =    14.80258


CASE =          15
ENRICHMENT =  0.9500000
WFWATER =  0.3750000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   138.9474     GRAMS
MIXTURE DENSITY =   2.452648     G/CC
COLHEIGHT =   2.123918     CM

      1  6.1541036E-02
     16  3.0770518E-02
   2351  3.7310468E-03
   2381  1.9389048E-04
H/U235 =    16.49431


CASE =          16
ENRICHMENT =  0.9500000
WFWATER =  0.4000000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   154.3860     GRAMS
MIXTURE DENSITY =   2.317961     G/CC
COLHEIGHT =   2.340969     CM

      1  6.2038939E-02
     16  3.1019470E-02
   2351  3.3851098E-03
   2381  1.7591326E-04
H/U235 =    18.32701


CASE =          17
ENRICHMENT =  0.9500000
WFWATER =  0.4250000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   171.1671     GRAMS
MIXTURE DENSITY =   2.197296     G/CC
COLHEIGHT =   2.576894     CM

      1  6.2485006E-02
     16  3.1242503E-02
```

```
    2351  3.0751892E-03
    2381  1.5980768E-04
H/U235 =    20.31908


CASE =          18
ENRICHMENT =  0.9500000
WFWATER =  0.4500000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   189.4737     GRAMS
MIXTURE DENSITY =   2.088573     G/CC
COLHEIGHT =   2.834266     CM

      1  6.2886931E-02
     16  3.1443466E-02
    2351  2.7959393E-03
    2381  1.4529596E-04
H/U235 =    22.49224


CASE =          19
ENRICHMENT =  0.9500000
WFWATER =  0.4750000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   209.5238     GRAMS
MIXTURE DENSITY =   1.990102     G/CC
COLHEIGHT =   3.116151     CM

      1  6.3250951E-02
     16  3.1625476E-02
    2351  2.5430212E-03
    2381  1.3215261E-04
H/U235 =    24.87236


CASE =          20
ENRICHMENT =  0.9500000
WFWATER =  0.5000000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   231.5789     GRAMS
MIXTURE DENSITY =   1.900497     G/CC
COLHEIGHT =   3.426224     CM

      1  6.3582197E-02
     16  3.1791098E-02
    2351  2.3128777E-03
    2381  1.2019280E-04
H/U235 =    27.49051


CASE =          21
ENRICHMENT =  0.9500000
WFWATER =  0.5250000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
```

```
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   255.9557     GRAMS
MIXTURE DENSITY =   1.818615     G/CC
COLHEIGHT =   3.768936     CM

      1  6.3884899E-02
     16  3.1942450E-02
   2351  2.1025657E-03
   2381  1.0926357E-04
H/U235 =    30.38426


CASE =          22
ENRICHMENT =  0.9500000
WFWATER =  0.5500000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   283.0409     GRAMS
MIXTURE DENSITY =   1.743496     G/CC
COLHEIGHT =   4.149727     CM

      1  6.4162590E-02
     16  3.2081295E-02
   2351  1.9096285E-03
   2381  9.9237237E-05
H/U235 =    33.59951


CASE =          23
ENRICHMENT =  0.9500000
WFWATER =  0.5750000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   313.3127     GRAMS
MIXTURE DENSITY =   1.674337     G/CC
COLHEIGHT =   4.575316     CM

      1  6.4418256E-02
     16  3.2209128E-02
   2351  1.7319975E-03
   2381  9.0006324E-05
H/U235 =    37.19304


CASE =          24
ENRICHMENT =  0.9500000
WFWATER =  0.6000000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   347.3684     GRAMS
MIXTURE DENSITY =   1.610455     G/CC
COLHEIGHT =   5.054106     CM

      1  6.4654410E-02
     16  3.2327205E-02
   2351  1.5679204E-03
   2381  8.1479775E-05
H/U235 =    41.23577
```

```
CASE =          25
ENRICHMENT =  0.9500000
WFWATER =  0.6250000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   385.9649     GRAMS
MIXTURE DENSITY =   1.551269     G/CC
COLHEIGHT =   5.596734     CM

      1  6.4873204E-02
     16  3.2436602E-02
   2351  1.4159038E-03
   2381  7.3579955E-05
H/U235 =    45.81752


CASE =          26
ENRICHMENT =  0.9500000
WFWATER =  0.6500000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   430.0753     GRAMS
MIXTURE DENSITY =   1.496279     G/CC
COLHEIGHT =   6.216881     CM

      1  6.5076500E-02
     16  3.2538250E-02
   2351  1.2746644E-03
   2381  6.6240202E-05
H/U235 =    51.05383


CASE =          27
ENRICHMENT =  0.9500000
WFWATER =  0.6750000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   480.9717     GRAMS
MIXTURE DENSITY =   1.445054     G/CC
COLHEIGHT =   6.932433     CM

      1  6.5265857E-02
     16  3.2632928E-02
   2351  1.1430960E-03
   2381  5.9403021E-05
H/U235 =    57.09569


CASE =          28
ENRICHMENT =  0.9500000
WFWATER =  0.7000000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   540.3509     GRAMS
MIXTURE DENSITY =   1.397220     G/CC
```

```
COLHEIGHT =   7.767244     CM

      1  6.5442681E-02
     16  3.2721341E-02
   2351  1.0202379E-03
   2381  5.3018473E-05
H/U235 =    64.14453


CASE =          29
ENRICHMENT =  0.9500000
WFWATER =  0.7250000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   610.5264     GRAMS
MIXTURE DENSITY =   1.352452     G/CC
COLHEIGHT =   8.753841     CM

      1  6.5608181E-02
     16  3.2804091E-02
   2351  9.0525253E-04
   2381  4.7043057E-05
H/U235 =    72.47501


CASE =          30
ENRICHMENT =  0.9500000
WFWATER =  0.7500000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   694.7369     GRAMS
MIXTURE DENSITY =   1.310463     G/CC
COLHEIGHT =   9.937755     CM

      1  6.5763399E-02
     16  3.2881700E-02
   2351  7.9740718E-04
   2381  4.1438681E-05
H/U235 =    82.47154


CASE =          31
ENRICHMENT =  0.9500000
WFWATER =  0.7750000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   797.6611     GRAMS
MIXTURE DENSITY =   1.271003     G/CC
COLHEIGHT =   11.38476     CM

      1  6.5909274E-02
     16  3.2954637E-02
   2351  6.9605629E-04
   2381  3.6171801E-05
H/U235 =    94.68958


CASE =          32
```

```
ENRICHMENT =  0.9500000
WFWATER =  0.8000000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   926.3159     GRAMS
MIXTURE DENSITY =   1.233850     G/CC
COLHEIGHT =   13.19352     CM

      1  6.6046625E-02
     16  3.3023313E-02
   2351  6.0063100E-04
   2381  3.1212858E-05
H/U235 =    109.9621


CASE =          33
ENRICHMENT =  0.9500000
WFWATER =  0.8250000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   1091.729     GRAMS
MIXTURE DENSITY =   1.198808     G/CC
COLHEIGHT =   15.51906     CM

      1  6.6176169E-02
     16  3.3088084E-02
   2351  5.1062595E-04
   2381  2.6535587E-05
H/U235 =    129.5981


CASE =          34
ENRICHMENT =  0.9500000
WFWATER =  0.8500000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   1312.281     GRAMS
MIXTURE DENSITY =   1.165700     G/CC
COLHEIGHT =   18.61979     CM

      1  6.6298559E-02
     16  3.3149280E-02
   2351  4.2559204E-04
   2381  2.2116647E-05
H/U235 =    155.7796


CASE =          35
ENRICHMENT =  0.9500000
WFWATER =  0.8750000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   1621.053     GRAMS
MIXTURE DENSITY =   1.134373     G/CC
COLHEIGHT =   22.96081     CM
```

```
      1  6.6414371E-02
     16  3.3207186E-02
   2351  3.4512876E-04
   2381  1.7935230E-05
H/U235 =    192.4336


CASE =          36
ENRICHMENT =  0.9500000
WFWATER =  0.9000000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   2084.211     GRAMS
MIXTURE DENSITY =   1.104685     G/CC
COLHEIGHT =   29.47235     CM

      1  6.6524118E-02
     16  3.3262059E-02
   2351  2.6887693E-04
   2381  1.3972668E-05
H/U235 =    247.4147


CASE =          37
ENRICHMENT =  0.9500000
WFWATER =  0.9250000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   2856.141     GRAMS
MIXTURE DENSITY =   1.076511     G/CC
COLHEIGHT =   40.32490     CM

      1  6.6628262E-02
     16  3.3314131E-02
   2351  1.9651472E-04
   2381  1.0212237E-05
H/U235 =    339.0497


CASE =          38
ENRICHMENT =  0.9500000
WFWATER =  0.9500000
U235 MASS =   220.0000     GRAMS
U238 MASS =   11.57895     GRAMS
TOTAL FUEL MASS =   231.5789     GRAMS
TOTAL WATER MASS =   4399.999     GRAMS
MIXTURE DENSITY =   1.049739     G/CC
COLHEIGHT =   62.02997     CM

      1  6.6727236E-02
     16  3.3363618E-02
   2351  1.2775174E-04
   2381  6.6388461E-06
H/U235 =    522.3196
```

6.7.2 Input/Output — TRIGA Type Fuels

6.7.2.1 Case XVII Fuel

6.7.2.1.1 GEMER Input Decks

This Appendix includes GEMER geometrical plots and input listings for the infinite cask array for TRIGA Case XVII fuel. Each basedeck contains a "header" with fuel material and geometry information. Since the program input is similar to the popular KENO program (and deviations from this were discussed previously). No further explanation of the inputs is provided.

6.7.2.1.1.1 Infinite (70% Enriched)

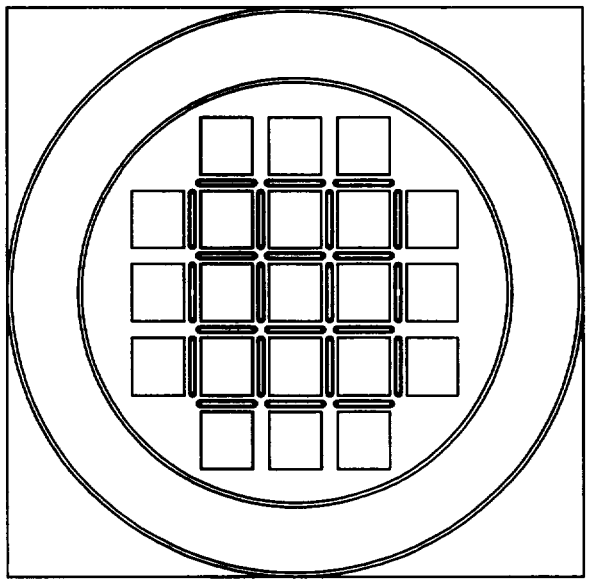

Figure 6.30. Unit Array for TRIGA Case XVII Fuel — Top View

```
TRIGA FUEL/ IF2000/7 ELEMENTS, SS+Pb SHIELDING. WFH2O IN FUEL=0.075 MASS
U235=1370 GRAMS
   125 /* # BATCHES
  1000  /* # NEUTRONS PER BATCH
     5  /* # BATCHES TO SKIP
 2123469/* INITIAL "SEED" (IF NON-ZERO)
     0  /* "IDUMP"
     0  /* "NRSTRT"
     0  /* "NBTED" (NON-ZERO IS PRINT EDITS)
     0  /* "KRED" (NUMBER OF COMBINED REGIONS IN EDITS)
     0  293   14  8
      11  293 0  0 U(70)ZRH+0.075 WF -H2O RHOMIX= 3.925214 g/cc     MAT
1
       1  4.2695317E-02
      16  9.8490156E-03
     401  1.5277529E-02
      12  1.4645401E-02
      14  1.8136440E-04
      24  1.7634179E-03
      26  6.4622704E-03
      28  6.9451093E-04
      55  1.8544278E-04
    2381  1.5621608E-04
    2351  3.6916722E-04
      3  293 0 0 Boral 0.25" Plate (60% Boron Loading)  MAT 2
    10    3.32658E-03
    11    6.7889E-05
   131    5.8001E-02
      2  293 0 0  MODERATOR IN CASK (100.00%)                    MAT 3
     1   6.69111121E-02
    16   3.34555566E-02
      2  293 0 0  INTERSPERSED MODERATOR (100.00%)            MAT4
     1   6.69111121E-02
    16   3.34555566E-02
      2  293 0 0 FULL DENSITY WATER                    MAT 5
     1    6.69111121E-02
    16    3.34555566E-02
      1  293 0 0 LEAD SHIELDING                        MAT 6
    82   3.29890E-02
      7  293 0 0 304 STAINLESS STEEL                   MAT 7
    12   6.82690E-05
    14   8.53360E-04
    24   1.53600E-02
    26   6.04950E-02
    28   6.82690E-03
    55   1.70670E-03
  1316   2.56010E-05
     2  293 0 0 FULL DENSITY WATER (VOID)             MAT 8
     1    6.69111121E-09
    16    3.34555566E-09
KENO GEOM
    14  /* "KREFM"
     6  /* "NBOX"
     1  /* "NBXMAX"
     1  /* "NBYMAX"
     1  /* "NBZMAX"
     1  /* "NXX"
     0  /* "NTYPST"
     1  /* "NEMBRG"
     0  /* "NGMCHK"
   -1.0  -1.0  -1.0  -1.0  -1.0  -1.0
```

```
BOX TYPE      1 /*MODEL 2000 CASK & STAINLESS SUPPORT STRUCTURE
CYLINDER      7  33.34      140.64      0.0     16*0.5
CYLINDER      3  33.65      140.64      0.0     16*0.5
CYLINDER      7  35.85      140.64      0.0     16*0.5
CYLINDER      6  46.34      140.64      0.0     16*0.5
CYLINDER      7  48.56      140.64    -14.90    16*0.5
BOX TYPE      2 /* CASK TOP
CYLINDER      6  30.96      158.42     140.64  16*0.5
CYLINDER      7  48.56      162.23     140.64  16*0.5
BOX TYPE      3 /* NBSR FUEL ASSEMBLY-COLLAPSED
CUBOID        1  4.4450 -4.4450  4.0005  -4.0005  133.6728  0.0   16*0.5
CUBOID        3  4.4450 -4.4450  4.0005  -4.0005  140.64  0.0   16*0.5
BOX TYPE      4 /* BORAL PLATE (VERT)
CUBOID        2  0.286  -0.286  4.12  -4.12  138.64  2.0   16*0.5
BOX TYPE      5 /* BORAL PLATE (HORIZ)
CUBOID        2  4.12  -4.12  0.286  -0.286  138.64  2.0   16*0.5
BOX TYPE      6  /* OVERALL BOX FOR THE PROBLEM
CUBOID        8  48.60    -48.60   48.60 -48.60 162.23 -14.91 16*0.5
CORE          0  48.60    -48.60   48.60 -48.60 162.23 -14.91 16*0.5
CUBOID        8  48.70    -48.70   48.70 -48.70 162.33 -14.92 16*0.5
6  1 1 1  1 1 1  1 1 1  1
BEGIN COMPLEX
/* PLACE FUEL ASSEMBLIES INTO CASK
COMPLEX  1  3   -22.860  -10.540  0.0  5  3  1  11.430  10.540  0.0
/*MIDDLE ROWS
COMPLEX  1  3   -11.430  -21.080  0.0  3  2  1  11.430  42.160  0.0
/*OUTER ROWS
/* PLACE BORAL PLATES INTO CASK
COMPLEX  1  4   -17.145  -10.540  0.0  4  3  1  11.430  10.540  0.0
/*VERT PLATES
COMPLEX  1  5   -11.430  -15.810  0.0  3  4  1  11.430  10.540  0.0
/*HORIZ PLATES
/* PLACE LOADED CASK INTO OVERALL PROBLEM BOX
COMPLEX  6  1  0.0     0.0     0.0   1 1 1   0.0     0.0     0.0
/* PLACE TOP INTO OVERALL PROBLEM BOX
COMPLEX  6  2  0.0     0.0     0.0   1 1 1   0.0     0.0     0.0
END GEOM
*END GEMER*
```

6.7.2.1.2 Number Density Calculations

6.7.2.1.2.1 FORTRAN Program (TRIGA Case XVII Fuel)

```
PROGRAM NUMBER
C
C   PRODUCTION RUN
C   9/18/96
C                        AKC
C    U-235 (70% ENRICHMENT CASE)
C    STAINLESS STEEL CLAD (FLIP TYPE OF TRIGA FUEL)
C    15" ACTIVE FUEL LENGTH, 1.475" O.D. FUEL ELEMENT,
C                            1.435" O.D. FUEL
C                            0.020" CLADDING THICKNESS
C     CENTRAL ZR ROD
C
      REAL M235,M238
      REAL U235MAS,U238MAS
      REAL MZR,MU,MH,MH16,MH20
      REAL N235,N238,NH,NZR,NZR1,N16,NHFUEL
      REAL NELEMENT
      REAL MNI,MCR,MMN,MFE,MC12,MSI
      REAL FEMAS,CRMAS,NIMAC,MNMAS
      REAL NNI,NMN,NFE,NCR,NSI,NC12
      REAL LREFL
C
      DATA PI/3.14159265/
C
      OPEN(6,FILE='P_70.OUT',STATUS='UNKNOWN')
      AV=0.6022
      M235 =235.0439
      M238 =238.0508
      MZR=91.224
      MH=1.00794
      MH16=1.6*MH
      MH2O=18.0153
C
C
C    STAINLESS STEEL 304
C     C12        0.080 %
C     SI         1.001 %
C     CR        18.012 %
C     FE        70.892 %
C     NI         8.010 %
C     MN         2.001 %
       MC12=11.8969
       MSI=27.844
       MCR=51.549
       MFE=55.365
       MNI=58.1826
       MMN=54.466
C
C
C     WRITE(6,*)  '  *************** GA SAR CASE TYPE 5 FUEL ******'
      DO 100 ITER=0,16,1
      WRITE(6,*) '   '
      WRITE(6,*) '     ****CASE ',ITER,' ****   '
      WFWATER=0.025*FLOAT(ITER)
```

```
      WRITE(6,*) ' WATER WEIGHT FRACTION =',WFWATER
C
C
C       *****INPUTS********
C     WT_U = WEIGHT OF URANIUM
C
C     RHOZR=ZR DENSITY (G/CC)
C     RHOREFL = REFLECTOR (GRAPHITE) DENSITY IN G/CC
      RHOZR=6.50
      RHOREFL = 1.60
C     U235GRAM = U235 WEIGHT PER ELEMENT IN GRAMS
C     ER-167 MASS IGNORED.
C
C
C      NELEMENT=1.0
C      NELEMENT=8.0
      NELEMENT=10.0
C     WEIGHT OF U-235 PER FUEL ELEMENT
      U235GRAM=137.0
C
      ENRICH=0.70
      U235MAS=NELEMENT*U235GRAM
      WRITE(6,*) ' U235 MASS PER ELEMENT =',U235MAS/NELEMENT,' GRAMS'
      WRITE(6,*) ' TOTAL U235 MASS=',U235MAS,' GRAMS'
      WRITE(6,*) ' NUMBER OF FUEL ELEMENTS =',NELEMENT
      WT_U=0.085
C
C    RHOSS = STAINLESS STEEL DENSITY (G/CC)
      RHOSS=7.8266
C
C    RFUEL = FUEL OUTER RADIUS (CM)
C    RCLAD = CLAD OUTER RADIUS (CM)
C
C
      RZRROD=0.25*2.54/2.0
      RFUEL=1.435*2.54/2.0
      RCLAD=1.475*2.54/2.0
C
C   FLENGTH = FUEL ACTIVE LENGTH IN CM
C   FCLENGTH = CLAD LENGTH + ACTIVE FUEL LENGTH IN CM
C
      FLENGTH=15.0*2.54
      FCLENGTH=(3.40+3.40)*2.54 + FLENGTH
      WRITE(6,*) ' FUEL OUTER RADIUS =',RFUEL,'CM   OR ',
     * RFUEL/2.54,' INCHES'
      WRITE(6,*) ' CLAD OUTER RADIUS =',RCLAD,'CM  OR ',
     *             RCLAD/2.54,' INCHES'
      WRITE(6,*) ' FUEL ELEMENT LENGTH =',FLENGTH,'CM OR ',
     *            FLENGTH/2.54,' INCHES'
      WRITE(6,*) ' TOTAL CLAD LENGTH =',FCLENGTH,'CM OR ',
     *            FCLENGTH/2.54,' INCHES'
C
C     CVOLUME=CLAD VOLUME
C     FVOLUME=FUEL VOLUME
C     FCVOLUME=FUEL + CLAD VOLUMES
C
C     VOL_ENDFIT= 118*1.224/8.01
C               = 18.01   (PREVIOUS DESIGN)
C    CLADDING IS STAINLESS STEEL-304
C    CLAD = FUEL CLAD + END FITS + CLAD OVER GRAPHITE REFLECTORS
C
```

```
C      VOL_ENDFIT = 69.153 CC (FROM S. JAIN  8/5/96)
C
       VOL_ENDFIT = 69.153
       CVOLUME = NELEMENT*PI*(RCLAD*RCLAD-RFUEL*RFUEL)*FCLENGTH
     *         + NELEMENT*VOL_ENDFIT
C
C       NEXT THE CENTRAL ZR ROD:
C
C       RZRROD=0.25*2.54/2.0
C
       ZRVOLUME = NELEMENT*PI*RZRROD*RZRROD*FLENGTH
       ZRRODMAS = ZRVOLUME*RHOZR
C
C      RREFL = GRAPHITE END REFLECTOR RADIUS (CM)
C      REFLVOLUME= REFLECTOR VOLUME (CC)
C      LREFL = TOTAL LENGTH OF BOTH REFLECTORS (CM)
C      REFLMAS = REFLECTOR MASS (G)
C
       RREFL = 1.40*2.54/2.0
       LREFL = (3.4+3.4)*2.54
       REFLVOLUME = NELEMENT*PI*RREFL*RREFL*LREFL
       REFLMAS= REFLVOLUME*RHOREFL
C
       FVOLUME=NELEMENT*PI*(RFUEL*RFUEL-RZRROD*RZRROD)*FLENGTH
       FCVOLUME=FVOLUME+CVOLUME
C
C     CALCULATING THE CLAD MASSES
C
       WTMN=0.020013
       WTCR=0.180116
       WTNI=0.080145
       WTFE=0.70892
       WTC12=0.0008
       WTSI=0.010006
C
       MNMAS = RHOSS*CVOLUME*WTMN
       CRMAS = RHOSS*CVOLUME*WTCR
       NIMAS = RHOSS*CVOLUME*WTNI
       FEMAS = RHOSS*CVOLUME*WTFE
       SIMAS = RHOSS*CVOLUME*WTSI
       C12MAS = RHOSS*CVOLUME*WTC12
C
       CLADMAS=MNMAS+CRMAS+NIMAS+FEMAS+C12MAS+SIMAS
C
C      WATER DENSITY (G/CC)
       RHOWATER=1.0
C
C
        U238MAS=U235MAS/ENRICH - U235MAS
C
        UMAS=U238MAS +U235MAS
        ZRHMAS=UMAS/WT_U - UMAS
        ZRMAS = ZRHMAS*MZR/(MZR+MH16)
        H16MAS = ZRHMAS*MH16/(MZR+MH16)
C
C
C      TOTAL2 = WATER MASS
C      TOTAL1 = FUEL ELEMENT MASS (UZRH  + CLAD + GRAHITE REFLECTORS +
END FITTINGS)
C      TOTAL = WATER + FUEL ELEMENT MASSES (HOMOGENOUS MIXTURE)
C
```

```
      TOTAL1= (ZRMAS + H16MAS + U238MAS +U235MAS) +CLADMAS
     *        + REFLMAS + ZRRODMAS
      TOTAL2 = TOTAL1/(1.0-WFWATER) - TOTAL1
      TOTAL = TOTAL1 + TOTAL2
      WATERVOL=TOTAL2/RHOWATER
      VOLTOT=WATERVOL + FCVOLUME + REFLVOLUME + ZRVOLUME
C
       WRITE(6,*) '    '
C
C   AREASLOT = SLOT AREA PER ELEMENT (cm^2)
C
       AREASLOT=71.12889
       RHOMIX = TOTAL/VOLTOT
       WRITE(6,*) ' FUEL DENSITY =',
     *   (ZRMAS + H16MAS + U238MAS +U235MAS)/FVOLUME,' G.CC'
       WRITE(6,*) ' MIXTURE DENSITY =',RHOMIX,' G/CC'
       COLHEIGHT=VOLTOT/AREASLOT
       WRITE(6,*) ' COLHEIGHT=',COLHEIGHT,' CM'
       WRITE(6,*) ' '
C
C     WRITING OUT THE SUMMARY TABLE
C
      WRITE(6,1005)
 1005 FORMAT(23X, ' VOLUME(CC)        MASS(G)',5X,'DENSITY (G/CC)')
      WRITE(6,1006) ZRVOLUME,ZRRODMAS,ZRRODMAS/ZRVOLUME
      WRITE(6,1007) REFLVOLUME,REFLMAS,REFLMAS/REFLVOLUME
      WRITE(6,1010) FVOLUME,H16MAS+U238MAS +U235MAS + ZRMAS,
     *              (H16MAS+U238MAS +U235MAS + ZRMAS)/FVOLUME
      WRITE(6,*) '    '
      WRITE(6,1024) U235MAS
      WRITE(6,1025) U238MAS
      WRITE(6,1026) U238MAS+U235MAS
      WRITE(6,1021) ZRMAS
      WRITE(6,1022) H16MAS
      WRITE(6,1023) ZRHMAS
      WRITE(6,*) '    '
 1021 FORMAT(1X,'     ZR MASS (FUEL)',14X,F14.3)
 1023 FORMAT(1X,'   ZRH MASS (FUEL) ',14X,F14.3)
 1022 FORMAT(1X,'    H16 MASS (FUEL)',14X,F14.3)
 1024 FORMAT(1X,'   U235 MASS (FUEL)',14X,F14.3)
 1025 FORMAT(1X,'   U238 MASS (FUEL)',14X,F14.3)
 1026 FORMAT(1X,' U235 + U238 (FUEL)',14X,F14.3)
C
      WRITE(6,1008) CVOLUME,CLADMAS,CLADMAS/CVOLUME
      WRITE(6,1009) WATERVOL,TOTAL2,RHOWATER
      WRITE(6,1013) VOLTOT,TOTAL,TOTAL/VOLTOT
 1006 FORMAT(1X,'  CENTRAL ZR ROD    ',3F14.3)
 1007 FORMAT(1X,'  END REFLECTORS    ',3F14.3)
 1008 FORMAT(1X,'  CLAD + END FITS   ',3F14.3)
 1009 FORMAT(1X,'  WATER ONLY        ',3F14.3)
 1010 FORMAT(1X,'  UZRH FUEL         ',3F14.3)
 1013 FORMAT(/,1X,'  TOTAL(FUEL+WATER)',3F14.3,/)
C
C
      N235 = U235MAS*AV/M235/VOLTOT
      N238 = U238MAS*AV/M238/VOLTOT
C     H  FROM FUEL AND WATER
      NH = H16MAS*AV/MH/VOLTOT + 2.0*TOTAL2*AV/VOLTOT/MH2O
      NHFUEL = H16MAS*AV/MH/VOLTOT
C     ZR NUMBER DENSITY = ZR IN FUEL + ZR ROD
      NZR = ZRMAS*AV/MZR/VOLTOT + ZRRODMAS/MZR/VOLTOT
```

```
      NZR1 = ZRMAS*AV/MZR/VOLTOT
      N16= TOTAL2*AV/VOLTOT/MH2O
C
      IF (N16.LE.0.0) N16=1.0E-9
C     STAINLESS STEEL
      NSI= SIMAS*AV/MSI/VOLTOT
C     C12 DENSITIES = STAINLESS STEEL + REFLECTOR
      NC12= C12MAS*AV/MC12/VOLTOT + REFLMAS*AV/MC12/VOLTOT
      NMN= MNMAS*AV/MMN/VOLTOT
      NFE= FEMAS*AV/MFE/VOLTOT
      NNI= NIMAS*AV/MNI/VOLTOT
      NCR= CRMAS*AV/MCR/VOLTOT
C
C
      WRITE(6,*) '      1',NH
      WRITE(6,*) '     16',N16
      WRITE(6,*) '    401',NZR
C
      WRITE(6,*) '     12',NC12
      WRITE(6,*) '     14',NSI
      WRITE(6,*) '     24',NCR
      WRITE(6,*) '     26',NFE
      WRITE(6,*) '     28',NNI
      WRITE(6,*) '     55',NMN
C
      WRITE(6,*) '   2381',N238
      WRITE(6,*) '   2351',N235
C
      RATIO1 = NHFUEL/NZR1
      WRITE(6,*) ' H/ZR (NUMBER DENSITIES IN FUEL) = ',RATIO1
      RATIO2 = NHFUEL/N235
      WRITE(6,*) ' H(IN FUEL)/U235 (NUMBER DENSITIES) = ',RATIO2
      RATIO3 = NH/N235
      WRITE(6,*) ' H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) = ',RATIO3
      RATIO4 = NC12/N235
      WRITE(6,*) ' C(IN REFL + CLAD)/U235 (NUMBER DENSITIES) = ',RATIO4
C
C
C
      BIAS = BIASFUN(RATIO3)
      WRITE(6,1700) RATIO3,BIAS
 1700  FORMAT(1X,'  BIAS (H/U-235 =',F12.6,' ) = ',F12.6)
 100  CONTINUE
       END
      FUNCTION BIASFUN(X)
      REAL X
      BIASFUN=-(1.0E-8*X*X - 2.0E-5*X +0.0006)
      RETURN
      END
```

6.7.2.1.2.2 FORTRAN Output (TRIGA Case XVII Fuel)

```
    ****CASE            0 ****
WATER WEIGHT FRACTION =  0.0000000E+00
U235 MASS PER ELEMENT =   137.0000     GRAMS
TOTAL U235 MASS=   1370.000     GRAMS
NUMBER OF FUEL ELEMENTS =   10.00000
FUEL OUTER RADIUS =   1.822450    CM   OR   0.7175000     INCHES
CLAD OUTER RADIUS =   1.873250    CM  OR   0.7375000     INCHES
FUEL ELEMENT LENGTH =   38.10000    CM OR    15.00000     INCHES
TOTAL CLAD LENGTH =   55.37200    CM OR    21.80000     INCHES

FUEL DENSITY =   5.973146     G.CC
MIXTURE DENSITY =   5.145658     G/CC
COLHEIGHT=   94.32075     CM

                        VOLUME(CC)        MASS(G)     DENSITY (G/CC)
 CENTRAL ZR ROD            120.660       784.288         6.500
 END REFLECTORS           1715.363      2744.581         1.600
 UZRH FUEL                3854.788     23025.213         5.973

  U235 MASS (FUEL)                      1370.000
  U238 MASS (FUEL)                       587.143
U235 + U238 (FUEL)                      1957.143
    ZR MASS (FUEL)                     20702.088
   H16 MASS (FUEL)                       365.982
  ZRH MASS (FUEL)                      21068.068

 CLAD + END FITS          1018.119      7967.782         7.826
 WATER ONLY                  0.000         0.000         1.000

 TOTAL(FUEL+WATER)        6708.930     34521.863         5.146

     1  3.2592110E-02
    16  9.9999997E-10
   401  2.1651555E-02
    12  2.0755693E-02
    14  2.5703249E-04
    24  2.4991434E-03
    26  9.1584306E-03
    28  9.8427176E-04
    55  2.6281242E-04
  2381  2.2139186E-04
  2351  5.2318955E-04
H/ZR (NUMBER DENSITIES IN FUEL) =    1.600000
H(IN FUEL)/U235 (NUMBER DENSITIES) =    62.29503
H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    62.29503
C(IN REFL + CLAD)/U235 (NUMBER DENSITIES) =    39.67146
 BIAS (H/U-235 =   62.295033 ) =     0.000607

    ****CASE            1 ****
WATER WEIGHT FRACTION =  2.5000000E-02
U235 MASS PER ELEMENT =   137.0000     GRAMS
TOTAL U235 MASS=   1370.000     GRAMS
NUMBER OF FUEL ELEMENTS =   10.00000
FUEL OUTER RADIUS =   1.822450    CM   OR   0.7175000     INCHES
CLAD OUTER RADIUS =   1.873250    CM  OR   0.7375000     INCHES
FUEL ELEMENT LENGTH =   38.10000    CM OR    15.00000     INCHES
TOTAL CLAD LENGTH =   55.37200    CM OR    21.80000     INCHES
```

```
FUEL DENSITY =   5.973146     G.CC
MIXTURE DENSITY =   4.662437     G/CC
COLHEIGHT=   106.7654     CM

                        VOLUME(CC)        MASS(G)     DENSITY (G/CC)
 CENTRAL ZR ROD           120.660        784.288         6.500
 END REFLECTORS          1715.363       2744.581         1.600
 UZRH FUEL               3854.788      23025.213         5.973

  U235 MASS (FUEL)                      1370.000
  U238 MASS (FUEL)                       587.143
U235 + U238 (FUEL)                      1957.143
    ZR MASS (FUEL)                     20702.088
   H16 MASS (FUEL)                       365.982
  ZRH MASS (FUEL)                      21068.068

 CLAD + END FITS         1018.119       7967.782         7.826
 WATER ONLY               885.176        885.176         1.000

 TOTAL(FUEL+WATER)       7594.106      35407.039         4.662

     1  3.6592364E-02
    16  3.8996094E-03
   401  1.9127831E-02
    12  1.8336391E-02
    14  2.2707254E-04
    24  2.2078410E-03
    26  8.0909161E-03
    28  8.6954416E-04
    55  2.3217876E-04
  2381  1.9558624E-04
  2351  4.6220611E-04
H/ZR (NUMBER DENSITIES IN FUEL) =    1.600000
H(IN FUEL)/U235 (NUMBER DENSITIES) =    62.29504
H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    79.16893
C(IN REFL + CLAD)/U235 (NUMBER DENSITIES) =    39.67146
 BIAS (H/U-235 =   79.168930 ) =     0.000921

    ****CASE            2 ****
WATER WEIGHT FRACTION =  5.0000001E-02
U235 MASS PER ELEMENT =   137.0000     GRAMS
TOTAL U235 MASS=   1370.000     GRAMS
NUMBER OF FUEL ELEMENTS =   10.00000
FUEL OUTER RADIUS =   1.822450    CM   OR   0.7175000     INCHES
CLAD OUTER RADIUS =   1.873250    CM  OR   0.7375000     INCHES
FUEL ELEMENT LENGTH =   38.10000    CM OR    15.00000     INCHES
TOTAL CLAD LENGTH =   55.37200    CM OR    21.80000     INCHES

FUEL DENSITY =   5.973146     G.CC
MIXTURE DENSITY =   4.262180     G/CC
COLHEIGHT=   119.8651     CM

                        VOLUME(CC)        MASS(G)     DENSITY (G/CC)
 CENTRAL ZR ROD           120.660        784.288         6.500
 END REFLECTORS          1715.363       2744.581         1.600
 UZRH FUEL               3854.788      23025.213         5.973

  U235 MASS (FUEL)                      1370.000
  U238 MASS (FUEL)                       587.143
U235 + U238 (FUEL)                      1957.143
```

```
   ZR MASS (FUEL)                    20702.088
  H16 MASS (FUEL)                      365.982
 ZRH MASS (FUEL)                     21068.068

CLAD + END FITS        1018.119      7967.782          7.826
WATER ONLY             1816.941      1816.941          1.000

TOTAL(FUEL+WATER)      8525.872     36338.805          4.262

    1  3.9905805E-02
   16  7.1296850E-03
  401  1.7037408E-02
   12  1.6332462E-02
   14  2.0225649E-04
   24  1.9665530E-03
   26  7.2066849E-03
   28  7.7451440E-04
   55  2.0680467E-04
 2381  1.7421122E-04
 2351  4.1169304E-04
H/ZR (NUMBER DENSITIES IN FUEL) =    1.600000
H(IN FUEL)/U235 (NUMBER DENSITIES) =    62.29504
H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    96.93097
C(IN REFL + CLAD)/U235 (NUMBER DENSITIES) =    39.67146
 BIAS (H/U-235 =   96.930969 ) =     0.001245

   ****CASE            3 ****
WATER WEIGHT FRACTION =  7.5000003E-02
U235 MASS PER ELEMENT =   137.0000     GRAMS
TOTAL U235 MASS=   1370.000     GRAMS
NUMBER OF FUEL ELEMENTS =   10.00000
FUEL OUTER RADIUS =   1.822450    CM   OR   0.7175000     INCHES
CLAD OUTER RADIUS =   1.873250    CM  OR   0.7375000     INCHES
FUEL ELEMENT LENGTH =   38.10000    CM OR    15.00000     INCHES
TOTAL CLAD LENGTH =   55.37200    CM OR    21.80000     INCHES

FUEL DENSITY =   5.973146     G.CC
MIXTURE DENSITY =   3.925214     G/CC
COLHEIGHT=   133.6728     CM

                       VOLUME(CC)        MASS(G)     DENSITY (G/CC)
 CENTRAL ZR ROD          120.660       784.288          6.500
 END REFLECTORS         1715.363      2744.581          1.600
 UZRH FUEL              3854.788     23025.213          5.973

  U235 MASS (FUEL)                     1370.000
  U238 MASS (FUEL)                      587.143
U235 + U238 (FUEL)                     1957.143
   ZR MASS (FUEL)                     20702.088
  H16 MASS (FUEL)                      365.982
 ZRH MASS (FUEL)                     21068.068

CLAD + END FITS        1018.119      7967.782          7.826
WATER ONLY             2799.070      2799.070          1.000

TOTAL(FUEL+WATER)      9508.001     37320.934          3.925

    1  4.2695317E-02
   16  9.8490156E-03
  401  1.5277529E-02
   12  1.4645401E-02
```

```
    14  1.8136440E-04
    24  1.7634179E-03
    26  6.4622704E-03
    28  6.9451093E-04
    55  1.8544278E-04
  2381  1.5621608E-04
  2351  3.6916722E-04
H/ZR (NUMBER DENSITIES IN FUEL) =    1.600000
H(IN FUEL)/U235 (NUMBER DENSITIES) =    62.29503
H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    115.6531
C(IN REFL + CLAD)/U235 (NUMBER DENSITIES) =    39.67146
 BIAS (H/U-235 =  115.653061 ) =     0.001579

    ****CASE            4 ****
WATER WEIGHT FRACTION =  0.1000000
U235 MASS PER ELEMENT =   137.0000     GRAMS
TOTAL U235 MASS=   1370.000     GRAMS
NUMBER OF FUEL ELEMENTS =   10.00000
FUEL OUTER RADIUS =   1.822450    CM   OR   0.7175000     INCHES
CLAD OUTER RADIUS =   1.873250    CM  OR   0.7375000     INCHES
FUEL ELEMENT LENGTH =   38.10000    CM OR    15.00000     INCHES
TOTAL CLAD LENGTH =   55.37200    CM OR    21.80000     INCHES

FUEL DENSITY =   5.973146     G.CC
MIXTURE DENSITY =   3.637624     G/CC
COLHEIGHT=   148.2477     CM

                        VOLUME(CC)        MASS(G)     DENSITY (G/CC)
 CENTRAL ZR ROD           120.660        784.288         6.500
 END REFLECTORS          1715.363       2744.581         1.600
 UZRH FUEL               3854.788      23025.213         5.973

  U235 MASS (FUEL)                      1370.000
  U238 MASS (FUEL)                       587.143
U235 + U238 (FUEL)                      1957.143
    ZR MASS (FUEL)                     20702.088
   H16 MASS (FUEL)                       365.982
  ZRH MASS (FUEL)                      21068.068

 CLAD + END FITS         1018.119       7967.782         7.826
 WATER ONLY              3835.762       3835.762         1.000

 TOTAL(FUEL+WATER)      10544.692      38357.625         3.638

     1  4.5076068E-02
    16  1.2169870E-02
   401  1.3775533E-02
    12  1.3205553E-02
    14  1.6353374E-04
    24  1.5900491E-03
    26  5.8269384E-03
    28  6.2623079E-04
    55  1.6721115E-04
  2381  1.4085784E-04
  2351  3.3287288E-04
H/ZR (NUMBER DENSITIES IN FUEL) =    1.600000
H(IN FUEL)/U235 (NUMBER DENSITIES) =    62.29504
H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    135.4153
C(IN REFL + CLAD)/U235 (NUMBER DENSITIES) =    39.67146
 BIAS (H/U-235 =  135.415268 ) =     0.001925
```

6.7.2.2 Case V Fuel

6.7.2.2.1 GEMER Input Decks

This Appendix includes GEMER geometrical plots and input listings for the infinite cask array for TRIGA Case V fuel. Each basedeck contains a "header" with fuel material and geometry information. Since the program input is similar to the popular KENO program (and deviations from this were discussed previously). No further explanation of the inputs is provided.

6.7.2.2.1.1 Infinite (94% Enriched)

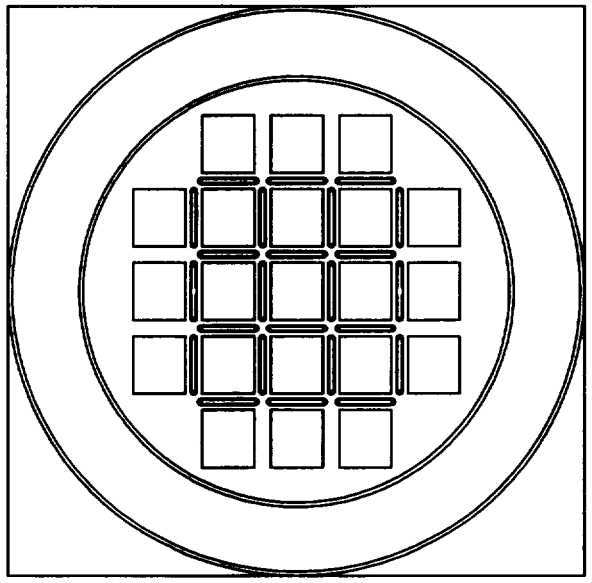

Figure 6.31. Unit Array for TRIGA Case V Fuel — Top View

```
TRIGA FUEL/ IF2000/7 ELEMENTS, SS+Pb SHIELDING. WFH2O IN FUEL=0.125 MASS
U235=1219.0 GRAMS
   125 /* # BATCHES
  1000  /* # NEUTRONS PER BATCH
     5  /* # BATCHES TO SKIP
 2123469/* INITIAL "SEED" (IF NON-ZERO)
     0  /* "IDUMP"
     0  /* "NRSTRT"
     0  /* "NBTED" (NON-ZERO IS PRINT EDITS)
     0  /* "KRED" (NUMBER OF COMBINED REGIONS IN EDITS)
     0  293   14  8
      11  293 0  0 U(94)ZRH+0.125 WF -H2O RHOMIX= 3.318661 g/cc     MAT
1
       1  4.5809846E-02
      16  1.3878455E-02
     401  1.2032967E-02
      12  1.2145552E-02
      14  1.5040702E-04
      24  1.4624174E-03
      26  5.3592152E-03
      28  5.7647959E-04
      55  1.5378925E-04
    2381  2.4526003E-05
    2351  3.8915648E-04
      3  293 0 0 Boral 0.25" Plate (60% Boron Loading)  MAT 2
    10    3.32658E-03
    11    6.7889E-05
   131    5.8001E-02
      2  293 0 0  MODERATOR IN CASK (100.00%)                    MAT 3
     1   6.69111121E-02
    16   3.34555566E-02
      2  293 0 0  INTERSPERSED MODERATOR (100.00%)            MAT4
     1   6.69111121E-02
    16   3.34555566E-02
      2  293 0 0 FULL DENSITY WATER                    MAT 5
     1    6.69111121E-02
    16    3.34555566E-02
      1  293 0 0 LEAD SHIELDING                        MAT 6
    82   3.29890E-02
      7  293 0 0 304 STAINLESS STEEL                   MAT 7
    12   6.82690E-05
    14   8.53360E-04
    24   1.53600E-02
    26   6.04950E-02
    28   6.82690E-03
    55   1.70670E-03
  1316   2.56010E-05
    2  293 0 0 FULL DENSITY WATER (VOID)             MAT 8
     1    6.69111121E-09
    16    3.34555566E-09
KENO GEOM
    14  /* "KREFM"
     6  /* "NBOX"
     1  /* "NBXMAX"
     1  /* "NBYMAX"
     1  /* "NBZMAX"
     1  /* "NXX"
     0  /* "NTYPST"
     1  /* "NEMBRG"
     0  /* "NGMCHK"
  -1.0  -1.0  -1.0  -1.0  -1.0  -1.0
```

```
BOX TYPE      1 /*MODEL 2000 CASK & STAINLESS SUPPORT STRUCTURE
CYLINDER      7  33.34      140.64      0.0     16*0.5
CYLINDER      3  33.65      140.64      0.0     16*0.5
CYLINDER      7  35.85      140.64      0.0     16*0.5
CYLINDER      6  46.34      140.64      0.0     16*0.5
CYLINDER      7  48.56      140.64    -14.90    16*0.5
BOX TYPE      2 /* CASK TOP
CYLINDER      6  30.96      158.42     140.64  16*0.5
CYLINDER      7  48.56      162.23     140.64  16*0.5
BOX TYPE      3 /* NBSR FUEL ASSEMBLY-COLLAPSED
CUBOID        1  4.4450 -4.4450  4.0005  -4.0005  112.8301  0.0   16*0.5
CUBOID        3  4.4450 -4.4450  4.0005  -4.0005  140.64  0.0   16*0.5
BOX TYPE      4 /* BORAL PLATE (VERT)
CUBOID        2  0.286  -0.286  4.12  -4.12  138.64  2.0   16*0.5
BOX TYPE      5 /* BORAL PLATE (HORIZ)
CUBOID        2  4.12  -4.12  0.286  -0.286  138.64  2.0   16*0.5
BOX TYPE      6  /* OVERALL BOX FOR THE PROBLEM
CUBOID        4  48.60    -48.60   48.60 -48.60 162.23 -14.91 16*0.5
CORE          0  48.60    -48.60   48.60 -48.60 162.23 -14.91 16*0.5
CUBOID        5  48.70    -48.70   48.70 -48.70 162.33 -14.92 16*0.5
6  1 1 1  1 1 1  1 1 1  1
BEGIN COMPLEX
/* PLACE FUEL ASSEMBLIES INTO CASK
COMPLEX  1  3   -22.860  -10.540  0.0  5  3  1  11.430  10.540  0.0
/*MIDDLE ROWS
COMPLEX  1  3   -11.430  -21.080  0.0  3  2  1  11.430  42.160  0.0
/*OUTER ROWS
/* PLACE BORAL PLATES INTO CASK
COMPLEX  1  4   -17.145  -10.540  0.0  4  3  1  11.430  10.540  0.0
/*VERT PLATES
COMPLEX  1  5   -11.430  -15.810  0.0  3  4  1  11.430  10.540  0.0
/*HORIZ PLATES
/* PLACE LOADED CASK INTO OVERALL PROBLEM BOX
COMPLEX  6  1  0.0     0.0     0.0   1 1 1   0.0     0.0     0.0
/* PLACE TOP INTO OVERALL PROBLEM BOX
COMPLEX  6  2  0.0     0.0     0.0   1 1 1   0.0     0.0     0.0
END GEOM
*END GEMER*
```

6.7.2.2.2 Number Sensity Calculations

6.7.2.2.2.1 FORTRAN Program (TRIGA Case V Fuel)

```
PROGRAM NUMBER
C
C   PRODUCTION RUN
C   8/2/96
C                        AKC
C    U-235 (94% ENRICHMENT CASE)
C    CASE 5 TYPE OF TRIGA FUEL
C    15" ACTIVE FUEL LENGTH, 1.475" O.D. FUEL ELEMENT,
C                            1.435" O.D. FUEL
C                            0.020" CLADDING THICKNESS
C     CENTRAL ZR ROD
C
      REAL M235,M238
      REAL U235MAS,U238MAS
      REAL MZR,MU,MH,MH16,MH20
      REAL N235,N238,NH,NZR,NZR1,N16,NHFUEL
      REAL NELEMENT
      REAL MNI,MCR,MMN,MFE,MC12,MSI
      REAL FEMAS,CRMAS,NIMAC,MNMAS
      REAL NNI,NMN,NFE,NCR,NSI,NC12
      REAL LREFL
C
      DATA PI/3.14159265/
C
      OPEN(6,FILE='P_94.OUT',STATUS='UNKNOWN')
      AV=0.6022
      M235 =235.0439
      M238 =238.0508
      MZR=91.224
      MH=1.00794
      MH16=1.6*MH
      MH2O=18.0153
C
C
C    STAINLESS STEEL 304
C     C12        0.080  %
C     SI         1.001  %
C     CR        18.012  %
C     FE        70.892  %
C     NI         8.010  %
C     MN         2.001  %
       MC12=11.8969
       MSI=27.844
       MCR=51.549
       MFE=55.365
       MNI=58.1826
       MMN=54.466
C
C
C     WRITE(6,*)  '  *************** GA SAR CASE TYPE 5 FUEL ******'
      DO 100 ITER=1,24
      WRITE(6,*) '    '
      WRITE(6,*) '     ****CASE ',ITER,' ****   '
C      WFWATER=0.05*FLOAT(ITER-1)
```

```
      WFWATER=0.025*FLOAT(ITER-1)
      WRITE(6,*) ' WATER WEIGHT FRACTION =',WFWATER
C
C
C       *****INPUTS********
C     WT_U = WEIGHT OF URANIUM
C
C     RHOZR=ZR DENSITY (G/CC)
C     RHOREFL = REFLECTOR (GRAPHITE) DENSITY IN G/CC
      RHOZR=6.50
      RHOREFL = 1.60
C     U235GRAM = U235 WEIGHT PER ELEMENT IN GRAMS
C     ER-167 MASS IGNORED.
C
C
      NELEMENT=7.0
C     WEIGHT OF U-235 PER FUEL ELEMENT
      U235GRAM=1219.0/7.0
C
      ENRICH=0.940
      U235MAS=NELEMENT*U235GRAM
      WRITE(6,*) ' U235 MASS PER ELEMENT =',U235MAS/NELEMENT,' GRAMS'
      WRITE(6,*) ' TOTAL U235 MASS=',U235MAS,' GRAMS'
      WRITE(6,*) ' NUMBER OF FUEL ELEMENTS =',NELEMENT
      WT_U=0.085
C
C    RHOSS = STAINLESS STEEL DENSITY (G/CC)
      RHOSS=7.8266
C
C    RFUEL = FUEL OUTER RADIUS (CM)
C    RCLAD = CLAD OUTER RADIUS (CM)
C
C
      RZRROD=0.25*2.54/2.0
      RFUEL=1.435*2.54/2.0
      RCLAD=1.475*2.54/2.0
C
C   FLENGTH = FUEL ACTIVE LENGTH IN CM
C   FCLENGTH = CLAD LENGTH + ACTIVE FUEL LENGTH IN CM
C
      FLENGTH=15.0*2.54
      FCLENGTH=(3.40+3.40)*2.54 + FLENGTH
      WRITE(6,*) ' FUEL OUTER RADIUS =',RFUEL,'CM   OR ',
     * RFUEL/2.54,' INCHES'
      WRITE(6,*) ' CLAD OUTER RADIUS =',RCLAD,'CM  OR ',
     *            RCLAD/2.54,' INCHES'
      WRITE(6,*) ' FUEL ELEMENT LENGTH =',FLENGTH,'CM OR ',
     *           FLENGTH/2.54,' INCHES'
      WRITE(6,*) ' TOTAL CLAD LENGTH =',FCLENGTH,'CM OR ',
     *           FCLENGTH/2.54,' INCHES'
C
C     CVOLUME=CLAD VOLUME
C     FVOLUME=FUEL VOLUME
C     FCVOLUME=FUEL + CLAD VOLUMES
C
C     VOL_ENDFIT= 118*1.224/8.01
C               = 18.01   (PREVIOUS DESIGN)
C    CLADDING IS STAINLESS STEEL-304
C    CLAD = FUEL CLAD + END FITS + CLAD OVER GRAPHITE REFLECTORS
C
C     VOL_ENDFIT = 69.153 CC (FROM S. JAIN  8/5/96)
```

```
C
      VOL_ENDFIT = 69.153
      CVOLUME = NELEMENT*PI*(RCLAD*RCLAD-RFUEL*RFUEL)*FCLENGTH
     *          + NELEMENT*VOL_ENDFIT
C
C      NEXT THE CENTRAL ZR ROD:
C
C      RZRROD=0.25*2.54/2.0
C
      ZRVOLUME = NELEMENT*PI*RZRROD*RZRROD*FLENGTH
      ZRRODMAS = ZRVOLUME*RHOZR
C
C     RREFL = GRAPHITE END REFLECTOR RADIUS (CM)
C     REFLVOLUME= REFLECTOR VOLUME (CC)
C     LREFL = TOTAL LENGTH OF BOTH REFLECTORS (CM)
C     REFLMAS = REFLECTOR MASS (G)
C
      RREFL = 1.40*2.54/2.0
      LREFL = (3.4+3.4)*2.54
      REFLVOLUME = NELEMENT*PI*RREFL*RREFL*LREFL
      REFLMAS= REFLVOLUME*RHOREFL
C
      FVOLUME=NELEMENT*PI*(RFUEL*RFUEL-RZRROD*RZRROD)*FLENGTH
      FCVOLUME=FVOLUME+CVOLUME
C
C    CALCULATING THE CLAD MASSES
C
      WTMN=0.020013
      WTCR=0.180116
      WTNI=0.080145
      WTFE=0.70892
      WTC12=0.0008
      WTSI=0.010006
C
      MNMAS = RHOSS*CVOLUME*WTMN
      CRMAS = RHOSS*CVOLUME*WTCR
      NIMAS = RHOSS*CVOLUME*WTNI
      FEMAS = RHOSS*CVOLUME*WTFE
      SIMAS = RHOSS*CVOLUME*WTSI
      C12MAS = RHOSS*CVOLUME*WTC12
C
      CLADMAS=MNMAS+CRMAS+NIMAS+FEMAS+C12MAS+SIMAS
C
C     WATER DENSITY (G/CC)
      RHOWATER=1.0
C
C
       U238MAS=U235MAS/ENRICH - U235MAS
C
       UMAS=U238MAS +U235MAS
       ZRHMAS=UMAS/WT_U - UMAS
       ZRMAS = ZRHMAS*MZR/(MZR+MH16)
       H16MAS = ZRHMAS*MH16/(MZR+MH16)
C
C
C     TOTAL2 = WATER MASS
C     TOTAL1 = FUEL ELEMENT MASS (UZRH  + CLAD + GRAHITE REFLECTORS +
END FITTINGS)
C     TOTAL = WATER + FUEL ELEMENT MASSES (HOMOGENOUS MIXTURE)
C
      TOTAL1= (ZRMAS + H16MAS + U238MAS +U235MAS) +CLADMAS
```

```
     *         + REFLMAS + ZRRODMAS
      TOTAL2 = TOTAL1/(1.0-WFWATER) - TOTAL1
      TOTAL = TOTAL1 + TOTAL2
      WATERVOL=TOTAL2/RHOWATER
      VOLTOT=WATERVOL + FCVOLUME + REFLVOLUME + ZRVOLUME
C
       WRITE(6,*) '    '
C
C   AREASLOT = SLOT AREA PER ELEMENT (cm^2)
C
       AREASLOT=71.12889
       RHOMIX = TOTAL/VOLTOT
       WRITE(6,*) ' FUEL DENSITY =',
     *   (ZRMAS + H16MAS + U238MAS +U235MAS)/FVOLUME,' G.CC'
       WRITE(6,*) ' MIXTURE DENSITY =',RHOMIX,' G/CC'
       COLHEIGHT=VOLTOT/AREASLOT
       WRITE(6,*) ' COLHEIGHT=',COLHEIGHT,' CM'
       WRITE(6,*) ' '
C
C     WRITING OUT THE SUMMARY TABLE
C
      WRITE(6,1005)
 1005 FORMAT(23X, ' VOLUME(CC)        MASS(G)',5X,'DENSITY (G/CC)')
      WRITE(6,1006) ZRVOLUME,ZRRODMAS,ZRRODMAS/ZRVOLUME
      WRITE(6,1007) REFLVOLUME,REFLMAS,REFLMAS/REFLVOLUME
      WRITE(6,1010) FVOLUME,H16MAS+U238MAS +U235MAS + ZRMAS,
     *              (H16MAS+U238MAS +U235MAS + ZRMAS)/FVOLUME
      WRITE(6,*) '    '
      WRITE(6,1024) U235MAS
      WRITE(6,1025) U238MAS
      WRITE(6,1026) U238MAS+U235MAS
      WRITE(6,1021) ZRMAS
      WRITE(6,1022) H16MAS
      WRITE(6,1023) ZRHMAS
      WRITE(6,*) '    '
 1021 FORMAT(1X,'      ZR MASS (FUEL)',14X,F14.3)
 1023 FORMAT(1X,'    ZRH MASS (FUEL) ',14X,F14.3)
 1022 FORMAT(1X,'     H16 MASS (FUEL)',14X,F14.3)
 1024 FORMAT(1X,'    U235 MASS (FUEL)',14X,F14.3)
 1025 FORMAT(1X,'    U238 MASS (FUEL)',14X,F14.3)
 1026 FORMAT(1X,' U235 + U238 (FUEL)',14X,F14.3)
C
      WRITE(6,1008) CVOLUME,CLADMAS,CLADMAS/CVOLUME
      WRITE(6,1009) WATERVOL,TOTAL2,RHOWATER
      WRITE(6,1013) VOLTOT,TOTAL,TOTAL/VOLTOT
 1006 FORMAT(1X,'  CENTRAL ZR ROD    ',3F14.3)
 1007 FORMAT(1X,'  END REFLECTORS    ',3F14.3)
 1008 FORMAT(1X,'  CLAD + END FITS   ',3F14.3)
 1009 FORMAT(1X,'  WATER ONLY        ',3F14.3)
 1010 FORMAT(1X,'  UZRH FUEL         ',3F14.3)
 1013 FORMAT(/,1X,'  TOTAL(FUEL+WATER)',3F14.3,/)
C
C
      N235 = U235MAS*AV/M235/VOLTOT
      N238 = U238MAS*AV/M238/VOLTOT
C     H  FROM FUEL AND WATER
      NH = H16MAS*AV/MH/VOLTOT + 2.0*TOTAL2*AV/VOLTOT/MH2O
      NHFUEL = H16MAS*AV/MH/VOLTOT
C     ZR NUMBER DENSITY = ZR IN FUEL + ZR ROD
      NZR = ZRMAS*AV/MZR/VOLTOT + ZRRODMAS/MZR/VOLTOT
      NZR1 = ZRMAS*AV/MZR/VOLTOT
```

```
      N16= TOTAL2*AV/VOLTOT/MH2O
C
      IF (N16.LE.0.0) N16=1.0E-9
C     STAINLESS STEEL
      NSI= SIMAS*AV/MSI/VOLTOT
C     C12 DENSITIES = STAINLESS STEEL + REFLECTOR
      NC12= C12MAS*AV/MC12/VOLTOT + REFLMAS*AV/MC12/VOLTOT
      NMN= MNMAS*AV/MMN/VOLTOT
      NFE= FEMAS*AV/MFE/VOLTOT
      NNI= NIMAS*AV/MNI/VOLTOT
      NCR= CRMAS*AV/MCR/VOLTOT
C
C
      WRITE(6,*) '      1',NH
      WRITE(6,*) '     16',N16
      WRITE(6,*) '    401',NZR
C
      WRITE(6,*) '     12',NC12
      WRITE(6,*) '     14',NSI
      WRITE(6,*) '     24',NCR
      WRITE(6,*) '     26',NFE
      WRITE(6,*) '     28',NNI
      WRITE(6,*) '     55',NMN
C
      WRITE(6,*) '   2381',N238
      WRITE(6,*) '   2351',N235
C
      RATIO1 = NHFUEL/NZR1
      WRITE(6,*) ' H/ZR (NUMBER DENSITIES IN FUEL) = ',RATIO1
      RATIO2 = NHFUEL/N235
      WRITE(6,*) ' H(IN FUEL)/U235 (NUMBER DENSITIES) = ',RATIO2
      RATIO3 = NH/N235
      WRITE(6,*) ' H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) = ',RATIO3
      RATIO4 = NC12/N235
      WRITE(6,*) ' C(IN REFL + CLAD)/U235 (NUMBER DENSITIES) = ',RATIO4
C
C
C
      BIAS = BIASFUN(RATIO3)
      WRITE(6,1700) RATIO3,BIAS
 1700  FORMAT(1X,'  BIAS (H/U-235 =',F12.6,' ) = ',F12.6)
 100  CONTINUE
       END
      FUNCTION BIASFUN(X)
      REAL X
      BIASFUN=-(1.0E-8*X*X - 2.0E-5*X +0.0006)
      RETURN
      END
```

6.7.2.2.2.2 FORTRAN Output (TRIGA Case V Fuel)

```
    ****CASE            1 ****
WATER WEIGHT FRACTION =  0.0000000E+00
U235 MASS PER ELEMENT =   174.1429     GRAMS
TOTAL U235 MASS=   1219.000     GRAMS
NUMBER OF FUEL ELEMENTS =   7.000000
FUEL OUTER RADIUS =   1.822450    CM   OR   0.7175000     INCHES
CLAD OUTER RADIUS =   1.873250    CM  OR   0.7375000     INCHES
FUEL ELEMENT LENGTH =   38.10000    CM OR    15.00000     INCHES
TOTAL CLAD LENGTH =   55.37200    CM OR    21.80000     INCHES

FUEL DENSITY =   5.654033     G.CC
MIXTURE DENSITY =   4.962389     G/CC
COLHEIGHT=   66.02452     CM

                      VOLUME(CC)        MASS(G)     DENSITY (G/CC)
 CENTRAL ZR ROD          84.462        549.002         6.500
 END REFLECTORS        1200.754       1921.206         1.600
 UZRH FUEL             2698.352      15256.570         5.654

  U235 MASS (FUEL)                     1219.000
  U238 MASS (FUEL)                       77.808
U235 + U238 (FUEL)                     1296.808
    ZR MASS (FUEL)                    13717.261
   H16 MASS (FUEL)                      242.501
  ZRH MASS (FUEL)                    13959.762

 CLAD + END FITS         712.683      5577.848         7.827
 WATER ONLY                0.000         0.000         1.000

 TOTAL(FUEL+WATER)      4696.251     23304.627         4.962

     1  3.0850891E-02
    16  9.9999997E-10
   401  2.0563291E-02
    12  2.0755690E-02
    14  2.5703249E-04
    24  2.4991438E-03
    26  9.1584316E-03
    28  9.8515337E-04
    55  2.6281242E-04
  2381  4.1912801E-05
  2351  6.6503452E-04
H/ZR (NUMBER DENSITIES IN FUEL) =    1.600000
H(IN FUEL)/U235 (NUMBER DENSITIES) =    46.38991
H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    46.38991
C(IN REFL + CLAD)/U235 (NUMBER DENSITIES) =    31.20994
 BIAS (H/U-235 =   46.389908 ) =     0.000306

    ****CASE            2 ****
WATER WEIGHT FRACTION =  2.5000000E-02
U235 MASS PER ELEMENT =   174.1429     GRAMS
TOTAL U235 MASS=   1219.000     GRAMS
NUMBER OF FUEL ELEMENTS =   7.000000
FUEL OUTER RADIUS =   1.822450    CM   OR   0.7175000     INCHES
CLAD OUTER RADIUS =   1.873250    CM  OR   0.7375000     INCHES
FUEL ELEMENT LENGTH =   38.10000    CM OR    15.00000     INCHES
TOTAL CLAD LENGTH =   55.37200    CM OR    21.80000     INCHES
```

```
FUEL DENSITY =    5.654033      G.CC
MIXTURE DENSITY =    4.515122      G/CC
COLHEIGHT=    74.42554      CM

                        VOLUME(CC)        MASS(G)      DENSITY (G/CC)
 CENTRAL ZR ROD            84.462        549.002          6.500
 END REFLECTORS          1200.754       1921.206          1.600
 UZRH FUEL               2698.352      15256.570          5.654

  U235 MASS (FUEL)                      1219.000
  U238 MASS (FUEL)                        77.808
U235 + U238 (FUEL)                      1296.808
    ZR MASS (FUEL)                     13717.261
   H16 MASS (FUEL)                       242.501
  ZRH MASS (FUEL)                      13959.762

 CLAD + END FITS          712.683       5577.848          7.827
 WATER ONLY               597.555        597.555          1.000

 TOTAL(FUEL+WATER)       5293.806      23902.182          4.515

     1  3.4921300E-02
    16  3.7763992E-03
   401  1.8242145E-02
    12  1.8412827E-02
    14  2.2801915E-04
    24  2.2170453E-03
    26  8.1246449E-03
    28  8.7395112E-04
    55  2.3314667E-04
  2381  3.7181762E-05
  2351  5.8996666E-04
H/ZR (NUMBER DENSITIES IN FUEL) =     1.600000
H(IN FUEL)/U235 (NUMBER DENSITIES) =     46.38992
H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =     59.19199
C(IN REFL + CLAD)/U235 (NUMBER DENSITIES) =     31.20994
 BIAS (H/U-235 =    59.191990 ) =      0.000549

    ****CASE              3 ****
WATER WEIGHT FRACTION =  5.0000001E-02
U235 MASS PER ELEMENT =    174.1429      GRAMS
TOTAL U235 MASS=    1219.000      GRAMS
NUMBER OF FUEL ELEMENTS =    7.000000
FUEL OUTER RADIUS =    1.822450     CM    OR    0.7175000      INCHES
CLAD OUTER RADIUS =    1.873250     CM   OR    0.7375000      INCHES
FUEL ELEMENT LENGTH =    38.10000     CM OR     15.00000      INCHES
TOTAL CLAD LENGTH =    55.37200     CM OR     21.80000      INCHES

FUEL DENSITY =    5.654033      G.CC
MIXTURE DENSITY =    4.141815      G/CC
COLHEIGHT=    83.26871      CM

                        VOLUME(CC)        MASS(G)      DENSITY (G/CC)
 CENTRAL ZR ROD            84.462        549.002          6.500
 END REFLECTORS          1200.754       1921.206          1.600
 UZRH FUEL               2698.352      15256.570          5.654

  U235 MASS (FUEL)                      1219.000
  U238 MASS (FUEL)                        77.808
U235 + U238 (FUEL)                      1296.808
```

```
   ZR MASS (FUEL)                    13717.261
  H16 MASS (FUEL)                      242.501
 ZRH MASS (FUEL)                     13959.762

CLAD + END FITS          712.683      5577.848          7.827
WATER ONLY              1226.561      1226.561          1.000

TOTAL(FUEL+WATER)       5922.812     24531.188          4.142

    1  3.8318634E-02
   16  6.9283415E-03
  401  1.6304819E-02
   12  1.6457375E-02
   14  2.0380339E-04
   24  1.9815939E-03
   26  7.2618034E-03
   28  7.8113703E-04
   55  2.0838637E-04
 2381  3.3233038E-05
 2351  5.2731187E-04
H/ZR (NUMBER DENSITIES IN FUEL) =    1.600000
H(IN FUEL)/U235 (NUMBER DENSITIES) =    46.38991
H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    72.66788
C(IN REFL + CLAD)/U235 (NUMBER DENSITIES) =    31.20995
 BIAS (H/U-235 =   72.667877 ) =     0.000801

   ****CASE            4 ****
WATER WEIGHT FRACTION =  7.5000003E-02
U235 MASS PER ELEMENT =   174.1429     GRAMS
TOTAL U235 MASS=   1219.000     GRAMS
NUMBER OF FUEL ELEMENTS =   7.000000
FUEL OUTER RADIUS =   1.822450    CM   OR   0.7175000     INCHES
CLAD OUTER RADIUS =   1.873250    CM  OR   0.7375000     INCHES
FUEL ELEMENT LENGTH =   38.10000    CM OR    15.00000     INCHES
TOTAL CLAD LENGTH =   55.37200    CM OR    21.80000     INCHES

FUEL DENSITY =   5.654033     G.CC
MIXTURE DENSITY =   3.825523     G/CC
COLHEIGHT=   92.58988     CM

                       VOLUME(CC)        MASS(G)     DENSITY (G/CC)
 CENTRAL ZR ROD           84.462       549.002          6.500
 END REFLECTORS         1200.754      1921.206          1.600
 UZRH FUEL              2698.352     15256.570          5.654

  U235 MASS (FUEL)                     1219.000
  U238 MASS (FUEL)                       77.808
U235 + U238 (FUEL)                     1296.808
    ZR MASS (FUEL)                    13717.261
   H16 MASS (FUEL)                      242.501
  ZRH MASS (FUEL)                     13959.762

 CLAD + END FITS          712.683      5577.848          7.827
 WATER ONLY              1889.564      1889.564          1.000

 TOTAL(FUEL+WATER)       6585.815     25194.191          3.826

    1  4.1197084E-02
   16  9.5988763E-03
  401  1.4663389E-02
   12  1.4800586E-02
```

```
    14  1.8328620E-04
    24  1.7821038E-03
    26  6.5307468E-03
    28  7.0249877E-04
    55  1.8740780E-04
  2381  2.9887420E-05
  2351  4.7422660E-04
H/ZR (NUMBER DENSITIES IN FUEL) =     1.600000
H(IN FUEL)/U235 (NUMBER DENSITIES) =     46.38992
H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =     86.87215
C(IN REFL + CLAD)/U235 (NUMBER DENSITIES) =     31.20994
 BIAS (H/U-235 =   86.872147 ) =     0.001062

    ****CASE            5 ****
WATER WEIGHT FRACTION =  0.1000000
U235 MASS PER ELEMENT =   174.1429     GRAMS
TOTAL U235 MASS=   1219.000     GRAMS
NUMBER OF FUEL ELEMENTS =   7.000000
FUEL OUTER RADIUS =   1.822450    CM   OR   0.7175000     INCHES
CLAD OUTER RADIUS =   1.873250    CM  OR   0.7375000     INCHES
FUEL ELEMENT LENGTH =   38.10000    CM OR    15.00000     INCHES
TOTAL CLAD LENGTH =   55.37200    CM OR    21.80000     INCHES

FUEL DENSITY =   5.654033     G.CC
MIXTURE DENSITY =   3.554111     G/CC
COLHEIGHT=   102.4289     CM

                      VOLUME(CC)        MASS(G)     DENSITY (G/CC)
 CENTRAL ZR ROD          84.462        549.002         6.500
 END REFLECTORS        1200.754       1921.206         1.600
 UZRH FUEL             2698.352      15256.570         5.654

  U235 MASS (FUEL)                     1219.000
  U238 MASS (FUEL)                       77.808
U235 + U238 (FUEL)                     1296.808
    ZR MASS (FUEL)                    13717.261
   H16 MASS (FUEL)                      242.501
  ZRH MASS (FUEL)                     13959.762

 CLAD + END FITS         712.683       5577.848         7.827
 WATER ONLY             2589.404       2589.404         1.000

 TOTAL(FUEL+WATER)      7285.655      25894.031         3.554

     1  4.3667100E-02
    16  1.1890482E-02
   401  1.3254864E-02
    12  1.3378883E-02
    14  1.6568023E-04
    24  1.6109198E-03
    26  5.9034214E-03
    28  6.3501869E-04
    55  1.6940592E-04
  2381  2.7016516E-05
  2351  4.2867372E-04
H/ZR (NUMBER DENSITIES IN FUEL) =     1.600000
H(IN FUEL)/U235 (NUMBER DENSITIES) =     46.38991
H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =     101.8656
C(IN REFL + CLAD)/U235 (NUMBER DENSITIES) =     31.20994
 BIAS (H/U-235 =  101.865585 ) =     0.001334
```

```
    ****CASE            6 ****
WATER WEIGHT FRACTION =  0.1250000
U235 MASS PER ELEMENT =   174.1429     GRAMS
TOTAL U235 MASS=   1219.000     GRAMS
NUMBER OF FUEL ELEMENTS =   7.000000
FUEL OUTER RADIUS =   1.822450    CM   OR   0.7175000     INCHES
CLAD OUTER RADIUS =   1.873250    CM  OR   0.7375000     INCHES
FUEL ELEMENT LENGTH =   38.10000    CM OR    15.00000     INCHES
TOTAL CLAD LENGTH =   55.37200    CM OR    21.80000     INCHES

FUEL DENSITY =   5.654033     G.CC
MIXTURE DENSITY =   3.318661     G/CC
COLHEIGHT=   112.8301     CM

                       VOLUME(CC)        MASS(G)     DENSITY (G/CC)
 CENTRAL ZR ROD           84.462        549.002         6.500
 END REFLECTORS         1200.754       1921.206         1.600
 UZRH FUEL              2698.352      15256.570         5.654

  U235 MASS (FUEL)                      1219.000
  U238 MASS (FUEL)                        77.808
U235 + U238 (FUEL)                      1296.808
    ZR MASS (FUEL)                     13717.261
   H16 MASS (FUEL)                       242.501
  ZRH MASS (FUEL)                      13959.762

 CLAD + END FITS         712.683       5577.848         7.827
 WATER ONLY             3329.232       3329.232         1.000

 TOTAL(FUEL+WATER)      8025.483      26633.859         3.319

     1  4.5809846E-02
    16  1.3878455E-02
   401  1.2032967E-02
    12  1.2145552E-02
    14  1.5040702E-04
    24  1.4624174E-03
    26  5.3592152E-03
    28  5.7647959E-04
    55  1.5378925E-04
  2381  2.4526003E-05
  2351  3.8915648E-04
H/ZR (NUMBER DENSITIES IN FUEL) =    1.600000
H(IN FUEL)/U235 (NUMBER DENSITIES) =    46.38991
H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    117.7157
C(IN REFL + CLAD)/U235 (NUMBER DENSITIES) =    31.20994
 BIAS (H/U-235 =  117.715744 ) =     0.001616

    ****CASE            7 ****
WATER WEIGHT FRACTION =  0.1500000
U235 MASS PER ELEMENT =   174.1429     GRAMS
TOTAL U235 MASS=   1219.000     GRAMS
NUMBER OF FUEL ELEMENTS =   7.000000
FUEL OUTER RADIUS =   1.822450    CM   OR   0.7175000     INCHES
CLAD OUTER RADIUS =   1.873250    CM  OR   0.7375000     INCHES
FUEL ELEMENT LENGTH =   38.10000    CM OR    15.00000     INCHES
TOTAL CLAD LENGTH =   55.37200    CM OR    21.80000     INCHES

FUEL DENSITY =   5.654033     G.CC
MIXTURE DENSITY =   3.112468     G/CC
COLHEIGHT=   123.8432     CM
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                        VOLUME(CC)        MASS(G)     DENSITY (G/CC)
 CENTRAL ZR ROD            84.462        549.002         6.500
 END REFLECTORS          1200.754       1921.206         1.600
 UZRH FUEL               2698.352      15256.570         5.654

  U235 MASS (FUEL)                      1219.000
  U238 MASS (FUEL)                        77.808
U235 + U238 (FUEL)                      1296.808
    ZR MASS (FUEL)                     13717.261
   H16 MASS (FUEL)                       242.501
  ZRH MASS (FUEL)                      13959.762

 CLAD + END FITS          712.683       5577.848         7.827
 WATER ONLY              4112.580       4112.580         1.000

 TOTAL(FUEL+WATER)       8808.831      27417.207         3.112

     1  4.7686331E-02
    16  1.5619399E-02
   401  1.0962904E-02
    12  1.1065478E-02
    14  1.3703170E-04
    24  1.3323682E-03
    26  4.8826332E-03
    28  5.2521465E-04
    55  1.4011316E-04
  2381  2.2344966E-05
  2351  3.5454976E-04
H/ZR (NUMBER DENSITIES IN FUEL) =    1.600000
H(IN FUEL)/U235 (NUMBER DENSITIES) =    46.38991
H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    134.4983
C(IN REFL + CLAD)/U235 (NUMBER DENSITIES) =    31.20995
 BIAS (H/U-235 =  134.498276 ) =     0.001909

    ****CASE            8 ****
WATER WEIGHT FRACTION =  0.1750000
U235 MASS PER ELEMENT =   174.1429     GRAMS
TOTAL U235 MASS=   1219.000     GRAMS
NUMBER OF FUEL ELEMENTS =   7.000000
FUEL OUTER RADIUS =   1.822450    CM   OR   0.7175000     INCHES
CLAD OUTER RADIUS =   1.873250    CM  OR   0.7375000     INCHES
FUEL ELEMENT LENGTH =   38.10000    CM OR    15.00000     INCHES
TOTAL CLAD LENGTH =   55.37200    CM OR    21.80000     INCHES

FUEL DENSITY =   5.654033     G.CC
MIXTURE DENSITY =   2.930398     G/CC
COLHEIGHT=   135.5238     CM

                        VOLUME(CC)        MASS(G)     DENSITY (G/CC)
 CENTRAL ZR ROD            84.462        549.002         6.500
 END REFLECTORS          1200.754       1921.206         1.600
 UZRH FUEL               2698.352      15256.570         5.654

  U235 MASS (FUEL)                      1219.000
  U238 MASS (FUEL)                        77.808
U235 + U238 (FUEL)                      1296.808
    ZR MASS (FUEL)                     13717.261
   H16 MASS (FUEL)                       242.501
  ZRH MASS (FUEL)                      13959.762
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 CLAD + END FITS          712.683      5577.848          7.827
 WATER ONLY              4943.406      4943.406          1.000

 TOTAL(FUEL+WATER)       9639.657     28248.033          2.930

     1  4.9343284E-02
    16  1.7156668E-02
   401  1.0018030E-02
    12  1.0111763E-02
    14  1.2522117E-04
    24  1.2175336E-03
    26  4.4618072E-03
    28  4.7994728E-04
    55  1.2803703E-04
  2381  2.0419089E-05
  2351  3.2399170E-04
H/ZR (NUMBER DENSITIES IN FUEL) =    1.600000
H(IN FUEL)/U235 (NUMBER DENSITIES) =    46.38991
H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    152.2980
C(IN REFL + CLAD)/U235 (NUMBER DENSITIES) =    31.20995
 BIAS (H/U-235 =  152.297989 ) =     0.002214

    ****CASE            9 ****
WATER WEIGHT FRACTION =  0.2000000
U235 MASS PER ELEMENT =   174.1429     GRAMS
TOTAL U235 MASS=   1219.000     GRAMS
NUMBER OF FUEL ELEMENTS =   7.000000
FUEL OUTER RADIUS =   1.822450    CM   OR   0.7175000     INCHES
CLAD OUTER RADIUS =   1.873250    CM  OR   0.7375000     INCHES
FUEL ELEMENT LENGTH =   38.10000    CM OR    15.00000     INCHES
TOTAL CLAD LENGTH =   55.37200    CM OR    21.80000     INCHES

FUEL DENSITY =   5.654033     G.CC
MIXTURE DENSITY =   2.768452     G/CC
COLHEIGHT=   147.9344     CM

                        VOLUME(CC)        MASS(G)     DENSITY (G/CC)
 CENTRAL ZR ROD            84.462       549.002          6.500
 END REFLECTORS          1200.754      1921.206          1.600
 UZRH FUEL               2698.352     15256.570          5.654

  U235 MASS (FUEL)                     1219.000
  U238 MASS (FUEL)                       77.808
U235 + U238 (FUEL)                     1296.808
    ZR MASS (FUEL)                    13717.261
   H16 MASS (FUEL)                      242.501
  ZRH MASS (FUEL)                    13959.762

 CLAD + END FITS          712.683      5577.848          7.827
 WATER ONLY              5826.156      5826.156          1.000

 TOTAL(FUEL+WATER)      10522.407     29130.783          2.768

     1  5.0817091E-02
    16  1.8524021E-02
   401  9.1775935E-03
    12  9.2634633E-03
    14  1.1471606E-04
    24  1.1153917E-03
    26  4.0874956E-03
    28  4.3968335E-04
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    55  1.1729571E-04
  2381  1.8706083E-05
  2351  2.9681125E-04
H/ZR (NUMBER DENSITIES IN FUEL) =    1.600000
H(IN FUEL)/U235 (NUMBER DENSITIES) =    46.38991
H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    171.2101
C(IN REFL + CLAD)/U235 (NUMBER DENSITIES) =    31.20995
 BIAS (H/U-235 =  171.210129 ) =     0.002531

    ****CASE           10 ****
WATER WEIGHT FRACTION =  0.2250000
U235 MASS PER ELEMENT =   174.1429     GRAMS
TOTAL U235 MASS=   1219.000     GRAMS
NUMBER OF FUEL ELEMENTS =   7.000000
FUEL OUTER RADIUS =   1.822450    CM   OR   0.7175000     INCHES
CLAD OUTER RADIUS =   1.873250    CM  OR   0.7375000     INCHES
FUEL ELEMENT LENGTH =   38.10000    CM OR    15.00000     INCHES
TOTAL CLAD LENGTH =   55.37200    CM OR    21.80000     INCHES

FUEL DENSITY =   5.654033     G.CC
MIXTURE DENSITY =   2.623468     G/CC
COLHEIGHT=   161.1457     CM

                       VOLUME(CC)        MASS(G)     DENSITY (G/CC)
 CENTRAL ZR ROD           84.462       549.002         6.500
 END REFLECTORS         1200.754      1921.206         1.600
 UZRH FUEL              2698.352     15256.570         5.654

  U235 MASS (FUEL)                     1219.000
  U238 MASS (FUEL)                       77.808
U235 + U238 (FUEL)                     1296.808
    ZR MASS (FUEL)                    13717.261
   H16 MASS (FUEL)                      242.501
  ZRH MASS (FUEL)                    13959.762

 CLAD + END FITS         712.683      5577.848         7.827
 WATER ONLY             6765.861      6765.861         1.000

 TOTAL(FUEL+WATER)     11462.112     30070.488         2.623

     1  5.2136533E-02
    16  1.9748161E-02
   401  8.4251808E-03
    12  8.5040107E-03
    14  1.0531122E-04
    24  1.0239480E-03
    26  3.7523881E-03
    28  4.0363654E-04
    55  1.0767938E-04
  2381  1.7172491E-05
  2351  2.7247760E-04
H/ZR (NUMBER DENSITIES IN FUEL) =    1.600000
H(IN FUEL)/U235 (NUMBER DENSITIES) =    46.38991
H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    191.3425
C(IN REFL + CLAD)/U235 (NUMBER DENSITIES) =    31.20994
 BIAS (H/U-235 =  191.342453 ) =     0.002861

    ****CASE           11 ****
WATER WEIGHT FRACTION =  0.2500000
U235 MASS PER ELEMENT =   174.1429     GRAMS
TOTAL U235 MASS=   1219.000     GRAMS
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NUMBER OF FUEL ELEMENTS =   7.000000
FUEL OUTER RADIUS =   1.822450    CM   OR   0.7175000     INCHES
CLAD OUTER RADIUS =   1.873250    CM  OR   0.7375000     INCHES
FUEL ELEMENT LENGTH =   38.10000    CM OR    15.00000     INCHES
TOTAL CLAD LENGTH =   55.37200    CM OR    21.80000     INCHES

FUEL DENSITY =   5.654033     G.CC
MIXTURE DENSITY =   2.492915     G/CC
COLHEIGHT=   175.2377     CM

                      VOLUME(CC)        MASS(G)     DENSITY (G/CC)
 CENTRAL ZR ROD          84.462        549.002         6.500
 END REFLECTORS        1200.754       1921.206         1.600
 UZRH FUEL             2698.352      15256.570         5.654

  U235 MASS (FUEL)                     1219.000
  U238 MASS (FUEL)                       77.808
U235 + U238 (FUEL)                     1296.808
    ZR MASS (FUEL)                    13717.261
   H16 MASS (FUEL)                      242.501
  ZRH MASS (FUEL)                    13959.762

 CLAD + END FITS        712.683       5577.848         7.827
 WATER ONLY            7768.209       7768.209         1.000

 TOTAL(FUEL+WATER)    12464.460      31072.836         2.493

     1  5.3324651E-02
    16  2.0850459E-02
   401  7.7476581E-03
    12  7.8201490E-03
    14  9.6842465E-05
    24  9.4160571E-04
    26  3.4506342E-03
    28  3.7117751E-04
    55  9.9020188E-05
  2381  1.5791540E-05
  2351  2.5056594E-04
H/ZR (NUMBER DENSITIES IN FUEL) =    1.600000
H(IN FUEL)/U235 (NUMBER DENSITIES) =    46.38991
H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    212.8168
C(IN REFL + CLAD)/U235 (NUMBER DENSITIES) =    31.20994
 BIAS (H/U-235 =  212.816849 ) =     0.003203

    ****CASE           12 ****
WATER WEIGHT FRACTION =  0.2750000
U235 MASS PER ELEMENT =   174.1429     GRAMS
TOTAL U235 MASS=   1219.000     GRAMS
NUMBER OF FUEL ELEMENTS =   7.000000
FUEL OUTER RADIUS =   1.822450    CM   OR   0.7175000     INCHES
CLAD OUTER RADIUS =   1.873250    CM  OR   0.7375000     INCHES
FUEL ELEMENT LENGTH =   38.10000    CM OR    15.00000     INCHES
TOTAL CLAD LENGTH =   55.37200    CM OR    21.80000     INCHES

FUEL DENSITY =   5.654033     G.CC
MIXTURE DENSITY =   2.374739     G/CC
COLHEIGHT=   190.3015     CM

                      VOLUME(CC)        MASS(G)     DENSITY (G/CC)
 CENTRAL ZR ROD          84.462        549.002         6.500
 END REFLECTORS        1200.754       1921.206         1.600
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 UZRH FUEL                2698.352      15256.570          5.654

  U235 MASS (FUEL)                       1219.000
  U238 MASS (FUEL)                         77.808
U235 + U238 (FUEL)                       1296.808
    ZR MASS (FUEL)                      13717.261
   H16 MASS (FUEL)                        242.501
  ZRH MASS (FUEL)                       13959.762

 CLAD + END FITS           712.683       5577.848          7.827
 WATER ONLY               8839.686       8839.686          1.000

 TOTAL(FUEL+WATER)       13535.937      32144.313          2.375

     1  5.4400127E-02
    16  2.1848254E-02
   401  7.1343696E-03
    12  7.2011217E-03
    14  8.9176618E-05
    24  8.6707016E-04
    26  3.1774892E-03
    28  3.4179588E-04
    55  9.1181952E-05
  2381  1.4541515E-05
  2351  2.3073165E-04
H/ZR (NUMBER DENSITIES IN FUEL) =     1.600000
H(IN FUEL)/U235 (NUMBER DENSITIES) =     46.38991
H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =     235.7723
C(IN REFL + CLAD)/U235 (NUMBER DENSITIES) =     31.20994
 BIAS (H/U-235 =  235.772278 ) =      0.003560

    ****CASE            13 ****
WATER WEIGHT FRACTION =  0.3000000
U235 MASS PER ELEMENT =   174.1429      GRAMS
TOTAL U235 MASS=   1219.000      GRAMS
NUMBER OF FUEL ELEMENTS =   7.000000
FUEL OUTER RADIUS =   1.822450    CM   OR   0.7175000      INCHES
CLAD OUTER RADIUS =   1.873250    CM  OR   0.7375000      INCHES
FUEL ELEMENT LENGTH =   38.10000    CM OR    15.00000      INCHES
TOTAL CLAD LENGTH =   55.37200    CM OR    21.80000      INCHES

FUEL DENSITY =   5.654033      G.CC
MIXTURE DENSITY =   2.267260      G/CC
COLHEIGHT=   206.4414      CM

                         VOLUME(CC)        MASS(G)      DENSITY (G/CC)
 CENTRAL ZR ROD             84.462        549.002          6.500
 END REFLECTORS           1200.754       1921.206          1.600
 UZRH FUEL                2698.352      15256.570          5.654

  U235 MASS (FUEL)                       1219.000
  U238 MASS (FUEL)                         77.808
U235 + U238 (FUEL)                       1296.808
    ZR MASS (FUEL)                      13717.261
   H16 MASS (FUEL)                        242.501
  ZRH MASS (FUEL)                       13959.762

 CLAD + END FITS           712.683       5577.848          7.827
 WATER ONLY               9987.697       9987.697          1.000

 TOTAL(FUEL+WATER)       14683.948      33292.324          2.267
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```
     1  5.5378255E-02
    16  2.2755729E-02
   401  6.5765944E-03
    12  6.6381278E-03
    14  8.2204664E-05
    24  7.9928141E-04
    26  2.9290686E-03
    28  3.1507379E-04
    55  8.4053223E-05
  2381  1.3404640E-05
  2351  2.1269273E-04
H/ZR (NUMBER DENSITIES IN FUEL) =    1.600000
H(IN FUEL)/U235 (NUMBER DENSITIES) =    46.38991
H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    260.3674
C(IN REFL + CLAD)/U235 (NUMBER DENSITIES) =    31.20994
 BIAS (H/U-235 =  260.367401 ) =     0.003929

    ****CASE           14 ****
WATER WEIGHT FRACTION =  0.3250000
U235 MASS PER ELEMENT =   174.1429     GRAMS
TOTAL U235 MASS=   1219.000     GRAMS
NUMBER OF FUEL ELEMENTS =   7.000000
FUEL OUTER RADIUS =   1.822450    CM   OR   0.7175000     INCHES
CLAD OUTER RADIUS =   1.873250    CM  OR   0.7375000     INCHES
FUEL ELEMENT LENGTH =   38.10000    CM OR    15.00000     INCHES
TOTAL CLAD LENGTH =   55.37200    CM OR    21.80000     INCHES

FUEL DENSITY =   5.654033     G.CC
MIXTURE DENSITY =   2.169089     G/CC
COLHEIGHT=   223.7768     CM

                      VOLUME(CC)        MASS(G)     DENSITY (G/CC)
 CENTRAL ZR ROD          84.462        549.002         6.500
 END REFLECTORS        1200.754       1921.206         1.600
 UZRH FUEL             2698.352      15256.570         5.654

  U235 MASS (FUEL)                     1219.000
  U238 MASS (FUEL)                       77.808
U235 + U238 (FUEL)                     1296.808
    ZR MASS (FUEL)                    13717.261
   H16 MASS (FUEL)                      242.501
  ZRH MASS (FUEL)                     13959.762

 CLAD + END FITS         712.683       5577.848         7.827
 WATER ONLY            11220.744      11220.744         1.000

 TOTAL(FUEL+WATER)     15916.995      34525.371         2.169

     1  5.6271672E-02
    16  2.3584615E-02
   401  6.0671233E-03
    12  6.1238897E-03
    14  7.5836491E-05
    24  7.3736318E-04
    26  2.7021614E-03
    28  2.9066586E-04
    55  7.7541845E-05
  2381  1.2366218E-05
  2351  1.9621599E-04
H/ZR (NUMBER DENSITIES IN FUEL) =    1.600000
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H(IN FUEL)/U235 (NUMBER DENSITIES) =    46.38991
H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    286.7843
C(IN REFL + CLAD)/U235 (NUMBER DENSITIES) =    31.20994
 BIAS (H/U-235 =  286.784332 ) =     0.004313

    ****CASE           15 ****
WATER WEIGHT FRACTION =  0.3500000
U235 MASS PER ELEMENT =   174.1429     GRAMS
TOTAL U235 MASS=   1219.000     GRAMS
NUMBER OF FUEL ELEMENTS =   7.000000
FUEL OUTER RADIUS =   1.822450    CM   OR   0.7175000     INCHES
CLAD OUTER RADIUS =   1.873250    CM  OR   0.7375000     INCHES
FUEL ELEMENT LENGTH =   38.10000    CM OR    15.00000     INCHES
TOTAL CLAD LENGTH =   55.37200    CM OR    21.80000     INCHES

FUEL DENSITY =   5.654033     G.CC
MIXTURE DENSITY =   2.079066     G/CC
COLHEIGHT=   242.4457     CM

                      VOLUME(CC)        MASS(G)     DENSITY (G/CC)
 CENTRAL ZR ROD           84.462       549.002         6.500
 END REFLECTORS         1200.754      1921.206         1.600
 UZRH FUEL              2698.352     15256.570         5.654

  U235 MASS (FUEL)                     1219.000
  U238 MASS (FUEL)                       77.808
U235 + U238 (FUEL)                     1296.808
    ZR MASS (FUEL)                    13717.261
   H16 MASS (FUEL)                      242.501
  ZRH MASS (FUEL)                    13959.762

 CLAD + END FITS         712.683      5577.848         7.827
 WATER ONLY            12548.643     12548.643         1.000

 TOTAL(FUEL+WATER)     17244.893     35853.270         2.079

     1  5.7090938E-02
    16  2.4344703E-02
   401  5.5999407E-03
    12  5.6523364E-03
    14  6.9996902E-05
    24  6.8058452E-04
    26  2.4940886E-03
    28  2.6828391E-04
    55  7.1570939E-05
  2381  1.1413990E-05
  2351  1.8110689E-04
H/ZR (NUMBER DENSITIES IN FUEL) =    1.600000
H(IN FUEL)/U235 (NUMBER DENSITIES) =    46.38991
H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    315.2334
C(IN REFL + CLAD)/U235 (NUMBER DENSITIES) =    31.20995
 BIAS (H/U-235 =  315.233368 ) =     0.004711

    ****CASE           16 ****
WATER WEIGHT FRACTION =  0.3750000
U235 MASS PER ELEMENT =   174.1429     GRAMS
TOTAL U235 MASS=   1219.000     GRAMS
NUMBER OF FUEL ELEMENTS =   7.000000
FUEL OUTER RADIUS =   1.822450    CM   OR   0.7175000     INCHES
CLAD OUTER RADIUS =   1.873250    CM  OR   0.7375000     INCHES
FUEL ELEMENT LENGTH =   38.10000    CM OR    15.00000     INCHES
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TOTAL CLAD LENGTH =   55.37200    CM OR    21.80000     INCHES

FUEL DENSITY =   5.654033     G.CC
MIXTURE DENSITY =   1.996218     G/CC
COLHEIGHT=   262.6081     CM

                        VOLUME(CC)        MASS(G)     DENSITY (G/CC)
 CENTRAL ZR ROD            84.462        549.002         6.500
 END REFLECTORS          1200.754       1921.206         1.600
 UZRH FUEL               2698.352      15256.570         5.654

  U235 MASS (FUEL)                      1219.000
  U238 MASS (FUEL)                        77.808
U235 + U238 (FUEL)                      1296.808
    ZR MASS (FUEL)                     13717.261
   H16 MASS (FUEL)                       242.501
  ZRH MASS (FUEL)                      13959.762

 CLAD + END FITS          712.683       5577.848         7.827
 WATER ONLY             13982.775      13982.775         1.000

 TOTAL(FUEL+WATER)      18679.025      37287.402         1.996

     1  5.7844907E-02
    16  2.5044212E-02
   401  5.1699900E-03
    12  5.2183624E-03
    14  6.4622698E-05
    24  6.2833080E-04
    26  2.3025982E-03
    28  2.4768570E-04
    55  6.6075889E-05
  2381  1.0537650E-05
  2351  1.6720193E-04
H/ZR (NUMBER DENSITIES IN FUEL) =    1.600000
H(IN FUEL)/U235 (NUMBER DENSITIES) =    46.38991
H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    345.9584
C(IN REFL + CLAD)/U235 (NUMBER DENSITIES) =    31.20994
 BIAS (H/U-235 =  345.958374 ) =     0.005122

    ****CASE           17 ****
WATER WEIGHT FRACTION =  0.4000000
U235 MASS PER ELEMENT =   174.1429     GRAMS
TOTAL U235 MASS=   1219.000     GRAMS
NUMBER OF FUEL ELEMENTS =   7.000000
FUEL OUTER RADIUS =   1.822450    CM   OR   0.7175000     INCHES
CLAD OUTER RADIUS =   1.873250    CM  OR   0.7375000     INCHES
FUEL ELEMENT LENGTH =   38.10000    CM OR    15.00000     INCHES
TOTAL CLAD LENGTH =   55.37200    CM OR    21.80000     INCHES

FUEL DENSITY =   5.654033     G.CC
MIXTURE DENSITY =   1.919719     G/CC
COLHEIGHT=   284.4507     CM

                        VOLUME(CC)        MASS(G)     DENSITY (G/CC)
 CENTRAL ZR ROD            84.462        549.002         6.500
 END REFLECTORS          1200.754       1921.206         1.600
 UZRH FUEL               2698.352      15256.570         5.654

  U235 MASS (FUEL)                      1219.000
  U238 MASS (FUEL)                        77.808
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U235 + U238 (FUEL)                    1296.808
    ZR MASS (FUEL)                   13717.261
   H16 MASS (FUEL)                     242.501
  ZRH MASS (FUEL)                    13959.762

 CLAD + END FITS          712.683     5577.848          7.827
 WATER ONLY             15536.416    15536.416          1.000

 TOTAL(FUEL+WATER)      20232.666    38841.043          1.920

     1  5.8541093E-02
    16  2.5690110E-02
   401  4.7729928E-03
    12  4.8176511E-03
    14  5.9660404E-05
    24  5.8008207E-04
    26  2.1257848E-03
    28  2.2866622E-04
    55  6.1002003E-05
  2381  9.7284774E-06
  2351  1.5436270E-04
H/ZR (NUMBER DENSITIES IN FUEL) =    1.600000
H(IN FUEL)/U235 (NUMBER DENSITIES) =    46.38991
H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    379.2438
C(IN REFL + CLAD)/U235 (NUMBER DENSITIES) =    31.20994
 BIAS (H/U-235 =  379.243774 ) =     0.005547

    ****CASE            18 ****
WATER WEIGHT FRACTION =  0.4250000
U235 MASS PER ELEMENT =   174.1429     GRAMS
TOTAL U235 MASS=   1219.000     GRAMS
NUMBER OF FUEL ELEMENTS =   7.000000
FUEL OUTER RADIUS =   1.822450    CM   OR   0.7175000     INCHES
CLAD OUTER RADIUS =   1.873250    CM  OR   0.7375000     INCHES
FUEL ELEMENT LENGTH =   38.10000    CM OR    15.00000     INCHES
TOTAL CLAD LENGTH =   55.37200    CM OR    21.80000     INCHES

FUEL DENSITY =   5.654033     G.CC
MIXTURE DENSITY =   1.848868     G/CC
COLHEIGHT=   308.1927     CM

                       VOLUME(CC)        MASS(G)     DENSITY (G/CC)
 CENTRAL ZR ROD           84.462       549.002          6.500
 END REFLECTORS         1200.754      1921.206          1.600
 UZRH FUEL              2698.352     15256.570          5.654

  U235 MASS (FUEL)                     1219.000
  U238 MASS (FUEL)                       77.808
U235 + U238 (FUEL)                     1296.808
    ZR MASS (FUEL)                    13717.261
   H16 MASS (FUEL)                      242.501
  ZRH MASS (FUEL)                    13959.762

 CLAD + END FITS          712.683     5577.848          7.827
 WATER ONLY             17225.158    17225.158          1.000

 TOTAL(FUEL+WATER)      21921.408    40529.785          1.849

     1  5.9185889E-02
    16  2.6288331E-02
   401  4.4052997E-03
```

```
    12  4.4465177E-03
    14  5.5064393E-05
    24  5.3539476E-04
    26  1.9620224E-03
    28  2.1105065E-04
    55  5.6302641E-05
  2381  8.9790319E-06
  2351  1.4247118E-04
H/ZR (NUMBER DENSITIES IN FUEL) =     1.600000
H(IN FUEL)/U235 (NUMBER DENSITIES) =     46.38991
H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =     415.4236
C(IN REFL + CLAD)/U235 (NUMBER DENSITIES) =     31.20994
 BIAS (H/U-235 =  415.423584 ) =     0.005983

    ****CASE           19 ****
WATER WEIGHT FRACTION =  0.4500000
U235 MASS PER ELEMENT =   174.1429     GRAMS
TOTAL U235 MASS=   1219.000     GRAMS
NUMBER OF FUEL ELEMENTS =   7.000000
FUEL OUTER RADIUS =   1.822450    CM   OR   0.7175000     INCHES
CLAD OUTER RADIUS =   1.873250    CM  OR   0.7375000     INCHES
FUEL ELEMENT LENGTH =   38.10000    CM OR    15.00000     INCHES
TOTAL CLAD LENGTH =   55.37200    CM OR    21.80000     INCHES

FUEL DENSITY =   5.654033     G.CC
MIXTURE DENSITY =   1.783060     G/CC
COLHEIGHT=   334.0931     CM

                        VOLUME(CC)        MASS(G)     DENSITY (G/CC)
 CENTRAL ZR ROD            84.462        549.002         6.500
 END REFLECTORS          1200.754       1921.206         1.600
 UZRH FUEL               2698.352      15256.570         5.654

  U235 MASS (FUEL)                      1219.000
  U238 MASS (FUEL)                        77.808
U235 + U238 (FUEL)                      1296.808
    ZR MASS (FUEL)                     13717.261
   H16 MASS (FUEL)                       242.501
  ZRH MASS (FUEL)                      13959.762

 CLAD + END FITS          712.683       5577.848         7.827
 WATER ONLY             19067.420      19067.420         1.000

 TOTAL(FUEL+WATER)      23763.670      42372.047         1.783

     1  5.9784777E-02
    16  2.6843963E-02
   401  4.0637818E-03
    12  4.1018045E-03
    14  5.0795566E-05
    24  4.9388863E-04
    26  1.8099180E-03
    28  1.9468908E-04
    55  5.1937815E-05
  2381  8.2829392E-06
  2351  1.3142620E-04
H/ZR (NUMBER DENSITIES IN FUEL) =     1.600000
H(IN FUEL)/U235 (NUMBER DENSITIES) =     46.38991
H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =     454.8924
C(IN REFL + CLAD)/U235 (NUMBER DENSITIES) =     31.20994
 BIAS (H/U-235 =  454.892365 ) =     0.006429
```

```
    ****CASE            20 ****
WATER WEIGHT FRACTION =  0.4750000
U235 MASS PER ELEMENT =   174.1429     GRAMS
TOTAL U235 MASS=   1219.000     GRAMS
NUMBER OF FUEL ELEMENTS =   7.000000
FUEL OUTER RADIUS =   1.822450    CM   OR   0.7175000     INCHES
CLAD OUTER RADIUS =   1.873250    CM  OR   0.7375000     INCHES
FUEL ELEMENT LENGTH =   38.10000    CM OR    15.00000     INCHES
TOTAL CLAD LENGTH =   55.37200    CM OR    21.80000     INCHES

FUEL DENSITY =   5.654033     G.CC
MIXTURE DENSITY =   1.721776     G/CC
COLHEIGHT=   362.4601     CM

                      VOLUME(CC)        MASS(G)     DENSITY (G/CC)
 CENTRAL ZR ROD          84.462        549.002         6.500
 END REFLECTORS        1200.754       1921.206         1.600
 UZRH FUEL             2698.352      15256.570         5.654

  U235 MASS (FUEL)                     1219.000
  U238 MASS (FUEL)                       77.808
U235 + U238 (FUEL)                     1296.808
    ZR MASS (FUEL)                    13717.261
   H16 MASS (FUEL)                      242.501
  ZRH MASS (FUEL)                     13959.762

 CLAD + END FITS         712.683       5577.848         7.827
 WATER ONLY            21085.135      21085.135         1.000

 TOTAL(FUEL+WATER)     25781.385      44389.762         1.722

     1  6.0342502E-02
    16  2.7361402E-02
   401  3.7457403E-03
    12  3.7807871E-03
    14  4.6820180E-05
    24  4.5523568E-04
    26  1.6682693E-03
    28  1.7945224E-04
    55  4.7873036E-05
  2381  7.6346960E-06
  2351  1.2114047E-04
H/ZR (NUMBER DENSITIES IN FUEL) =    1.600000
H(IN FUEL)/U235 (NUMBER DENSITIES) =    46.38991
H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    498.1201
C(IN REFL + CLAD)/U235 (NUMBER DENSITIES) =    31.20994
 BIAS (H/U-235 =  498.120117 ) =     0.006881

    ****CASE            21 ****
WATER WEIGHT FRACTION =  0.5000000
U235 MASS PER ELEMENT =   174.1429     GRAMS
TOTAL U235 MASS=   1219.000     GRAMS
NUMBER OF FUEL ELEMENTS =   7.000000
FUEL OUTER RADIUS =   1.822450    CM   OR   0.7175000     INCHES
CLAD OUTER RADIUS =   1.873250    CM  OR   0.7375000     INCHES
FUEL ELEMENT LENGTH =   38.10000    CM OR    15.00000     INCHES
TOTAL CLAD LENGTH =   55.37200    CM OR    21.80000     INCHES

FUEL DENSITY =   5.654033     G.CC
MIXTURE DENSITY =   1.664564     G/CC
```

```
COLHEIGHT=   393.6639     CM

                        VOLUME(CC)        MASS(G)     DENSITY (G/CC)
 CENTRAL ZR ROD            84.462        549.002         6.500
 END REFLECTORS          1200.754       1921.206         1.600
 UZRH FUEL               2698.352      15256.570         5.654

  U235 MASS (FUEL)                      1219.000
  U238 MASS (FUEL)                        77.808
U235 + U238 (FUEL)                      1296.808
    ZR MASS (FUEL)                     13717.261
   H16 MASS (FUEL)                       242.501
  ZRH MASS (FUEL)                      13959.762

 CLAD + END FITS          712.683       5577.848         7.827
 WATER ONLY             23304.627      23304.627         1.000

 TOTAL(FUEL+WATER)      28000.877      46609.254         1.665

     1  6.0863160E-02
    16  2.7844455E-02
   401  3.4488339E-03
    12  3.4811026E-03
    14  4.3108972E-05
    24  4.1915139E-04
    26  1.5360337E-03
    28  1.6522795E-04
    55  4.4078373E-05
  2381  7.0295309E-06
  2351  1.1153825E-04
H/ZR (NUMBER DENSITIES IN FUEL) =    1.600000
H(IN FUEL)/U235 (NUMBER DENSITIES) =    46.38991
H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    545.6707
C(IN REFL + CLAD)/U235 (NUMBER DENSITIES) =    31.20994
 BIAS (H/U-235 =  545.670715 ) =     0.007336

    ****CASE           22 ****
WATER WEIGHT FRACTION =  0.5250000
U235 MASS PER ELEMENT =   174.1429     GRAMS
TOTAL U235 MASS=   1219.000     GRAMS
NUMBER OF FUEL ELEMENTS =   7.000000
FUEL OUTER RADIUS =   1.822450    CM   OR   0.7175000     INCHES
CLAD OUTER RADIUS =   1.873250    CM  OR   0.7375000     INCHES
FUEL ELEMENT LENGTH =   38.10000    CM OR    15.00000     INCHES
TOTAL CLAD LENGTH =   55.37200    CM OR    21.80000     INCHES

FUEL DENSITY =   5.654033     G.CC
MIXTURE DENSITY =   1.611032     G/CC
COLHEIGHT=   428.1523     CM

                        VOLUME(CC)        MASS(G)     DENSITY (G/CC)
 CENTRAL ZR ROD            84.462        549.002         6.500
 END REFLECTORS          1200.754       1921.206         1.600
 UZRH FUEL               2698.352      15256.570         5.654

  U235 MASS (FUEL)                      1219.000
  U238 MASS (FUEL)                        77.808
U235 + U238 (FUEL)                      1296.808
    ZR MASS (FUEL)                     13717.261
   H16 MASS (FUEL)                       242.501
  ZRH MASS (FUEL)                      13959.762
```

```
 CLAD + END FITS          712.683      5577.848          7.827
 WATER ONLY             25757.748     25757.748          1.000

 TOTAL(FUEL+WATER)      30453.998     49062.375          1.611

     1  6.1350338E-02
    16  2.8296441E-02
   401  3.1710246E-03
    12  3.2006940E-03
    14  3.9636474E-05
    24  3.8538803E-04
    26  1.4123037E-03
    28  1.5191855E-04
    55  4.0527786E-05
  2381  6.4632904E-06
  2351  1.0255366E-04
H/ZR (NUMBER DENSITIES IN FUEL) =    1.600000
H(IN FUEL)/U235 (NUMBER DENSITIES) =    46.38991
H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    598.2267
C(IN REFL + CLAD)/U235 (NUMBER DENSITIES) =    31.20994
 BIAS (H/U-235 =  598.226685 ) =     0.007786

    ****CASE           23 ****
WATER WEIGHT FRACTION =  0.5500000
U235 MASS PER ELEMENT =   174.1429     GRAMS
TOTAL U235 MASS=   1219.000     GRAMS
NUMBER OF FUEL ELEMENTS =   7.000000
FUEL OUTER RADIUS =   1.822450    CM   OR   0.7175000     INCHES
CLAD OUTER RADIUS =   1.873250    CM  OR   0.7375000     INCHES
FUEL ELEMENT LENGTH =   38.10000    CM OR    15.00000     INCHES
TOTAL CLAD LENGTH =   55.37200    CM OR    21.80000     INCHES

FUEL DENSITY =   5.654033     G.CC
MIXTURE DENSITY =   1.560836     G/CC
COLHEIGHT=   466.4727     CM

                       VOLUME(CC)        MASS(G)     DENSITY (G/CC)
 CENTRAL ZR ROD           84.462       549.002          6.500
 END REFLECTORS         1200.754      1921.206          1.600
 UZRH FUEL              2698.352     15256.570          5.654

  U235 MASS (FUEL)                     1219.000
  U238 MASS (FUEL)                       77.808
U235 + U238 (FUEL)                     1296.808
    ZR MASS (FUEL)                    13717.261
   H16 MASS (FUEL)                      242.501
  ZRH MASS (FUEL)                    13959.762

 CLAD + END FITS          712.683      5577.848          7.827
 WATER ONLY             28483.436     28483.436          1.000

 TOTAL(FUEL+WATER)      33179.688     51788.063          1.561

     1  6.1807144E-02
    16  2.8720256E-02
   401  2.9105267E-03
    12  2.9377590E-03
    14  3.6380363E-05
    24  3.5372865E-04
    26  1.2962838E-03
```

```
    28  1.3943855E-04
    55  3.7198457E-05
  2381  5.9323352E-06
  2351  9.4128947E-05
H/ZR (NUMBER DENSITIES IN FUEL) =    1.600000
H(IN FUEL)/U235 (NUMBER DENSITIES) =    46.38991
H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    656.6221
C(IN REFL + CLAD)/U235 (NUMBER DENSITIES) =    31.20994
 BIAS (H/U-235 =  656.622070 ) =     0.008221

    ****CASE           24 ****
WATER WEIGHT FRACTION =  0.5750000
U235 MASS PER ELEMENT =   174.1429     GRAMS
TOTAL U235 MASS=   1219.000     GRAMS
NUMBER OF FUEL ELEMENTS =   7.000000
FUEL OUTER RADIUS =   1.822450    CM   OR   0.7175000     INCHES
CLAD OUTER RADIUS =   1.873250    CM  OR   0.7375000     INCHES
FUEL ELEMENT LENGTH =   38.10000    CM OR    15.00000     INCHES
TOTAL CLAD LENGTH =   55.37200    CM OR    21.80000     INCHES

FUEL DENSITY =   5.654033     G.CC
MIXTURE DENSITY =   1.513674     G/CC
COLHEIGHT=   509.3013     CM

                      VOLUME(CC)        MASS(G)     DENSITY (G/CC)
 CENTRAL ZR ROD          84.462        549.002         6.500
 END REFLECTORS        1200.754       1921.206         1.600
 UZRH FUEL             2698.352      15256.570         5.654

  U235 MASS (FUEL)                     1219.000
  U238 MASS (FUEL)                       77.808
U235 + U238 (FUEL)                     1296.808
    ZR MASS (FUEL)                    13717.261
   H16 MASS (FUEL)                      242.501
  ZRH MASS (FUEL)                     13959.762

 CLAD + END FITS         712.683       5577.848         7.827
 WATER ONLY            31529.787      31529.787         1.000

 TOTAL(FUEL+WATER)     36226.039      54834.414         1.514

     1  6.2236346E-02
    16  2.9118458E-02
   401  2.6657723E-03
    12  2.6907146E-03
    14  3.3321034E-05
    24  3.2398262E-04
    26  1.1872756E-03
    28  1.2771276E-04
    55  3.4070330E-05
  2381  5.4334682E-06
  2351  8.6213367E-05
H/ZR (NUMBER DENSITIES IN FUEL) =    1.600000
H(IN FUEL)/U235 (NUMBER DENSITIES) =    46.38992
H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    721.8875
C(IN REFL + CLAD)/U235 (NUMBER DENSITIES) =    31.20995
 BIAS (H/U-235 =  721.887451 ) =     0.008627
```

6.7.2.3 Case VIII Fuel

6.7.2.3.1 GEMER Input Decks

This Appendix includes GEMER geometrical plots and input listings for the single container, normal array, accident array, and infinite array for the TRIGA Case VIII fuel. Each basedeck contains a "header" with fuel material and geometry information. Since the program input is similar to the popular KENO program (and deviations from this were discussed previously) no further explanation of the inputs are provided.

6.7.2.3.1.1 Normal (93% Enriched TRIGA Case VIII Fuel)

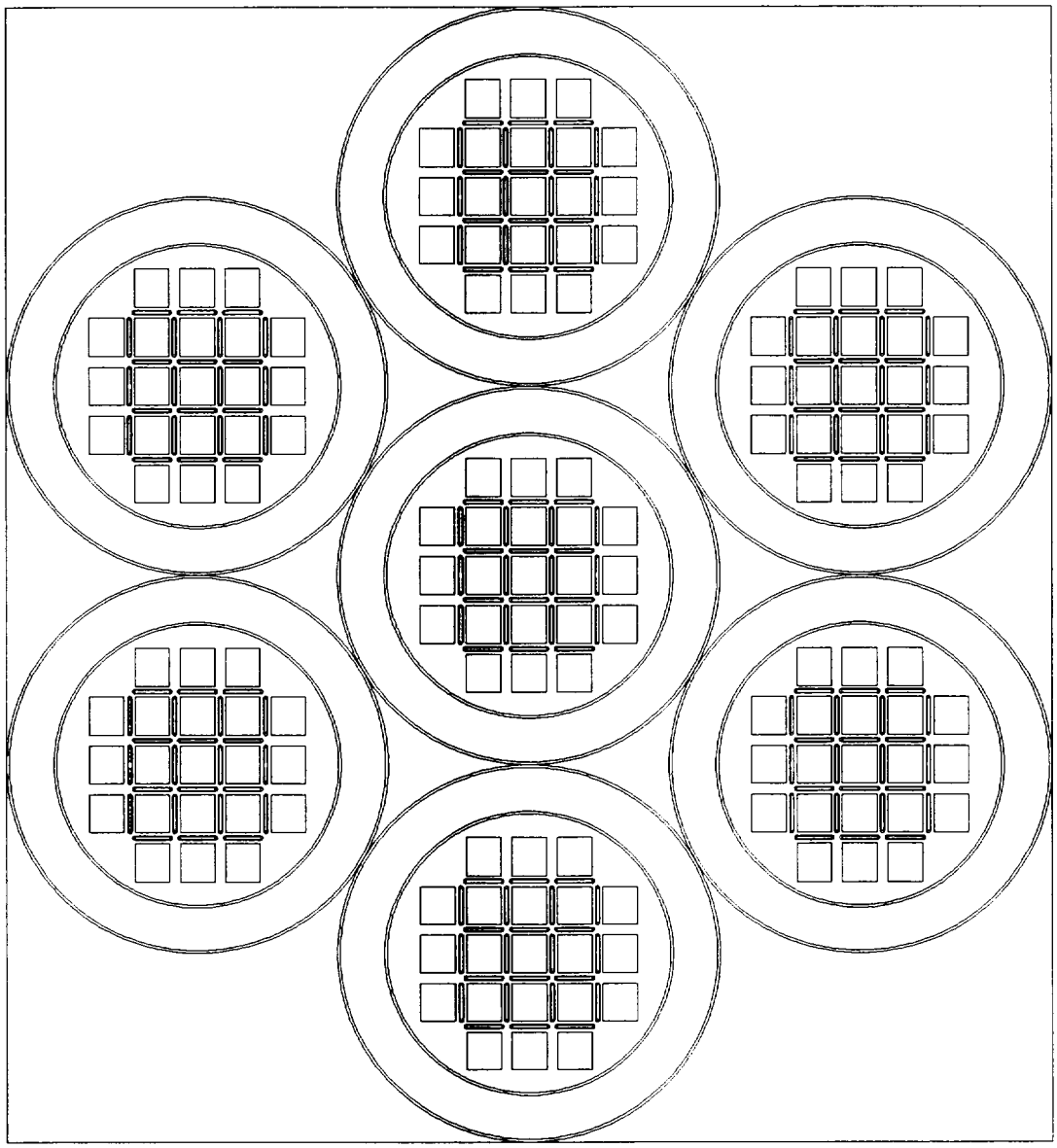

Figure 6.32. Normal Container for TRIGA Case VIII Fuel — Top View

```
NBSR FUEL/ IF2000/21 ELEMENTS, SS+Pb SHIELDING. WFH2O IN FUEL=0.05. 12
FUEL ELEMENTS, 493.92 G U235
    65 /* # BATCHES
  1000  /* # NEUTRONS PER BATCH
     5  /* # BATCHES TO SKIP
 2123469/* INITIAL "SEED" (IF NON-ZERO)
     0  /* "IDUMP"
     0  /* "NRSTRT"
```

```
      0  /* "NBTED" (NON-ZERO IS PRINT EDITS)
      0  /* "KRED" (NUMBER OF COMBINED REGIONS IN EDITS)
      0  293   14  7
      9  293 0  0 U(93%)3O8+0.05 WF -H2O RHOMIX=5.142578 g/cc     MAT 1
      1  4.7083944E-02
     16  8.6023863E-03
    401  1.8674480E-02
     55  1.8489466E-04
     24  4.1024731E-03
     28  5.5372729E-03
     26  8.3667198E-03
   2381  5.6644043E-05
   2351  7.6218374E-04
      3  293 0 0 Boral 0.25" Plate (60% Boron Loading)  MAT 2
     10   3.32658E-03
     11   6.7889E-05
    131   5.8001E-02
      2  293 0 0  MODERATOR IN CASK (5.00%)                    MAT 3
      1  3.34555656E-03
     16  1.67277878E-03
      2  293 0 0  INTERSPERSED MODERATOR (2.00%)            MAT4
      1  1.33822322E-03
     16  6.69112111E-04
      2  293 0 0 FULL DENSITY WATER                     MAT 5
      1   6.69111121E-02
     16   3.34555566E-02
      1  293 0 0 LEAD SHIELDING                         MAT 6
     82  3.29890E-02
      7  293 0 0 304 STAINLESS STEEL                    MAT 7
     12  6.82690E-05
     14  8.53360E-04
     24  1.53600E-02
     26  6.04950E-02
     28  6.82690E-03
     55  1.70670E-03
   1316  2.56010E-05
KENO GEOM
     14  /* "KREFM"
      6  /* "NBOX"
      1  /* "NBXMAX"
      1  /* "NBYMAX"
      1  /* "NBZMAX"
      0  /* "NXX"
      0  /* "NTYPST"
      1  /* "NEMBRG"
      0  /* "NGMCHK"
BOX TYPE      1 /*MODEL 2000 CASK & STAINLESS SUPPORT STRUCTURE
CYLINDER      7  33.34     140.64     0.0    16*0.5
CYLINDER      3  33.65     140.64     0.0    16*0.5
CYLINDER      7  35.85     140.64     0.0    16*0.5
CYLINDER      6  46.34     140.64     0.0    16*0.5
CYLINDER      7  48.56     140.64   -14.90   16*0.5
BOX TYPE      2 /* CASK TOP
CYLINDER      6  30.96     158.42    140.64  16*0.5
CYLINDER      7  48.56     162.23    140.64  16*0.5
BOX TYPE      3 /* NBSR FUEL ASSEMBLY-COLLAPSED
CUBOID        1  4.4450 -4.4450  4.0005  -4.0005  23.34225  0.0   16*0.5
CUBOID        3  4.4450 -4.4450  4.0005  -4.0005  140.64  0.0   16*0.5
BOX TYPE      4 /* BORAL PLATE (VERT)
CUBOID        2  0.286  -0.286  4.12  -4.12  138.64  2.0   16*0.5
BOX TYPE      5 /* BORAL PLATE (HORIZ)
```

```
CUBOID        2  4.12  -4.12  0.286  -0.286  138.64  2.0   16*0.5
BOX TYPE      6  /* OVERALL BOX FOR THE PROBLEM
CUBOID        4  146.80  -146.80  133.70  -133.70  162.30  -15.24  16*0.5
CORE          0  146.80  -146.80  133.70  -133.70  162.30  -15.24  16*0.5
CUBOID        5  177.30  -177.30  164.20  -164.20  192.80  -45.74  16*0.5
6  1 1 1  1 1 1  1 1 1  1
BEGIN COMPLEX
/* PLACE FUEL ASSEMBLIES INTO CASK
COMPLEX  1  3   -22.860  -10.540  0.0  5  3  1  11.430  10.540  0.0
/*MIDDLE ROWS
COMPLEX  1  3   -11.430  -21.080  0.0  3  2  1  11.430  42.160  0.0
/*OUTER ROWS
/* PLACE BORAL PLATES INTO CASK
COMPLEX  1  4   -17.145  -10.540  0.0  4  3  1  11.430  10.540  0.0
/*VERT PLATES
COMPLEX  1  5   -11.430  -15.810  0.0  3  4  1  11.430  10.540  0.0
/*HORIZ PLATES
/* PLACE 7 LOADED CASKS INTO OVERALL PROBLEM BOX
COMPLEX  6  1    -97.5    0.0    0.0   3 1 1   97.5    0.0   0.0
/*MIDDLE ROW
COMPLEX  6  1    -48.8  -84.4    0.0   2 2 1   97.5  168.9   0.0 /*OUTER
ROW
/* PLACE TOPS INTO OVERALL PROBLEM BOX
COMPLEX  6  2    -97.5    0.0    0.0   3 1 1   97.5    0.0   0.0
/*MIDDLE ROW
COMPLEX  6  2    -48.8  -84.4    0.0   2 2 1   97.5  168.9   0.0 /*OUTER
ROW
END GEOM
*END GEMER*
```

6.7.2.3.1.2 Single (93% Enriched TRIGA CASE VIII Fuel)

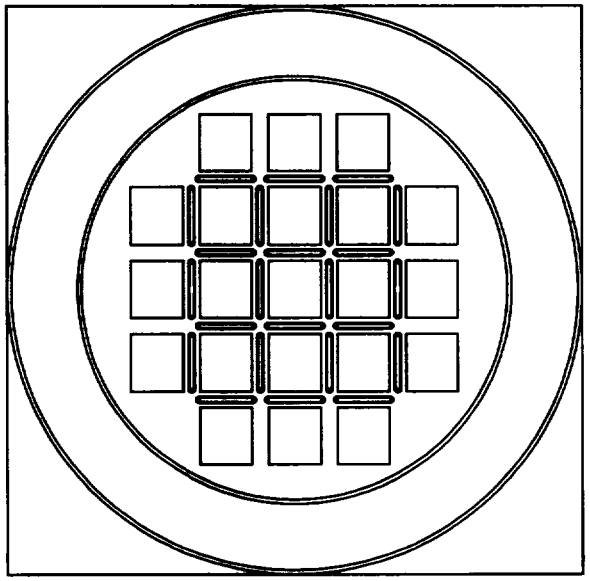

Figure 6.33. Single Container for TRIGA Case VIII Fuel — Top View

```
TRIGA FUEL/ IF2000/12 ELEMENTS, SS+Pb SHIELDING. WFH2O IN FUEL=0.20 MASS
U235=493.92 GRAMS
    65 /* # BATCHES
  1000  /* # NEUTRONS PER BATCH
    5  /* # BATCHES TO SKIP
 2123469/* INITIAL "SEED" (IF NON-ZERO)
     0  /* "IDUMP"
     0  /* "NRSTRT"
     0  /* "NBTED" (NON-ZERO IS PRINT EDITS)
     0  /* "KRED" (NUMBER OF COMBINED REGIONS IN EDITS)
     0  293   14  7
      9  293 0  0 U(93)ZRH+0.20 WF -H2O RHOMIX=3.109004 g/cc     MAT 1
      1  5.6817014E-02
     16  2.0802697E-02
    401  9.5072612E-03
     55  9.4130693E-05
     24  2.0885873E-03
     28  2.8190501E-03
     26  4.2595342E-03
   2381  2.8837732E-05
   2351  3.8803110E-04
      3  293 0 0 Boral 0.25" Plate (60% Boron Loading)  MAT 2
     10    3.32658E-03
     11    6.7889E-05
    131    5.8001E-02
      2  293 0 0  MODERATOR IN CASK (100.00%)                    MAT 3
      1  6.69111121E-02
     16  3.34555566E-02
      2  293 0 0  INTERSPERSED MODERATOR (100.00%)            MAT4
      1  6.69111121E-02
     16  3.34555566E-02
      2  293 0 0 FULL DENSITY WATER                    MAT 5
      1    6.69111121E-02
     16    3.34555566E-02
      1  293 0 0 LEAD SHIELDING                        MAT 6
     82  3.29890E-02
      7  293 0 0 304 STAINLESS STEEL                   MAT 7
     12  6.82690E-05
     14  8.53360E-04
     24  1.53600E-02
     26  6.04950E-02
     28  6.82690E-03
     55  1.70670E-03
   1316  2.56010E-05
KENO GEOM
     14  /* "KREFM"
      6  /* "NBOX"
      1  /* "NBXMAX"
      1  /* "NBYMAX"
      1  /* "NBZMAX"
      0  /* "NXX"
      0  /* "NTYPST"
      1  /* "NEMBRG"
      0  /* "NGMCHK"
BOX TYPE      1 /*MODEL 2000 CASK & STAINLESS SUPPORT STRUCTURE
CYLINDER      7  33.34     140.64     0.0    16*0.5
CYLINDER      3  33.65     140.64     0.0    16*0.5
CYLINDER      7  35.85     140.64     0.0    16*0.5
CYLINDER      6  46.34     140.64     0.0    16*0.5
CYLINDER      7  48.56     140.64   -14.90   16*0.5
BOX TYPE      2 /* CASK TOP
```

```
CYLINDER     6  30.96     158.42    140.64  16*0.5
CYLINDER     7  48.56     162.23    140.64  16*0.5
BOX TYPE     3 /* NBSR FUEL ASSEMBLY-COLLAPSED
CUBOID       1  4.4450 -4.4450  4.0005  -4.0005  45.84963  0.0   16*0.5
CUBOID       3  4.4450 -4.4450  4.0005  -4.0005  140.64  0.0   16*0.5
BOX TYPE     4 /* BORAL PLATE (VERT)
CUBOID       2  0.286  -0.286  4.12  -4.12  138.64  2.0   16*0.5
BOX TYPE     5 /* BORAL PLATE (HORIZ)
CUBOID       2  4.12  -4.12  0.286  -0.286  138.64  2.0   16*0.5
BOX TYPE     6  /* OVERALL BOX FOR THE PROBLEM
CUBOID       4  48.60    -48.60   48.60 -48.60 162.23 -15.24 16*0.5
CORE         0  48.60    -48.60   48.60 -48.60 162.23 -15.24 16*0.5
CUBOID       5  79.10    -79.10   79.10 -79.10 192.71 -45.72 16*0.5
6  1 1 1  1 1 1  1 1 1  1
BEGIN COMPLEX
/* PLACE FUEL ASSEMBLIES INTO CASK
COMPLEX  1  3   -22.860  -10.540  0.0  5  3  1  11.430  10.540  0.0
/*MIDDLE ROWS
COMPLEX  1  3   -11.430  -21.080  0.0  3  2  1  11.430  42.160  0.0
/*OUTER ROWS
/* PLACE BORAL PLATES INTO CASK
COMPLEX  1  4   -17.145  -10.540  0.0  4  3  1  11.430  10.540  0.0
/*VERT PLATES
COMPLEX  1  5   -11.430  -15.810  0.0  3  4  1  11.430  10.540  0.0
/*HORIZ PLATES
/* PLACE LOADED CASK INTO OVERALL PROBLEM BOX
COMPLEX  6  1  0.0     0.0    0.0   1 1 1   0.0    0.0    0.0
/* PLACE TOP INTO OVERALL PROBLEM BOX
COMPLEX  6  2  0.0     0.0    0.0   1 1 1   0.0    0.0    0.0
END GEOM
*END GEMER*
```

6.7.2.3.1.3 Accident (93% Enriched TRIGA Case VIII Fuel)

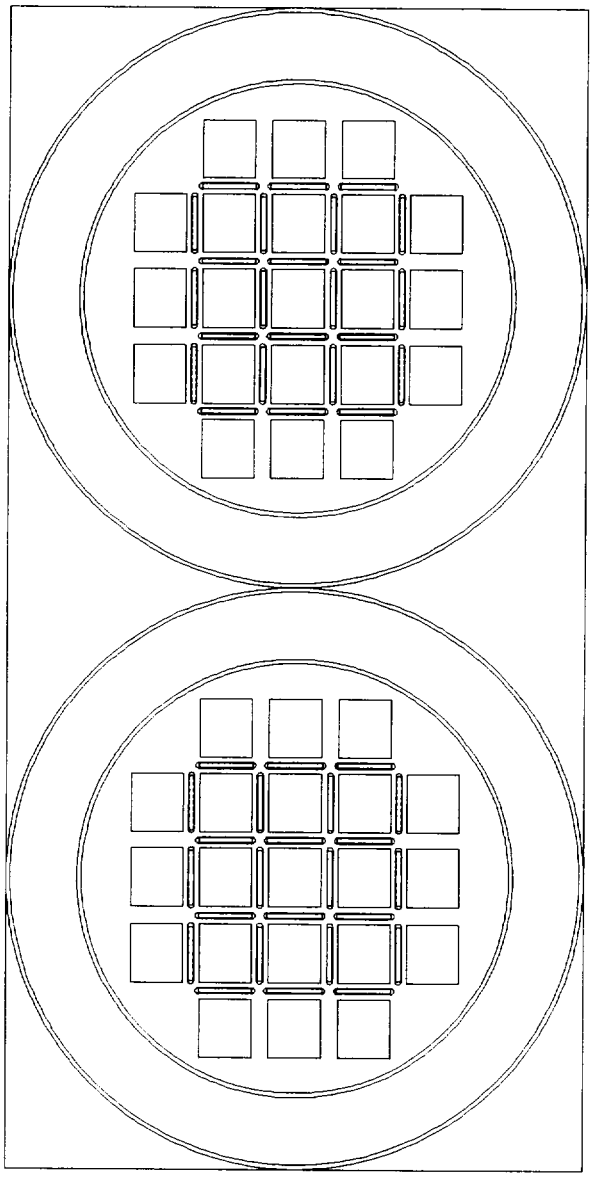

Figure 6.34. Accident Array for TRIGA Case VIII Fuel — Top View

```
TRIGA FUEL/ IF2000/ SS+Pb SHIELDING. WFH2O IN FUEL=0.20.  MASS U235 IN
12.0 ELEMENTS = 493.92 G
    65 /* # BATCHES
  1000  /* # NEUTRONS PER BATCH
    5  /* # BATCHES TO SKIP
 2123469/* INITIAL "SEED" (IF NON-ZERO)
     0  /* "IDUMP"
     0  /* "NRSTRT"
     0  /* "NBTED" (NON-ZERO IS PRINT EDITS)
     0  /* "KRED" (NUMBER OF COMBINED REGIONS IN EDITS)
     0  293   14  7
      9  293 0  0 U(93%)ZRH +0.20 WF -H2O RHOMIX=3.109004   MAT 1
      1  5.6817014E-02
     16  2.0802697E-02
    401  9.5072612E-03
     55  9.4130693E-05
     24  2.0885873E-03
     28  2.8190501E-03
     26  4.2595342E-03
   2381  2.8837732E-05
   2351  3.8803110E-04
      3  293 0 0 Boral 0.25" Plate (60% Boron Loading)  MAT 2
   10     3.32658E-03
   11     6.7889E-05
  131     5.8001E-02
     2  293 0 0  MODERATOR IN CASK (2.00%)                    MAT 3
     1   1.33822322E-03
    16   6.69112111E-04
     2  293 0 0  INTERSPERSED MODERATOR (2.00%)            MAT4
     1   1.33822322E-03
    16   6.69112111E-04
     2  293 0 0 FULL DENSITY WATER                     MAT 5
     1    6.69111121E-02
    16    3.34555566E-02
     1  293 0 0 LEAD SHIELDING                         MAT 6
    82   3.29890E-02
     7  293 0 0 304 STAINLESS STEEL                    MAT 7
    12   6.82690E-05
    14   8.53360E-04
    24   1.53600E-02
    26   6.04950E-02
    28   6.82690E-03
    55   1.70670E-03
  1316   2.56010E-05
KENO GEOM
    14  /* "KREFM"
     6  /* "NBOX"
     1  /* "NBXMAX"
     1  /* "NBYMAX"
     1  /* "NBZMAX"
     0  /* "NXX"
     0  /* "NTYPST"
     1  /* "NEMBRG"
     0  /* "NGMCHK"
BOX TYPE     1 /*MODEL 2000 CASK & STAINLESS SUPPORT STRUCTURE
CYLINDER     7  33.34     140.64     0.0    16*0.5
CYLINDER     3  33.65     140.64     0.0    16*0.5
CYLINDER     7  35.85     140.64     0.0    16*0.5
CYLINDER     6  46.34     140.64     0.0    16*0.5
CYLINDER     7  48.56     140.64   -14.90   16*0.5
BOX TYPE     2 /* CASK TOP
```

```
CYLINDER     6  30.96     158.42    140.64  16*0.5
CYLINDER     7  48.56     162.23    140.64  16*0.5
BOX TYPE     3 /* TRIGA FUEL ASSEMBLY-COLLAPSED
CUBOID       1  4.4450 -4.4450  4.0005  -4.0005  45.84963  0.0   16*0.5
CUBOID       3  4.4450 -4.4450  4.0005  -4.0005  140.64  0.0   16*0.5
BOX TYPE     4 /* BORAL PLATE (VERT)
CUBOID       2  0.286  -0.286  4.12  -4.12  138.64  2.0   16*0.5
BOX TYPE     5 /* BORAL PLATE (HORIZ)
CUBOID       2  4.12  -4.12  0.286  -0.286  138.64  2.0   16*0.5
BOX TYPE     6  /* OVERALL BOX FOR THE PROBLEM
CUBOID       4  97.20    -97.20   48.60 -48.60 162.23 -15.24 16*0.5
CORE         0  97.20    -97.20   48.60 -48.60 162.23 -15.24 16*0.5
CUBOID       5  127.70  -127.70   79.10 -79.10 192.73 -45.74 16*0.5
6  1 1 1  1 1 1  1 1 1  1
BEGIN COMPLEX
/* PLACE FUEL ASSEMBLIES INTO CASK
COMPLEX  1  3   -22.860  -10.540  0.0  5  3  1  11.430  10.540  0.0
/*MIDDLE ROWS
COMPLEX  1  3   -11.430  -21.080  0.0  3  2  1  11.430  42.160  0.0
/*OUTER ROWS
/* PLACE BORAL PLATES INTO CASK
COMPLEX  1  4   -17.145  -10.540  0.0  4  3  1  11.430  10.540  0.0
/*VERT PLATES
COMPLEX  1  5   -11.430  -15.810  0.0  3  4  1  11.430  10.540  0.0
/*HORIZ PLATES
/* PLACE 2 LOADED CASKS INTO OVERALL PROBLEM BOX
COMPLEX  6  1  -48.6     0.0    0.0   2 1 1   97.2    0.0    0.0
/* PLACE TOPS INTO OVERALL PROBLEM BOX
COMPLEX  6  2  -48.6     0.0    0.0   2 1 1   97.2    0.0    0.0
END GEOM
*END GEMER*
```

6.7.2.3.1.4 Infinite (94% Enriched TRIGA Case VIII Fuel)

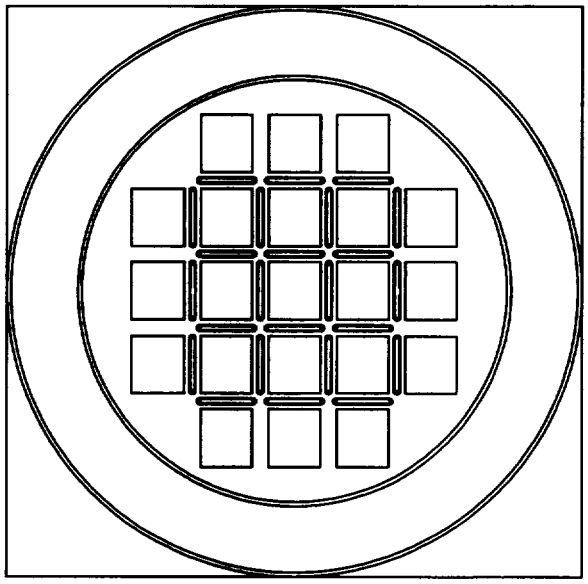

Figure 6.35. Unit Array for TRIGA Case VIII Fuel — Top View

```
TRIGA FUEL/ IF2000/12 ELEMENTS, SS+Pb SHIELDING. WFH2O IN FUEL=0.20 MASS
U235=493.92 GRAMS
   125 /* # BATCHES
  1000  /* # NEUTRONS PER BATCH
    5  /* # BATCHES TO SKIP
 2123469/* INITIAL "SEED" (IF NON-ZERO)
     0  /* "IDUMP"
     0  /* "NRSTRT"
     0  /* "NBTED" (NON-ZERO IS PRINT EDITS)
     0  /* "KRED" (NUMBER OF COMBINED REGIONS IN EDITS)
     0  293   14  8
      9  293 0  0 U(94)ZRH+0.20 WF -H2O RHOMIX= 3.100779 g/cc     MAT 1
      1  5.6610569E-02
     16  2.0747654E-02
    401  9.4470372E-03
     55  9.4540177E-05
     24  2.0976730E-03
     28  2.8313135E-03
     26  4.2780638E-03
   2381  2.4561485E-05
   2351  3.8971912E-04
      3  293 0 0 Boral 0.25" Plate (60% Boron Loading)  MAT 2
   10     3.32658E-03
   11     6.7889E-05
  131     5.8001E-02
      2  293 0 0  MODERATOR IN CASK (100.00%)                    MAT 3
    1    6.69111121E-02
   16    3.34555566E-02
      2  293 0 0  INTERSPERSED MODERATOR (100.00%)            MAT4
    1    6.69111121E-02
```

```
    16   3.34555566E-02
     2  293 0 0 FULL DENSITY WATER                    MAT 5
     1    6.69111121E-02
    16    3.34555566E-02
     1  293 0 0 LEAD SHIELDING                        MAT 6
    82   3.29890E-02
     7  293 0 0 304 STAINLESS STEEL                   MAT 7
    12   6.82690E-05
    14   8.53360E-04
    24   1.53600E-02
    26   6.04950E-02
    28   6.82690E-03
    55   1.70670E-03
  1316   2.56010E-05
     2  293 0 0 FULL DENSITY WATER (VOID)             MAT 8
     1    6.69111121E-09
    16    3.34555566E-09
KENO GEOM
    14  /* "KREFM"
     6  /* "NBOX"
     1  /* "NBXMAX"
     1  /* "NBYMAX"
     1  /* "NBZMAX"
     1  /* "NXX"
     0  /* "NTYPST"
     1  /* "NEMBRG"
     0  /* "NGMCHK"
  -1.0  -1.0  -1.0  -1.0  -1.0  -1.0
BOX TYPE     1 /*MODEL 2000 CASK & STAINLESS SUPPORT STRUCTURE
CYLINDER     7  33.34     140.64     0.0    16*0.5
CYLINDER     3  33.65     140.64     0.0    16*0.5
CYLINDER     7  35.85     140.64     0.0    16*0.5
CYLINDER     6  46.34     140.64     0.0    16*0.5
CYLINDER     7  48.56     140.64   -14.90   16*0.5
BOX TYPE     2 /* CASK TOP
CYLINDER     6  30.96     158.42    140.64  16*0.5
CYLINDER     7  48.56     162.23    140.64  16*0.5
BOX TYPE     3 /* NBSR FUEL ASSEMBLY-COLLAPSED
CUBOID       1  4.4450 -4.4450  4.0005  -4.0005  45.65104  0.0   16*0.5
CUBOID       3  4.4450 -4.4450  4.0005  -4.0005  140.64  0.0   16*0.5
BOX TYPE     4 /* BORAL PLATE (VERT)
CUBOID       2  0.286  -0.286  4.12  -4.12  138.64  2.0   16*0.5
BOX TYPE     5 /* BORAL PLATE (HORIZ)
CUBOID       2  4.12  -4.12  0.286  -0.286  138.64  2.0   16*0.5
BOX TYPE     6  /* OVERALL BOX FOR THE PROBLEM
CUBOID       8  48.60    -48.60   48.60 -48.60 162.23 -14.91 16*0.5
CORE         0  48.60    -48.60   48.60 -48.60 162.23 -14.91 16*0.5
CUBOID       8  48.70    -48.70   48.70 -48.70 162.33 -14.92 16*0.5
6  1 1 1  1 1 1  1 1 1  1
BEGIN COMPLEX
/* PLACE FUEL ASSEMBLIES INTO CASK
COMPLEX  1  3   -22.860  -10.540  0.0  5  3  1  11.430  10.540  0.0
/*MIDDLE ROWS
COMPLEX  1  3   -11.430  -21.080  0.0  3  2  1  11.430  42.160  0.0
/*OUTER ROWS
/* PLACE BORAL PLATES INTO CASK
COMPLEX  1  4   -17.145  -10.540  0.0  4  3  1  11.430  10.540  0.0
/*VERT PLATES
COMPLEX  1  5   -11.430  -15.810  0.0  3  4  1  11.430  10.540  0.0
/*HORIZ PLATES
/* PLACE LOADED CASK INTO OVERALL PROBLEM BOX
```

```
COMPLEX  6  1  0.0     0.0    0.0   1 1 1   0.0    0.0    0.0
/* PLACE TOP INTO OVERALL PROBLEM BOX
COMPLEX  6  2  0.0     0.0    0.0   1 1 1   0.0    0.0    0.0
END GEOM
*END GEMER*
```

6.7.2.3.2 Number Density Calculations

6.7.2.3.2.1 FORTRAN Program (TRIGA CaseVIII Fuel)

The FORTRAN program used to calculate the number densities for the GEMER run is attached below. In addition, the FORTRAN output for the 12-element case with 493.93 grams of 94% enriched U235 is also attached below.

```
PROGRAM NUMBER
C
C   PRODUCTION RUN
C   7/3/96
C                        AKC
C    U-235 (94% ENRICHMENT CASE)
C    CASE 8 TYPE OF TRIGA FUEL
C
C
      REAL M235,M238
      REAL U235MAS,U238MAS
      REAL MZR,MU,MH,MH16,MH20
      REAL N235,N238,NH,NZR,N16,NHFUEL
      REAL NELEMENT
      REAL MNI,MCR,MMN,MFE
      REAL FEMAS,CRMAS,NIMAC,MNMAS
      REAL NNI,NMN,NFE,NCR
C
      DATA PI/3.14159265/
C
      OPEN(6,FILE='P_94.OUT',STATUS='UNKNOWN')
      AV=0.6022
      M235 =235.0439
      M238 =238.0508
      MZR=91.224
      MH=1.00794
      MH16=1.6*MH
      MH2O=18.0153
C
C    INCOLOY CLADDING
C    NOMIBAL COMPOSITION  8.01 G/CC
C    1% MN   21% CR  32% NI  46% FE
C
      MCR=51.9961
      MMN=54.9380
      MFE=55.8470
      MNI=58.6900
C
C
      DO 100 ITER=1,12
      WRITE(6,*) '   '
      WRITE(6,*) '     ****CASE ',ITER,' ****   '
      WFWATER=0.05*FLOAT(ITER-1)
```

```
      WRITE(6,*) ' WATER WEIGHT FRACTION =',WFWATER
C
C
C       *****INPUTS********
C     WT_U = 45% WEIGHT
C     25 FUEL ELEMENTS
C     RHOINCON = INCONEL DENSITY (G/CM^3)
C
C     U235GRAM = U235 WEIGHT PER ELEMENT IN GRAMS
C     ER-167 MASS IGNORED.
C
C
      U235GRAM=1029.0/25.0
C      NELEMENT=8.0
C      NELEMENT=8.2605
C      NELEMENT=9.0
C      NELEMENT=10.0
      NELEMENT=12.0
C      ENRICH=0.930
      ENRICH=0.940
      U235MAS=NELEMENT*U235GRAM
      WRITE(6,*) ' U235 MASS PER ELEMENT =',U235MAS/NELEMENT,' GRAMS'
      WRITE(6,*) ' TOTAL U235 MASS=',U235MAS,' GRAMS'
      WRITE(6,*) ' NUMBER OF FUEL ELEMENTS =',NELEMENT
      WT_U=0.10
      RHOINCON=8.01
C
C    RFUEL = FUEL OUTER RADIUS (CM)
C    RCLAD = CLAD OUTER RADIUS (CM)
C
      RFUEL=0.510*2.54/2.0
      RCLAD=0.542*2.54/2.0
C
C   FLENGTH = FUEL TOTAL LENGTH IN CM
C   FCLENGTH = CLAD TOTAL LENGTH (LONGER THAN FUEL LENGTH) IN CM
C
      FLENGTH=22.0*2.54
      FCLENGTH=65.10
      WRITE(6,*) ' FUEL OUTER RADIUS =',RFUEL,'CM   OR ',
     * RFUEL/2.54,' INCHES'
      WRITE(6,*) ' CLAD OUTER RADIUS =',RCLAD,'CM  OR ',
     *             RCLAD/2.54,' INCHES'
      WRITE(6,*) ' FUEL ELEMENT LENGTH =',FLENGTH,'CM OR ',
     *            FLENGTH/2.54,' INCHES'
C
C     CVOLUME=CLAD VOLUME
C     FVOLUME=FUEL VOLUME
C     FCVOLUME=FUEL + CLAD VOLUMES
C
      CVOLUME = NELEMENT*PI*(RCLAD*RCLAD-RFUEL*RFUEL)*FCLENGTH
     *         + NELEMENT*118.0*1.224/RHOINCON
      FVOLUME=NELEMENT*PI*RFUEL*RFUEL*FLENGTH
      FCVOLUME=FVOLUME+CVOLUME
C
C    CALCULATING THE CLAD MASSES
C
      WTMN=0.01
      WTCR=0.21
      WTNI=0.32
      WTFE=0.46
      MNMAS = RHOINCON*CVOLUME*WTMN
```

```
      CRMAS = RHOINCON*CVOLUME*WTCR
      NIMAS = RHOINCON*CVOLUME*WTNI
      FEMAS = RHOINCON*CVOLUME*WTFE
      CLADMAS=MNMAS + CRMAS+NIMAS+FEMAS
C
      RHOWATER=1.0
      RHOH2O = 1.0
C
C
      MU= 1.0/(ENRICH/M235 + (1.0-ENRICH)/M238)
C
       U238MAS=U235MAS/ENRICH - U235MAS
C
       UMAS=U238MAS +U235MAS
       ZRHMAS=UMAS/WT_U - UMAS
       ZRMAS = ZRHMAS*MZR/(MZR+MH16)
       H16MAS = ZRHMAS*MH16/(MZR+MH16)
C
       WRITE(6,*) ' ZRH        MASS =',ZRHMAS
       WRITE(6,*) ' U238      MASS =',U238MAS
       WRITE(6,*) ' U235      MASS =',U235MAS
       WRITE(6,*) ' TOTAL U(U235+U238) MASS =',UMAS

       WRITE(6,*) ' ZR      MASS =',ZRMAS
       WRITE(6,*) ' H16      MASS =',H16MAS
C
C
C
C
C     TOTAL2 = WATER MASS
c     TOTAL1 = FUEL ELEMENT MASS (UZRH  + CLAD)
C     TOTAL = WATER + FUEL ELEMENT MASSES (HOMOGENOUS MIXTURE)
      TOTAL1=ZRMAS + H16MAS + U238MAS +U235MAS+CLADMAS
      TOTAL2 = TOTAL1/(1.0-WFWATER) - TOTAL1
      TOTAL = TOTAL1 + TOTAL2
      WATERVOL=TOTAL2/RHOWATER
      VOLTOT=WATERVOL + FCVOLUME
C
C
       WRITE(6,*) 'TOTAL MASS (FUEL) IN GRAMS =',TOTAL1-CLADMAS
       WRITE(6,*) 'TOTAL MASS (CLAD) IN GRAMS =',CLADMAS
       WRITE(6,*) 'TOTAL MASS (WATER ONLY) IN GRAMS=',TOTAL2
       WRITE(6,*) 'TOTAL MASS (WATER +FUEL(ZRH)) IN GRAMS =',TOTAL
       WRITE(6,*) 'FUEL(UZRH) VOLUME IN CM^3=',FVOLUME
       WRITE(6,*) 'CLAD VOLUME IN CM^3=',CVOLUME
       WRITE(6,*) 'TOTAL VOLUME (WATER ONLY) IN CM^3 =',WATERVOL
       WRITE(6,*) 'TOTAL VOLUME (WATER +FUEL(UZRH)) IN CM^3 =',VOLTOT
C
C   AREASLOT = SLOT AREA PER ELEMENT (cm^2)
C
       AREASLOT=71.12889
       RHOMIX = TOTAL/VOLTOT
       WRITE(6,*) ' MIXTURE DENSITY =',RHOMIX,' G/CC'
       COLHEIGHT=VOLTOT/AREASLOT
       WRITE(6,*) ' COLHEIGHT=',COLHEIGHT,' CM'
       WRITE(6,*) ' '
C
      N235 = U235MAS*AV/M235/VOLTOT
      N238 = U238MAS*AV/M238/VOLTOT
      NH = H16MAS*AV/MH/VOLTOT + 2.0*TOTAL2*AV/VOLTOT/MH2O
      NHFUEL = H16MAS*AV/MH/VOLTOT
```

```
      NZR = ZRMAS*AV/MZR/VOLTOT
      N16= TOTAL2*AV/VOLTOT/MH2O
      IF (N16.LE.0.0) N16=1.0E-9
      NMN= MNMAS*AV/MMN/VOLTOT
      NFE= FEMAS*AV/MFE/VOLTOT
      NNI= NIMAS*AV/MNI/VOLTOT
      NCR= CRMAS*AV/MCR/VOLTOT
C


      WRITE(6,*) '      1',NH
      WRITE(6,*) '     16',N16
      WRITE(6,*) '    401',NZR
      WRITE(6,*) '     55',NMN
      WRITE(6,*) '     24',NCR
      WRITE(6,*) '     28',NNI
      WRITE(6,*) '     26',NFE
      WRITE(6,*) '   2381',N238
      WRITE(6,*) '   2351',N235
C
      RATIO1 = NHFUEL/NZR
      WRITE(6,*) ' H/ZR (NUMBER DENSITIES) = ',RATIO1
      RATIO2 = NHFUEL/N235
      WRITE(6,*) ' H(IN FUEL)/U235 (NUMBER DENSITIES) = ',RATIO2
      RATIO3 = NH/N235
      WRITE(6,*) ' H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) = ',RATIO3
      BIAS = BIASFUN(RATIO3)
      WRITE(6,1700) RATIO3,BIAS
 1700  FORMAT(1X,'  BIAS (H/U-235 =',F12.6,' ) = ',F12.6)
 100  CONTINUE
       END
      FUNCTION BIASFUN(X)
      REAL X
      BIASFUN=-(1.0E-8*X*X - 2.0E-5*X +0.0006)
      RETURN
      END
```

6.7.2.3.2.2 FORTRAN Output (TRIGA Case VIII Fuel)

```
    ****CASE            1 ****
 WATER WEIGHT FRACTION =  0.0000000E+00
 U235 MASS PER ELEMENT =   41.16000     GRAMS
 TOTAL U235 MASS=   493.9200     GRAMS
 NUMBER OF FUEL ELEMENTS =   12.00000
 FUEL OUTER RADIUS =  0.6477000    CM   OR   0.2550000     INCHES
 CLAD OUTER RADIUS =  0.6883400    CM  OR   0.2710000     INCHES
 FUEL ELEMENT LENGTH =   55.88000    CM OR    22.00000     INCHES
 ZRH        MASS =   4729.021
 U238      MASS =   31.52682
 U235      MASS =   493.9200
 TOTAL U(U235+U238) MASS =   525.4468
 ZR      MASS =   4646.872
 H16      MASS =   82.14976
TOTAL MASS (FUEL) IN GRAMS =   5254.469
TOTAL MASS (CLAD) IN GRAMS =   2800.382
TOTAL MASS (WATER ONLY) IN GRAMS=  0.0000000E+00
TOTAL MASS (WATER +FUEL(ZRH)) IN GRAMS =   8054.851
FUEL(UZRH) VOLUME IN CM^3=   883.7618
CLAD VOLUME IN CM^3=   349.6332
TOTAL VOLUME (WATER ONLY) IN CM^3 =  0.0000000E+00
```

```
TOTAL VOLUME (WATER +FUEL(UZRH)) IN CM^3 =   1233.395
 MIXTURE DENSITY =   6.530633     G/CC
 COLHEIGHT=   17.34028     CM

      1  3.9793309E-02
     16  9.9999997E-10
    401  2.4870820E-02
     55  2.4889197E-04
     24  5.5224556E-03
     28  7.4538803E-03
     26  1.1262679E-02
   2381  6.4661988E-05
   2351  1.0259971E-03
 H/ZR (NUMBER DENSITIES) =    1.600000
 H(IN FUEL)/U235 (NUMBER DENSITIES) =    38.78501
 H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    38.78501
  BIAS (H/U-235 =   38.785011 ) =     0.000161

     ****CASE            2 ****
 WATER WEIGHT FRACTION =  5.0000001E-02
 U235 MASS PER ELEMENT =   41.16000     GRAMS
 TOTAL U235 MASS=   493.9200     GRAMS
 NUMBER OF FUEL ELEMENTS =   12.00000
 FUEL OUTER RADIUS =  0.6477000    CM   OR   0.2550000     INCHES
 CLAD OUTER RADIUS =  0.6883400    CM  OR   0.2710000     INCHES
 FUEL ELEMENT LENGTH =   55.88000    CM OR    22.00000     INCHES
 ZRH        MASS =   4729.021
 U238      MASS =   31.52682
 U235      MASS =   493.9200
 TOTAL U(U235+U238) MASS =   525.4468
 ZR      MASS =   4646.872
 H16      MASS =   82.14976
TOTAL MASS (FUEL) IN GRAMS =   5254.469
TOTAL MASS (CLAD) IN GRAMS =   2800.382
TOTAL MASS (WATER ONLY) IN GRAMS=   423.9399
TOTAL MASS (WATER +FUEL(ZRH)) IN GRAMS =   8478.791
FUEL(UZRH) VOLUME IN CM^3=   883.7618
CLAD VOLUME IN CM^3=   349.6332
TOTAL VOLUME (WATER ONLY) IN CM^3 =   423.9399
TOTAL VOLUME (WATER +FUEL(UZRH)) IN CM^3 =   1657.335
 MIXTURE DENSITY =   5.115918     G/CC
 COLHEIGHT=   23.30045     CM

      1  4.6729941E-02
     16  8.5578021E-03
    401  1.8508960E-02
     55  1.8522635E-04
     24  4.1098325E-03
     28  5.5472064E-03
     26  8.3817290E-03
   2381  4.8121703E-05
   2351  7.6355104E-04
 H/ZR (NUMBER DENSITIES) =    1.600000
 H(IN FUEL)/U235 (NUMBER DENSITIES) =    38.78501
 H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    61.20081
  BIAS (H/U-235 =   61.200809 ) =     0.000587

     ****CASE            3 ****
 WATER WEIGHT FRACTION =  0.1000000
 U235 MASS PER ELEMENT =   41.16000     GRAMS
 TOTAL U235 MASS=   493.9200     GRAMS
```

```
 NUMBER OF FUEL ELEMENTS =   12.00000
 FUEL OUTER RADIUS =  0.6477000    CM   OR   0.2550000     INCHES
 CLAD OUTER RADIUS =  0.6883400    CM  OR   0.2710000     INCHES
 FUEL ELEMENT LENGTH =   55.88000    CM OR    22.00000     INCHES
 ZRH        MASS =   4729.021
 U238      MASS =   31.52682
 U235      MASS =   493.9200
 TOTAL U(U235+U238) MASS =   525.4468
 ZR      MASS =   4646.872
 H16      MASS =   82.14976
TOTAL MASS (FUEL) IN GRAMS =   5254.469
TOTAL MASS (CLAD) IN GRAMS =   2800.382
TOTAL MASS (WATER ONLY) IN GRAMS=   894.9839
TOTAL MASS (WATER +FUEL(ZRH)) IN GRAMS =   8949.835
FUEL(UZRH) VOLUME IN CM^3=   883.7618
CLAD VOLUME IN CM^3=   349.6332
TOTAL VOLUME (WATER ONLY) IN CM^3 =   894.9839
TOTAL VOLUME (WATER +FUEL(UZRH)) IN CM^3 =   2128.379
 MIXTURE DENSITY =   4.205000     G/CC
 COLHEIGHT=   29.92285     CM

     1  5.1196352E-02
    16  1.4068069E-02
   401  1.4412633E-02
    55  1.4423282E-04
    24  3.2002616E-03
    28  4.3195216E-03
    26  6.5267193E-03
  2381  3.7471607E-05
  2351  5.9456506E-04
 H/ZR (NUMBER DENSITIES) =    1.600000
 H(IN FUEL)/U235 (NUMBER DENSITIES) =    38.78501
 H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    86.10723
  BIAS (H/U-235 =   86.107231 ) =     0.001048

    ****CASE            4 ****
 WATER WEIGHT FRACTION =  0.1500000
 U235 MASS PER ELEMENT =   41.16000     GRAMS
 TOTAL U235 MASS=   493.9200     GRAMS
 NUMBER OF FUEL ELEMENTS =   12.00000
 FUEL OUTER RADIUS =  0.6477000    CM   OR   0.2550000     INCHES
 CLAD OUTER RADIUS =  0.6883400    CM  OR   0.2710000     INCHES
 FUEL ELEMENT LENGTH =   55.88000    CM OR    22.00000     INCHES
 ZRH        MASS =   4729.021
 U238      MASS =   31.52682
 U235      MASS =   493.9200
 TOTAL U(U235+U238) MASS =   525.4468
 ZR      MASS =   4646.872
 H16      MASS =   82.14976
TOTAL MASS (FUEL) IN GRAMS =   5254.469
TOTAL MASS (CLAD) IN GRAMS =   2800.382
TOTAL MASS (WATER ONLY) IN GRAMS=   1421.444
TOTAL MASS (WATER +FUEL(ZRH)) IN GRAMS =   9476.295
FUEL(UZRH) VOLUME IN CM^3=   883.7618
CLAD VOLUME IN CM^3=   349.6332
TOTAL VOLUME (WATER ONLY) IN CM^3 =   1421.444
TOTAL VOLUME (WATER +FUEL(UZRH)) IN CM^3 =   2654.839
 MIXTURE DENSITY =   3.569442     G/CC
 COLHEIGHT=   37.32434     CM
```

```
     1  5.4312620E-02
    16  1.7912647E-02
   401  1.1554579E-02
    55  1.1563116E-04
    24  2.5656433E-03
    28  3.4629516E-03
    26  5.2324580E-03
  2381  3.0040912E-05
  2351  4.7666160E-04
 H/ZR (NUMBER DENSITIES) =    1.600000
 H(IN FUEL)/U235 (NUMBER DENSITIES) =    38.78501
 H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    113.9438
  BIAS (H/U-235 =  113.943771 ) =     0.001549

    ****CASE            5 ****
 WATER WEIGHT FRACTION =  0.2000000
 U235 MASS PER ELEMENT =   41.16000     GRAMS
 TOTAL U235 MASS=   493.9200     GRAMS
 NUMBER OF FUEL ELEMENTS =   12.00000
 FUEL OUTER RADIUS =  0.6477000    CM   OR   0.2550000     INCHES
 CLAD OUTER RADIUS =  0.6883400    CM  OR   0.2710000     INCHES
 FUEL ELEMENT LENGTH =   55.88000    CM OR    22.00000     INCHES
 ZRH        MASS =   4729.021
 U238      MASS =   31.52682
 U235      MASS =   493.9200
 TOTAL U(U235+U238) MASS =   525.4468
 ZR      MASS =   4646.872
 H16      MASS =   82.14976
TOTAL MASS (FUEL) IN GRAMS =   5254.469
TOTAL MASS (CLAD) IN GRAMS =   2800.382
TOTAL MASS (WATER ONLY) IN GRAMS=   2013.712
TOTAL MASS (WATER +FUEL(ZRH)) IN GRAMS =   10068.56
FUEL(UZRH) VOLUME IN CM^3=   883.7618
CLAD VOLUME IN CM^3=   349.6332
TOTAL VOLUME (WATER ONLY) IN CM^3 =   2013.712
TOTAL VOLUME (WATER +FUEL(UZRH)) IN CM^3 =   3247.108
 MIXTURE DENSITY =   3.100779     G/CC
 COLHEIGHT=   45.65104     CM

     1  5.6610569E-02
    16  2.0747654E-02
   401  9.4470372E-03
    55  9.4540177E-05
    24  2.0976730E-03
    28  2.8313135E-03
    26  4.2780638E-03
  2381  2.4561485E-05
  2351  3.8971912E-04
 H/ZR (NUMBER DENSITIES) =    1.600000
 H(IN FUEL)/U235 (NUMBER DENSITIES) =    38.78501
 H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    145.2599
  BIAS (H/U-235 =  145.259918 ) =     0.002094

    ****CASE            6 ****
 WATER WEIGHT FRACTION =  0.2500000
 U235 MASS PER ELEMENT =   41.16000     GRAMS
 TOTAL U235 MASS=   493.9200     GRAMS
 NUMBER OF FUEL ELEMENTS =   12.00000
 FUEL OUTER RADIUS =  0.6477000    CM   OR   0.2550000     INCHES
 CLAD OUTER RADIUS =  0.6883400    CM  OR   0.2710000     INCHES
 FUEL ELEMENT LENGTH =   55.88000    CM OR    22.00000     INCHES
```

```
 ZRH        MASS =   4729.021
 U238      MASS =   31.52682
 U235      MASS =   493.9200
 TOTAL U(U235+U238) MASS =   525.4468
 ZR      MASS =   4646.872
 H16      MASS =   82.14976
TOTAL MASS (FUEL) IN GRAMS =   5254.469
TOTAL MASS (CLAD) IN GRAMS =   2800.382
TOTAL MASS (WATER ONLY) IN GRAMS=   2684.951
TOTAL MASS (WATER +FUEL(ZRH)) IN GRAMS =   10739.80
FUEL(UZRH) VOLUME IN CM^3=   883.7618
CLAD VOLUME IN CM^3=   349.6332
TOTAL VOLUME (WATER ONLY) IN CM^3 =   2684.951
TOTAL VOLUME (WATER +FUEL(UZRH)) IN CM^3 =   3918.346
 MIXTURE DENSITY =   2.740902     G/CC
 COLHEIGHT=   55.08797     CM

      1  5.8375113E-02
     16  2.2924598E-02
    401  7.8286985E-03
     55  7.8344827E-05
     24  1.7383279E-03
     28  2.3462910E-03
     26  3.5452035E-03
   2381  2.0353942E-05
   2351  3.2295767E-04
 H/ZR (NUMBER DENSITIES) =    1.600000
 H(IN FUEL)/U235 (NUMBER DENSITIES) =    38.78501
 H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    180.7516
  BIAS (H/U-235 =  180.751587 ) =     0.002688

     ****CASE            7 ****
 WATER WEIGHT FRACTION =  0.3000000
 U235 MASS PER ELEMENT =   41.16000     GRAMS
 TOTAL U235 MASS=   493.9200     GRAMS
 NUMBER OF FUEL ELEMENTS =   12.00000
 FUEL OUTER RADIUS =  0.6477000    CM   OR   0.2550000     INCHES
 CLAD OUTER RADIUS =  0.6883400    CM  OR   0.2710000     INCHES
 FUEL ELEMENT LENGTH =   55.88000    CM OR    22.00000     INCHES
 ZRH        MASS =   4729.021
 U238      MASS =   31.52682
 U235      MASS =   493.9200
 TOTAL U(U235+U238) MASS =   525.4468
 ZR      MASS =   4646.872
 H16      MASS =   82.14976
TOTAL MASS (FUEL) IN GRAMS =   5254.469
TOTAL MASS (CLAD) IN GRAMS =   2800.382
TOTAL MASS (WATER ONLY) IN GRAMS=   3452.080
TOTAL MASS (WATER +FUEL(ZRH)) IN GRAMS =   11506.93
FUEL(UZRH) VOLUME IN CM^3=   883.7618
CLAD VOLUME IN CM^3=   349.6332
TOTAL VOLUME (WATER ONLY) IN CM^3 =   3452.080
TOTAL VOLUME (WATER +FUEL(UZRH)) IN CM^3 =   4685.475
 MIXTURE DENSITY =   2.455873     G/CC
 COLHEIGHT=   65.87302     CM

      1  5.9772674E-02
     16  2.4648780E-02
    401  6.5469458E-03
     55  6.5517830E-05
     24  1.4537204E-03
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    28  1.9621449E-03
    26  2.9647655E-03
  2381  1.7021495E-05
  2351  2.7008148E-04
H/ZR (NUMBER DENSITIES) =    1.600000
H(IN FUEL)/U235 (NUMBER DENSITIES) =    38.78501
H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    221.3135
 BIAS (H/U-235 =  221.313492 ) =     0.003336

    ****CASE            8 ****
WATER WEIGHT FRACTION =  0.3500000
U235 MASS PER ELEMENT =   41.16000     GRAMS
TOTAL U235 MASS=   493.9200     GRAMS
NUMBER OF FUEL ELEMENTS =   12.00000
FUEL OUTER RADIUS =  0.6477000    CM   OR   0.2550000     INCHES
CLAD OUTER RADIUS =  0.6883400    CM  OR   0.2710000     INCHES
FUEL ELEMENT LENGTH =   55.88000    CM OR    22.00000     INCHES
ZRH        MASS =   4729.021
U238      MASS =   31.52682
U235      MASS =   493.9200
TOTAL U(U235+U238) MASS =   525.4468
ZR      MASS =   4646.872
H16      MASS =   82.14976
TOTAL MASS (FUEL) IN GRAMS =   5254.469
TOTAL MASS (CLAD) IN GRAMS =   2800.382
TOTAL MASS (WATER ONLY) IN GRAMS=   4337.227
TOTAL MASS (WATER +FUEL(ZRH)) IN GRAMS =   12392.08
FUEL(UZRH) VOLUME IN CM^3=   883.7618
CLAD VOLUME IN CM^3=   349.6332
TOTAL VOLUME (WATER ONLY) IN CM^3 =   4337.227
TOTAL VOLUME (WATER +FUEL(UZRH)) IN CM^3 =   5570.622
 MIXTURE DENSITY =   2.224541     G/CC
 COLHEIGHT=   78.31729     CM

     1  6.0906939E-02
    16  2.6048137E-02
   401  5.5066650E-03
    55  5.5107335E-05
    24  1.2227306E-03
    28  1.6503686E-03
    26  2.4936772E-03
  2381  1.4316855E-05
  2351  2.2716672E-04
H/ZR (NUMBER DENSITIES) =    1.600000
H(IN FUEL)/U235 (NUMBER DENSITIES) =    38.78501
H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    268.1156
 BIAS (H/U-235 =  268.115601 ) =     0.004043

    ****CASE            9 ****
WATER WEIGHT FRACTION =  0.4000000
U235 MASS PER ELEMENT =   41.16000     GRAMS
TOTAL U235 MASS=   493.9200     GRAMS
NUMBER OF FUEL ELEMENTS =   12.00000
FUEL OUTER RADIUS =  0.6477000    CM   OR   0.2550000     INCHES
CLAD OUTER RADIUS =  0.6883400    CM  OR   0.2710000     INCHES
FUEL ELEMENT LENGTH =   55.88000    CM OR    22.00000     INCHES
ZRH        MASS =   4729.021
U238      MASS =   31.52682
U235      MASS =   493.9200
TOTAL U(U235+U238) MASS =   525.4468
ZR      MASS =   4646.872
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 H16      MASS =   82.14976
TOTAL MASS (FUEL) IN GRAMS =   5254.469
TOTAL MASS (CLAD) IN GRAMS =   2800.382
TOTAL MASS (WATER ONLY) IN GRAMS=   5369.900
TOTAL MASS (WATER +FUEL(ZRH)) IN GRAMS =   13424.75
FUEL(UZRH) VOLUME IN CM^3=   883.7618
CLAD VOLUME IN CM^3=   349.6332
TOTAL VOLUME (WATER ONLY) IN CM^3 =   5369.900
TOTAL VOLUME (WATER +FUEL(UZRH)) IN CM^3 =   6603.295
 MIXTURE DENSITY =   2.033038     G/CC
 COLHEIGHT=   92.83562     CM

      1  6.1845917E-02
     16  2.7206566E-02
    401  4.6454910E-03
     55  4.6489236E-05
     24  1.0315108E-03
     28  1.3922716E-03
     26  2.1036973E-03
   2381  1.2077878E-05
   2351  1.9164068E-04
 H/ZR (NUMBER DENSITIES) =    1.600000
 H(IN FUEL)/U235 (NUMBER DENSITIES) =    38.78501
 H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    322.7181
  BIAS (H/U-235 =  322.718109 ) =     0.004813

     ****CASE           10 ****
 WATER WEIGHT FRACTION =  0.4500000
 U235 MASS PER ELEMENT =   41.16000     GRAMS
 TOTAL U235 MASS=   493.9200     GRAMS
 NUMBER OF FUEL ELEMENTS =   12.00000
 FUEL OUTER RADIUS =  0.6477000    CM   OR   0.2550000     INCHES
 CLAD OUTER RADIUS =  0.6883400    CM  OR   0.2710000     INCHES
 FUEL ELEMENT LENGTH =   55.88000    CM OR    22.00000     INCHES
 ZRH        MASS =   4729.021
 U238      MASS =   31.52682
 U235      MASS =   493.9200
 TOTAL U(U235+U238) MASS =   525.4468
 ZR      MASS =   4646.872
 H16      MASS =   82.14976
TOTAL MASS (FUEL) IN GRAMS =   5254.469
TOTAL MASS (CLAD) IN GRAMS =   2800.382
TOTAL MASS (WATER ONLY) IN GRAMS=   6590.333
TOTAL MASS (WATER +FUEL(ZRH)) IN GRAMS =   14645.18
FUEL(UZRH) VOLUME IN CM^3=   883.7618
CLAD VOLUME IN CM^3=   349.6332
TOTAL VOLUME (WATER ONLY) IN CM^3 =   6590.333
TOTAL VOLUME (WATER +FUEL(UZRH)) IN CM^3 =   7823.728
 MIXTURE DENSITY =   1.871893     G/CC
 COLHEIGHT=   109.9937     CM

      1  6.2636040E-02
     16  2.8181352E-02
    401  3.9208354E-03
     55  3.9237322E-05
     24  8.7060418E-04
     28  1.1750894E-03
     26  1.7755390E-03
   2381  1.0193835E-05
   2351  1.6174641E-04
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 H/ZR (NUMBER DENSITIES) =    1.600000
 H(IN FUEL)/U235 (NUMBER DENSITIES) =    38.78501
 H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    387.2484
  BIAS (H/U-235 =  387.248413 ) =     0.005645

     ****CASE           11 ****
 WATER WEIGHT FRACTION =  0.5000000
 U235 MASS PER ELEMENT =   41.16000     GRAMS
 TOTAL U235 MASS=   493.9200     GRAMS
 NUMBER OF FUEL ELEMENTS =   12.00000
 FUEL OUTER RADIUS =  0.6477000    CM   OR   0.2550000     INCHES
 CLAD OUTER RADIUS =  0.6883400    CM  OR   0.2710000     INCHES
 FUEL ELEMENT LENGTH =   55.88000    CM OR    22.00000     INCHES
 ZRH        MASS =   4729.021
 U238      MASS =   31.52682
 U235      MASS =   493.9200
 TOTAL U(U235+U238) MASS =   525.4468
 ZR      MASS =   4646.872
 H16      MASS =   82.14976
TOTAL MASS (FUEL) IN GRAMS =   5254.469
TOTAL MASS (CLAD) IN GRAMS =   2800.382
TOTAL MASS (WATER ONLY) IN GRAMS=   8054.851
TOTAL MASS (WATER +FUEL(ZRH)) IN GRAMS =   16109.70
FUEL(UZRH) VOLUME IN CM^3=   883.7618
CLAD VOLUME IN CM^3=   349.6332
TOTAL VOLUME (WATER ONLY) IN CM^3 =   8054.851
TOTAL VOLUME (WATER +FUEL(UZRH)) IN CM^3 =   9288.246
 MIXTURE DENSITY =   1.734418     G/CC
 COLHEIGHT=   130.5833     CM

     1  6.3310109E-02
    16  2.9012958E-02
   401  3.3026200E-03
    55  3.3050601E-05
    24  7.3333218E-04
    28  9.8980789E-04
    26  1.4955819E-03
  2381  8.5865286E-06
  2351  1.3624315E-04
 H/ZR (NUMBER DENSITIES) =    1.600000
 H(IN FUEL)/U235 (NUMBER DENSITIES) =    38.78501
 H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    464.6847
  BIAS (H/U-235 =  464.684723 ) =     0.006534

     ****CASE           12 ****
 WATER WEIGHT FRACTION =  0.5500000
 U235 MASS PER ELEMENT =   41.16000     GRAMS
 TOTAL U235 MASS=   493.9200     GRAMS
 NUMBER OF FUEL ELEMENTS =   12.00000
 FUEL OUTER RADIUS =  0.6477000    CM   OR   0.2550000     INCHES
 CLAD OUTER RADIUS =  0.6883400    CM  OR   0.2710000     INCHES
 FUEL ELEMENT LENGTH =   55.88000    CM OR    22.00000     INCHES
 ZRH        MASS =   4729.021
 U238      MASS =   31.52682
 U235      MASS =   493.9200
 TOTAL U(U235+U238) MASS =   525.4468
 ZR      MASS =   4646.872
 H16      MASS =   82.14976
TOTAL MASS (FUEL) IN GRAMS =   5254.469
TOTAL MASS (CLAD) IN GRAMS =   2800.382
TOTAL MASS (WATER ONLY) IN GRAMS=   9844.819
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TOTAL MASS (WATER +FUEL(ZRH)) IN GRAMS =   17899.67
FUEL(UZRH) VOLUME IN CM^3=   883.7618
CLAD VOLUME IN CM^3=   349.6332
TOTAL VOLUME (WATER ONLY) IN CM^3 =   9844.819
TOTAL VOLUME (WATER +FUEL(UZRH)) IN CM^3 =   11078.21
 MIXTURE DENSITY =   1.615754     G/CC
 COLHEIGHT=   155.7485     CM

      1  6.3891940E-02
     16  2.9730771E-02
    401  2.7689973E-03
     55  2.7710434E-05
     24  6.1484362E-04
     28  8.2987914E-04
     26  1.2539325E-03
   2381  7.1991549E-06
   2351  1.1422959E-04
 H/ZR (NUMBER DENSITIES) =    1.600000
 H(IN FUEL)/U235 (NUMBER DENSITIES) =    38.78501
 H(IN FUEL + WATER)/U235 (NUMBER DENSITIES) =    559.3292
  BIAS (H/U-235 =  559.329163 ) =     0.007458
```

6.7.3. Criticality Evaluation (TSR)

6.7.3.1 Discussion and Results

6.7.3.1.1 General

The Model 2000 cask, as discussed earlier in Subsection 6.1.2, is a cylindrical cask with lead shielding. The cask has a cavity that is 26.5 inches inside diameter and 55 inches high for holding nuclear radioactive material, including special nuclear material.

The TSR reactor is specifically considered for two reasons:

1. The TSR fuel consists of highly enriched uranium metal mixed with aluminum, different from the U_3O_8, U_3Si_2, and UAl_x fuel used in other MTRs, and
2. The reactor geometry and structure are very different from other MTR type of reactors.

6.7.3.1.2 Applicable Regulatory Criteria

The applicable regulatory criteria for the TSR fuel shipment remain the same as discussed earlier in Subsection 6.1.1.1 and will not be elaborated further here.

6.7.3.1.3 Container Description

The Model 2000 cask has been discussed earlier in Subsection 6.1.2. The cask remains the same externally. However, to accommodate for the TSR fuel assemblies, the cask interior has been redesigned. There are no borated aluminum plates in the TSR fuel shipment. The cask support consists of three compartments with fuel dividers in the top compartment.

6.7.3.1.4 Calculational Methods

The GEMER01V code is used to demonstrate the subcriticality of the Model 2000 cask with the TSR fuel assemblies loaded in the cask. Critical benchmark experiments using GEMER01V confirm the accuracy of the calculational method chosen for the present analysis and provide the basis for calculational bias. This has been discussed earlier in Subsection 6.1.4.

6.7.3.1.5 Summary of Results

Tables 6.55 through 6.57 summarize the results of the criticality evaluations for the TSR type of fuel for normal, single and accident arrays. Table 6.55 provides results for the normal conditions of transport (number of undamaged packages ≥ 5 X N) demonstration for the TSR case. Table 6.56 and Table 6.57 provide results for the single container and accident array (2 X N) cases, respectively, for the TSR case. Table 6.58 provides results for the infinite cask array for TSR fuel.

Table 6.55. Summary of Results — Normal Conditions of Transport for the TSR Type of Fuel (93.2% Enrichment)

Condition/Parameter	Quantity/Comment
Number of Containers in Demonstration	7 (Close packed Triangular Array)
Hydrogenous Moderation (In Fuel)	0.05 Weight Fraction H_2O (Dry)
Optimum Hydrogenous Moderation (Interspersed Moderation)	0.0 Weight Fraction H_2O (Between Casks) 0.0 Weight Fraction H_2O (Inside Casks)
Reflector	30.5 cm (1 ft) Full Density H_2O
Maximum Multiplication Factor $k_{eff} + 2\sigma$ + Bias	0.42644

Table 6.56. Summary of Results — Single Container for the TSR Type of Fuel (93.2% Enrichment)

Condition/Parameter	Quantity/Comment
Number of Containers in Demonstration	1
Optimum Hydrogenous Moderation (In Fuel)	0.50 Weight Fraction H_2O
Optimum Hydrogenous Moderation (Interspersed Moderation)	0.10 Weight Fraction H_2O
Reflector	30.5 cm (1 ft) Full Density H_2O
Maximum Multiplication Factor $k_{eff} + 2\sigma$ + Bias	0.90527

Table 6.57. Summary of Results — Accident Condition (Conservatively Treated as Flooded) for the TSR Type of Fuel (93.2% Enrichment)

Condition/Parameter	Quantity/Comment
Number of Containers in Demonstration	2 (Side-By-Side)
Optimum Hydrogenous Moderation (In Fuel)	0.50 Weight Fraction H_2O
Optimum Hydrogenous Moderation (Interspersed Moderation)	0.1 Weight Fraction H_2O (Between Casks) 0.1 Weight Fraction H_2O (Inside Casks)
Reflector	30.5 cm (1 ft) Full Density H_2O
Maximum Multiplication Factor $k_{eff} + 2\sigma$ + Bias	0.91500

Table 6.58. Summary of Results — Infinite Cask Scenario for TSR Type Fuel (94% Enruchment)

Condition/Parameter	Quantity/Comment
Number of Containers in Demonstration	Infinite Array
Optimum Hydrogenous Moderation (In Fuel)	0.50 Weight Fraction H_2O
Maximum Multiplication Factor $k_{eff} + 2\sigma$ + Bias	0.92694

6.7.3.2 Package Fuel Loading

Table 6.59 summarizes the maximum fuel load (mass), as well as some significant constraints for the form of the TSR type of fuel.

The loading specified in Table 6.60 described herein qualifies as an infinite (N=∞) Fissile Class III package with a zero transport index under the provisions of 10CFR71.61 based on the infinite cask analysis. This loading also meets the IAEA Safety Standards for an infinite shipment (N=∞) with a zero Transport Index for criticality safety. Table 6.61 shows the package parameters for the TSR fuel shipment.

Table 6.59. Model 2000 235U Mass Limit for a Single (N=1) Shipment for the TSR Type of Fuel

Compartment	Number of Assemblies	Total ^{235}U Mass (gm)
Top	6 Annular and 1 Cylindrical	2677
Mid	4 Lune Plates	304
Bottom	4 Lower or 4 Upper Plates	1412
Total		4393

Table 6.60. Model 2000 ^{235}U Mass Limit for an Infinite (N=∞) Shipment of the TSR Type of Fuel

Compartment	Number of Assemblies	Total ^{235}U Mass (gm)
Top	6 Annular and 1 Cylindrical	2677
Mid	4 Lune Plates	304
Bottom	4 Lower or 4 Upper Plates	1412
Total		4393

Table 6.61. Package Parameters for the Model 2000 Cask for the TSR Type of Fuel (94% Enrichment)

Parameter	Quantity/Comment
Fuel Construction	TSR-Type Fuel Plates
Fuel Material	U(20%) + Al (80%)
Cladding Material	Al
Maximum Fuel Enrichment	94.0%
Minimum Fuel Burnup	N/A
Burnable Poison Materials (e.g., Gd)	None
Maximum U metal Density (100% T.D.)	19.1 gm/cm^3
Nominal Al Density	2.699 gm/cm^3

6.7.3.3 Model Specification

6.7.3.3.1 Description of Calulational Models

Similar models are used to evaluate the normal condition, single container and accident array. The models are identical except in their representation of the number of casks and the interspersed moderation. The single container model assumes that there is one (1) cask fully loaded with well-moderated fuel assemblies. The normal condition model assumes that there are two (2) casks; each cask is fully loaded with dry fuel assemblies and in contact with each other in a triangular array. The accident array assumes there are two casks with well-moderated fuel assemblies, side-by-side and touching. All models assume fresh, un-depleted fuel in the active fuel region, neglecting any as-built poisons or fission products. All models omit the overpack from consideration, which brings the water reflector closer to the fissile material and adds an extra degree of conservatism to the analysis.

The model for normal condition consists of two (2) fully loaded casks, touching in a hexagonal configuration (triangular array). This places the units of fissile material inside each cask nearest the other for the most reactive configuration. Also, in the calculational model the fuel atoms are dispersed over the full volume of each fuel slot/position to maximize the projected target area for neutrons. The hydrogen-to-fissile ratio outside each cask is varied to find the peak k-effective value for the normal condition model. The inside of each cask is dry in the undamaged condition, which is conservatively modeled as having 5 wt% (a specific gravity of 0.05) interspersed water in the fuel region and inside the remainder of container. The array is surrounded by a 12 inch (30.5 cm) thick parallelogram of full density water (reflection on all sides). The cask with fuel is highly undermoderated in the normal condition of transport, as will be seen from the results.

The model for the single container case is one (1) cask that is filled with partial density water to achieve optimum moderation. Even though it has been shown that the cask remains water tight under hypothetical accident conditions, Section 71.55 of 10CFR71 and Section V of the IAEA Safety Standards require that a single cask be shown safe under optimum moderation conditions. For a Fissile Class III shipment of one Model 2000 cask, the single container case bounds the hypothetical accident condition array (of one unit). The accident array (according to the 10CFR criteria) would be dry and severely undermoderated. In the single container case, the hydrogen-to-fissile ratio within the fissile fuel and the interspersed moderation inside the cask are varied to find the peak k-effective. The outside of the cask is surrounded by a 12 inch (30.5 cm) thick water reflector.

The model for the accident array case is two (2) casks side-by-side, flooded with partial density water to achieve optimum moderation. The cask is treated as flooded even though it has been shown that the Model 2000 remains water tight under hypothetical accident conditions. Neutron multiplication is relatively insensitive to the number of casks in the array; the casks are nearly neutronically decoupled. The k-effective values for the single container demonstration and the flooded two-cask array are very close.

Similar to the single container case, the hydrogen-to-fissile ratio within the fissile fuel and the interspersed moderation are varied to find the peak k-effective. The outside of the cask is surrounded by a 12 inch (30.5 cm) thick water reflector.

All models utilize the same basic interior geometry. The fuel elements inside the cask are constrained by the compartment separation plates, stainless steel pipes and top compartment fuel dividers. The separation between the three active fuel regions is always maintained by the configuration of the two separation plates.

Figure 6.6 shows the cask geometry and pertinent dimensions used for modeling the cask loaded with TSR fuel assemblies. The fuel is homogenized by distributing the maximum mass of ^{235}U throughout the entire active fuel region (individual fuel plates within each assembly are not explicitly modeled).

The Model 2000 cask is modeled in three dimensions. Only the cask (without the overpack) and fuel are modeled. The cask is cylindrical with an interior cavity. This cavity is 26.5 inches (67.31 cm) in diameter and 54 inches (137.16 cm) in height. The cask outside diameter is 38.5 inches (97.79 cm). The total cask radial wall and bottom plate thickness is 6.0 inches (15.24 cm). The Model 2000 cask consists of a layered radial wall design composed of 1.0 inch (2.54 cm) of 304 stainless steel, 4.0 inches (10.16 cm) of lead, and then another 1.0 inch of 304 stainless steel. The cask bottom consists of 6 inches (15.24 cm) of 304 stainless steel. The top of the cask was modeled as having a 1.5 inch (3.81 cm) thick 304 stainless steel plate inside the cask at the top, then 4.5 inches (11.43 cm) of lead, and then a 1.75 inch (4.45 cm) thick 304 stainless steel plate on the top of the cask. For conservatism, the model reduces the wall thickness of stainless steel portions of the cask in areas where neutron absorption in the stainless steel reduces the neutron multiplication (i.e., cask walls and cask top).

6.7.3.3.2 Package Regional Densities

The fuel assembly model assumes the maximum possible fissile mass of ^{235}U per fuel assembly with a maximum enrichment of 94.0%. Each assembly is considered to be a homogeneous mixture of U metal, Al and water. For every container, the fuel assembly height is allowed to vary as the weight fraction of water varies (Table 6.62). The density of the fuel-water mixture varies as

$$\rho_{mix} = \left[\frac{(1 - WF)}{\rho_{FE}} + \frac{WF}{\rho_{H_2O}} \right]^{-1} \tag{4}$$

where WF is the weight fraction of water and ρ_{FE} is the density of a homogenized fuel element (20% U and 80% Al). The value of ρ_{FE} may be obtained from the densities provided in Table 6.62. In the normal array model, the fuel atoms are spread over the entire fuel region/slot to maximize the projected target area between casks. Table 6.63 also shows the variation in fuel density and mixture height as the water weight fraction in the fuel/water mixture is changed.

Subsection 6.7.3.5.1.2.1 lists the FORTRAN program used to calculate the fuel/water mixture height, as well as the fuel/water densities used in this analysis.

Material densities and corresponding number densities are based on standard material specifications. These materials have been calculated earlier (Subsection 6.3.2). Table 6.63 presents the material densities and number densities for substances (materials) in the criticality model. Substances composed of more than one element are broken into their elemental number densities in the number density column.

Table 6.62. Selected Densities as a Function of WF for the TSR Type of Fuel

WF H_2O in Fuel	Mixture Density (gm/cm^3)	Mixture Height (cm)
Top Compartment		**(Coaxial Cylinder) H_1**
0.00	2.801	8.752
0.05	2.569	10.042
0.20	2.059	14.880
0.40	1.628	25.093
0.50	1.474	33.263
0.60	1.346	45.519
Middle Compartment		**(Circular Cylinder) H_2**
0.00	2.901	0.395
0.05	2.650	0.455
0.20	2.102	0.681
0.40	1.648	1.158
0.50	1.487	1.540
0.60	1.355	2.113
Bottom Compartment		**(Circular Cylinder) H_3**
0.00	2.790	4.106
0.05	2.561	4.709
0.20	2.054	6.969
0.40	1.626	11.742
0.50	1.472	15.560
0.60	1.345	21.288

Table 6.63. Material Densities Used in the Model 2000 for the TSR Type of Fuel

Region	Material	Component Density (gm/cm^3)	Number Density (atom/barn-cm)
304 Stainless Steel	SS304	7.800	2.4627E-04 1.7881E-05 5.2194E-02 8.5985E-03 (H) 4.2993E-03 (O)
Lead Shielding	Pb	11.35	3.2989E-02
Water (Reflector)	H_2O	1.00	6.691E-02 (H) 3.345E-03 (O)

6.7.3.3.3 TSR Physical Description

The Tower Shielding Reactor (TSR) fuel basket is a stainless steel weldment of plate, tubing and pipe designed to fit inside the Model 2000 cask cavity. The TSR fuel basket is a three piece (stacking sections) assembly with cavities for the various TSR fuel elements, and is designed to accept just over one-half of the TSR fuel elements. The three basket sections maintain the TSR fuel element separation under worst case accident conditions.

The lower of the three sections of the TSR fuel basket can hold up to four Upper Fuel Elements or four Lower Fuel Elements, as shown in Figure 6.36. Total fuel loading in the lower section is limited to a maximum of 1412 grams ^{235}U. The section consists of a 26-1/4 inch OD by 14-3/8 inch high thick stainless steel tube welded to a stainless steel base plate. The pie-shaped fuel elements are contained in a compartment constructed of 3/8 inch stainless steel plate and a central stainless steel pipe. The stainless steel pipe extends up to the top of the basket to serve as a lifting bar for the basket.

The middle section of the TSR fuel basket can hold up to four Fuel Cover (Lune) Plates, as shown in Figure 6.36. Total fuel loading in the middle section is limited to a maximum of 304 grams ^{235}U. This section consists of a 26-1/4 inch OD by 11-5/8 inch high thick stainless steel tube welded to a stainless steel base plate. Each of the fuel elements is shored by stainless steel rods welded to the base plate.

The upper TSR fuel basket section can hold up to six Annular Fuel Elements and one Cylindrical Fuel Element, as shown in Figure 6.37. Total fuel loading in the upper section is limited to a maximum of 2677 grams ^{235}U. This section consists of a 26-1/4 inch OD by 27-3/8 inch high stainless steel tube welded to a stainless steel base plate. The annular fuel elements are contained in compartments constructed of 3/8 inch stainless steel plate and a centrally positioned stainless steel pipe. The cylindrical fuel element is contained in a separate stainless steel pipe.

All TSR fuel basket cavities and sections contain water drain passages compatible with the Model 2000 Cask drainage system.

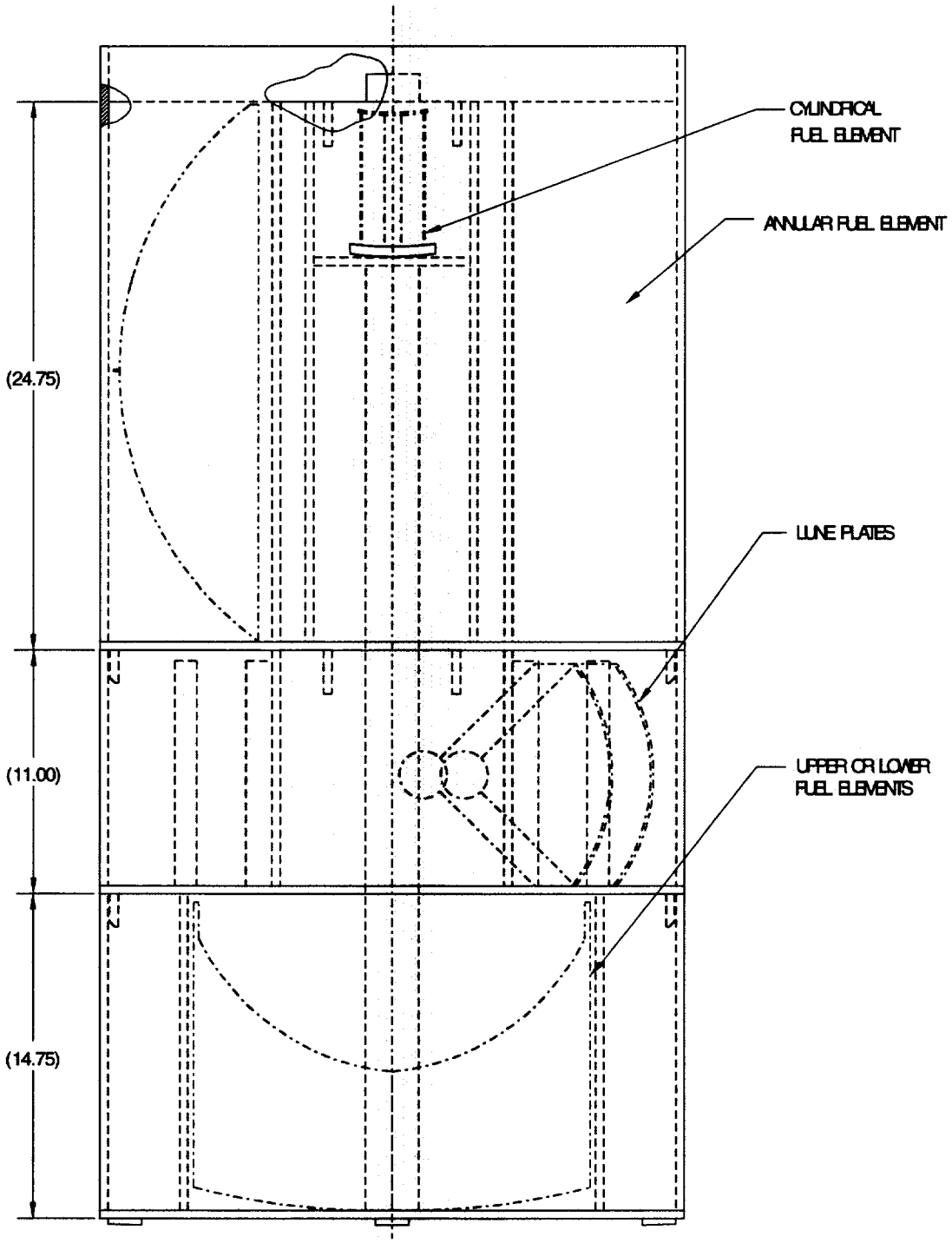

Figure 6.36. TSR Fuel Shipping Rack (Elevation)

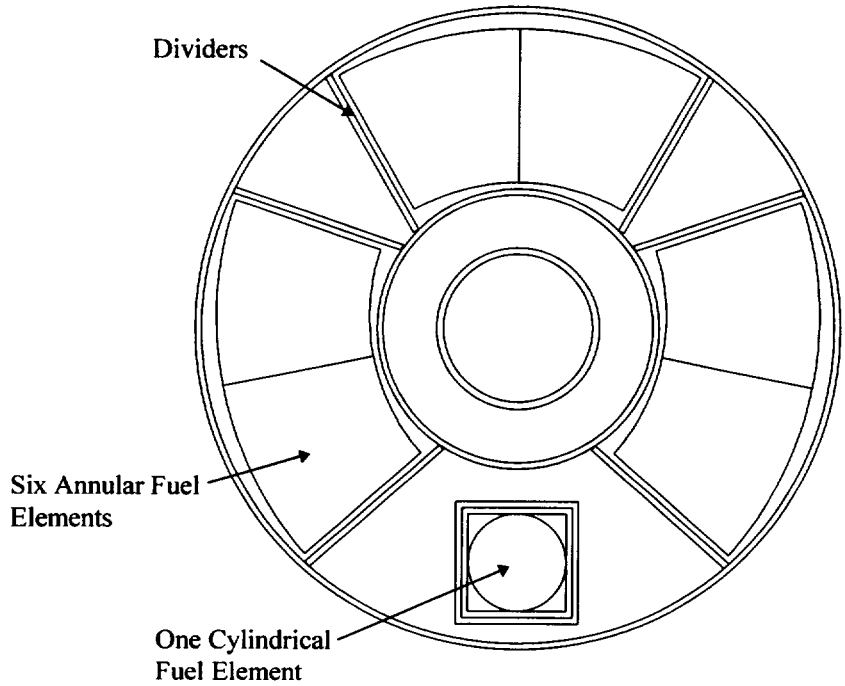

Figure 6.37. TSR Top Compartment Depicting the Fuel Dividers

Table 6.64 tabulates the amount of U-235 contained in each element type. It also lists the total weight (^{235}U + ^{238}U + Aluminum) for each element type. Table 6.65 lists the limiting mass of ^{235}U that was used in this analysis.

Table 6.64. TSR Element Types

Element Types	Quantity	U235 Mass (grams), each	Total weight (grams)
Annular	12	441	11000
Upper	4	353	10000
Lower	4	353	10000
Cylindrical	1	31	2000
Lune Plate	4*	76	1000

Notes: *Four lune plates per reactor core. Additional four lune plates, containing 59 grams of U-235 each, are in storage.

Table 6.65. Breakdown of U-235 in TSR Shipment with the Highest Fissile Content

Element Type	Shipment Limit
	U235 x Quantity = Total
Annular	441 x 6 = 2646 g
Upper or Lower (any combination)	353 x 4 = 1412 g
Cylindrical	31 x 1 = 31 g
Lune Plate	76 x 4 = 304 g
Total	**4393 g**

6.7.3.3.4 Structural Integrity Requirements

For this criticality analysis to be valid, the following structural integrity requirements must be met:

1. The two stainless steel plates dividing the three compartments must stay structurally intact under all normal and accident conditions, and the top compartment fuel must not crumble onto the middle compartment fuel or the bottom compartment fuel. The structural integrity of the stainless steel divider plates is very important as this would prevent the fuel from lumping together under normal and accident conditions.
2. The fuel dividers in the top compartment must also stay intact such that no more than four elements lump together under all normal and accident conditions. This will ensure that the top fuel will not be lumped into a single mass lying on one side.
3. The central pipes of the top compartment must remain structurally intact under all normal and accident conditions. In other words, the central pipes will maintain a separation distance and will not be collapsed into smaller central pipes. The structural integrity of the central pipes will ensure that the fuel in the top compartment will be in a leaky configuration that makes it acceptable from a criticality viewpoint.

6.7.3.3.5 Geometry Model

For the worst credible accident scenario, we would like to maximize the neutron interaction between the three compartments and to solidify the fuel mass as much as possible. As is done in the previous NBSR/ORR analyses, additional water is mixed with the fuel/clad structure to form a homogenous solution. This conservative assumption will maximize the reactivity in the system.

For this analysis, we assume the following worst credible geometry (Figure 6.38):

1. The fuel in the top compartment is sitting on the upper surface of the top separation plate.
2. The fuel in the middle compartment is collapsed into a circular cylinder lying right below the top separation plate. This scenario is possible when the cask rolls on its side and the mid-compartment fuel collapses near the top separation plate.
3. The fuel in the bottom compartment is collapsed into a circular cylinder lying right below the bottom separation plate. This scenario is credible when the cask rolls off the truck and lies on its side.
4. The top compartment fuel dividers which are made of stainless steel plates are treated as water. This is a conservative assumption as water is a good neutron moderator with little neutron absorption while stainless steel is a neutron absorber.

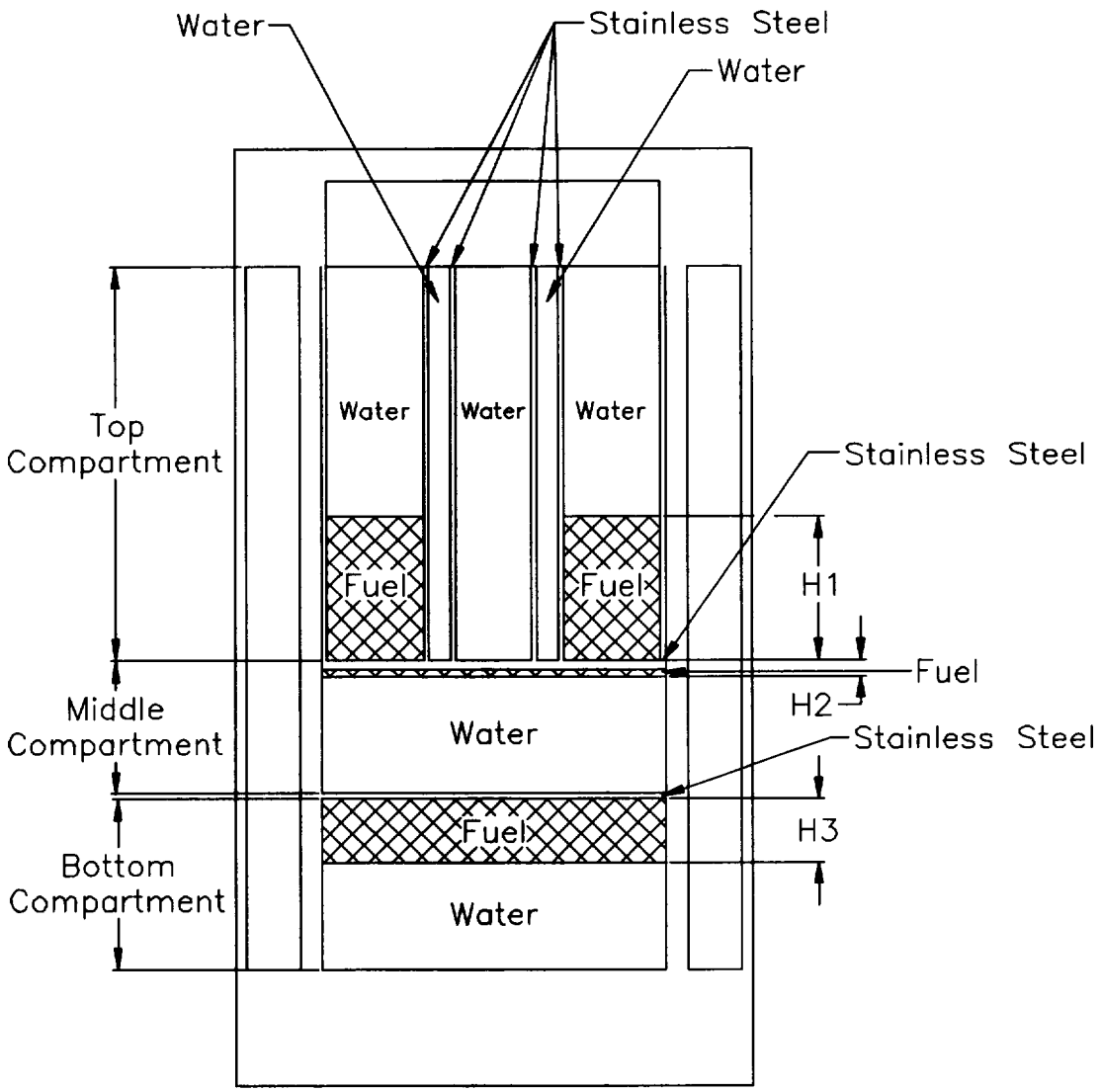

Figure 6.38. GEMER Geometry Model for Modeling the TSR Fuel Assemblies

The basic geometrical model is shown in Figure 6.38. The three compartments are described in Tables 6.66 through 6.68.

Table 6.66. TSR Top Compartment

Inner Radius (cm)	Outer Radius (cm)	Height Designation (cm, cm)	Description	Material
0.0	7.70255	62.865 to 140.64	central space	water
7.70255	8.41375	62.865 to 140.64	inner central pipe	stainless steel
8.41375	12.7254	62.865 to 140.64	space between the central pipes	water
12.7254	13.6525	62.865 to 140.64	outer central pipe	stainless steel
13.6525	32.7025	62.865 to 62.865 + H_1	reactor element	fuel/water mixture
13.6525	32.7025	62.865 + H_1 to 140.64	space	water
32.7025	33.340	62.865 to 140.64	outer container	stainless steel

Table 6.67. TSR Middle Compartment

Inner Radius (cm)	Outer Radius (cm)	Height Designation (cm, cm)	Description	Material
0.0	33.340	36.83 to 62.23 - H_2	space	water
0.0	33.340	62.23 - H_2 to 62.23	fuel element	fuel
0.0	33.340	62.23 to 62.865	support structure	stainless steel

Table 6.68. TSR Bottom Compartment

Inner Radius (cm)	Outer Radius (cm)	Height Designation (cm, cm)	Material
0.0	33.340	0.00 to 0.6350	stainless steel
0.0	33.340	0.6350 to 31.4877	water
0.0	33.340	31.4877 to 31.4877 + H_3	fuel
0.0	33.340	31.4877 + H_3 to 36.830	stainless steel

6.7.3.4 Criticality Calculation

6.7.3.4.1 Calculational Method

The computational tool used in this evaluation is the GE MERit code (GEMER).

6.7.3.4.2 Fuel Loading Optimization

Fuel assemblies are held within the basket structure during both normal conditions of transport and during hypothetical accident, so the geometry to be analyzed is well defined. Like other light water reactor fuels, the fuels considered here are substantially subcritical when placed in air due to a lack of neutron moderation. Increasing the moderation within an assembly by adding water to it results in an increase in k_{eff}.

During the hypothetical accident conditions in the Model 2000 cask, the fuel assemblies are calculated to be confined to each compartment as defined earlier.

The boundary condition around the cask in all criticality calculations is a leakage boundary condition with 12 inch water reflection surrounding all sides of the arrays. This corresponds to a finite array of casks in their most reactive array configuration with full reflection by water. The reflector is a parallelogram (CUBOID) of full density water surrounding the system. In the normal condition array, regions outside the casks but within the reflected boundary are treated as regions of interspersed water.

6.7.3.4.3 GEMER Results

Table 6.69 provides GEMER01V results for the normal condition array for the TSR cases. The k_{eff} values are substantially subcritical; dry fuel (0.05 WF H_2O) is severely under-moderated. The effect of varying the interspersed water density is shown. The maximum k-effective, accounting for uncertainty and bias, for the normal case is estimated to be 0.42644, which is substantially subcritical.

Table 6.69. GEMER Results for the Normal Condition Array for the TSR Case (93.2% Enriched Fuel)

Interspersed Water Density Outside Cask (gm/cm^3)	H/U^{235} Ratio (in Fuel)	k_{eff}	$\pm\sigma$	Bias	$k_{eff} + 2\sigma +$ Bias
0.00	27	0.41726	0.00249	0.0000	0.42224
0.02	**27**	**0.42124**	**0.00260**	**0.0000**	**0.42644**
0.05	27	0.41293	0.00280	0.0000	0.41853
0.10	27	0.41078	0.00269	0.0000	0.41616
1.00	27	0.41108	0.00253	0.0000	0.41614

Table 6.70 shows results for the single container cases for the TSR reactor. This table provides $k_{eff} + 2\sigma + Bias$ for a variety of weight fractions of water within the fuel. The maximum k_{eff}, accounting for uncertainty and bias, is 0.90527 for the TSR case. The single container is closely reflected by full density water. Empty spaces within the cask not occupied by the fuel-water mixture are filled with full density water (i.e., in the gap between the cask inner wall, holes between the central pipes in the top compartment).

Table 6.70. GEMER Results for a Single Container for the TSR Case (93.2% Enriched Fuel)

WF H_2O (in Fuel)	$H/^{235}U$ Ratio (in Fuel)	k_{eff}	$\pm\sigma$	Bias	$k_{eff} + 2\sigma +$ Bias
0.05	27.2	0.41396	0.00290	0.0000	0.41976
0.10	57.5	0.50205	0.00301	0.0005	0.50860
0.15	91.4	0.58619	0.00326	0.0011	0.59385
0.20	129.5	0.66287	0.00339	0.0018	0.67148
025	172.8	0.72849	0.00289	0.0026	0.73683
0.30	222.2	0.79647	0.00322	0.0033	0.80626
0.35	279.3	0.83817	0.00296	0.0042	0.84829
0.40	345.9	0.87186	0.00344	0.0051	0.88386
0.45	424.6	0.89230	0.00328	0.0061	0.90495
0.50	**519.1**	**0.89138**	**0.00340**	**0.0071**	**0.90527**
0.55	634.6	0.88497	0.00248	0.0081	0.89800

Table 6.71 provides the results for the accident array case for the TSR reactor. The accident array is treated as flooded, despite test results which indicate that the Model 2000 will not leak. This table provides $k_{eff} + 2\sigma + Bias$ for a variety of weight fractions of water within the fuel as well as within the interspersed regions (i.e., between the casks, in the gap between the cask inner wall, and in holes between the central pipes in the top compartment). The maximum k_{eff} for the TSR case, accounting for uncertainty and bias, is 0.91500, which is below the subcriticality limit of 0.95. For the TSR case, the interspersed water density is varied from 0.00 to 1.00 at the 0.50 weight fraction case. The change in k_{eff} is small from 0.90585 to 0.91021, showing the negligible effect of interspersed moderation. The two containers are closely reflected by a 1 ft. (30.5 cm) thick parallelogram of full density water.

Table 6.72 provides the results for the infinite array case for the TSR reactor. This table provides $k_{eff} + 2\sigma + Bias$ for a variety of weight fractions of water within the fuel. The maximum keff for the TSR case, accounting for uncertainty and bias, is 0.92694, which is below the subcriticality limit of 0.95.

Table 6.71. GEMER Results for the Accident Array (Conservatively Treated as Flooded) for the TSR Case (93.2% Enriched Fuel)

WF H_2O (in Fuel)	$H/^{235}U$ Ratio (in Fuel)	H_2O Density (Interspersed)	k_{eff}	$\pm\sigma$	Bias	$k_{eff} + 2\sigma +$ Bias
0.25	172.8	0.10	0.73623	0.00319	0.0026	0.74517
0.30	222.2	0.10	0.79494	0.00318	0.0033	0.80465
0.35	279.3	0.10	0.83997	0.00341	0.0042	0.85099
0.40	345.9	0.10	0.88036	0.00324	0.0051	0.89196
0.45	424.6	0.10	0.89078	0.00297	0.0061	0.90281
0.50	519.1	0.00	0.89318	0.00279	0.0071	0.90585
0.50	519.1	0.02	0.89869	0.00295	0.0071	0.91168
0.50	519.1	0.05	0.89784	0.00292	0.0071	0.91077
0.50	**519.1**	**0.10**	**0.90181**	**0.00305**	**0.0071**	**0.91500**
0.50	519.1	0.50	0.88813	0.00221	0.0071	0.89964
0.50	519.1	1.00	0.89714	0.00299	0.0071	0.91021
0.55	634.6	0.10	0.88187	0.00256	0.0081	0.89506
0.60	779.0	0.10	0.86417	0.00279	0.0089	0.87866

Table 6.72. GEMER Results — Infinite Cask Scenario for TSR Fuel (94% Enriched Fuel)

WF H_2O (in Fuel)	$H/^{235}U$ Ratio (in Fuel)	H_2O Density (Interspersed)	K_{eff}	$\pm\sigma$	Bias	$K_{eff} + 2\sigma +$ Bias
0.00	0.00	0	0.35100	0.00221	0.00000	0.35542
0.05	27.22	0	0.42315	0.00245	0.00000	0.42805
0.10	57.50	0	0.51106	0.00296	0.00052	0.51750
0.15	91.37	0	0.60480	0.00297	0.00114	0.61188
0.20	129.51	0	0.68220	0.00335	0.00182	0.69072
0.25	172.76	0	0.74995	0.00294	0.00256	0.75839
0.30	222.21	0	0.81232	0.00322	0.00335	0.82211
0.35	279.29	0	0.85804	0.00290	0.00421	0.86805
0.40	345.90	0	0.89249	0.00253	0.00512	0.90267
0.45	424.64	0	0.90986	0.00296	0.00609	0.92187
0.50	**519.14**	**0**	**0.91493**	**0.00246**	**0.00709**	**0.92694**
0.55	634.65	0	0.90414	0.00229	0.00807	0.91679
0.60	779.06	0	0.88235	0.00238	0.00891	0.89602

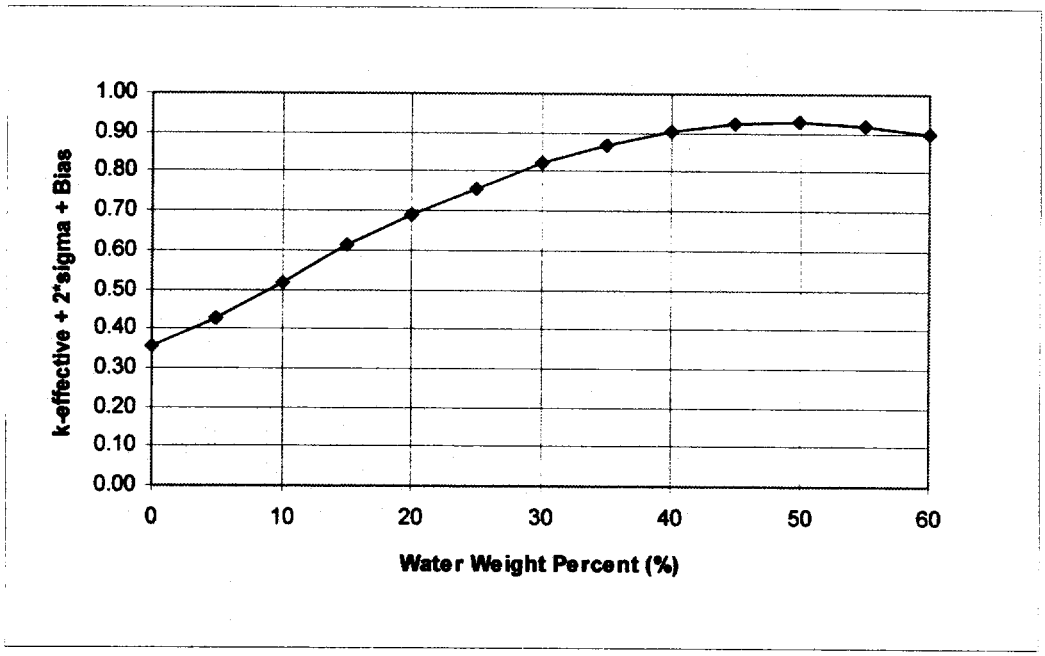

Figure 6.39. TSR Fuel, Infinite Cask Array (94% Enriched Fuel)

Figure 6.39 shows $k_{eff} + 2\sigma + bias$ for varying water weight percentages.

Other geometry shapes might be possible. For example, the bottom compartment might be collapsed into a sphere. However, this case will be less severe from what we have in GEMER model now (i.e., a circular cylinder lying next to the bottom separation plate). The present geometry will maximize the neutron interaction between the three compartments.

6.7.3.4.4 Conclusions

All results, including the conservative accident condition cases, are subcritical. The maximum k-effective for the worst TSR case, after accounting for uncertainty and bias, is 0.92694 for the worst case. The effective multiplication factors are all less than 0.95. The above conclusion is reached based on the requirement that the structural integrity of the compartment separation plates, the fuel dividers, and the central pipes in the top compartment, is maintained under all accident conditions. This meets the NRC requirements for criticality safety analysis.

6.7.3.5 Input/Output — TSR Type Fuels

6.7.3.5.1 GEMER Input Decks

This Appendix includes GEMER geometrical plots and input listings for the single container, normal array, accident array, and infinite array. Each TSR basedeck contains a "header" with fuel material and geometry information.

6.7.3.5.1.1 Normal (93.2% Enriched Fuel)

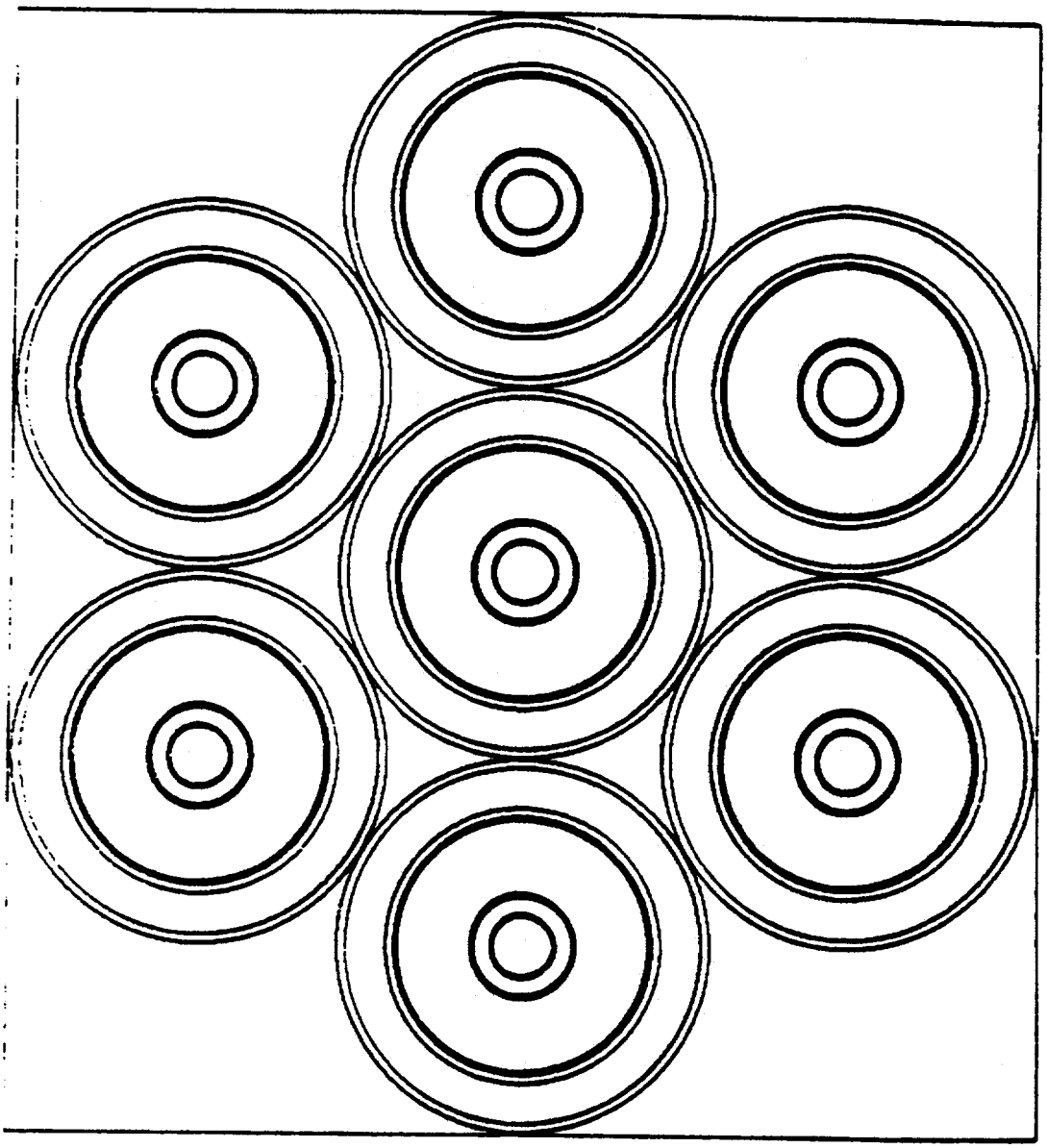

Figure 6.40. Normal Container for TSR Fuel — Top View

```
TSR FUEL/ IF2000/  1/2 LOADING; SS+Pb SHIELDING. WFH2O IN FUEL=0.05 MASS
U235
    65 /* # BATCHES
  1000  /* # NEUTRONS PER BATCH
    5  /* # BATCHES TO SKIP
 2123469/* INITIAL "SEED" (IF NON-ZERO)
     0  /* "IDUMP"
     0  /* "NRSTRT"
     0  /* "NBTED" (NON-ZERO IS PRINT EDITS)
     0  /* "KRED" (NUMBER OF COMBINED REGIONS IN EDITS)
     0  293   28  9   /* LPRB  MODTH  NHMAX  MMAX
      5  293 0  0 U(93.2)+0.05 WF -H2O RHOMIX=2.570141 g/cc TOP MAT 1
       1  8.5985484E-03
      16  4.2992742E-03
     131  5.2194621E-02
    2381  1.7881279E-05
    2351  2.4627015E-04
      4  293 0 0 Boral 0.25" Plate +/- 10% (60% Boron Loading)  MAT 2
    10    3.254E-03
    11    1.310E-02
    12    6.815E-03
   131    4.376E-02
      2  293 0 0  MODERATOR IN CASK (100.0%)                    MAT 3
      1   6.69111121E-02
    16   3.34555566E-02
      2  293 0 0  INTERSPERSED MODERATOR (100.00%)            MAT4
      1   6.69111121E-02
    16   3.34555566E-02
      2  293 0 0 FULL DENSITY WATER                    MAT 5
      1    6.69111121E-02
    16    3.34555566E-02
      1  293 0 0 LEAD SHIELDING                        MAT 6
    82   3.29890E-02
      7  293 0 0 304 STAINLESS STEEL                   MAT 7
    12   6.82690E-05
    14   8.53360E-04
    24   1.53600E-02
    26   6.04950E-02
    28   6.82690E-03
    55   1.70670E-03
  1316   2.56010E-05
      5  293 0  0 U(93.2)+0.05 WF -H2O RHOMIX=2.651094 g/cc MID MAT 8
       1  8.8693826E-03
      16  4.4346913E-03
     131  5.1627927E-02
    2381  3.5607482E-05
    2351  4.9040408E-04
      5  293 0  0 U(93.2)+0.05 WF -H2O RHOMIX=2.561455 g/cc BOTTOM MAT 9
       1  8.5694930E-03
      16  4.2847465E-03
     131  5.2255418E-02
    2381  1.5979516E-05
    2351  2.2007813E-04
KENO GEOM
    28  /* "KREFM"
     7  /* "NBOX"
     1  /* "NBXMAX"
     1  /* "NBYMAX"
     1  /* "NBZMAX"
     0  /* "NXX"
     0  /* "NTYPST"
```

```
     1  /* "NEMBRG"
     0  /* "NGMCHK"
BOX TYPE    1 /*MODEL 2000 CASK & STAINLESS SUPPORT STRUCTURE
CYLINDER     7  33.34     140.64     0.0    16*0.5
CYLINDER     3  33.65     140.64     0.0    16*0.5
CYLINDER     7  35.85     140.64     0.0    16*0.5
CYLINDER     6  46.34     140.64     0.0    16*0.5
CYLINDER     7  48.56     140.64   -14.90   16*0.5
BOX TYPE    2 /* CASK TOP
CYLINDER     6  30.96     158.42    140.64  16*0.5
CYLINDER     7  48.56     162.23    140.64  16*0.5
BOX TYPE    3  /*  TOP SECTION (TOP COMPARTMENT)
CYLINDER     5    7.70255    140.64     72.9039    16*0.5   /* TOP WATER
CYLINDER     7    8.41375    140.64     72.9039    16*0.5   /* TOP S.S.
CYLINDER     5   12.7254     140.64     72.9039    16*0.5   /* TOP WATER
CYLINDER     7   13.6525     140.64     72.9039    16*0.5   /* TOP S.S.
CYLINDER     5   32.7025     140.64     72.9039    16*0.5   /* TOP WATER
CYLINDER     7   33.3400     140.64     72.9039    16*0.5   /* TOP WATER
BOX TYPE    4  /* BOTTOM SECTION (TOP COMPARTMENT) CONC. FUEL H=10.03892
CYLINDER     5    7.70255    72.9039    62.865    16*0.5   /* TOP WATER
CYLINDER     7    8.41375    72.9039    62.865    16*0.5   /* TOP S.S.
CYLINDER     5   12.7254     72.9039    62.865    16*0.5   /* TOP WATER
CYLINDER     7   13.6525     72.9039    62.865    16*0.5   /* TOP S.S
CYLINDER     1   32.7025     72.9039    62.865    16*0.5   /* TOP FUEL
CYLINDER     7   33.340      72.9039    62.865    16*0.5   /* TOP WATER
BOX TYPE    5  /* MID FUEL (CYL. PANCAKE) H=0.4548102
CYLINDER     5  33.340     61.7752    36.83    16*0.5   /* ***MID WATER
CYLINDER     8  33.340     62.230    36.83    16*0.5   /* MID FUEL
CYLINDER     7  33.340     62.865     36.83    16*0.5   /* MID  S.S.
BOX TYPE    6  /* BOTTOM FUEL(CYL. PANCAKE) H=4.707263
CYLINDER     7  33.340      0.6350   0.000    16*0.5   /*  BOTTOM S.S.
CYLINDER     5  33.340     31.4877   0.000    16*0.5   /*  ***BOTTOM
WATER
CYLINDER     9  33.340     36.195   0.000    16*0.5   /*   BOTTOM FUEL
CYLINDER     7  33.340     36.830   0.000    16*0.5   /*   BOTTOM S.S.
BOX TYPE    7  /* OVERALL BOX FOR THE PROBLEM
CUBOID       4  146.80  -146.80  133.70  -133.70  162.30  -15.24  16*0.5
CUBOID       5  177.30  -177.30  164.20  -164.20  192.80  -45.74  16*0.5
 7  1 1 1  1 1 1  1 1 1  1
BEGIN COMPLEX
/* PLACE FUEL AT THE THREE COMPARTMENTS
COMPLEX  1  3   0.000    0.0000  0.000  1  1  1   0.000   0.000  0.0
COMPLEX  1  4   0.000    0.0000  0.000  1  1  1   0.000   0.000  0.0
COMPLEX  1  5   0.000    0.0000  0.000  1  1  1   0.000   0.000  0.0
COMPLEX  1  6   0.000    0.0000  0.000  1  1  1   0.000   0.000  0.0
/*
/* PLACE LOADED CASK INTO OVERALL PROBLEM BOX
/* PLACE 7 LOADED CASKS INTO OVERALL PROBLEM BOX
COMPLEX  7  1    -97.5    0.0    0.0   3 1 1   97.5    0.0   0.0
/*MIDDLE ROW
COMPLEX  7  1    -48.8  -84.4    0.0   2 2 1   97.5  168.9   0.0 /*OUTER
ROW
/* PLACE TOPS INTO OVERALL PROBLEM BOX
COMPLEX  7  2    -97.5    0.0    0.0   3 1 1   97.5    0.0   0.0
/*MIDDLE ROW
COMPLEX  7  2    -48.8  -84.4    0.0   2 2 1   97.5  168.9   0.0 /*OUTER
ROW
END GEOM
*END GEMER*
```

6.7.3.5.1.2 Single (93.2% Enriched Fuel)

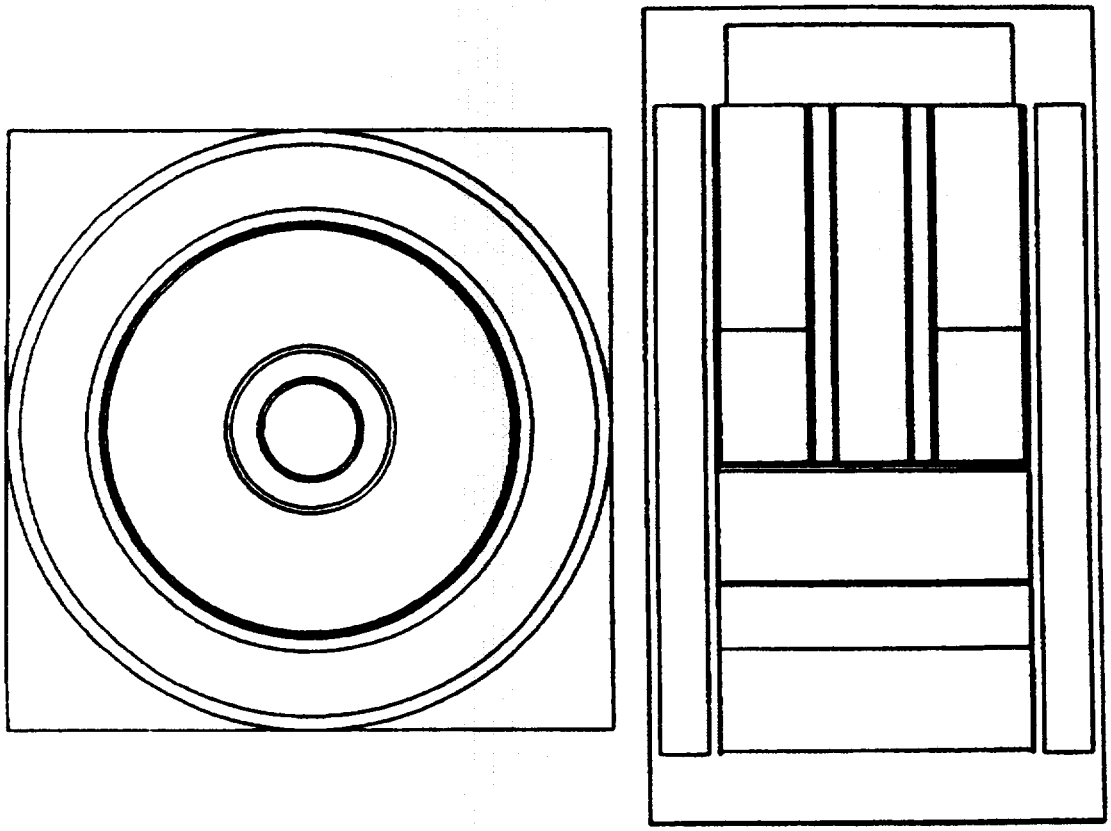

Figure 6.41. Single Container for TSR Fuel — Top/Side View

```
TSR FUEL/ IF2000/  1/2 LOADING; SS+Pb SHIELDING. WFH2O IN FUEL=0.05 MASS
U235
    65 /* # BATCHES
  1000  /* # NEUTRONS PER BATCH
     5  /* # BATCHES TO SKIP
 2123469/* INITIAL "SEED" (IF NON-ZERO)
     0  /* "IDUMP"
     0  /* "NRSTRT"
     0  /* "NBTED" (NON-ZERO IS PRINT EDITS)
     0  /* "KRED" (NUMBER OF COMBINED REGIONS IN EDITS)
     0  293   28   9   /* LPRB  MODTH  NHMAX  MMAX
      5  293 0  0 U(93.2)+0.05 WF -H2O RHOMIX=2.570141 g/cc TOP MAT 1
      1  8.5985484E-03
     16  4.2992742E-03
    131  5.2194621E-02
   2381  1.7881279E-05
   2351  2.4627015E-04
      4  293 0 0 Boral 0.25" Plate +/- 10% (60% Boron Loading)  MAT 2
   10    3.254E-03
   11    1.310E-02
   12    6.815E-03
  131    4.376E-02
      2  293 0 0  MODERATOR IN CASK (100.00%)                    MAT 3
      1   6.69111121E-03
   16   3.34555566E-03
      2  293 0 0  INTERSPERSED MODERATOR (100.00%)            MAT4
     1   6.69111121E-03
   16   3.34555566E-03
      2  293 0 0 FULL DENSITY WATER                     MAT 5
     1    6.69111121E-02
   16    3.34555566E-02
      1  293 0 0 LEAD SHIELDING                         MAT 6
   82   3.29890E-02
      7  293 0 0 304 STAINLESS STEEL                    MAT 7
   12   6.82690E-05
   14   8.53360E-04
   24   1.53600E-02
   26   6.04950E-02
   28   6.82690E-03
   55   1.70670E-03
 1316   2.56010E-05
      5  293 0  0 U(93.2)+0.05 WF -H2O RHOMIX=2.651094 g/cc MID MAT 8
      1  8.8693826E-03
     16  4.4346913E-03
    131  5.1627927E-02
   2381  3.5607482E-05
   2351  4.9040408E-04
      5  293 0  0 U(93.2)+0.05 WF -H2O RHOMIX=2.561455 g/cc BOTTOM MAT 9
      1  8.5694930E-03
     16  4.2847465E-03
    131  5.2255418E-02
   2381  1.5979516E-05
   2351  2.2007813E-04
KENO GEOM
    28  /* "KREFM"
     7  /* "NBOX"
     1  /* "NBXMAX"
     1  /* "NBYMAX"
     1  /* "NBZMAX"
     0  /* "NXX"
     0  /* "NTYPST"
```

```
     1  /* "NEMBRG"
     0  /* "NGMCHK"
BOX TYPE    1 /*MODEL 2000 CASK & STAINLESS SUPPORT STRUCTURE
CYLINDER     7  33.34     140.64     0.0    16*0.5
CYLINDER     3  33.65     140.64     0.0    16*0.5
CYLINDER     7  35.85     140.64     0.0    16*0.5
CYLINDER     6  46.34     140.64     0.0    16*0.5
CYLINDER     7  48.56     140.64   -14.90   16*0.5
BOX TYPE    2 /* CASK TOP
CYLINDER     6  30.96     158.42    140.64  16*0.5
CYLINDER     7  48.56     162.23    140.64  16*0.5
BOX TYPE    3  /*  TOP SECTION (TOP COMPARTMENT)
CYLINDER     5    7.70255    140.64     72.9039    16*0.5   /* TOP WATER
CYLINDER     7    8.41375    140.64     72.9039    16*0.5   /* TOP S.S.
CYLINDER     5   12.7254     140.64     72.9039    16*0.5   /* TOP WATER
CYLINDER     7   13.6525     140.64     72.9039    16*0.5   /* TOP S.S.
CYLINDER     5   32.7025     140.64     72.9039    16*0.5   /* TOP WATER
CYLINDER     7   33.3400     140.64     72.9039    16*0.5   /* TOP WATER
BOX TYPE    4  /* BOTTOM SECTION (TOP COMPARTMENT) CONC. FUEL H=10.03892
CYLINDER     5    7.70255    72.9039    62.865    16*0.5   /* TOP WATER
CYLINDER     7    8.41375    72.9039    62.865    16*0.5   /* TOP S.S.
CYLINDER     5   12.7254     72.9039    62.865    16*0.5   /* TOP WATER
CYLINDER     7   13.6525     72.9039    62.865    16*0.5   /* TOP S.S
CYLINDER     1   32.7025     72.9039    62.865    16*0.5   /* TOP FUEL
CYLINDER     7   33.340      72.9039    62.865    16*0.5   /* TOP WATER
BOX TYPE    5  /* MID FUEL (CYL. PANCAKE) H=0.4548102
CYLINDER     5  33.340     61.7752    36.83    16*0.5   /* ***MID WATER
CYLINDER     8  33.340     62.230    36.83    16*0.5   /* MID FUEL
CYLINDER     7  33.340     62.865     36.83    16*0.5   /* MID  S.S.
BOX TYPE    6  /* BOTTOM FUEL(CYL. PANCAKE) H=4.707263
CYLINDER     7  33.340      0.6350   0.000    16*0.5   /*  BOTTOM S.S.
CYLINDER     5  33.340     31.4877   0.000    16*0.5   /*  ***BOTTOM
WATER
CYLINDER     9  33.340     36.195   0.000    16*0.5   /*   BOTTOM FUEL
CYLINDER     7  33.340     36.830   0.000    16*0.5   /*   BOTTOM S.S.
BOX TYPE    7  /* OVERALL BOX FOR THE PROBLEM
CUBOID       4  146.80  -146.80  133.70  -133.70  162.30  -15.24  16*0.5
CUBOID       5  177.30  -177.30  164.20  -164.20  192.80  -45.74  16*0.5
 7  1 1 1  1 1 1  1 1 1  1
BEGIN COMPLEX
/* PLACE FUEL AT THE THREE COMPARTMENTS
COMPLEX  1  3   0.000    0.0000  0.000  1  1  1   0.000   0.000  0.0
COMPLEX  1  4   0.000    0.0000  0.000  1  1  1   0.000   0.000  0.0
COMPLEX  1  5   0.000    0.0000  0.000  1  1  1   0.000   0.000  0.0
COMPLEX  1  6   0.000    0.0000  0.000  1  1  1   0.000   0.000  0.0
/*
/* PLACE LOADED CASK INTO OVERALL PROBLEM BOX
/* PLACE 7 LOADED CASKS INTO OVERALL PROBLEM BOX
COMPLEX  7  1    -97.5    0.0    0.0   3 1 1   97.5    0.0   0.0
/*MIDDLE ROW
COMPLEX  7  1    -48.8  -84.4    0.0   2 2 1   97.5  168.9   0.0 /*OUTER
ROW
/* PLACE TOPS INTO OVERALL PROBLEM BOX
COMPLEX  7  2    -97.5    0.0    0.0   3 1 1   97.5    0.0   0.0
/*MIDDLE ROW
COMPLEX  7  2    -48.8  -84.4    0.0   2 2 1   97.5  168.9   0.0 /*OUTER
ROW
END GEOM
*END GEMER*
```

6.7.3.5.1.3 Accident (93.2% Enriched Fuel)

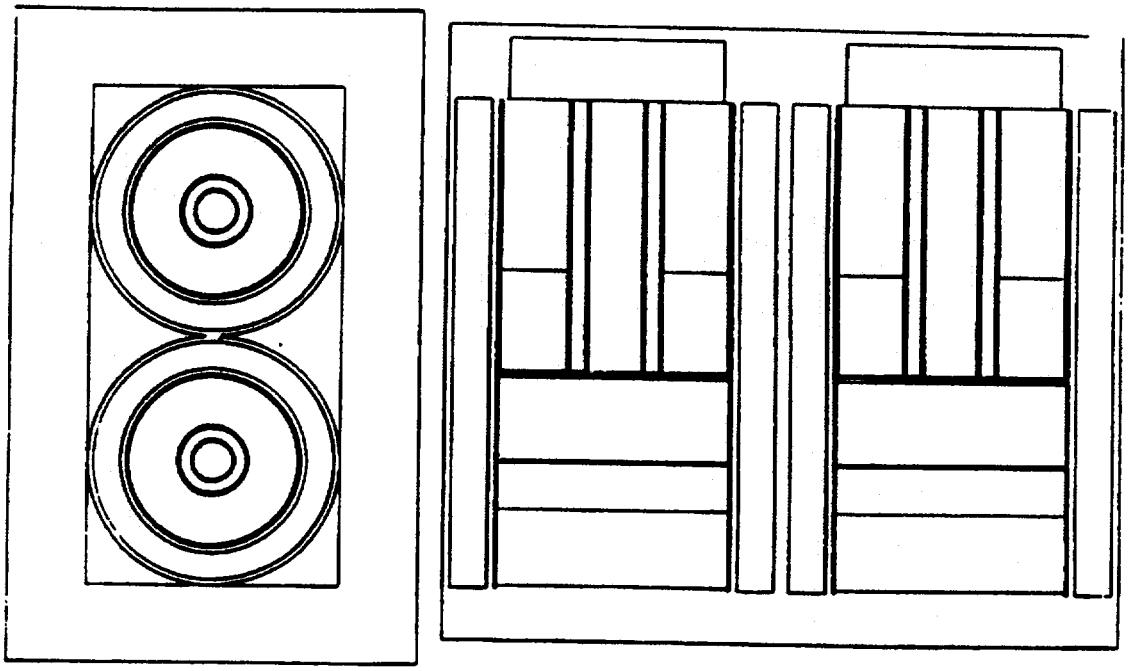

Figure 6.42. Accident Array for TSR Fuel — Top/Side View

```
TSR FUEL/ IF2000/  1/2 LOADING; SS+Pb SHIELDING. WFH2O IN FUEL=0.40 MASS
U235
    65 /* # BATCHES
  1000  /* # NEUTRONS PER BATCH
    5  /* # BATCHES TO SKIP
 2123469/* INITIAL "SEED" (IF NON-ZERO)
     0  /* "IDUMP"
     0  /* "NRSTRT"
     0  /* "NBTED" (NON-ZERO IS PRINT EDITS)
     0  /* "KRED" (NUMBER OF COMBINED REGIONS IN EDITS)
     0  293   28  9   /* LPRB  MODTH  NHMAX  MMAX
      5  293 0  0 U(93.2)+0.40 WF -H2O RHOMIX=1.628245 g/cc TOP MAT 1
       1  4.3579075E-02
      16  2.1789538E-02
     131  2.0884125E-02
    2381  7.1546610E-06
    2351  9.8537668E-05
      4  293 0 0 Boral 0.25" Plate +/- 10% (60% Boron Loading)  MAT 2
    10    3.254E-03
    11    1.310E-02
    12    6.815E-03
   131    4.376E-02
      2  293 0 0  MODERATOR IN CASK (100.00%)                   MAT 3
     1   6.69111121E-02
```

```
    16   3.34555566E-02
     2   293 0 0  INTERSPERSED MODERATOR (10.00%)            MAT4
     1   6.69111121E-03
    16   3.34555566E-03
     2   293 0 0 FULL DENSITY WATER                    MAT 5
     1    6.69111121E-02
    16    3.34555566E-02
     1   293 0 0 LEAD SHIELDING                        MAT 6
    82   3.29890E-02
     7   293 0 0 304 STAINLESS STEEL                   MAT 7
    12   6.82690E-05
    14   8.53360E-04
    24   1.53600E-02
    26   6.04950E-02
    28   6.82690E-03
    55   1.70670E-03
  1316   2.56010E-05
     5   293 0  0 U(93.2)+0.40 WF -H2O RHOMIX=1.648385 g/cc MID MAT 8
     1   4.4118110E-02
    16   2.2059055E-02
   131   2.0274300E-02
  2381   1.3983066E-05
  2351   1.9258181E-04
     5   293 0  0 U(93.2)+0.40 WF -H2O RHOMIX=1.626039 g/cc BOTTOM MAT 9
     1   4.3520026E-02
    16   2.1760013E-02
   131   2.0950921E-02
  2381   6.4067144E-06
  2351   8.8236578E-05
KENO GEOM
    28  /* "KREFM"
     7  /* "NBOX"
     1  /* "NBXMAX"
     1  /* "NBYMAX"
     1  /* "NBZMAX"
     0  /* "NXX"
     0  /* "NTYPST"
     1  /* "NEMBRG"
     0  /* "NGMCHK"
BOX TYPE     1 /*MODEL 2000 CASK & STAINLESS SUPPORT STRUCTURE
CYLINDER      7  33.34      140.64      0.0     16*0.5
CYLINDER      3  33.65      140.64      0.0     16*0.5
CYLINDER      7  35.85      140.64      0.0     16*0.5
CYLINDER      6  46.34      140.64      0.0     16*0.5
CYLINDER      7  48.56      140.64    -14.90    16*0.5
BOX TYPE     2 /* CASK TOP
CYLINDER      6  30.96      158.42     140.64  16*0.5
CYLINDER      7  48.56      162.23     140.64  16*0.5
BOX TYPE     3  /*  TOP SECTION (TOP COMPARTMENT)
CYLINDER      5    7.70255    140.64      87.95476      16*0.5   /* TOP
WATER
CYLINDER      7    8.41375    140.64      87.95476      16*0.5   /* TOP
S.S.
CYLINDER      5   12.7254     140.64      87.95476      16*0.5   /* TOP
WATER
CYLINDER      7   13.6525     140.64      87.95476      16*0.5   /* TOP
S.S.
CYLINDER      5   32.7025     140.64      87.95476      16*0.5   /* TOP
WATER
CYLINDER      7   33.3400     140.64      87.95476      16*0.5   /* TOP
WATER
```

```
BOX TYPE     4  /* BOTTOM SECTION (TOP COMPARTMENT) CONCENTRIC FUEL
H=25.08976
CYLINDER     5    7.70255    87.95476     62.8650    16*0.5   /* TOP
WATER
CYLINDER     7    8.41375    87.95476     62.8650    16*0.5   /* TOP
S.S.
CYLINDER     5   12.7254     87.95476     62.8650    16*0.5   /* TOP
WATER
CYLINDER     7   13.6525     87.95476     62.8650    16*0.5   /* TOP S.S
CYLINDER     1   32.7025     87.95476     62.8650    16*0.5   /* TOP
FUEL
CYLINDER     7   33.340       87.95476     62.8650   16*0.5   /* TOP
WATER
BOX TYPE     5  /* MID FUEL (CYL. PANCAKE) H=1.158161
CYLINDER     5  33.340     61.0718    36.83    16*0.5   /* MID WATER
CYLINDER     8  33.340     62.2300    36.83    16*0.5   /* MID FUEL
CYLINDER     7  33.340     62.8650    36.83    16*0.5   /* MID S.S.
BOX TYPE     6  /* BOTTOM FUEL(CYL. PANCAKE) H=11.74077
CYLINDER     7  33.340      0.6350   0.000    16*0.5   /* BOTTOM S.S.
CYLINDER     5  33.340     24.45423   0.000    16*0.5   /* BOTTOM WATER
CYLINDER     9  33.340     36.1950   0.000    16*0.5   /* BOTTOM FUEL
CYLINDER     7  33.340     36.830   0.000    16*0.5   /* BOTTOM S.S.
BOX TYPE     7  /* OVERALL BOX FOR THE PROBLEM
CUBOID       4  97.20    -97.20   48.60 -48.60 162.23 -15.24 16*0.5
CUBOID       5  127.20  -127.20   79.10 -79.10 192.71 -45.72 16*0.5
 7  1 1 1  1 1 1  1 1 1  1
BEGIN COMPLEX
/* PLACE FUEL AT THE THREE COMPARTMENTS
COMPLEX  1  3   0.000    0.0000  0.000  1  1  1   0.000   0.000  0.0
COMPLEX  1  4   0.000    0.0000  0.000  1  1  1   0.000   0.000  0.0
COMPLEX  1  5   0.000    0.0000  0.000  1  1  1   0.000   0.000  0.0
COMPLEX  1  6   0.000    0.0000  0.000  1  1  1   0.000   0.000  0.0
/*
/* PLACE LOADED CASK INTO OVERALL PROBLEM BOX
COMPLEX  7  1  -48.6     0.0    0.0   2 1 1   97.2    0.0    0.0
/* PLACE TOP INTO OVERALL PROBLEM BOX
COMPLEX  7  2  -48.6     0.0    0.0   2 1 1   97.2    0.0    0.0
END GEOM
*END GEMER*
```

6.7.3.5.1.4 Infinite (94.0% Enriched Fuel)

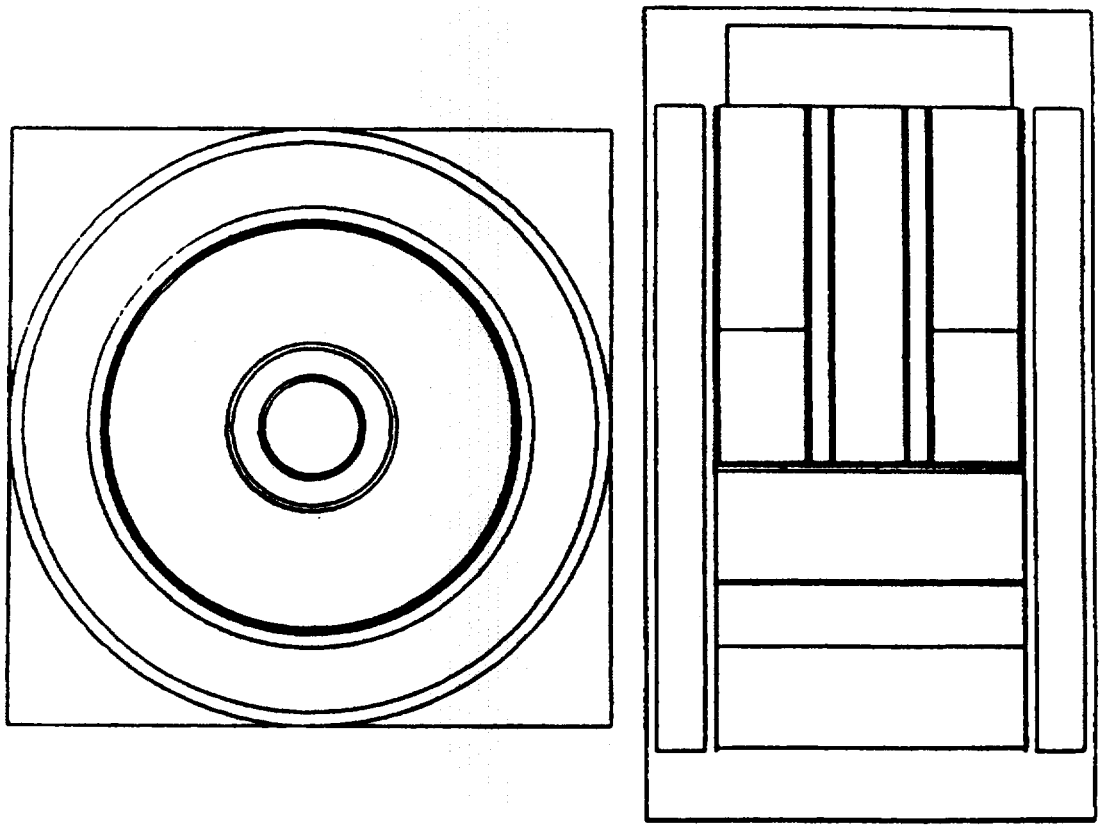

Figure 6.43. Unit Array for TSR Fuel — Top/Side View

```
TSR FUEL/ IF2000/  1/2 LOADING; SS+Pb SHIELDING. WFH2O IN FUEL 0.50 WF
MASS U235
    65 /* # BATCHES
  1000  /* # NEUTRONS PER BATCH
    5  /* # BATCHES TO SKIP
 2123469/* INITIAL "SEED" (IF NON-ZERO)
     0  /* "IDUMP"
     0  /* "NRSTRT"
     0  /* "NBTED" (NON-ZERO IS PRINT EDITS)
     0  /* "KRED" (NUMBER OF COMBINED REGIONS IN EDITS)
     0  293   28  10   /* LPRB  MODTH  NHMAX  MMAX
      5  293 0  0 U(94)+ 0.50 WF -H2O RHOMIX=2.800714 g/cc TOP MAT 1
       1  4.9306229E-02
      16  2.4653114E-02
     131  1.5758760E-02
    2381  4.6842210E-06
    2351  7.4324977E-05
      4  293 0 0 Boral 0.25" Plate +/- 10% (60% Boron Loading)  MAT 2
    10    3.254E-03
    11    1.310E-02
    12    6.815E-03
   131    4.376E-02
      2  293 0 0  MODERATOR IN CASK (100.00%)                    MAT 3
     1   6.69111121E-02
    16   3.34555566E-02
      2  293 0 0  INTERSPERSED MODERATOR (100.00%)            MAT4
     1   6.69111121E-02
    16   3.34555566E-02
      2  293 0 0 FULL DENSITY WATER                     MAT 5
     1    6.69111121E-02
    16    3.34555566E-02
      1  293 0 0 LEAD SHIELDING                         MAT 6
    82   3.29890E-02
      7  293 0 0 304 STAINLESS STEEL                    MAT 7
    12   6.82690E-05
    14   8.53360E-04
    24   1.53600E-02
    26   6.04950E-02
    28   6.82690E-03
    55   1.70670E-03
  1316   2.56010E-05
      5  293 0  0 U(94)+ 0.50 WF -H2O RHOMIX= 1.487366g/cc MID MAT 8
       1  4.9760666E-02
      16  2.4880333E-02
     131  1.5257123E-02
    2381  9.1263328E-06
    2351  1.4480825E-04
      5  293 0  0 U(94)+ 0.50 WF -H2O RHOMIX=1.472290 g/cc BOTTOM MAT 9
       1  4.9256280E-02
      16  2.4628140E-02
     131  1.5813896E-02
    2381  4.1959734E-06
    2351  6.6577864E-05
    2  293 0 0 FULL DENSITY WATER (VOID)             MAT 10
     1    6.69111121E-09
    16    3.34555566E-09
KENO GEOM
    28  /* "KREFM"
     7  /* "NBOX"
     1  /* "NBXMAX"
     1  /* "NBYMAX"
```

```
     1  /* "NBZMAX"
     1  /* "NXX"
     0  /* "NTYPST"
     1  /* "NEMBRG"
     0  /* "NGMCHK"
  -1.0  -1.0  -1.0  -1.0  -1.0  -1.0
BOX TYPE    1 /*MODEL 2000 CASK & STAINLESS SUPPORT STRUCTURE
CYLINDER     7  33.34     140.64     0.0    16*0.5
CYLINDER     3  33.65     140.64     0.0    16*0.5
CYLINDER     7  35.85     140.64     0.0    16*0.5
CYLINDER     6  46.34     140.64     0.0    16*0.5
CYLINDER     7  48.56     140.64   -14.90   16*0.5
BOX TYPE    2 /* CASK TOP
CYLINDER     6  30.96     158.42    140.64  16*0.5
CYLINDER     7  48.56     162.23    140.64  16*0.5
BOX TYPE    3  /*  TOP SECTION (TOP COMPARTMENT)
CYLINDER     5    7.70255    140.64     96.1282    16*0.5   /* TOP WATER
CYLINDER     7    8.41375    140.64     96.1282    16*0.5   /* TOP S.S.
CYLINDER     5   12.7254     140.64     96.1282    16*0.5   /* TOP WATER
CYLINDER     7   13.6525     140.64     96.1282    16*0.5   /* TOP S.S.
CYLINDER     5   32.7025     140.64     96.1282    16*0.5   /* TOP WATER
CYLINDER     7   33.3400     140.64     96.1282    16*0.5   /* TOP WATER
BOX TYPE    4  /* BOTTOM SECTION (TOP COMPARTMENT) CONC. FUEL H=33.26319
CYLINDER     5    7.70255    96.1282    62.865    16*0.5   /* TOP WATER
CYLINDER     7    8.41375    96.1282    62.865    16*0.5   /* TOP S.S.
CYLINDER     5   12.7254     96.1282    62.865    16*0.5   /* TOP WATER
CYLINDER     7   13.6525     96.1282    62.865    16*0.5   /* TOP S.S
CYLINDER     1   32.7025     96.1282    62.865    16*0.5   /* TOP FUEL
CYLINDER     7   33.340      96.1282    62.865    16*0.5   /* TOP WATER
BOX TYPE    5  /* MID FUEL (CYL. PANCAKE) H=1.539980
CYLINDER     5  33.340     60.68975    36.83    16*0.5   /* ********MID
WATER
CYLINDER     8  33.340     62.2300    36.83    16*0.5   /* MID FUEL
CYLINDER     7  33.340     62.8650    36.83    16*0.5   /* MID S.S.
BOX TYPE    6  /* BOTTOM FUEL(CYL. PANCAKE) H=15.55897
CYLINDER     7  33.340      0.6350   0.000    16*0.5   /* BOTTOM S.S.
CYLINDER     5  33.340     20.63479   0.000    16*0.5   /* *******BOTTOM
WATER
CYLINDER     9  33.340     36.1950   0.000    16*0.5   /* BOTTOM FUEL
CYLINDER     7  33.340     36.830   0.000    16*0.5   /* BOTTOM S.S.
BOX TYPE    7  /* OVERALL BOX FOR THE PROBLEM
CUBOID      10  48.60    -48.60   48.60 -48.60 162.23 -14.91 16*0.5
CUBOID      10  48.70    -48.70   48.70 -48.70 162.33 -15.01 16*0.5
 7  1 1 1  1 1 1  1 1 1  1
BEGIN COMPLEX
/* PLACE FUEL AT THE THREE COMPARTMENTS
COMPLEX  1  3   0.000    0.0000  0.000  1  1  1   0.000   0.000  0.0
COMPLEX  1  4   0.000    0.0000  0.000  1  1  1   0.000   0.000  0.0
COMPLEX  1  5   0.000    0.0000  0.000  1  1  1   0.000   0.000  0.0
COMPLEX  1  6   0.000    0.0000  0.000  1  1  1   0.000   0.000  0.0
/*
/* PLACE LOADED CASK INTO OVERALL PROBLEM BOX
COMPLEX  7  1  0.0     0.0    0.0   1 1 1   0.0    0.0    0.0
/* PLACE TOP INTO OVERALL PROBLEM BOX
COMPLEX  7  2  0.0     0.0    0.0   1 1 1   0.0    0.0    0.0
END GEOM
*END GEMER*
```

6.7.3.5.2 Number Density Calculations

6.7.3.5.2.1 FORTRAN Program

```
PROGRAM P4
C
C     PROGRAM TO CALCULATE THE FUEL/WATER MIXTURE HEIGHT AND
C       THE FUEL/WATER MIXTURE NUMBER DENSITIES.
C
C                 A. CHUNG 7/26/95
C
C    FOR TSR REACTOR
C    THREE COMPARTMENTS
C
C  INDEX FOR THE ARRAY:
C
C   1  -- ANNULAR
C   2  -- UPPER
C   3  -- LOWER
C   4  -- CYLINDRICAL
C   5  -- LUBE PLATE
C
        DIMENSION U235(5),U238(5),ALFUEL(5),ALCLAD(5),NELEMENT(5)
        DIMENSION WF(5),WEIGHT(5)
        DIMENSION HZ(3)
        DIMENSION U235TOT(3),U238TOT(3),ALFUELTOT(3),ALCLADTOT(3)
        DIMENSION H_PARTS(3),U_PARTS(3)
        REAL N238,N235,N16,N131,N1
        REAL M238,M235,MAL,MO16,MH20,MH
C
        DATA PI/3.1415926/
        DATA U235/441.0,353.0,353.0,31.0,76.0/
        DATA WF/0.20,0.20,0.20,0.20,0.30/
        DATA NELEMENT/6,2,2,1,4/
C        DATA NELEMENT/4,2,1,0,3/
        DATA WEIGHT/11000.0,10000.0,10000.0,2000.0,1000.0/
        DATA HZ/62.865,62.230,36.1950/
        RHOU=19.1
        RHOAL=2.7
C
C        ENRICH=0.9315
        ENRICH=0.940
        RHOWATER=1.0
        OPEN(6,FILE='TSR_94.OUT',STATUS='UNKNOWN')
      AV=0.6022
      M235 =235.0439
      M238 =238.0508
      MAL = 26.98
      MO16 = 16.000
      MH2O=18.0
      MH=1.0
C
C
        WRITE(6,*) '   ON UNIT ELEMNET BASIS '
        WRITE(6,110)
 110   format(6x,'U235',9x,'U238',8x,'AL(FUEL)',7X,'AL(CLAD)',8X,
     1   'NELEMENT')
C
C    PER ELEMENT BASIS
```

```
C
        DO 100 I=1,5
        U238(I)=(U235(I)/ENRICH-U235(I))
        ALFUEL(I)=((U235(I)+U238(I))/WF(I)*(1.0-WF(I)))
        ALCLAD(I)=(WEIGHT(I)-(ALFUEL(I)+U235(I)+U238(I)))
        WRITE(6,*) U235(I),U238(I),ALFUEL(I),ALCLAD(I),NELEMENT(I)
 100    CONTINUE
C
        WRITE(6,*) '  ON ALL ELEMENT BASIS'
        WRITE(6,110)
        DO 170 I=1,5
        Z=FLOAT(NELEMENT(I))
        U238(I)=U238(I)*Z
        U235(I)=U235(I)*Z
        ALFUEL(I)=ALFUEL(I)*Z
        ALCLAD(I)=ALCLAD(I)*Z
        WRITE(6,*) U235(I),U238(I),ALFUEL(I),ALCLAD(I),NELEMENT(I)
 170    CONTINUE
C
C     TOP COMPARTMENT
C
c    use this section to lump the middle compartment fuel
c              to the top compartment (variation #1)
c       U235TOT(1)=U235(1)+U235(4)+u235(5)
c       U238TOT(1)=U238(1)+U238(4)+u238(5)
c       ALFUELTOT(1)=ALFUEL(1)+ALFUEL(4)+alfuel(5)
c       ALCLADTOT(1)=ALCLAD(1)+ALCLAD(4)+alclad(5)
       U235TOT(1)=U235(1)+U235(4)
       U238TOT(1)=U238(1)+U238(4)
       ALFUELTOT(1)=ALFUEL(1)+ALFUEL(4)
       ALCLADTOT(1)=ALCLAD(1)+ALCLAD(4)
C    MID-COMPARTMENT
       U235TOT(2)=U235(5)
       U238TOT(2)=U238(5)
       ALFUELTOT(2)=ALFUEL(5)
       ALCLADTOT(2)=ALCLAD(5)
C    BOTTOM COMPARTMENT
       U235TOT(3)=U235(2)+U235(3)
       U238TOT(3)=U238(2)+U238(3)
       ALFUELTOT(3)=ALFUEL(2)+ALFUEL(3)
       ALCLADTOT(3)=ALCLAD(2)+ALCLAD(3)
C
C
       DO 300 I=0,15
       WRITE(6,*) ' ****************************************'
       DO 400 J=1,3
       WRITE(6,*) ' ****************************************'
       IF (J.EQ.1) WRITE(6,*) '  TOP COMPARTMENT'
       IF (J.EQ.2) WRITE(6,*) '  MIDDLE-COMPARTMENT'
       IF (J.EQ.3) WRITE(6,*) '  BOTTOM COMPARTMENT'

       ALTOTAL=ALFUELTOT(J)+ALCLADTOT(J)
       TOTAL=U235TOT(J)+U238TOT(J)+ALFUELTOT(J)+ALCLADTOT(J)
       VOLU = (U235TOT(J)+U238TOT(J))/RHOU
       VOLAL =(ALFUELTOT(J) + ALCLADTOT(J))/RHOAL
       RHOMIX1=TOTAL/(VOLU+VOLAL)
       WRITE(6,*) ' SOLID MIXTURE DENSITY =',RHOMIX1,' G/CM^3)'
       WRITE(6,*) ' MASSSE OF U235, U238 AND U235+U238 (GRAMS) =',
     *      U235TOT(J),U238TOT(J),U235TOT(J)+U238TOT(J)
       WRITE(6,*) ' VOLUME OF U235 +U238 =',VOLU,' CM^3'
       WRITE(6,*) ' VOLUME OF AL(FUEL) +AL(CLAD) =',VOLAL,' CM^3'
```

```
      WRITE(6,*) ' TOTAL MASS (AL + U) =',TOTAL,' GRAMS'
C
      WRITE(6,*) '  '
      WFWATER=.05*FLOAT(I)
      WRITE(6,*) ' WEIGHT FRACTION OF WATER (WFWATER)=',WFWATER
      WATERMAS=TOTAL/(1.0-WFWATER)*WFWATER
      WRITE(6,*) ' WATER MASS (GRAMS) =',WATERMAS
      VOLTOT=WATERMAS/RHOWATER + TOTAL/RHOMIX1
      WRITE(6,*) ' TOTAL VOLUME(FUEL+CLAD+WATER)=',VOLTOT,' CM^3'
C      RADIUS=(VOLTOT*3.0/4.0/PI)**(1./3.)
C      WRITE(6,*) ' SPHERICAL RADIUS =',RADIUS,' CM'
C
C     RADIUS=0.55*HEIGHT
C
C
C      HEIGHT1=(VOLTOT/(PI*.55*.55))**(1./3.)
C
C      RADIUS1=0.55*HEIGHT1
C
C      WRITE(6,*) ' CYLINDRICAL HEIGHT =',HEIGHT1,' CM'
C      WRITE(6,*) ' CYLINDRICAL RADIUS =',RADIUS1,' CM'
C
     IF (J.EQ.1) THEN
     RINNER=13.6525
     ROUTER=32.7025
     END IF
     IF ((J.EQ.2).OR.(J.EQ.3)) THEN
     RINNER=0.000
     ROUTER=33.340
     END IF
C
     HEIGHT2=VOLTOT/(PI*(ROUTER*ROUTER-RINNER*RINNER))
      WRITE(6,*) '   '
      WRITE (6,*) ' CONCENTRIC CYLINDER CASE '
      WRITE(6,*) ' CYLINDRICAL HEIGHT =',HEIGHT2,' CM'
      IF (J.EQ.1) WRITE(6,*) ' HZ(',J,') =',HEIGHT2+HZ(J),' CM'
      IF (J.EQ.2) WRITE(6,*) ' HZ(',J,') =',HZ(J)-HEIGHT2,' CM'
      IF (J.EQ.3) WRITE(6,*) ' HZ(',J,') =',HZ(J)-HEIGHT2,' CM'
      WRITE(6,*) ' INNER CONCENTRIC RADIUS =',RINNER,' CM'
      WRITE(6,*) ' OUTER CONCENTRIC RADIUS =',ROUTER,' CM'
C
     N235 = U235TOT(J)*AV/M235/VOLTOT
     N238 = U238TOT(J)*AV/M238/VOLTOT
     N16 =  WATERMAS*AV/VOLTOT/MH2O
     N131= ALTOTAL*AV/MAL/VOLTOT
     N1= 2.0*N16
     HURATIO=N1/N235
C
C      N1 = NUMBER DENSITY OF H-1
C     N16 = NUMBER DENSITY OF O-16
C    N131 = NUMBER DENSITY OF AL-27
C    N238 = NUMBER DENSITY OF U-238
C    N235 = NUMBER DENSITY OF U-235
C
     WRITE(6,*) ' N1  N16  N131  N238  N235'
     WRITE(6,*) '      1',N1
     WRITE(6,*) '     16',N16
     WRITE(6,*) '    131',N131
     WRITE(6,*) '   2381',N238
     WRITE(6,*) '   2351',N235
     WRITE(6,*) 'TOTAL',N1+N16+N131+N238+N235
```

```
      WRITE(6,*) ' H/U-235 RATIO =',HURATIO
       RHOMIX2=(TOTAL+WATERMAS)/VOLTOT
       WRITE(6,*) ' MIXTURE DENSITY =',RHOMIX2,' G/CC'
C
       U_PARTS(J)=N235
       H_PARTS(J)=N1
 400   CONTINUE
       HURAT=(H_PARTS(1)+H_PARTS(2)+H_PARTS(3))/
     *       (U_PARTS(1)+U_PARTS(2)+U_PARTS(3))
       WRITE(6,*) ' OVERALL H/U-235 RATIO =',HURAT


 300   CONTINUE
       END
```

6.7.3.5.2.2 FORTRAN Output

```
   ON UNIT ELEMNET BASIS
     U235          U238         AL(FUEL)        AL(CLAD)         NELEMENT
  441.0000       28.14893       1876.596        8654.256                6
  353.0000       22.53192       1502.128        8122.340                2
  353.0000       22.53192       1502.128        8122.340                2
  31.00000       1.978722       131.9149        1835.106                1
  76.00000       4.851067       188.6525        730.4965                4
  ON ALL ELEMENT BASIS
     U235          U238         AL(FUEL)        AL(CLAD)         NELEMENT
  2646.000       168.8936       11259.57        51925.54                6
  706.0000       45.06384       3004.255        16244.68                2
  706.0000       45.06384       3004.255        16244.68                2
  31.00000       1.978722       131.9149        1835.106                1
  304.0000       19.40427       754.6099        2921.986                4
 ****************************************
 ****************************************
  TOP COMPARTMENT
 SOLID MIXTURE DENSITY =   2.800714     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   2677.000       170.8723
  2847.872
 VOLUME OF U235 +U238 =   149.1033     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   24130.42     CM^3
 TOTAL MASS (AL + U) =   68000.00     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.0000000E+00
 WATER MASS (GRAMS) =  0.0000000E+00
 TOTAL VOLUME(FUEL+CLAD+WATER)=   24279.52     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   8.751826     CM
 HZ(           1) =   71.61683     CM
 INNER CONCENTRIC RADIUS =   13.65250     CM
 OUTER CONCENTRIC RADIUS =   32.70250     CM
 N1  N16  N131  N238  N235
      1  0.0000000E+00
     16  0.0000000E+00
    131  5.9894547E-02
   2381  1.7803386E-05
   2351  2.8248801E-04
TOTAL  6.0194839E-02
 H/U-235 RATIO =  0.0000000E+00
 MIXTURE DENSITY =   2.800714     G/CC
 ****************************************
```

```
 MIDDLE-COMPARTMENT
SOLID MIXTURE DENSITY =   2.901422     G/CM^3)
MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   304.0000       19.40427
 323.4043
VOLUME OF U235 +U238 =   16.93216     CM^3
VOLUME OF AL(FUEL) +AL(CLAD) =   1361.702     CM^3
TOTAL MASS (AL + U) =   4000.000     GRAMS

WEIGHT FRACTION OF WATER (WFWATER)=  0.0000000E+00
WATER MASS (GRAMS) =  0.0000000E+00
TOTAL VOLUME(FUEL+CLAD+WATER)=   1378.634     CM^3

CONCENTRIC CYLINDER CASE
CYLINDRICAL HEIGHT =  0.3947917     CM
HZ(           2) =   61.83521     CM
INNER CONCENTRIC RADIUS =  0.0000000E+00 CM
OUTER CONCENTRIC RADIUS =   33.34000     CM
N1  N16  N131  N238  N235
     1  0.0000000E+00
    16  0.0000000E+00
   131  5.9524477E-02
  2381  3.5605673E-05
  2351  5.6495814E-04
TOTAL  6.0125042E-02
H/U-235 RATIO =  0.0000000E+00
MIXTURE DENSITY =   2.901422     G/CC
*****************************************
 BOTTOM COMPARTMENT
SOLID MIXTURE DENSITY =   2.789961     G/CM^3)
MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   1412.000       90.12769
 1502.128
VOLUME OF U235 +U238 =   78.64542     CM^3
VOLUME OF AL(FUEL) +AL(CLAD) =   14258.47     CM^3
TOTAL MASS (AL + U) =   40000.00     GRAMS

WEIGHT FRACTION OF WATER (WFWATER)=  0.0000000E+00
WATER MASS (GRAMS) =  0.0000000E+00
TOTAL VOLUME(FUEL+CLAD+WATER)=   14337.12     CM^3

CONCENTRIC CYLINDER CASE
CYLINDRICAL HEIGHT =   4.105639     CM
HZ(           3) =   32.08936     CM
INNER CONCENTRIC RADIUS =  0.0000000E+00 CM
OUTER CONCENTRIC RADIUS =   33.34000     CM
N1  N16  N131  N238  N235
     1  0.0000000E+00
    16  0.0000000E+00
   131  5.9934057E-02
  2381  1.5902577E-05
  2351  2.5232753E-04
TOTAL  6.0202289E-02
H/U-235 RATIO =  0.0000000E+00
MIXTURE DENSITY =   2.789961     G/CC
OVERALL H/U-235 RATIO =  0.0000000E+00
*****************************************
*****************************************
 TOP COMPARTMENT
SOLID MIXTURE DENSITY =   2.800714     G/CM^3)
MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   2677.000       170.8723
 2847.872
VOLUME OF U235 +U238 =   149.1033     CM^3
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 VOLUME OF AL(FUEL) +AL(CLAD) =   24130.42     CM^3
 TOTAL MASS (AL + U) =   68000.00     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  5.0000001E-02
 WATER MASS (GRAMS) =   3578.947
 TOTAL VOLUME(FUEL+CLAD+WATER)=   27858.47     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   10.04190     CM
 HZ(           1) =   72.90690     CM
 INNER CONCENTRIC RADIUS =   13.65250     CM
 OUTER CONCENTRIC RADIUS =   32.70250     CM
 N1  N16  N131  N238  N235
      1  8.5959975E-03
     16  4.2979987E-03
    131  5.2199960E-02
   2381  1.5516203E-05
   2351  2.4619707E-04
TOTAL  6.5355673E-02
 H/U-235 RATIO =   34.91511
 MIXTURE DENSITY =   2.569378     G/CC
 ****************************************
  MIDDLE-COMPARTMENT
 SOLID MIXTURE DENSITY =   2.901422     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   304.0000       19.40427
  323.4043
 VOLUME OF U235 +U238 =   16.93216     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   1361.702     CM^3
 TOTAL MASS (AL + U) =   4000.000     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  5.0000001E-02
 WATER MASS (GRAMS) =   210.5263
 TOTAL VOLUME(FUEL+CLAD+WATER)=   1589.161     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =  0.4550789     CM
 HZ(           2) =   61.77492     CM
 INNER CONCENTRIC RADIUS =  0.0000000E+00 CM
 OUTER CONCENTRIC RADIUS =   33.34000     CM
 N1  N16  N131  N238  N235
      1  8.8641448E-03
     16  4.4320724E-03
    131  5.1638886E-02
   2381  3.0888761E-05
   2351  4.9011450E-04
TOTAL  6.5456107E-02
 H/U-235 RATIO =   18.08587
 MIXTURE DENSITY =   2.649529     G/CC
 ****************************************
  BOTTOM COMPARTMENT
 SOLID MIXTURE DENSITY =   2.789961     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   1412.000       90.12769
  1502.128
 VOLUME OF U235 +U238 =   78.64542     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   14258.47     CM^3
 TOTAL MASS (AL + U) =   40000.00     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  5.0000001E-02
 WATER MASS (GRAMS) =   2105.263
 TOTAL VOLUME(FUEL+CLAD+WATER)=   16442.38     CM^3
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 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   4.708511     CM
 HZ(           3) =   31.48649     CM
 INNER CONCENTRIC RADIUS =  0.0000000E+00 CM
 OUTER CONCENTRIC RADIUS =   33.34000     CM
 N1  N16  N131  N238  N235
      1  8.5672215E-03
     16  4.2836107E-03
    131  5.2260172E-02
   2381  1.3866430E-05
   2351  2.2001981E-04
TOTAL  6.5344892E-02
 H/U-235 RATIO =   38.93841
 MIXTURE DENSITY =   2.560777     G/CC
 OVERALL H/U-235 RATIO =   27.21584
 ****************************************
 ****************************************
  TOP COMPARTMENT
 SOLID MIXTURE DENSITY =   2.800714     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   2677.000       170.8723
  2847.872
 VOLUME OF U235 +U238 =   149.1033     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   24130.42     CM^3
 TOTAL MASS (AL + U) =   68000.00     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.1000000
 WATER MASS (GRAMS) =   7555.556
 TOTAL VOLUME(FUEL+CLAD+WATER)=   31835.08     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   11.47531     CM
 HZ(           1) =   74.34032     CM
 INNER CONCENTRIC RADIUS =   13.65250     CM
 OUTER CONCENTRIC RADIUS =   32.70250     CM
 N1  N16  N131  N238  N235
      1  1.5880302E-02
     16  7.9401508E-03
    131  4.5679517E-02
   2381  1.3578031E-05
   2351  2.1544390E-04
TOTAL  6.9728985E-02
 H/U-235 RATIO =   73.70969
 MIXTURE DENSITY =   2.373343     G/CC
 ****************************************
  MIDDLE-COMPARTMENT
 SOLID MIXTURE DENSITY =   2.901422     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   304.0000       19.40427
  323.4043
 VOLUME OF U235 +U238 =   16.93216     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   1361.702     CM^3
 TOTAL MASS (AL + U) =   4000.000     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.1000000
 WATER MASS (GRAMS) =   444.4444
 TOTAL VOLUME(FUEL+CLAD+WATER)=   1823.079     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =  0.5220647     CM
 HZ(           2) =   61.70794     CM
 INNER CONCENTRIC RADIUS =  0.0000000E+00 CM
 OUTER CONCENTRIC RADIUS =   33.34000     CM
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 N1  N16  N131  N238  N235
      1  1.6312115E-02
     16  8.1560574E-03
    131  4.5013133E-02
   2381  2.6925443E-05
   2351  4.2722819E-04
TOTAL  6.9935463E-02
 H/U-235 RATIO =   38.18127
 MIXTURE DENSITY =   2.437878     G/CC
 ****************************************
  BOTTOM COMPARTMENT
 SOLID MIXTURE DENSITY =   2.789961     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   1412.000       90.12769
  1502.128
 VOLUME OF U235 +U238 =   78.64542     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   14258.47     CM^3
 TOTAL MASS (AL + U) =   40000.00     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.1000000
 WATER MASS (GRAMS) =   4444.445
 TOTAL VOLUME(FUEL+CLAD+WATER)=   18781.56     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   5.378369     CM
 HZ(           3) =   30.81663     CM
 INNER CONCENTRIC RADIUS =  0.0000000E+00 CM
 OUTER CONCENTRIC RADIUS =   33.34000     CM
 N1  N16  N131  N238  N235
      1  1.5833760E-02
     16  7.9168798E-03
    131  4.5751341E-02
   2381  1.2139411E-05
   2351  1.9261707E-04
TOTAL  6.9706738E-02
 H/U-235 RATIO =   82.20331
 MIXTURE DENSITY =   2.366387     G/CC
 OVERALL H/U-235 RATIO =   57.49647
 ****************************************
 ****************************************
  TOP COMPARTMENT
 SOLID MIXTURE DENSITY =   2.800714     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   2677.000       170.8723
  2847.872
 VOLUME OF U235 +U238 =   149.1033     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   24130.42     CM^3
 TOTAL MASS (AL + U) =   68000.00     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.1500000
 WATER MASS (GRAMS) =   12000.00
 TOTAL VOLUME(FUEL+CLAD+WATER)=   36279.52     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   13.07736     CM
 HZ(           1) =   75.94237     CM
 INNER CONCENTRIC RADIUS =   13.65250     CM
 OUTER CONCENTRIC RADIUS =   32.70250     CM
 N1  N16  N131  N238  N235
      1  2.2131860E-02
     16  1.1065930E-02
    131  4.0083516E-02
   2381  1.1914646E-05
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   2351  1.8905081E-04
TOTAL  7.3482275E-02
 H/U-235 RATIO =   117.0683
 MIXTURE DENSITY =   2.205101     G/CC
 ****************************************
  MIDDLE-COMPARTMENT
 SOLID MIXTURE DENSITY =   2.901422     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   304.0000       19.40427
  323.4043
 VOLUME OF U235 +U238 =   16.93216     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   1361.702     CM^3
 TOTAL MASS (AL + U) =   4000.000     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.1500000
 WATER MASS (GRAMS) =   705.8824
 TOTAL VOLUME(FUEL+CLAD+WATER)=   2084.517     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =  0.5969312     CM
 HZ(           2) =   61.63307     CM
 INNER CONCENTRIC RADIUS =  0.0000000E+00 CM
 OUTER CONCENTRIC RADIUS =   33.34000     CM
 N1  N16  N131  N238  N235
      1  2.2658192E-02
     16  1.1329096E-02
    131  3.9367635E-02
   2381  2.3548484E-05
   2351  3.7364569E-04
TOTAL  7.3752120E-02
 H/U-235 RATIO =   60.64085
 MIXTURE DENSITY =   2.257541     G/CC
 ****************************************
  BOTTOM COMPARTMENT
 SOLID MIXTURE DENSITY =   2.789961     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   1412.000       90.12769
  1502.128
 VOLUME OF U235 +U238 =   78.64542     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   14258.47     CM^3
 TOTAL MASS (AL + U) =   40000.00     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.1500000
 WATER MASS (GRAMS) =   7058.823
 TOTAL VOLUME(FUEL+CLAD+WATER)=   21395.94     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   6.127034     CM
 HZ(           3) =   30.06797     CM
 INNER CONCENTRIC RADIUS =  0.0000000E+00 CM
 OUTER CONCENTRIC RADIUS =   33.34000     CM
 N1  N16  N131  N238  N235
      1  2.2074921E-02
     16  1.1037461E-02
    131  4.0160965E-02
   2381  1.0656092E-05
   2351  1.6908110E-04
TOTAL  7.3453084E-02
 H/U-235 RATIO =   130.5582
 MIXTURE DENSITY =   2.199428     G/CC
 OVERALL H/U-235 RATIO =   91.37336
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 TOP COMPARTMENT
SOLID MIXTURE DENSITY =   2.800714     G/CM^3)
MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   2677.000        170.8723
 2847.872
VOLUME OF U235 +U238 =   149.1033     CM^3
VOLUME OF AL(FUEL) +AL(CLAD) =   24130.42     CM^3
TOTAL MASS (AL + U) =   68000.00     GRAMS

WEIGHT FRACTION OF WATER (WFWATER)=  0.2000000
WATER MASS (GRAMS) =   17000.00
TOTAL VOLUME(FUEL+CLAD+WATER)=   41279.52     CM^3

CONCENTRIC CYLINDER CASE
CYLINDRICAL HEIGHT =   14.87967     CM
HZ(           1) =   77.74467     CM
INNER CONCENTRIC RADIUS =   13.65250     CM
OUTER CONCENTRIC RADIUS =   32.70250     CM
N1  N16  N131  N238  N235
     1  2.7555764E-02
    16  1.3777882E-02
   131  3.5228387E-02
  2381  1.0471479E-05
  2351  1.6615195E-04
TOTAL  7.6738656E-02
H/U-235 RATIO =   165.8468
MIXTURE DENSITY =   2.059132     G/CC
****************************************
 MIDDLE-COMPARTMENT
SOLID MIXTURE DENSITY =   2.901422     G/CM^3)
MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   304.0000        19.40427
 323.4043
VOLUME OF U235 +U238 =   16.93216     CM^3
VOLUME OF AL(FUEL) +AL(CLAD) =   1361.702     CM^3
TOTAL MASS (AL + U) =   4000.000     GRAMS

WEIGHT FRACTION OF WATER (WFWATER)=  0.2000000
WATER MASS (GRAMS) =   1000.000
TOTAL VOLUME(FUEL+CLAD+WATER)=   2378.634     CM^3

CONCENTRIC CYLINDER CASE
CYLINDRICAL HEIGHT =  0.6811560     CM
HZ(           2) =   61.54884     CM
INNER CONCENTRIC RADIUS =  0.0000000E+00 CM
OUTER CONCENTRIC RADIUS =   33.34000     CM
N1  N16  N131  N238  N235
     1  2.8130051E-02
    16  1.4065025E-02
   131  3.4499831E-02
  2381  2.0636719E-05
  2351  3.2744446E-04
TOTAL  7.7042997E-02
H/U-235 RATIO =   85.90785
MIXTURE DENSITY =   2.102046     G/CC
****************************************
 BOTTOM COMPARTMENT
SOLID MIXTURE DENSITY =   2.789961     G/CM^3)
MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   1412.000        90.12769
 1502.128
VOLUME OF U235 +U238 =   78.64542     CM^3
VOLUME OF AL(FUEL) +AL(CLAD) =   14258.47     CM^3
TOTAL MASS (AL + U) =   40000.00     GRAMS
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 WEIGHT FRACTION OF WATER (WFWATER)=  0.2000000
 WATER MASS (GRAMS) =   10000.00
 TOTAL VOLUME(FUEL+CLAD+WATER)=   24337.12     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   6.969283     CM
 HZ(           3) =   29.22572     CM
 INNER CONCENTRIC RADIUS =  0.0000000E+00 CM
 OUTER CONCENTRIC RADIUS =   33.34000     CM
 N1  N16  N131  N238  N235
      1  2.7493440E-02
     16  1.3746720E-02
    131  3.5307452E-02
   2381  9.3682866E-06
   2351  1.4864739E-04
TOTAL  7.6705627E-02
 H/U-235 RATIO =   184.9574
 MIXTURE DENSITY =   2.054475     G/CC
 OVERALL H/U-235 RATIO =   129.5135
 ****************************************
 ****************************************
  TOP COMPARTMENT
 SOLID MIXTURE DENSITY =   2.800714     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   2677.000       170.8723
  2847.872
 VOLUME OF U235 +U238 =   149.1033     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   24130.42     CM^3
 TOTAL MASS (AL + U) =   68000.00     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.2500000
 WATER MASS (GRAMS) =   22666.67
 TOTAL VOLUME(FUEL+CLAD+WATER)=   46946.19     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   16.92228     CM
 HZ(           1) =   79.78728     CM
 INNER CONCENTRIC RADIUS =   13.65250     CM
 OUTER CONCENTRIC RADIUS =   32.70250     CM
 N1  N16  N131  N238  N235
      1  3.2306176E-02
     16  1.6153088E-02
    131  3.0976124E-02
   2381  9.2075143E-06
   2351  1.4609650E-04
TOTAL  7.9590701E-02
 H/U-235 RATIO =   221.1290
 MIXTURE DENSITY =   1.931289     G/CC
 ****************************************
  MIDDLE-COMPARTMENT
 SOLID MIXTURE DENSITY =   2.901422     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   304.0000       19.40427
  323.4043
 VOLUME OF U235 +U238 =   16.93216     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   1361.702     CM^3
 TOTAL MASS (AL + U) =   4000.000     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.2500000
 WATER MASS (GRAMS) =   1333.333
 TOTAL VOLUME(FUEL+CLAD+WATER)=   2711.968     CM^3
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 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =  0.7766109     CM
 HZ(           2) =   61.45339     CM
 INNER CONCENTRIC RADIUS =  0.0000000E+00 CM
 OUTER CONCENTRIC RADIUS =   33.34000     CM
 N1  N16  N131  N238  N235
      1  3.2896712E-02
     16  1.6448356E-02
    131  3.0259388E-02
   2381  1.8100216E-05
   2351  2.8719759E-04
TOTAL  7.9909749E-02
 H/U-235 RATIO =   114.5438
 MIXTURE DENSITY =   1.966592     G/CC
 ****************************************
  BOTTOM COMPARTMENT
 SOLID MIXTURE DENSITY =   2.789961     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   1412.000       90.12769
  1502.128
 VOLUME OF U235 +U238 =   78.64542     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   14258.47     CM^3
 TOTAL MASS (AL + U) =   40000.00     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.2500000
 WATER MASS (GRAMS) =   13333.33
 TOTAL VOLUME(FUEL+CLAD+WATER)=   27670.45     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   7.923830     CM
 HZ(           3) =   28.27117     CM
 INNER CONCENTRIC RADIUS =  0.0000000E+00 CM
 OUTER CONCENTRIC RADIUS =   33.34000     CM
 N1  N16  N131  N238  N235
      1  3.2241907E-02
     16  1.6120953E-02
    131  3.1054124E-02
   2381  8.2397319E-06
   2351  1.3074053E-04
TOTAL  7.9555973E-02
 H/U-235 RATIO =   246.6099
 MIXTURE DENSITY =   1.927447     G/CC
 OVERALL H/U-235 RATIO =   172.7639
 ****************************************
 ****************************************
  TOP COMPARTMENT
 SOLID MIXTURE DENSITY =   2.800714     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   2677.000       170.8723
  2847.872
 VOLUME OF U235 +U238 =   149.1033     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   24130.42     CM^3
 TOTAL MASS (AL + U) =   68000.00     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.3000000
 WATER MASS (GRAMS) =   29142.86
 TOTAL VOLUME(FUEL+CLAD+WATER)=   53422.38     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   19.25670     CM
 HZ(           1) =   82.12170     CM
 INNER CONCENTRIC RADIUS =   13.65250     CM
 OUTER CONCENTRIC RADIUS =   32.70250     CM
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 N1  N16  N131  N238  N235
      1  3.6501195E-02
     16  1.8250598E-02
    131  2.7221005E-02
   2381  8.0913214E-06
   2351  1.2838577E-04
TOTAL  8.2109280E-02
 H/U-235 RATIO =   284.3087
 MIXTURE DENSITY =   1.818393     G/CC
 ****************************************
  MIDDLE-COMPARTMENT
 SOLID MIXTURE DENSITY =   2.901422     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   304.0000       19.40427
  323.4043
 VOLUME OF U235 +U238 =   16.93216     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   1361.702     CM^3
 TOTAL MASS (AL + U) =   4000.000     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.3000000
 WATER MASS (GRAMS) =   1714.286
 TOTAL VOLUME(FUEL+CLAD+WATER)=   3092.920     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =  0.8857020     CM
 HZ(           2) =   61.34430     CM
 INNER CONCENTRIC RADIUS =  0.0000000E+00 CM
 OUTER CONCENTRIC RADIUS =   33.34000     CM
 N1  N16  N131  N238  N235
      1  3.7086233E-02
     16  1.8543117E-02
    131  2.6532365E-02
   2381  1.5870828E-05
   2351  2.5182372E-04
TOTAL  8.2429409E-02
 H/U-235 RATIO =   147.2706
 MIXTURE DENSITY =   1.847537     G/CC
 ****************************************
  BOTTOM COMPARTMENT
 SOLID MIXTURE DENSITY =   2.789961     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   1412.000       90.12769
  1502.128
 VOLUME OF U235 +U238 =   78.64542     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   14258.47     CM^3
 TOTAL MASS (AL + U) =   40000.00     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.3000000
 WATER MASS (GRAMS) =   17142.86
 TOTAL VOLUME(FUEL+CLAD+WATER)=   31479.98     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   9.014743     CM
 HZ(           3) =   27.18026     CM
 INNER CONCENTRIC RADIUS =  0.0000000E+00 CM
 OUTER CONCENTRIC RADIUS =   33.34000     CM
 N1  N16  N131  N238  N235
      1  3.6437377E-02
     16  1.8218689E-02
    131  2.7296131E-02
   2381  7.2426069E-06
   2351  1.1491905E-04
TOTAL  8.2074359E-02
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 H/U-235 RATIO =   317.0699
 MIXTURE DENSITY =   1.815213     G/CC
 OVERALL H/U-235 RATIO =   222.2146
 ****************************************
 ****************************************
  TOP COMPARTMENT
 SOLID MIXTURE DENSITY =   2.800714     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   2677.000       170.8723
  2847.872
 VOLUME OF U235 +U238 =   149.1033     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   24130.42     CM^3
 TOTAL MASS (AL + U) =   68000.00     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.3500000
 WATER MASS (GRAMS) =   36615.38
 TOTAL VOLUME(FUEL+CLAD+WATER)=   60894.90     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   21.95025     CM
 HZ(           1) =   84.81525     CM
 INNER CONCENTRIC RADIUS =   13.65250     CM
 OUTER CONCENTRIC RADIUS =   32.70250     CM
 N1  N16  N131  N238  N235
      1  4.0232852E-02
     16  2.0116426E-02
    131  2.3880668E-02
   2381  7.0984215E-06
   2351  1.1263133E-04
TOTAL  8.4349677E-02
 H/U-235 RATIO =   357.2083
 MIXTURE DENSITY =   1.717966     G/CC
 ****************************************
  MIDDLE-COMPARTMENT
 SOLID MIXTURE DENSITY =   2.901422     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   304.0000       19.40427
  323.4043
 VOLUME OF U235 +U238 =   16.93216     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   1361.702     CM^3
 TOTAL MASS (AL + U) =   4000.000     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.3500000
 WATER MASS (GRAMS) =   2153.846
 TOTAL VOLUME(FUEL+CLAD+WATER)=   3532.480     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   1.011576     CM
 HZ(           2) =   61.21842     CM
 INNER CONCENTRIC RADIUS =  0.0000000E+00 CM
 OUTER CONCENTRIC RADIUS =   33.34000     CM
 N1  N16  N131  N238  N235
      1  4.0797461E-02
     16  2.0398730E-02
    131  2.3230841E-02
   2381  1.3895960E-05
   2351  2.2048832E-04
TOTAL  8.4661417E-02
 H/U-235 RATIO =   185.0323
 MIXTURE DENSITY =   1.742075     G/CC
 ****************************************
  BOTTOM COMPARTMENT
 SOLID MIXTURE DENSITY =   2.789961     G/CM^3)
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 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   1412.000        90.12769
  1502.128
 VOLUME OF U235 +U238 =   78.64542     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   14258.47     CM^3
 TOTAL MASS (AL + U) =   40000.00     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.3500000
 WATER MASS (GRAMS) =   21538.46
 TOTAL VOLUME(FUEL+CLAD+WATER)=   35875.57     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   10.27349     CM
 HZ(           3) =   25.92151     CM
 INNER CONCENTRIC RADIUS =  0.0000000E+00 CM
 OUTER CONCENTRIC RADIUS =   33.34000     CM
 N1  N16  N131  N238  N235
      1  4.0171124E-02
     16  2.0085562E-02
    131  2.3951715E-02
   2381  6.3552179E-06
   2351  1.0083878E-04
TOTAL  8.4315591E-02
 H/U-235 RATIO =   398.3698
 MIXTURE DENSITY =   1.715330     G/CC
 OVERALL H/U-235 RATIO =   279.2928
 ****************************************
 ****************************************
  TOP COMPARTMENT
 SOLID MIXTURE DENSITY =   2.800714     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   2677.000        170.8723
  2847.872
 VOLUME OF U235 +U238 =   149.1033     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   24130.42     CM^3
 TOTAL MASS (AL + U) =   68000.00     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.4000000
 WATER MASS (GRAMS) =   45333.33
 TOTAL VOLUME(FUEL+CLAD+WATER)=   69612.85     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   25.09274     CM
 HZ(           1) =   87.95774     CM
 INNER CONCENTRIC RADIUS =   13.65250     CM
 OUTER CONCENTRIC RADIUS =   32.70250     CM
 N1  N16  N131  N238  N235
      1  4.3573901E-02
     16  2.1786951E-02
    131  2.0889979E-02
   2381  6.2094523E-06
   2351  9.8525968E-05
TOTAL  8.6355567E-02
 H/U-235 RATIO =   442.2580
 MIXTURE DENSITY =   1.628052     G/CC
 ****************************************
  MIDDLE-COMPARTMENT
 SOLID MIXTURE DENSITY =   2.901422     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   304.0000        19.40427
  323.4043
 VOLUME OF U235 +U238 =   16.93216     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   1361.702     CM^3
 TOTAL MASS (AL + U) =   4000.000     GRAMS
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 WEIGHT FRACTION OF WATER (WFWATER)=  0.4000000
 WATER MASS (GRAMS) =   2666.667
 TOTAL VOLUME(FUEL+CLAD+WATER)=   4045.301     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   1.158430     CM
 HZ(           2) =   61.07157     CM
 INNER CONCENTRIC RADIUS =  0.0000000E+00 CM
 OUTER CONCENTRIC RADIUS =   33.34000     CM
 N1  N16  N131  N238  N235
      1  4.4107873E-02
     16  2.2053936E-02
    131  2.0285878E-02
   2381  1.2134376E-05
   2351  1.9253713E-04
TOTAL  8.6652368E-02
 H/U-235 RATIO =   229.0876
 MIXTURE DENSITY =   1.648003     G/CC
 ****************************************
  BOTTOM COMPARTMENT
 SOLID MIXTURE DENSITY =   2.789961     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   1412.000       90.12769
  1502.128
 VOLUME OF U235 +U238 =   78.64542     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   14258.47     CM^3
 TOTAL MASS (AL + U) =   40000.00     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.4000000
 WATER MASS (GRAMS) =   26666.67
 TOTAL VOLUME(FUEL+CLAD+WATER)=   41003.78     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   11.74202     CM
 HZ(           3) =   24.45298     CM
 INNER CONCENTRIC RADIUS =  0.0000000E+00 CM
 OUTER CONCENTRIC RADIUS =   33.34000     CM
 N1  N16  N131  N238  N235
      1  4.3515403E-02
     16  2.1757701E-02
    131  2.0956155E-02
   2381  5.5603919E-06
   2351  8.8227207E-05
TOTAL  8.6323053E-02
 H/U-235 RATIO =   493.2198
 MIXTURE DENSITY =   1.625866     G/CC
 OVERALL H/U-235 RATIO =   345.9018
 ****************************************
 ****************************************
  TOP COMPARTMENT
 SOLID MIXTURE DENSITY =   2.800714     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   2677.000       170.8723
  2847.872
 VOLUME OF U235 +U238 =   149.1033     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   24130.42     CM^3
 TOTAL MASS (AL + U) =   68000.00     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.4500000
 WATER MASS (GRAMS) =   55636.36
 TOTAL VOLUME(FUEL+CLAD+WATER)=   79915.88     CM^3
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 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   28.80658     CM
 HZ(           1) =   91.67158     CM
 INNER CONCENTRIC RADIUS =   13.65250     CM
 OUTER CONCENTRIC RADIUS =   32.70250     CM
 N1  N16  N131  N238  N235
      1  4.6582613E-02
     16  2.3291307E-02
    131  1.8196769E-02
   2381  5.4089082E-06
   2351  8.5823660E-05
TOTAL  8.8161923E-02
 H/U-235 RATIO =   542.7712
 MIXTURE DENSITY =   1.547081     G/CC
 ****************************************
  MIDDLE-COMPARTMENT
 SOLID MIXTURE DENSITY =   2.901422     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   304.0000       19.40427
  323.4043
 VOLUME OF U235 +U238 =   16.93216     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   1361.702     CM^3
 TOTAL MASS (AL + U) =   4000.000     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.4500000
 WATER MASS (GRAMS) =   3272.727
 TOTAL VOLUME(FUEL+CLAD+WATER)=   4651.362     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   1.331984     CM
 HZ(           2) =   60.89801     CM
 INNER CONCENTRIC RADIUS =  0.0000000E+00 CM
 OUTER CONCENTRIC RADIUS =   33.34000     CM
 N1  N16  N131  N238  N235
      1  4.7079075E-02
     16  2.3539538E-02
    131  1.7642679E-02
   2381  1.0553297E-05
   2351  1.6745002E-04
TOTAL  8.8439293E-02
 H/U-235 RATIO =   281.1530
 MIXTURE DENSITY =   1.563570     G/CC
 ****************************************
  BOTTOM COMPARTMENT
 SOLID MIXTURE DENSITY =   2.789961     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   1412.000       90.12769
  1502.128
 VOLUME OF U235 +U238 =   78.64542     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   14258.47     CM^3
 TOTAL MASS (AL + U) =   40000.00     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.4500000
 WATER MASS (GRAMS) =   32727.27
 TOTAL VOLUME(FUEL+CLAD+WATER)=   47064.39     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   13.47756     CM
 HZ(           3) =   22.71744     CM
 INNER CONCENTRIC RADIUS =  0.0000000E+00 CM
 OUTER CONCENTRIC RADIUS =   33.34000     CM
 N1  N16  N131  N238  N235
      1  4.6528131E-02
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     16  2.3264065E-02
    131  1.8257573E-02
   2381  4.8443653E-06
   2351  7.6865952E-05
TOTAL  8.8131480E-02
 H/U-235 RATIO =   605.3152
 MIXTURE DENSITY =   1.545272     G/CC
 OVERALL H/U-235 RATIO =   424.6380
 ****************************************
 ****************************************
  TOP COMPARTMENT
 SOLID MIXTURE DENSITY =   2.800714     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   2677.000       170.8723
  2847.872
 VOLUME OF U235 +U238 =   149.1033     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   24130.42     CM^3
 TOTAL MASS (AL + U) =   68000.00     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.5000000
 WATER MASS (GRAMS) =   68000.00
 TOTAL VOLUME(FUEL+CLAD+WATER)=   92279.52     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   33.26319     CM
 HZ(           1) =   96.12820     CM
 INNER CONCENTRIC RADIUS =   13.65250     CM
 OUTER CONCENTRIC RADIUS =   32.70250     CM
 N1  N16  N131  N238  N235
      1  4.9306229E-02
     16  2.4653114E-02
    131  1.5758760E-02
   2381  4.6842210E-06
   2351  7.4324977E-05
TOTAL  8.9797117E-02
 H/U-235 RATIO =   663.3871
 MIXTURE DENSITY =   1.473783     G/CC
 ****************************************
  MIDDLE-COMPARTMENT
 SOLID MIXTURE DENSITY =   2.901422     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   304.0000       19.40427
  323.4043
 VOLUME OF U235 +U238 =   16.93216     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   1361.702     CM^3
 TOTAL MASS (AL + U) =   4000.000     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.5000000
 WATER MASS (GRAMS) =   4000.000
 TOTAL VOLUME(FUEL+CLAD+WATER)=   5378.634     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   1.540249     CM
 HZ(           2) =   60.68975     CM
 INNER CONCENTRIC RADIUS =  0.0000000E+00 CM
 OUTER CONCENTRIC RADIUS =   33.34000     CM
 N1  N16  N131  N238  N235
      1  4.9760666E-02
     16  2.4880333E-02
    131  1.5257123E-02
   2381  9.1263328E-06
   2351  1.4480825E-04
TOTAL  9.0052053E-02
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 H/U-235 RATIO =   343.6314
 MIXTURE DENSITY =   1.487366     G/CC
 ****************************************
  BOTTOM COMPARTMENT
 SOLID MIXTURE DENSITY =   2.789961     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   1412.000       90.12769
  1502.128
 VOLUME OF U235 +U238 =   78.64542     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   14258.47     CM^3
 TOTAL MASS (AL + U) =   40000.00     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.5000000
 WATER MASS (GRAMS) =   40000.00
 TOTAL VOLUME(FUEL+CLAD+WATER)=   54337.12     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   15.56021     CM
 HZ(           3) =   20.63479     CM
 INNER CONCENTRIC RADIUS =  0.0000000E+00 CM
 OUTER CONCENTRIC RADIUS =   33.34000     CM
 N1  N16  N131  N238  N235
      1  4.9256280E-02
     16  2.4628140E-02
    131  1.5813896E-02
   2381  4.1959734E-06
   2351  6.6577864E-05
TOTAL  8.9769088E-02
 H/U-235 RATIO =   739.8297
 MIXTURE DENSITY =   1.472290     G/CC
 OVERALL H/U-235 RATIO =   519.1369
 ****************************************
 ****************************************
  TOP COMPARTMENT
 SOLID MIXTURE DENSITY =   2.800714     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   2677.000       170.8723
  2847.872
 VOLUME OF U235 +U238 =   149.1033     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   24130.42     CM^3
 TOTAL MASS (AL + U) =   68000.00     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.5500000
 WATER MASS (GRAMS) =   83111.11
 TOTAL VOLUME(FUEL+CLAD+WATER)=   107390.6     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   38.71016     CM
 HZ(           1) =   101.5752     CM
 INNER CONCENTRIC RADIUS =   13.65250     CM
 OUTER CONCENTRIC RADIUS =   32.70250     CM
 N1  N16  N131  N238  N235
      1  5.1783439E-02
     16  2.5891719E-02
    131  1.3541320E-02
   2381  4.0250966E-06
   2351  6.3866588E-05
TOTAL  9.1284364E-02
 H/U-235 RATIO =   810.8064
 MIXTURE DENSITY =   1.407116     G/CC
 ****************************************
  MIDDLE-COMPARTMENT
 SOLID MIXTURE DENSITY =   2.901422     G/CM^3)
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 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   304.0000        19.40427
  323.4043
 VOLUME OF U235 +U238 =   16.93216     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   1361.702     CM^3
 TOTAL MASS (AL + U) =   4000.000     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.5500000
 WATER MASS (GRAMS) =   4888.889
 TOTAL VOLUME(FUEL+CLAD+WATER)=   6267.523     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   1.794795     CM
 HZ(           2) =   60.43520     CM
 INNER CONCENTRIC RADIUS =  0.0000000E+00 CM
 OUTER CONCENTRIC RADIUS =   33.34000     CM
 N1  N16  N131  N238  N235
      1  5.2193023E-02
     16  2.6096512E-02
    131  1.3093288E-02
   2381  7.8319945E-06
   2351  1.2427088E-04
TOTAL  9.1514923E-02
 H/U-235 RATIO =   419.9940
 MIXTURE DENSITY =   1.418246     G/CC
 ****************************************
  BOTTOM COMPARTMENT
 SOLID MIXTURE DENSITY =   2.789961     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   1412.000        90.12769
  1502.128
 VOLUME OF U235 +U238 =   78.64542     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   14258.47     CM^3
 TOTAL MASS (AL + U) =   40000.00     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.5500000
 WATER MASS (GRAMS) =   48888.89
 TOTAL VOLUME(FUEL+CLAD+WATER)=   63226.01     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   18.10567     CM
 HZ(           3) =   18.08932     CM
 INNER CONCENTRIC RADIUS =  0.0000000E+00 CM
 OUTER CONCENTRIC RADIUS =   33.34000     CM
 N1  N16  N131  N238  N235
      1  5.1738359E-02
     16  2.5869180E-02
    131  1.3590635E-02
   2381  3.6060651E-06
   2351  5.7217738E-05
TOTAL  9.1259003E-02
 H/U-235 RATIO =   904.2364
 MIXTURE DENSITY =   1.405891     G/CC
 OVERALL H/U-235 RATIO =   634.6506
 ****************************************
 ****************************************
  TOP COMPARTMENT
 SOLID MIXTURE DENSITY =   2.800714     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   2677.000        170.8723
  2847.872
 VOLUME OF U235 +U238 =   149.1033     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   24130.42     CM^3
 TOTAL MASS (AL + U) =   68000.00     GRAMS
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 WEIGHT FRACTION OF WATER (WFWATER)=  0.6000000
 WATER MASS (GRAMS) =   102000.0
 TOTAL VOLUME(FUEL+CLAD+WATER)=   126279.5     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   45.51888     CM
 HZ(           1) =   108.3839     CM
 INNER CONCENTRIC RADIUS =   13.65250     CM
 OUTER CONCENTRIC RADIUS =   32.70250     CM
 N1  N16  N131  N238  N235
      1  5.4046236E-02
     16  2.7023118E-02
    131  1.1515808E-02
   2381  3.4230222E-06
   2351  5.4313419E-05
TOTAL  9.2642903E-02
 H/U-235 RATIO =   995.0807
 MIXTURE DENSITY =   1.346220     G/CC
 ****************************************
  MIDDLE-COMPARTMENT
 SOLID MIXTURE DENSITY =   2.901422     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   304.0000       19.40427
  323.4043
 VOLUME OF U235 +U238 =   16.93216     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   1361.702     CM^3
 TOTAL MASS (AL + U) =   4000.000     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.6000000
 WATER MASS (GRAMS) =   6000.001
 TOTAL VOLUME(FUEL+CLAD+WATER)=   7378.635     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   2.112978     CM
 HZ(           2) =   60.11702     CM
 INNER CONCENTRIC RADIUS =  0.0000000E+00 CM
 OUTER CONCENTRIC RADIUS =   33.34000     CM
 N1  N16  N131  N238  N235
      1  5.4409344E-02
     16  2.7204672E-02
    131  1.1121634E-02
   2381  6.6526127E-06
   2351  1.0555755E-04
TOTAL  9.2847869E-02
 H/U-235 RATIO =   515.4472
 MIXTURE DENSITY =   1.355264     G/CC
 ****************************************
  BOTTOM COMPARTMENT
 SOLID MIXTURE DENSITY =   2.789961     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   1412.000       90.12769
  1502.128
 VOLUME OF U235 +U238 =   78.64542     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   14258.47     CM^3
 TOTAL MASS (AL + U) =   40000.00     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.6000000
 WATER MASS (GRAMS) =   60000.01
 TOTAL VOLUME(FUEL+CLAD+WATER)=   74337.13     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   21.28750     CM
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 HZ(           3) =   14.90750     CM
 INNER CONCENTRIC RADIUS =  0.0000000E+00 CM
 OUTER CONCENTRIC RADIUS =   33.34000     CM
 N1  N16  N131  N238  N235
      1  5.4006219E-02
     16  2.7003109E-02
    131  1.1559252E-02
   2381  3.0670690E-06
   2351  4.8665443E-05
TOTAL  9.2620321E-02
 H/U-235 RATIO =   1109.745
 MIXTURE DENSITY =   1.345223     G/CC
 OVERALL H/U-235 RATIO =   779.0573
 ****************************************
 ****************************************
  TOP COMPARTMENT
 SOLID MIXTURE DENSITY =   2.800714     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   2677.000       170.8723
  2847.872
 VOLUME OF U235 +U238 =   149.1033     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   24130.42     CM^3
 TOTAL MASS (AL + U) =   68000.00     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.6500000
 WATER MASS (GRAMS) =   126285.7
 TOTAL VOLUME(FUEL+CLAD+WATER)=   150565.3     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   54.27294     CM
 HZ(           1) =   117.1379     CM
 INNER CONCENTRIC RADIUS =   13.65250     CM
 OUTER CONCENTRIC RADIUS =   32.70250     CM
 N1  N16  N131  N238  N235
      1  5.6121305E-02
     16  2.8060652E-02
    131  9.6583441E-03
   2381  2.8708994E-06
   2351  4.5552832E-05
TOTAL  9.3888722E-02
 H/U-235 RATIO =   1232.005
 MIXTURE DENSITY =   1.290376     G/CC
 ****************************************
  MIDDLE-COMPARTMENT
 SOLID MIXTURE DENSITY =   2.901422     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   304.0000       19.40427
  323.4043
 VOLUME OF U235 +U238 =   16.93216     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   1361.702     CM^3
 TOTAL MASS (AL + U) =   4000.000     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.6500000
 WATER MASS (GRAMS) =   7428.572
 TOTAL VOLUME(FUEL+CLAD+WATER)=   8807.207     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   2.522070     CM
 HZ(           2) =   59.70793     CM
 INNER CONCENTRIC RADIUS =  0.0000000E+00 CM
 OUTER CONCENTRIC RADIUS =   33.34000     CM
 N1  N16  N131  N238  N235
      1  5.6437187E-02
```

```
     16  2.8218593E-02
    131  9.3176514E-03
   2381  5.5735268E-06
   2351  8.8435598E-05
TOTAL  9.4067447E-02
 H/U-235 RATIO =   638.1727
 MIXTURE DENSITY =   1.297639     G/CC
 ****************************************
  BOTTOM COMPARTMENT
 SOLID MIXTURE DENSITY =   2.789961     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   1412.000       90.12769
  1502.128
 VOLUME OF U235 +U238 =   78.64542     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   14258.47     CM^3
 TOTAL MASS (AL + U) =   40000.00     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.6500000
 WATER MASS (GRAMS) =   74285.73
 TOTAL VOLUME(FUEL+CLAD+WATER)=   88622.84     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   25.37842     CM
 HZ(           3) =   10.81658     CM
 INNER CONCENTRIC RADIUS =  0.0000000E+00 CM
 OUTER CONCENTRIC RADIUS =   33.34000     CM
 N1  N16  N131  N238  N235
      1  5.6086447E-02
     16  2.8043224E-02
    131  9.6959379E-03
   2381  2.5726674E-06
   2351  4.0820731E-05
TOTAL  9.3869001E-02
 H/U-235 RATIO =   1373.970
 MIXTURE DENSITY =   1.289574     G/CC
 OVERALL H/U-235 RATIO =   964.7374
 ****************************************
 ****************************************
  TOP COMPARTMENT
 SOLID MIXTURE DENSITY =   2.800714     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   2677.000       170.8723
  2847.872
 VOLUME OF U235 +U238 =   149.1033     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   24130.42     CM^3
 TOTAL MASS (AL + U) =   68000.00     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.7000000
 WATER MASS (GRAMS) =   158666.7
 TOTAL VOLUME(FUEL+CLAD+WATER)=   182946.2     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   65.94501     CM
 HZ(           1) =   128.8100     CM
 INNER CONCENTRIC RADIUS =   13.65250     CM
 OUTER CONCENTRIC RADIUS =   32.70250     CM
 N1  N16  N131  N238  N235
      1  5.8031067E-02
     16  2.9015534E-02
    131  7.9488456E-03
   2381  2.3627588E-06
   2351  3.7490117E-05
TOTAL  9.5035300E-02
```

```
 H/U-235 RATIO =   1547.903
 MIXTURE DENSITY =   1.238980     G/CC
 ****************************************
  MIDDLE-COMPARTMENT
 SOLID MIXTURE DENSITY =   2.901422     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   304.0000       19.40427
  323.4043
 VOLUME OF U235 +U238 =   16.93216     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   1361.702     CM^3
 TOTAL MASS (AL + U) =   4000.000     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.7000000
 WATER MASS (GRAMS) =   9333.333
 TOTAL VOLUME(FUEL+CLAD+WATER)=   10711.97     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   3.067526     CM
 HZ(           2) =   59.16248     CM
 INNER CONCENTRIC RADIUS =  0.0000000E+00 CM
 OUTER CONCENTRIC RADIUS =   33.34000     CM
 N1  N16  N131  N238  N235
      1  5.8299620E-02
     16  2.9149810E-02
    131  7.6608225E-03
   2381  4.5824636E-06
   2351  7.2710325E-05
TOTAL  9.5187545E-02
 H/U-235 RATIO =   801.8066
 MIXTURE DENSITY =   1.244714     G/CC
 ****************************************
  BOTTOM COMPARTMENT
 SOLID MIXTURE DENSITY =   2.789961     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   1412.000       90.12769
  1502.128
 VOLUME OF U235 +U238 =   78.64542     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   14258.47     CM^3
 TOTAL MASS (AL + U) =   40000.00     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.7000000
 WATER MASS (GRAMS) =   93333.33
 TOTAL VOLUME(FUEL+CLAD+WATER)=   107670.4     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   30.83298     CM
 HZ(           3) =   5.362024     CM
 INNER CONCENTRIC RADIUS =  0.0000000E+00 CM
 OUTER CONCENTRIC RADIUS =   33.34000     CM
 N1  N16  N131  N238  N235
      1  5.8001399E-02
     16  2.9000700E-02
    131  7.9806633E-03
   2381  2.1175458E-06
   2351  3.3599277E-05
TOTAL  9.5018484E-02
 H/U-235 RATIO =   1726.269
 MIXTURE DENSITY =   1.238347     G/CC
 OVERALL H/U-235 RATIO =   1212.326
 ****************************************
 ****************************************
  TOP COMPARTMENT
 SOLID MIXTURE DENSITY =   2.800714     G/CM^3)
```

```
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   2677.000        170.8723
  2847.872
 VOLUME OF U235 +U238 =   149.1033     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   24130.42     CM^3
 TOTAL MASS (AL + U) =   68000.00     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.7500000
 WATER MASS (GRAMS) =   204000.0
 TOTAL VOLUME(FUEL+CLAD+WATER)=   228279.5     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   82.28592     CM
 HZ(           1) =   145.1509     CM
 INNER CONCENTRIC RADIUS =   13.65250     CM
 OUTER CONCENTRIC RADIUS =   32.70250     CM
 N1  N16  N131  N238  N235
      1  5.9794530E-02
     16  2.9897265E-02
    131  6.3703083E-03
   2381  1.8935457E-06
   2351  3.0045068E-05
TOTAL  9.6094042E-02
 H/U-235 RATIO =   1990.161
 MIXTURE DENSITY =   1.191522     G/CC
 ****************************************
  MIDDLE-COMPARTMENT
 SOLID MIXTURE DENSITY =   2.901422     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   304.0000        19.40427
  323.4043
 VOLUME OF U235 +U238 =   16.93216     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   1361.702     CM^3
 TOTAL MASS (AL + U) =   4000.000     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.7500000
 WATER MASS (GRAMS) =   12000.00
 TOTAL VOLUME(FUEL+CLAD+WATER)=   13378.63     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   3.831164     CM
 HZ(           2) =   58.39883     CM
 INNER CONCENTRIC RADIUS =  0.0000000E+00 CM
 OUTER CONCENTRIC RADIUS =   33.34000     CM
 N1  N16  N131  N238  N235
      1  6.0016088E-02
     16  3.0008044E-02
    131  6.1338460E-03
   2381  3.6690742E-06
   2351  5.8217498E-05
TOTAL  9.6219867E-02
 H/U-235 RATIO =   1030.894
 MIXTURE DENSITY =   1.195937     G/CC
 ****************************************
  BOTTOM COMPARTMENT
 SOLID MIXTURE DENSITY =   2.789961     G/CM^3)
 MASSSE OF U235, U238 AND U235+U238 (GRAMS) =   1412.000        90.12769
  1502.128
 VOLUME OF U235 +U238 =   78.64542     CM^3
 VOLUME OF AL(FUEL) +AL(CLAD) =   14258.47     CM^3
 TOTAL MASS (AL + U) =   40000.00     GRAMS

 WEIGHT FRACTION OF WATER (WFWATER)=  0.7500000
```

```
 WATER MASS (GRAMS) =   120000.0
 TOTAL VOLUME(FUEL+CLAD+WATER)=   134337.1     CM^3

 CONCENTRIC CYLINDER CASE
 CYLINDRICAL HEIGHT =   38.46936     CM
 HZ(           3) =  -2.274357     CM
 INNER CONCENTRIC RADIUS =  0.0000000E+00 CM
 OUTER CONCENTRIC RADIUS =   33.34000     CM
 N1  N16  N131  N238  N235
      1  5.9770033E-02
     16  2.9885016E-02
    131  6.3964571E-03
   2381  1.6972011E-06
   2351  2.6929632E-05
TOTAL  9.6080132E-02
 H/U-235 RATIO =   2219.489
 MIXTURE DENSITY =   1.191033     G/CC
 OVERALL H/U-235 RATIO =   1558.965
```

6.7.4 Validation of Infinite Cask Methodology (ICM)

In order to achieve a zero transport index (i.e., an infinite number of casks) from a criticality stand point, we have applied the NRC approved GEMER methodology to analyze an infinite array of Model 2000 shipping casks.

A unit cell consisting of the cask surrounded by water in a square pitch is chosen for the analysis. The sides of the cell are fully reflecting, thus making this system an infinite array of identical unit cells. One of the definitions of the multiplication factor of a system is:

$$k = \frac{\textit{net neutron production rate}}{\textit{net neutron loss rate due to capture and leakage}} \tag{1}$$

In an infinite array, the neutron leakage is zero; therefore, all the loss from the system is as a result of absorption reactions within the system. The k_{eff} in this case is denoted by the infinite multiplication factor k_∞. Thus if k_∞ is less than 1, the system will never go critical.

6.7.4.1 Methodology Validation

The MTR Case I fuel (U_3O_8) with 93.2% enrichment is used as an example demonstration for this ICM. From the previous submittal, the k-effective from the three scenarios (normal, single, and accident arrays) are shown in Tables 6.73 through 6.75. The maximum $k_{eff} + 2\sigma + Bias$ in this example is 0.93559 for the accident array as shown in Table 6.75. All three scenarios (normal, single, and accident arrays) have one-foot thick rectangular water reflectors on all sides. As a result of the limited U-235 mass (710 grams per divider slot and 14910 grams total in each cask), as well as the presence of boral plates between the divider slots, the cask is designed to be subcritical under all normal and accident conditions, as shown by the $k_{eff} + 2\sigma + Bias$ in Tables 6.73 through

6.75. As discussed in the previous submittal, only 60% of the boron density is used in these calculations as an added degree of conservatism.

The unit cask in the ICM is shown in Figure 6.44. The cask used in the earlier submittal, with identical number densities for the 45 weight percent water, is used. The 45 water weight percent is chosen as this represents the optimally moderated cask in the accident array calculations (Table 6.76).

For the ICM, the edge-to-edge distance (L), defined as the shortest distance from the cask edge to the rectangular box edge, and the interstitial water density (ρ) are important parameters. For any system, the interstitial water will act as both a neutron moderator and neutron absorber. Any neutrons leaking out of the cask can be moderated and reflected back into the cask or absorbed by water. These two parameters (L and ρ) will quantify the moderation and absorption effect in water. They will be varied to study their effect on the neutron multiplication factor.

Figure 6.45 shows the k-effective generated for different cases with varying edge-to-edge distances and water density (ρ).

An additional case (fully leaking case) where all neutrons hitting the system boundary will be lost, is set up for comparison purposes.

Table 6.73. GEMER Results for the Normal Condition Array for Case I (U_3O_8)

Interspersed Water Density Outside Cask (gm/cm^3)	$H/^{235}U$ Ratio (in Fuel)	k_{eff}	$\pm\sigma$	Bias	$k_{eff} + 2\sigma$ + Bias
0.00	9	0.46649	0.00236	.00000	0.47121
0.02	**9**	**0.46772**	**0.00191**	**.00000**	**0.47154**
0.05	9	0.46027	0.00198	.00000	0.46423
0.10	9	0.46587	0.00205	.00000	0.46997
0.50	9	0.46303	0.00206	.00000	0.46715
1.00	9	0.45459	0.00210	.00000	0.45879

Table 6.74. GEMER Results for a Single Container for Case I (U_3O_8)

WF H_2O (in Fuel)	$H/^{235}U$ Ratio (in Fuel)	k_{eff}	$\pm\sigma$	Bias	$k_{eff} + 2\sigma + Bias$
0.05	9	0.47429	0.00227	0.0000	0.47883
0.10	20	0.59499	0.00269	0.0000	0.60037
0.15	31	0.69974	0.00350	0.0000	0.70675
0.20	45	0.77266	0.00305	0.0003	0.77904
025	59	0.82551	0.00272	0.0006	0.83150
0.30	76	0.87577	0.00260	0.0009	0.88183
0.35	96	0.89519	0.00316	0.0012	0.90274
0.40	**119**	**0.90934**	**0.00292**	**0.0016**	**0.91682**
0.45	146	0.90879	0.00295	0.0021	0.91680
0.50	178	0.90548	0.00331	0.0026	0.91474
0.55	218	0.88840	0.00273	0.0033	0.89714

Table 6.75. GEMER Results for the Accident Array (Conservatively Treated as Flooded) for Case I (U_3O_8)

WF H_2O (in Fuel)	$H/^{235}U$ Ratio (in Fuel)	H_2O Density (Interspersed)	k_{eff}	$\pm\sigma$	Bias	$k_{eff} + 2\sigma +$ Bias
0.25	59	0.00	0.83878	0.00333	0.0005	0.84599
0.30	76	0.00	0.87553	0.00278	0.0009	0.88195
0.35	96	0.00	0.90358	0.00270	0.0012	0.91021
0.40	119	0.00	0.92091	0.00292	0.0016	0.92839
0.45	146	0.00	0.92044	0.00330	0.0021	0.92915
0.45	**146**	**0.02**	**0.92772**	**0.00288**	**0.0021**	**0.93559**
0.45	146	0.05	0.92423	0.00289	0.0021	0.93212
0.45	146	0.10	0.92323	0.00302	0.0021	0.93138
0.45	146	1.00	0.91386	0.00284	0.0021	0.92615
0.50	178	0.00	0.91733	0.00320	0.0026	0.92637

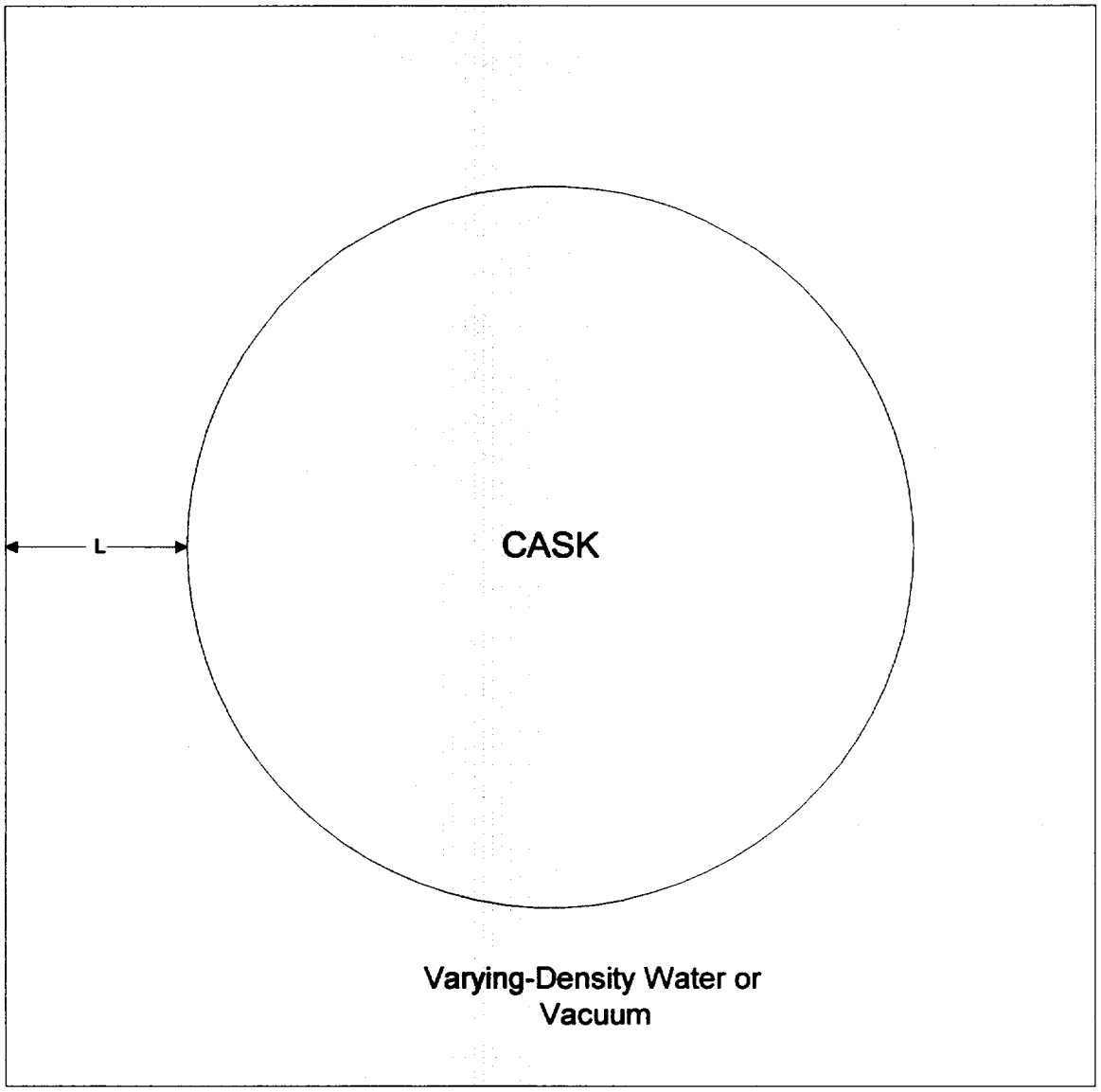

Figure 6.44. Unit Cask Schematic

Table 6.76. Infinite Cask Calculations (93.2% Enriched Fuel)

Water Density ρ (g/cc)	Edge-to-Edge Distance L (cm)	k_{eff}	± σ	Bias	k_{eff}+2σ+Bias
0	0.1	0.94063	0.00123	0.0021	0.94519
0.01	0.1	0.93868	0.00109	0.0021	0.94296
0.1	0.1	0.92383	0.00111	0.0021	0.92815
0.25	0.1	0.92155	0.00107	0.0021	0.92579
0.5	0.1	0.91952	0.00107	0.0021	0.92376
1	0.1	0.91788	0.00125	0.0021	0.92248
0	1	0.93877	0.00107	0.0021	0.94301
0.01	1	0.93659	0.00113	0.0021	0.94095
0.1	1	0.92345	0.00106	0.0021	0.92767
0.25	1	0.91813	0.00108	0.0021	0.92239
0.5	1	0.91532	0.00108	0.0021	0.91958
1	1	0.91222	0.0011	0.0021	0.91652
0	5	0.93582	0.00103	0.0021	0.93998
0.01	5	0.92996	0.00103	0.0021	0.93412
0.1	5	0.91664	0.00105	0.0021	0.92084
0.25	5	0.91219	0.00107	0.0021	0.91643
0.5	5	0.91196	0.00111	0.0021	0.91628
1	5	0.91303	0.0011	0.0021	0.91733
0	10	0.93444	0.00126	0.0021	0.93906
0.01	10	0.92486	0.00107	0.0021	0.9291
0.1	10	0.91712	0.00106	0.0021	0.92134
0.25	10	0.91278	0.00113	0.0021	0.91714
0.5	10	0.91324	0.00108	0.0021	0.9175
1	10	0.91231	0.00109	0.0021	0.91659

Table 6.76. Infinite Cask Calculations (93.2% Enriched Fuel) (Continued)

Fully Leaking Configuration					
0	0.1	0.91056	0.00098	0.0021	0.91462
0.05	0.1	0.91089	0.00100	0.0021	0.91499
0.1	0.1	0.91026	0.0011	0.0021	0.91456
0.25	0.1	0.91133	0.00117	0.0021	0.91577
0.5	0.1	0.91096	0.00111	0.0021	0.91528
1	0.1	0.91178	0.00113	0.0021	0.91614

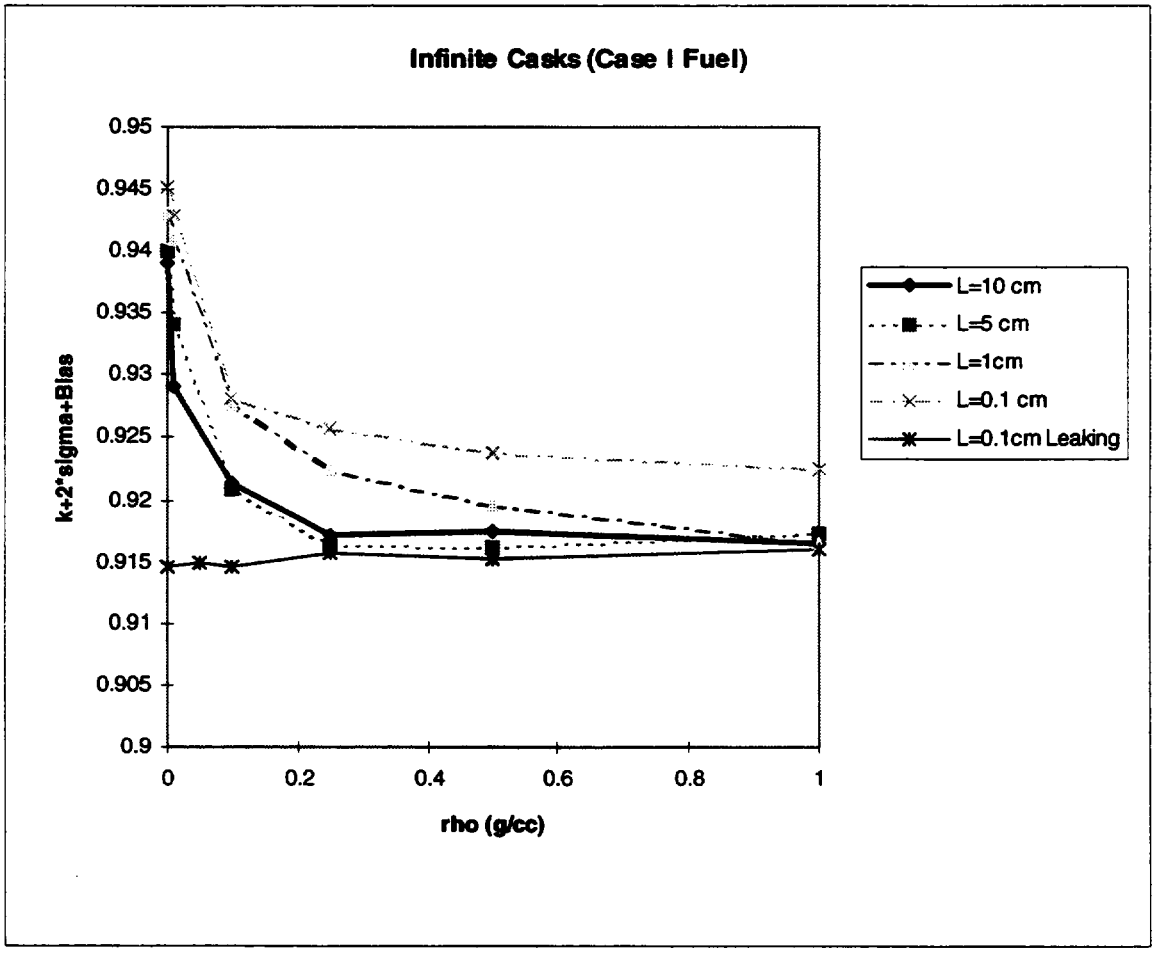

Figure 6.45. ICM K.effectives

6.7.4.2 Discussion and Conclusions

From Figure 6.45, as the edge-to-edge distance increases for a fixed water density, the k-effective decreases as a result of the greater neutron absorption in the interstitial water. For the totally-leaking configuration, the k-effective is the smallest. This is not surprising as any neutrons leaking out of the system will not return. The totally leaking system is about 3% (0.91462) lower in reactivity than the leak-proof case (0.94519) at zero water density.

The maximum $k_{eff} + 2\sigma + Bias$ from Tables 6.73 through 6.75 is 0.93559. This number should be less than the leak-proof case (0.94519), which validates the ICM.

Also, as the water density increases for a fixed edge-to-edge distance, the k-effective decreases as a result of neutron absorption in the interstitial water.

This section clearly shows that by applying the ICM to any cask loaded with any fuel elements, we have covered an infinite array of identical shipping casks loaded with the same fuel elements. This justifies the use of a zero Transport Index in Model 2000 shipping cask shipments if the ICM is applied in the GEMER calculations.

6.7.5 Criticality Evaluation (Discrete Model) for MTR-Fuel Divider SN 01 (DELETED)

6.7.6 Criticality Evaluation (Discrete Model) for MTR-Fuel Divider SN 01

6.7.6.1. Discussion and Results

6.7.6.1.1 General

The Model 2000 cask, as discussed earlier in Subsection 6.1.2, is a cylindrical cask with lead shielding. The cask has a cavity that is 26.5 inches inside diameter and 54 inches high for holding nuclear radioactive material, including special nuclear material.

This application serves two purposes:

First, this application applies the discrete fuel modeling approach to the MTR Type I, II, III, and IV fuels. This represents a more realistic approach in modeling the MTR Type I, II, III, and IV fues and is different from the homogenous fuel model discussed earlier in Section 6.4.3. The NBSR fuel was found to be the most limiting U_3O_8-based fuels and was chosen to envelope the MTR Type I fuel study. Similarly, the ORR fuel was chosen to envelope the U_3Si_2-based MTR Type II fuel and the SAPHIR fuel was chosen to envelope the UAl_x-based MTR Type III fuel. MTR Type IV fuel was chosen to envelope the metallic form of the MTR fuel.

Second, the steel ingot and boral plates are shorter than the previous application (boral plates are 125.27 cm versus the previous submittal of 136.64 cm). As such, some fuels are more likely to protrude from the steel ingot into the top cask space due to double stacking of the fuel elements. This application shows that even with this dimensional change, this criticality safety analysis demonstrates that for the MTR Type I, II, III, and IV fuels, the worst-case discrete fuel modeling k-effective are all below the subcriticality limit of 0.95.

6.7.6.1.2 Applicable Regulatory Criteria

The applicable regulatory criteria for the MTR fuel shipment remain the same as discussed earlier in Subsection 6.1.1.1 and will not be elaborated further here.

6.7.6.1.3 Container Description

The Model 2000 cask has been discussed earlier in Subsection 6.1.2. The cask remains the same internally and externally.

6.7.6.1.4 Calculational Methods

The GEMER01V code is used to demonstrate the subcriticality of the Model 2000 cask with the MTR fuel assemblies loaded in the cask. Critical benchmark experiments using GEMER01V confirm the accuracy of the calculational method chosen for the present analysis and provide the basis for calculational bias.

The key assumptions used in the criticality analysis of MTR Type I, II, III, and IV fuels are as follows:

1. The borated aluminum plates used for reactivity control are conservatively modeled. Only 75% of the boron atoms are accounted for in the calculations.
2. The borated aluminum plates, typically 3.25 inches (8.255 cm) x 0.25 inch (0.635 cm) x 49.32 inch (125.2728 cm), are conservatively treated as 3.1 inches (7,874 cm) x 0.21inch (0.5334 cm) x 49.32 inch (125.2728 cm).
3. The fission products in the MTR Type I, II, III, and IV fuels will be ignored in this analysis. This is a conservative assumption.
4. All MTR Type I, II, III, and IV are analyzed in fresh fuel condition. All burnable poisons will be zeroed out in the fresh fuel. This is a conservative assumption.
5. The MTR fuel elements are modeled in a most conservative but credible position, with all fuel elements protruding from the 21 slots to the maximum possible extent. This maximizes the reactivity in the system.

Table 6.95 provides dimensions and nuclear data for MTR fuel to which this analysis applies.

MTR Type I covers the U_3O_8 chemical form, MTR Type II covers the U_3Si_2 chemical form, while MTR Type III covers the U-Al chemical form. MTR Type IV data which covers the pure U chemical composition is presented in Table 6.96. This represents an MTR-equivalent reactor with U-235 as the active fuel.

For U_3O_8-based system as shown in Table 6.95, the maximum U-235 loading is 175x4=700 grams per divider position for the two double-stacked NBSR fuel elements and the maximum U-235 enrichment is 93%. For conservatism purposes, the maximum loading analyzed for MTR Type I is taken to be 710 grams and 94% enrichment.

For U_3Si_5-based system as shown in Table 6.95, the maximum U-235 loading is 344x2 = 688 grams per divider position for two ORR fuel elements and the maximum U-235 enrichment is 20%. For conservatism purposes, the maximum loading analyzed for MTR Type II is taken to be 694 grams and 20% enrichment.

For UAl-based system as shown in Table 6.95, the maximum U-235 loading is 287x2 = 574 grams per divider position for two SAPHIR fuel elements and the maximum U-235 enrichment is 93%. For conservatism purposes, the maximum loading analyzed for MTR Type III is taken to be 580 grams and 94% enrichment.

For U-235-based system as shown in Table 6.96, the maximum U-235 loading is 130x2 = 260 grams per divider position for two MTR-equivalent fuel elements and the maximum U-235 enrichment is 95%. The maximum loading analyzed for MTR Type IV is taken to be 260 grams and 95% enrichment.

6.7.6.1.5 MTR Type I Fuel (U_3O_8)

Fuel assemblies for these reactors are similarly constructed aluminum clad plates with U_3O_8 fuel material. The GEMER model for the MTR Type I fuel consists of two double-stacked NBSR fuel elements loaded into each divider position. A total of 710 grams of 94% enriched U-235 per divider position in the fuel divider is modeled in this criticality analysis. Based on this mass, the corresponding masses of U-238 and cladding material can be estimated. Subsection 6.7.6.5.3 shows the simple FORTRAN program used to calculate the fuel number densities (U-235, U-238, Al, and O) for the case of MTR Type I fuel elements and its associated FORTRAN output.

6.7.6.1.6 MTR Type II Fuel (U_3Si_2)

Table 6.96 provides dimensions and nuclear data for MTR Type II fuel (ORR) to which this analysis applies. Fuel assemblies for these reactors are similarly constructed aluminum clad plates with U_3Si_2 fuel material. The GEMER model for the MTR Type II fuel consists of two ORR fuel elements loaded into each divider position. A total of 694 grams of 20% enriched U-235 per divider position in the fuel divider is modeled in this criticality analysis. Based on this mass, the corresponding masses of U-238 and cladding material can be estimated. Subsection 6.7.6.5.7 shows the simple FORTRAN program used to calculate the fuel number densities (U-235, U-238, Si, and Al) for the case of MTR Type II fuel elements and the associated FORTRAN output.

6.7.6.1.7 MTR Type III Fuel (UAl)

Table 6.96 provides dimensions and nuclear data for MTR Type III fuel (SAPHIR) to which this analysis applies. Fuel assemblies for these reactors are similarly constructed aluminum clad plates with UAl fuel material. The GEMER model for the MTR Type III fuel consists of two SAPHIR fuel elements loaded into each divider position. A total of 580 grams of 94% enriched U-235 per divider position in the fuel divider is modeled in this criticality analysis. Based on this mass, the corresponding masses of U-238 and cladding material can be estimated. Subsection 6.7.6.5.11 shows the simple FORTRAN program used to calculate the fuel number densities (U-235, U-238, and Al) for the case of MTR Type III fuel elements and its associated FORTRAN output.

6.7.6.1.8 MTR Type IV Fuel (Metallic U)

Table 6.96 provides dimensions and nuclear data for MTR Type IV fuel (Metallic U) to which this analysis applies. Fuel assemblies for these reactors are similarly constructed with metallic U fuel material. The fuel assembly is in a typical MTR physical form (BSR fuel assembly). The GEMER model for the MTR Type IV fuel consists of two U-235-based fuel elements loaded into each divider position. A total of 220 grams of 95% enriched U-235 per divider position in the fuel divider is modeled in this criticality analysis. Based on this mass, the corresponding masses of U-238 and cladding material can be estimated. Subsection 6.7.6.5.15 shows the simple FORTRAN program used to calculate the fuel number densities (U-235 and U-238) for the case of MTR Type IV fuel elements and its associated FORTRAN output.

Table 6.95. MTR Type I, II, and III Fuel Data

FUEL TYPE		GEOMETRY												NUCLEAR DATA					
REACTOR CLASS	Composition	TRIMMED LENGTH (IN)	FUEL DIMENSION (IN)											MAX. TOTAL g U-235	MAX. U-235 g per Plate	MAX. No. of Fuel Plate/Elem	Nominal Enrichment (%)	BURNUP (MWd)	BURNUP (%)
			a	b	t_{SP}	d	e	f	g	t_{WC}	L_{AF}	L_{EL}							
NBSR	U3O8-Al	13.313	3.000	3.368	0.187	2.500	0.015	0.020	0.050	0.116	11.00	13.39		350*2	10.3*2	17*2	93.0	170-200	65-73
OWR	U3O8-Al	n/a	3.031	3.303	0.187	2.547	0.015	0.020	0.050	0.116	23.54	42.625		235	12.2	19	93.0		50
HFBR	U3O8-Al	24.625	2.878	3.218	0.187	2.252	0.014	0.023	0.050	0.096	22.86	57.250		355	19.7	18	93.0		44-48
ORR #2	U3O8-Al	n/a	2.992	3.150	0.187	2.500	0.015	0.020	0.050	0.116	23.62	38.39		285	15.0	19	93.0		
ORR	U3Si2-Al	n/a	3.034	3.188	0.187	2.500	0.015	0.020	0.050	0.116	23.62	38.39		344	18.000	19	20.0	20-172	6-50
BSR	UAl-Al	n/a	2.996	3.313	0.187	2.500	0.015	0.020	0.051	0.116	23.53	37.125		223	11.7	19	93.0	88	40
SAPHIR	UAl-Al	n/a	2.996	2.968	0.177	2.469	0.015	0.020	0.050	0.088	23.61	34.39		287	12.5	23	93.0	155	71/64
ORR #1	UAl-Al	n/a	2.992	3.150	0.187	2.500	0.015	0.020	0.050	0.116	23.62	38.39		202	10.6	19	93.0		
GRR #1	UAl-Al	n/a	2.992	3.150	0.177	2.480	0.015	0.020	0.050	0.116	23.62	37.40		180.5	9.5	19	93.0		
GRR#2	UAl-Al	n/a	2.992	3.150	0.177	2.480	0.015	0.020	0.050	0.124	23.62	37.40		187.2	10.4	18	93.0		
GRR#3	UAl-Al	n/a	2.992	3.150	0.177	2.480	0.020	0.020	0.060	0.114	23.62	37.40		180.9	10.05	18	93.0		
ASTRA	UAl-Al	n/a	2.992	3.150	0.177	2.472	0.015	0.020	0.050	0.088	24.61	34.37		281	12.22	23	93.0		
TSR	MTR													8687				83.300	

Nomenclature:

a = Element width, inch

b = Assembly maximum depth, inch

t_{SP} = Side plate thickness, inch

d = Active fuel width, inch

e = Cladding thickness, inch

f = Active fuel thickness, inch

g = Plate thickness, inch

t_{WC} = Water channel thickness, inch

L_{AF} = Active fuel length, inch

L_{EL} = Element length, inch

ORR = Oak Ridge Research Reactor, Oak Ridge USA

NFBR = High Flux Beam Reactor, Brookhaven USA

OWR = Omega West Reactor, Los Alamos USA

BSR = Bulk Shielding Reactor, Oak Ridge USA

NBSR = National Institute of Standards Test Reactor, Washington D.C. USA

GRR = Greek Research Reactor, Greece

ASTRA = Adapter Schwimmbecken Tank Reaktor, Austria

SAPHIR = Reseach Reactor, Switzerland

Table 6.96. MTR Type IV Fuel Data

FUEL TYPE		GEOMETRY											NUCLEAR DATA					
REACTOR CLASS	Composition	TRIMMED LENGTH (IN)	FUEL DIMENSION (IN)										MAX. TOTAL g U-235	MAX. U-235 g per Plate	MAX. No. of Fuel Plate/Elem	Nominal Enrichment (%)	BURNUP (MWd)	BURNUP (%)
			a	b	t_{SP}	d	e	f	g	t_{WC}	L_{AF}	L_{EL}						
MTR Equivalent	U	n/a	2.996	3.313	0.187	2.500	0.015	0.020	0.051	0.116	23.53	37.125	260	15.29	19	95.0		

Nomenclature:

Refer to Table 6.95.

6.7.6.1.9 Summary of Results

Tables 6.97 through 6.100 summarize the results of the criticality evaluations for the MTR Type I, II, III, and IV fuel, respectively, for the case of infinite cask arrays.

Table 6.97. Summary of Results for the Infinite Cask Scenario for MTR Type I Fuel (94% Enrichment) — Discrete Fuel Model

Condition/Parameter	Quantity/Comment
Number of Containers in Demonstration	Infinite Array
Optimum Hydrogenous Moderation	1.0 Weight Fraction H_2O
Maximum Multiplication Factor $k_{eff} + 2\sigma$ + Bias	**0.90776**

Table 6.98. Summary of Results for the Infinite Cask Scenario for MTR Type II Fuel (20% Enrichment) — Discrete Fuel Model

Condition/Parameter	Quantity/Comment
Number of Containers in Demonstration	Infinite Array
Optimum Hydrogenous Moderation	1.0 Weight Fraction H_2O
Maximum Multiplication Factor $k_{eff} + 2\sigma$ + Bias	**0.88127**

Table 6.99. Summary of Results for the Infinite Cask Scenario for MTR Type III Fuel (94% Enrichment) — Discrete Fuel Model

Condition/Parameter	Quantity/Comment
Number of Containers in Demonstration	Infinite Array
Optimum Hydrogenous Moderation	1.0 Weight Fraction H_2O
Maximum Multiplication Factor $k_{eff} + 2\sigma$ + Bias	**0.90260**

Table 6.100. Summary of Results for the Infinite Cask Scenario for MTR Type IV Fuel (95% Enrichment) — Discrete Fuel Model

Condition/Parameter	Quantity/Comment
Number of Containers in Demonstration	Infinite Array
Optimum Hydrogenous Moderation	1.0 Weight Fraction H_2O
Maximum Multiplication Factor $k_{eff} + 2\sigma$ + Bias	**0.62514**

6.7.6.2 Package Fuel Loading

Tables 6.101 through 6.104 summarize the maximum fuel load (mass), as well as some significant constraints for the form of the MTR Type I, II, III, and IV fuel, respectively. The loading specified in Tables 6.101 through 6.104 described herein qualifies as an infinite (N=∞) Fissile Class III package with a zero transport index under the provisions of 10CFR71.61, based on the infinite cask analysis. This loading also meets the IAEA Safety Standards for an infinite shipment (N=∞) with a zero Transport Index for criticality safety.

Table 6.101. Package Parameters for Model 2000 Cask with MTR Type I Fuel (U_3O_8)

Parameter	Quantity/Comment
Fuel Construction	MTR Type Fuel Plates
Fuel Material	U_3O_8 (41.6%) + Al (58.4%)
Cladding Material	Al
Minimum Fuel Burnup	N/A
Total ^{235}U mass per divider position	710 grams
Maximum Fuel Enrichment	94.0%
^{238}U mass per divider position	45.3 grams
Burnable Poison Materials (e.g., Gd)	None
Maximum U_3O_8 Density (100% T.D.)	8.39 gm/cm^3
Nominal Al Density	2.699 gm/cm^3

Table 6.102. Package Parameters for Model 2000 Cask with MTR Type II Fuel (U_3Si_2)

Parameter	Quantity/Comment
Fuel Construction	MTR Type Fuel Plates
Fuel Material	U_3Si_2 (80%) + Al (20%)
Cladding Material	Al
Total ^{235}U mass per divider position	694 grams
Maximum Fuel Enrichment	20.0%
^{238}U mass per divider position	2774.4 grams
Minimum Fuel Burnup	N/A
Burnable Poison Materials (e.g., Gd)	None
Maximum U_3Si_2 Density (100% T.D.)	12.02 gm/cm^3
Nominal Al Density	2.699 gm/cm^3

Table 6.103. Package Parameters for Model 2000 Cask with MTR Type III Fuel (UAl_x)

Parameters	Quantity/Comment
Fuel type	UAl/Al
Fuel/Aluminum ratio	22.5/77.5
^{235}U mass per plate	12.11 grams
Number of plates/fuel element	19
Number of fuel elements per divider position	2
Total ^{235}U mass per divider position	580 grams
^{235}U enrichment	94.0%
^{238}U mass per divider position	29.4 grams
Al mass (fuel) per divider position	56.1 grams
UAl_X density	6 g/cc
Al density	2.7 g/cc

Table 6.104. Package Parameters for Model 2000 Cask with MTR Type IV Fuel (Metallic U)

Parameters	Quantity/Comment
Fuel type	U
Fuel/Aluminum ratio	100.0/0.0
^{235}U mass per plate	15.29 grams
Number of plates/fuel element	19
Number of fuel elements per divider position	2
Total ^{235}U mass per divider position	260 grams
^{235}U enrichment	95.0%
^{238}U mass per divider position	11.6 grams
Al mass (fuel) per divider position	0.0 grams
U density	19.1 g/cc

6.7.6.3 Model Specification

6.7.6.3.1 Description of Calulational Models

The model assumes fresh, undepleted fuel in the active fuel region, neglecting any as-built poisons or fission products. The model also omits the overpack from consideration, which brings the water reflector closer to the fissile material and adds an extra degree of conservatism to the analysis.

The Model 2000 cask is modeled in three dimensions. Only the cask (without the overpack) and fuel are modeled. The cask is cylindrical with an interior cavity. This cavity is 26.5 inches (67.31 cm) in diameter and 54 inches (137.16 cm) in height. The cask outside diameter is 38.5 inches (97.79 cm). The total cask radial wall and bottom plate thickness is 6.0 inches (15.24 cm). The Model 2000 cask consists of a layered radial wall design composed of 1.0 inch (2.54 cm) of 304 stainless steel, 4.0 inches (10.16 cm) of lead, and then another 1.0 inch of 304 stainless steel. The cask bottom consists of 6 inches (15.24 cm) of 304 stainless steel. The top of the cask was modeled as having a 1.5 inch (3.81 cm) thick 304 stainless steel plate inside the cask at the top, then 4.5 inches (11.43 cm) of lead, and then a 1.75 inch (4.45 cm) thick 304 stainless steel plate on the top of the cask. For conservatism, the model reduces the wall thickness of stainless steel portions of the cask in areas where neutron absorption in the stainless steel reduces the neutron multiplication (i.e., cask walls and cask top).

The MTR fuel elements are modeled in a most conservative but credible position, with all fuel elements protruding from the 21 slots to the maximum possible extent. This maximizes the reactivity in the system. Subsection 6.7.6.5.4 show the sectional and side views of the GEMER geometrical model.

The fuel is treated discretely:

1. The MTR Type I fuel consists of 17 fueled plates. The dimensions of the active fuel are 0.0508 cm x 6.1341 cm x 133.4008 cm. The outer Aluminum clad dimensions are 0.127 cm x 6.6675 x 133.4008 cm.

2. The MTR Type II fuel consists of 19 fueled plates. The dimensions of the active fuel are 0.0508 cm x 6.3500 cm x 119.9363 cm. The outer Aluminum clad dimensions are 0.127 cm x 7.112 x 119.9363 cm.

3. The MTR Type III fuel consists of 19 fueled plates. The dimensions of the active fuel are 0.0508 cm x 6.3500 cm x 119.5324 cm. The outer Aluminum clad dimensions are 0.12954 cm x 7.10946 x 119.5324 cm.

4. The MTR Type IV fuel consists of 19 fueled plates. The dimensions of the active fuel are 0.0508 cm x 6.3500 cm x 119.5324 cm. The outer Aluminum clad dimensions are 0.12954 cm x 7.10946 x 119.5324 cm.

The stainless ingot is 125.27 cm high and the boral plates extend to a height of 125.27 cm.

6.7.6.3.2 Package Regional Densities

The fuel assembly model assumes the maximum possible fissile mass of ^{235}U per fuel assembly with a maximum enrichment of 20% for MTR Type II fuel, 94% for MTR Type I and III fuel, and 95% for MTR Type IV fuel. Subsection 6.7.6.5.3 lists the FORTRAN program used to calculate the fuel densities used in this analysis.

Material densities and corresponding number densities are based on standard material specifications. These materials have been calculated earlier (Subsection 6.3.2). Tables 6.105 and 6.106 present the material densities and number densities for substances (materials) in the criticality model. Substances composed of more than one element are broken into their elemental number densities in the number density column.

Table 6.105. Material Densities Used in the Model 2000 for the MTR Type of Fuel

Region	Material	Component Density (gm/cm^3)	Number Density (atom/barn-cm)
304 Stainless Steel	SS304	7.800	6.82690E-05 (C-12) 8.53360E-04 (Si) 1.53600E-02 (Cr) 6.04950E-02 (Fe) 6.82690E-03 (Ni) 1.70670E-03 (Mn) 2.56010E-05 (S-16)
Lead Shielding	Pb	11.35	3.2989E-02 (Pb)
Water (Reflector)	H_2O	1.00	6.691E-02 (H) 3.345E-03 (O)

Table 6.106. Material Densities of Borated Aluminum

Nuclide	Number Density (atom/bn-cm) (Used in GEMER Analysis*)	Number Density (atom/bn-cm) (Actual Design Requirement)
B-10*	4.15822E-03	5.5443E-03
B-11*	8.48616E-05	1.1315E-04
Al*	5.8001E-02	5.8001E-02

Notes: * The B-10, B-11 and Al number densities are calculated as follows:

[lines deleted]

N(B-10) = 98% B-10 * 3.5 weight percent of Boron * 2.693 g/cm^3 in the mixture * Avogardo's number / Boron Atomic Weight * (75% reduction factor)

= .98 * .035 * 2.693 * 6.022E23 *.75 / (.98*10.01294 + .02*11.00931)

= 4.15822×10^{21} number/cm^3

N(B-11) = 0.02/.98 * N(B-10)

= 8.48616×10^{19} number/cm^3

N(Al) = 0.965 * 2.693 * 6.022E23/26.98153

= 5.8001×10^{22} number/cm^3

6.7.6.4 Criticality Calculation

6.7.6.4.1 Calculational Method

The computational tool used in this evaluation is the GE MERit code (GEMER).

6.7.6.4.2 Fuel Loading Optimization

Fuel assemblies are held within the basket structure during both normal conditions of transport and during hypothetical accident, so the geometry to be analyzed is well defined. Like other light water reactor fuels, the fuels considered here are substantially subcritical when placed in air due to a lack of neutron moderation. Increasing the moderation within an assembly by adding water to it results in an increase in k_{eff}.

The boundary condition around the cask in all criticality calculations is a leakage-proof boundary condition with perfect reflection surrounding all sides of the arrays. This corresponds to an infinite array of casks in their most reactive array configuration with full reflection.

6.7.6.4.3 GEMER Results

6.7.6.4.3.1 MTR Type I Fuel

Table 6.107 displays the GEMER results for the infinite cask scenario for MTR Type I for the Discrete Model. Table 6.108 and Figure 6.61 show the variation of the k-effectives as the number of fuel plates is varied from 1 to 17, maintaining the same fissile content within each divider slot (i.e., 710 grams) and at full-density water. In addition, the fuel plates are assumed to be equally spaced within the divider slot. The optimum number of fuel plates is found to be 14, and the 14-plate case is expanded to include full range of water moderation (i.e., varying H/U^{235} ratios). These results are shown in Table 6.109 and Figure 6.62. In addition, the17-plate case is also studied for the full range of water density (Table 6.110 and Figure 6.62). The 14-plate case is also studied with a varying pitch and the results are shown in Table 6.111 and Figure 6.63.

The water reflection (WR) case denotes the case when the surrounding materials outside of the fuel basket is replaced by full-density water and the perfectly reflecting boundary conditions are applied on all sides and the top and bottom.

The pitch sensitivity case shows that the system tends to be under-moderated and hence increasing the fuel plate pitch tends to increase the k-effective. The equally-spaced pitch used in the base model represents a condition very close to the worst configuration.

It is also noted that the k-effective between the nominal case with 17 plates and the optimal case with 14 fuel plates is very small (less than 1% reactivity). Hence, it is concluded that if the k-efective is much below 0.95, the fuel plate number sensitivity can be omitted for other MTR fuel types.

The maximum k_{eff} for MTR Type I fuel is 0.90776 for the discrete case after accounting for uncertainty and bias. These values are below the subcriticality limit of 0.95.

Table 6.107. Summary of Results — Infinite Cask Scenario for MTR Type I Fuel (U_3O_8)

Condition/Parameter	Quantity/Comment
Number of Containers in Demonstration	Infinite Array
Optimum Hydrogenous Moderation	1.00 Weight Fraction H_2O
Maximum Multiplication Factor $k_{eff} + 2\sigma$ + Bias	**0.90776**

Table 6.108. GEMER Results — Infinite Cask Scenario for MTR Type I Fuel (Discrete Model, Fuel Plate Number Sensitivity)

H_2O Density Weight %	$H/^{235}U$ Ratio	Number of Fuel Plates	K_{eff}	$\pm\sigma$	Bias	$k+2\sigma$ +Bias
100	352.806	17	0.89442	0.00287	0.00000	0.90016
100	356.960	16	0.88027	0.00263	0.00526	0.89079
100	361.115	15	0.89408	0.00302	0.00532	0.90544
100	365.269	14	0.89601	0.00319	0.00537	0.90776
100	369.423	13	0.89560	0.00313	0.00542	0.90728
100	373.577	12	0.89390	0.00289	0.00548	0.90516
100	377.732	11	0.88641	0.00317	0.00553	0.89828
100	381.886	10	0.88963	0.00273	0.00558	0.90067
100	386.040	9	0.88737	0.00283	0.00563	0.89866
100	390.194	8	0.88221	0.00291	0.00568	0.89371
100	394.349	7	0.87050	0.00289	0.00573	0.88201
100	398.503	6	0.85628	0.00280	0.00578	0.86766
100	402.657	5	0.83685	0.00301	0.00583	0.84870
100	406.811	4	0.81440	0.00270	0.00588	0.82568
100	410.966	3	0.75903	0.00309	0.00593	0.77114
100	415.120	2	0.65328	0.00269	0.00598	0.66464
100	419.274	1	0.45602	0.00270	0.00603	0.46745

Table 6.109. GEMER Results — Infinite Cask Scenario for MTR Type I Fuel (Discrete Model, Water Density Sensitivity, 14 Plates)

H_2O Density Weight %	Number of Fuel Plates	$H/^{235}U$ Ratio	K_{eff}	$\pm\sigma$	Bias	$k+2\sigma$ +Bias
0	14	0.000	0.17212	0.00056	0.00000	0.17324
10	14	36.527	0.30925	0.00150	0.00012	0.31237
20	14	73.054	0.47828	0.00178	0.00081	0.48265
30	14	109.581	0.60554	0.00267	0.00147	0.61235
40	14	146.108	0.70248	0.00268	0.00211	0.70995
50	14	182.634	0.77117	0.00299	0.00272	0.77987
60	14	219.161	0.81553	0.00337	0.00330	0.82557
70	14	255.688	0.84695	0.00357	0.00386	0.85795
80	14	292.215	0.86725	0.00341	0.00439	0.87846
90	14	328.742	0.88585	0.00306	0.00489	0.89686
100	**14**	**365.269**	**0.89601**	**0.00319**	**0.00537**	**0.90776**
WR	14	403.820	0.88020	0.00321	0.00585	0.89247

Table 6.110. GEMER Results — Infinite Cask Scenario for MTR Type I Fuel (Discrete Model, Water Density Sensitivity, 17 Plates)

H_2O Density Weight %	Number of Fuel Plates	$H/^{235}U$ Ratio	K_{eff}	± σ	Bias	k+2σ +Bias
0	17	0.000	0.17198	0.00045	0.00000	0.17288
10	17	35.281	0.30566	0.00164	0.00009	0.30903
20	17	70.561	0.47050	0.00211	0.00076	0.47548
30	17	105.842	0.60412	0.00251	0.00140	0.61054
40	17	141.122	0.68719	0.00276	0.00202	0.69473
50	17	176.403	0.76302	0.00256	0.00262	0.77076
60	17	211.684	0.80916	0.00299	0.00319	0.81833
70	17	246.964	0.84638	0.00277	0.00373	0.85565
80	17	282.245	0.86465	0.00271	0.00425	0.87432
90	17	317.525	0.88187	0.00321	0.00474	0.89303
100	17	352.806	0.89442	0.00287	0.00521	0.90537
WR	17	391.361	0.88431	0.00298	0.00570	0.89597

Table 6.111. GEMER Results — Infinite Cask Scenario for MTR Type I Fuel (Discrete Model, Water Density Sensitivity, 14 and 17 Plates, Pitch Sensitivity)

H_2O Density Weight %	Number of Fuel Plates	Pitch	$H/^{235}U$ Ratio	K_{eff}	± σ	Bias	k+2σ +Bias
100	14	1.0787	365.2688	0.52500	0.00277	0.00537	0.53591
100	14	2.5748	365.2688	0.69280	0.00264	0.00537	0.70345
100	14	4.1496	365.2688	0.84530	0.00318	0.00537	0.85703
100	14	5.0000	365.2688	0.89601	0.00319	0.00537	0.90776
100	17	1.0787	352.806	0.53695	0.00281	0.00521	0.54778
100	17	2.5748	352.806	0.74597	0.00276	0.00521	0.75670
100	17	3.3622	352.806	0.83070	0.00299	0.00521	0.84189
100	17	4.1176	352.806	0.89442	0.00287	0.00521	0.90537

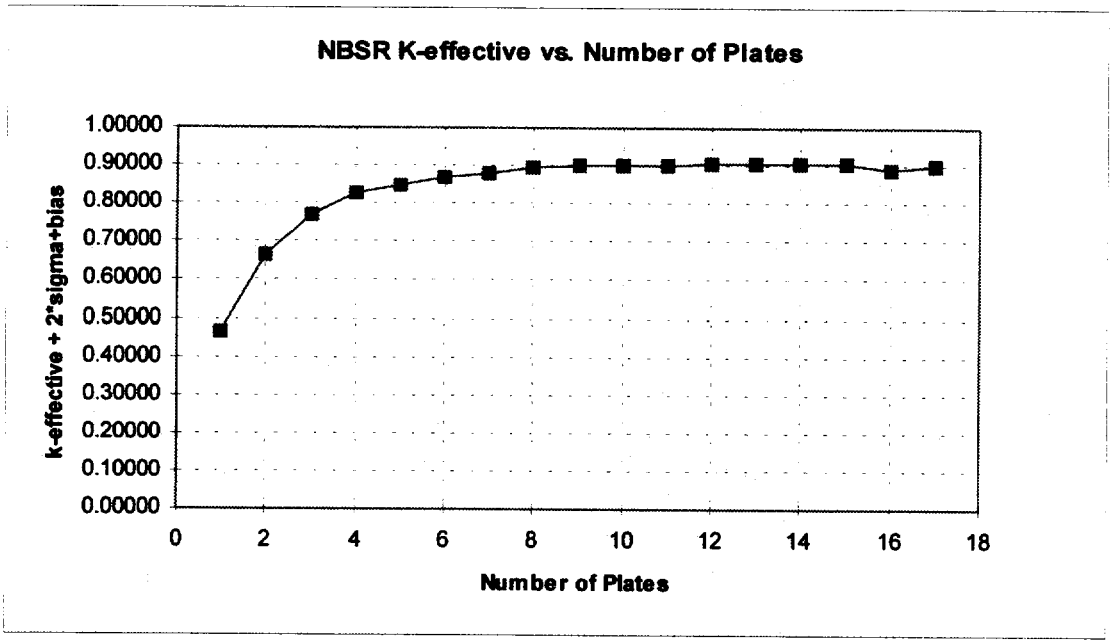

Figure 6.61. MTR Type I Fuel, Sensitivity of the Number of Fuel Plates

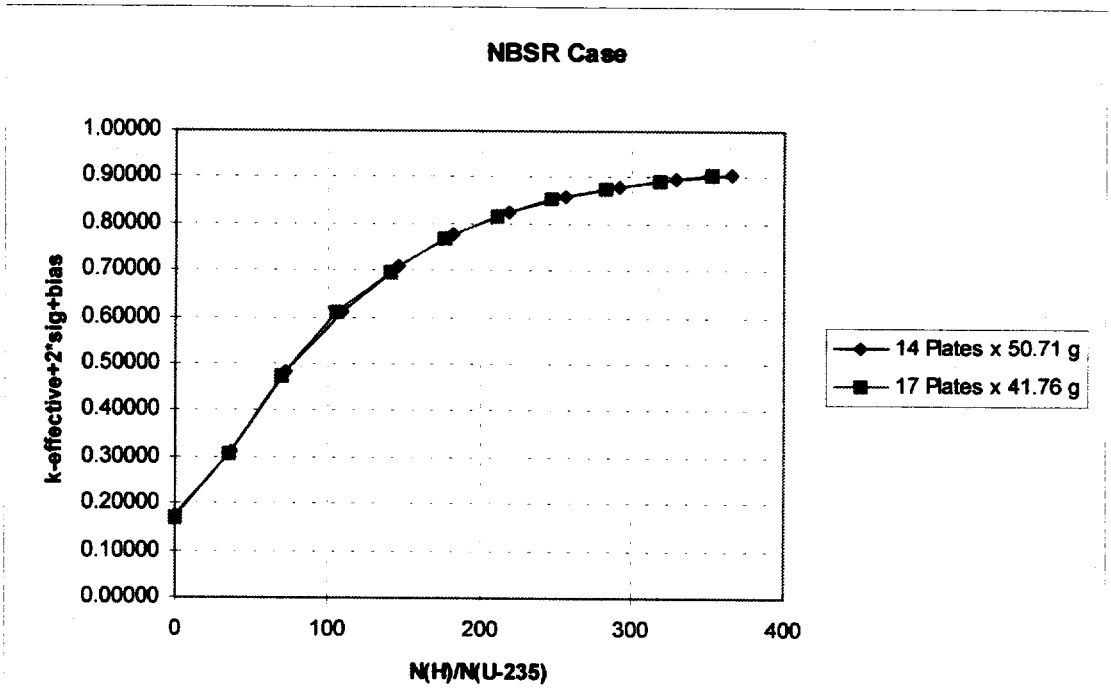

Figure 6.62. MTR Type I Fuel, Infinite Cask Array, Water Variation for the 14-Plate and 17-Plate Cases

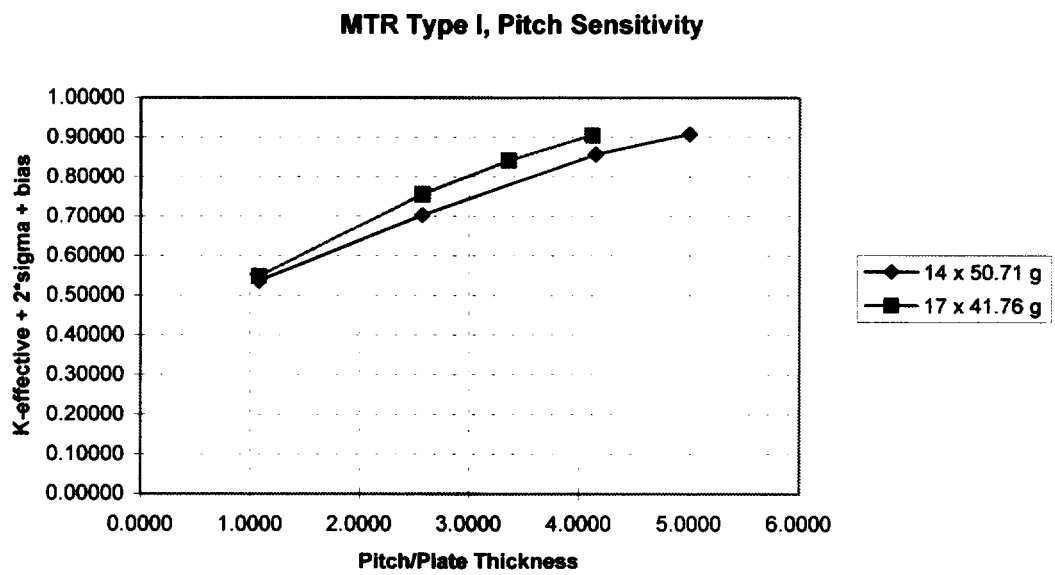

Figure 6.63. MTR Type I Fuel, Infinite Cask Array, Pitch Sensitivity for the 14-Plate and 17-Plate Cases

6.7.6.4.3.2 MTR Type II Fuel

Table 6.112 displays the GEMER results for the infinite cask scenario for MTR Type II for the Discrete Model. Table 6.113 shows the variation of k-effective as a function of water density. Figure 6.64 is a plot of the discrete model k-effectives under varying H/U^{235} ratios.

Additional pitch and fuel plate number sensitivity studies were not performed as the k-**effective is much below 0.95.**

The water reflection (WR) case denotes the case when the surrounding materials outside of the fuel basket is replaced by full-density water and the perfectly reflecting boundary conditions are applied on all sides and the top and bottom.

The maximum k_{eff} for MTR Type II fuel is 0.88127 for the discrete case after accounting for uncertainty and bias. These values are below the subcriticality limit of 0.95.

Table 6.112. Summary of Results — Infinite Cask Scenario for MTR Type II Fuel (U_3Si_s)

Condition/Parameter	Quantity/Comment
Number of Containers in Demonstration	Infinite Array
Optimum Hydrogenous Moderation	1.00 Weight Fraction H_2O
Maximum Multiplication Factor $k_{eff} + 2\sigma$ + Bias	**0.88127**

Table 6.113. GEMER Results — Infinite Cask Scenario for MTR Type II Fuel (Discrete Model, 19 Fuel Plates)

H_2O Density Weight %	$H/^{235}U$ Ratio	K_{eff}	$\pm\sigma$	Bias	$k+2\sigma$ +Bias
0	0.000	0.17584	0.00055	0.00000	0.17694
10	35.596	0.30297	0.00124	0.00010	0.30555
20	71.191	0.45818	0.00215	0.00077	0.46325
30	106.787	0.57400	0.00206	0.00142	0.57954
40	142.382	0.66850	0.00255	0.00204	0.67564
50	177.978	0.73558	0.00240	0.00264	0.74302
60	213.573	0.79084	0.00275	0.00322	0.79956
70	249.169	0.81899	0.00289	0.00376	0.82853
80	284.764	0.84718	0.00288	0.00428	0.85722
90	320.360	0.86992	0.00273	0.00478	0.88016
100	**355.955**	**0.87082**	**0.00260**	**0.00525**	**0.88127**
WR	395.417	0.86441	0.00330	0.00574	0.87675

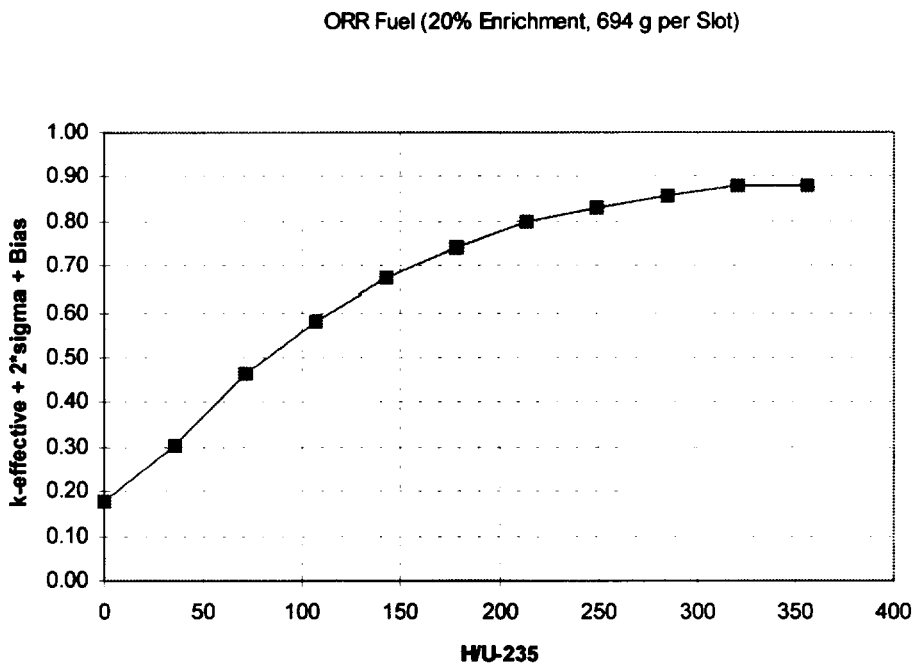

Figure 6.64. MTR Type II Fuel, Infinite Cask Array

6.7.6.4.3.3 MTR Type III Fuel

Table 6.114 displays the GEMER results for the infinite cask scenario for MTR Type III for the Discrete Model. Table 6.115 shows the variation of k-effective as a function of water density. Figure 6.65 is a plot comparing the discrete model k-effectives under varying H/U^{235} ratios (from dry to fully moderated condition).

The water reflection (WR) case denotes the case when the surrounding materials outside of the fuel basket is replaced by full-density water and the perfectly reflecting boundary conditions are applied on all sides and the top and bottom.

Additional pitch and fuel plate number sensitivity studies were not performed as the k-effective is much below 0.95.

The maximum k_{eff} for MTR Type III fuel is 0.90260 for the discrete case after accounting for uncertainty and bias. These values are below the subcriticality limit of 0.95.

Table 6.114. Summary of Results — Infinite Cask Scenario for MTR Type III Fuel (UAl_x)

Condition/Parameter	Quantity/Comment
Number of Containers in Demonstration	Infinite Array
Optimum Hydrogenous Moderation	1.00 Weight Fraction H_2O
Maximum Multiplication Factor $k_{eff} + 2\sigma$ + Bias	**0.90260**

Table 6.115. GEMER Results — Infinite Cask Scenario for MTR Type III Fuel (Discrete Model)

H_2O Density Weight %	$H/^{235}U$ Ratio	K_{eff}	$\pm\sigma$	Bias	$k+2\sigma$ +Bias
0	0.000	0.15308	0.00048	0.00000	0.15404
10	42.417	0.29086	0.00151	0.00023	0.29411
20	84.834	0.45191	0.00218	0.00102	0.45729
30	127.251	0.57977	0.00242	0.00178	0.58639
40	169.669	0.67591	0.00253	0.00251	0.68348
50	212.086	0.75194	0.00308	0.00319	0.76129
60	254.503	0.79711	0.00269	0.00384	0.80633
70	296.921	0.83378	0.00321	0.00446	0.84466
80	339.338	0.85434	0.00272	0.00504	0.86482
90	381.755	0.86903	0.00278	0.00558	0.88017
100	**424.172**	**0.89060**	**0.00296**	**0.00608**	**0.90260**
WR	471.391	0.87625	0.00283	0.00661	0.88852

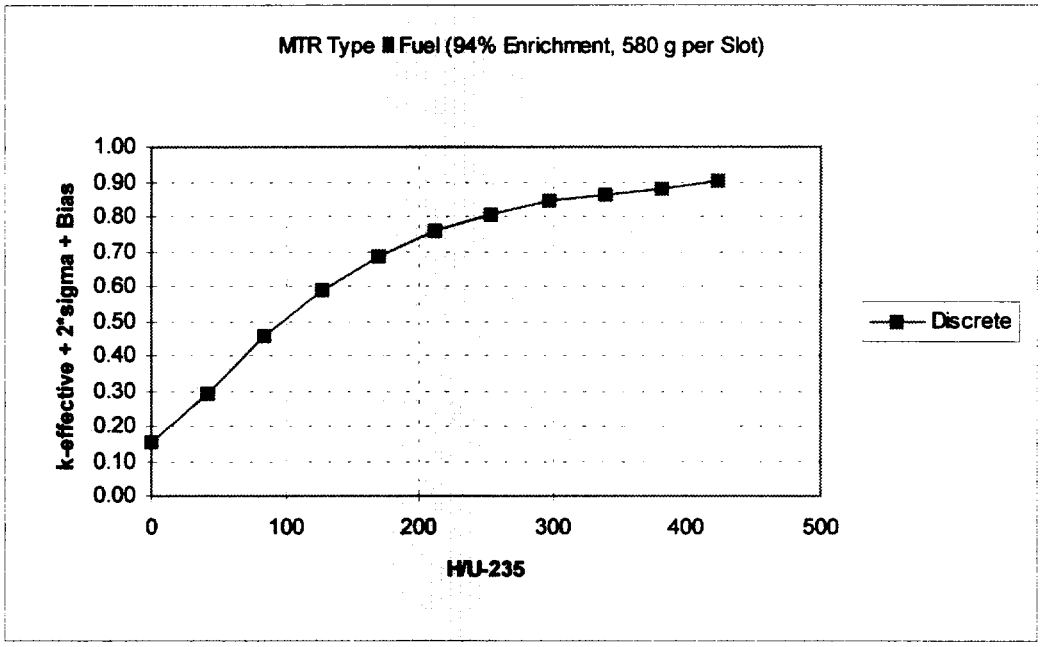

Figure 6.65. MTR Type III Fuel, Infinite Cask Array

6.7.6.4.3.4 TR Type IV Fuel

Table 6.116 displays the GEMER results for the infinite cask scenario for MTR Type IV for the Discrete Model. Table 6.117 shows the variation of k-effective as a function of water density. Figure 6.66 is a plot comparing the discrete model k-effectives under varying H/U^{235} ratios.

The water reflection (WR) case denotes the case when the surrounding materials outside of the fuel basket is replaced by full-density water and the perfectly reflecting boundary conditions are applied on all sides and the top and bottom.

Additional pitch and fuel plate number sensitivity studies were not performed as the k-effective is much below 0.95.

The maximum k_{eff} for MTR Type III fuel is 0.62514 for the discrete case after accounting for uncertainty and bias. These values are below the subcriticality limit of 0.95.

Table 6.116. Summary of Results — Infinite Cask Scenario for MTR Type IV Fuel (Metallic U)

Condition/Parameter	Quantity/Comment
Number of Containers in Demonstration	Infinite Array
Optimum Hydrogenous Moderation	1.00 Weight Fraction H_2O
Maximum Multiplication Factor $k_{eff} + 2\sigma$ + Bias	**0.62514**

Table 6.117. GEMER Results — Infinite Cask Scenario for MTR Type IV Fuel (Discrete Model)

H_2O Density Weight %	# of Plates	$H/^{235}U$ Ratio	K_{eff}	$\pm\sigma$	Bias	$k+2\sigma$ +Bias
0	19	0.000	0.06761	0.00027	0.00000	0.06815
10	19	111.827	0.16596	0.00106	0.00151	0.16959
20	19	223.655	0.29698	0.00161	0.00337	0.30357
30	19	335.482	0.39477	0.00222	0.00498	0.40419
40	19	447.309	0.47123	0.00192	0.00635	0.48142
50	19	559.136	0.52484	0.00234	0.00746	0.53698
60	19	670.963	0.55898	0.00202	0.00832	0.57134
70	19	782.791	0.58401	0.00231	0.00893	0.59756
80	19	894.618	0.60109	0.00231	0.00929	0.61500
90	19	1006.445	0.61046	0.00225	0.00940	0.62436
100	**19**	**1118.272**	**0.61158**	**0.00215**	**0.00926**	**0.62514**
WR	19	1242.758	0.60796	0.00217	0.00881	0.62111

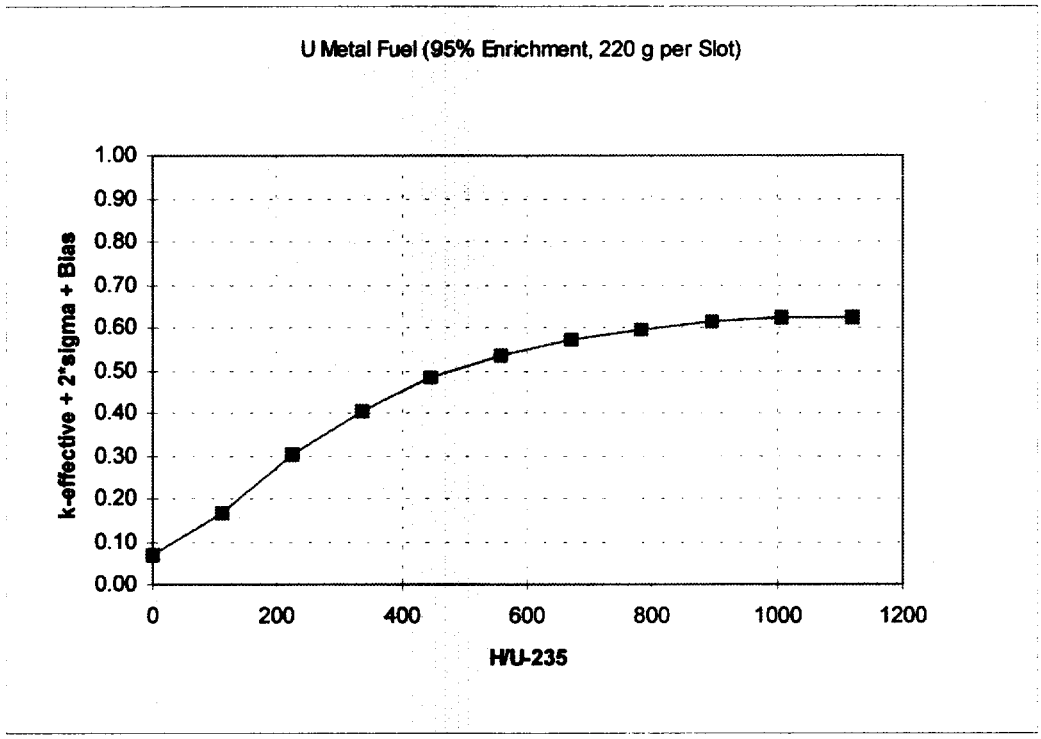

Figure 6.66. MTR Type IV Fuel, Infinite Cask Array

6.7.6.4.4 Conclusions

All results, including the conservative accident condition cases, are subcritical. The maximum k-effectives for the worst MTR Type I, II, III, and IV cases, after accounting for uncertainty and bias, are 0.90776, 0.88127, 0.90260, and 0.62514, respectively. The effective multiplication factors are all less than 0.95. It is generally true that the discrete model will tend to have lower k-effective than the homogenous model because the worst case homogenous model tends to be optimally moderated.

The system will be subcritical under all conceivable and realistic accident scenarios. This conclusion is reached based on the requirement that the borated aluminum poison structure is maintained under all credible accident conditions. This meets all NRC requirements for the subcriticality safety analysis and the MTR Type I, II, III, and IV fuel can be safely transported using the Model 2000 cask.

6.7.6.5 Input/Output — MTR Type I, II, III, and IV Fuels

6.7.6.5.1 GEMER Input Decks (MTR Type I Fuel)

This section includes GEMER geometrical plots and input listings for the infinite array. Each NBSR basedeck contains a "header" with fuel material and geometry information.

6.7.6.5.2 Infinite MTR Type I Case (94.0% Enriched Fuel)

```
NBSR FUEL/ IF2000/21 ELEMENTS, SS+Pb SHIELDING. MASS U235 IN EACH
ELEM=710G
   105 /* # BATCHES
  1000  /* # NEUTRONS PER BATCH
     5  /* # BATCHES TO SKIP
 2123469/* INITIAL "SEED" (IF NON-ZERO)
     0  /* "IDUMP"
     0  /* "NRSTRT"
     0  /* "NBTED" (NON-ZERO IS PRINT EDITS)
     0  /* "KRED" (NUMBER OF COMBINED REGIONS IN EDITS)
     0  293   19  7
      4  293 0  0 U(94.0)3O8  RHOMIX= 3.035427 g/cc     MAT 1
     16  8.8621089E-03
    131  4.8045460E-02
   2381  1.9699350E-04
   2351  3.1262971E-03
      3  293 0 0 Boral 0.25" Plate (75% Boron Loading)  MAT 2
   10    4.15822E-03
   11    8.48616E-05
  131    5.8001E-02
      2  293 0 0  MODERATOR IN CASK (100.00%)                    MAT 3
    1   6.69111121E-02
   16   3.34555566E-02
      1  293 0 0 LEAD SHIELDING                        MAT 4
   82   3.29890E-02
      7  293 0 0 304 STAINLESS STEEL                   MAT 5
   12   6.82690E-05
   14   8.53360E-04
   24   1.53600E-02
   26   6.04950E-02
   28   6.82690E-03
   55   1.70670E-03
 1316   2.56010E-05
     2  293 0 0 FULL DENSITY WATER (100%)             MAT 6
     1    6.69111121E-02
   16     3.34555566E-02
     1  293 0 0 AL CLADDING             MAT 7
  131     6.026464E-02
KENO GEOM
   19  /* "KREFM"
   11  /* "NBOX"
    1  /* "NBXMAX"
    1  /* "NBYMAX"
    1  /* "NBZMAX"
    1  /* "NXX"
    0  /* "NTYPST"
    1  /* "NEMBRG"
```

```
     0  /* "NGMCHK"
 -1.0  -1.0  -1.0  -1.0  -1.0  -1.0
BOX TYPE      1 /*MODEL 2000 CASK & STAINLESS SUPPORT STRUCTURE
CYLINDER      6  33.65     140.64     0.0    16*0.5
CYLINDER      5  35.85     140.64     0.0    16*0.5
CYLINDER      4  46.34     140.64     0.0    16*0.5
CYLINDER      5  48.56     140.64   -14.90   16*0.5
BOX TYPE      2 /* CASK TOP
CYLINDER      4  30.96     158.42    140.64  16*0.5
CYLINDER      5  48.56     162.23    140.64  16*0.5
BOX TYPE      3 /* 21 SLOTS FILLED WITH WATER  125.2778 CM HIGH
CUBOID        6  4.4450 -4.4450  4.0005  -4.0005  125.2728  0.0   16*0.5
BOX TYPE      4 /* 21 SLOTS FILLED WITH WATER      ***   EXTENDED HEIGHT
CUBOID        6  4.4450 -4.4450  4.0005  -4.0005  15.35  0.00  16*0.5
BOX TYPE      5 /* BORAL PLATE (VERT)  125.2728 CM (49.32")
CUBOID        2  0.2667  -0.2667  3.937  -3.937  125.2728  0.0   16*0.5
BOX TYPE      6 /* BORAL PLATE (HORIZ) MODELED AS 3.1" X 0.21" X 49.32"
MIN DIMENSIONS
CUBOID        2  3.937  -3.937  0.2667  -0.2667  125.2728  0.0   16*0.5
BOX TYPE      7  /* FUEL PLATES        133.408 CM TOTAL H
CUBOID        1  0.0254 -0.0254  3.06705 -3.06705  125.2728  7.2148
16*0.5  /* *** FUEL
CUBOID        7  0.0635 -0.0635  3.33375 -3.33375  125.2728  7.2148
16*0.5  /* *** CLAD
BOX TYPE      8  /* FUEL PLATES        133.408 CM TOTAL H
CUBOID        1  0.0254 -0.0254  3.06705 -3.06705  15.350  0.00   16*0.5
/*  *** FUEL
CUBOID        7  0.0635 -0.0635  3.33375 -3.33375  15.350  0.00   16*0.5
/*  *** CLAD
BOX TYPE      9
CYLINDER      5  33.34     125.2728     0.0    16*0.5
BOX TYPE     10  /*          ***
CYLINDER      6  33.34     15.350     0.0    16*0.5
BOX TYPE     11  /* OVERALL BOX FOR THE PROBLEM
CUBOID        6  48.60    -48.60   48.60 -48.60 162.23 -14.91 16*0.5
CORE          0  48.60    -48.60   48.60 -48.60 162.23 -14.91 16*0.5
CUBOID        6  48.70    -48.70   48.70 -48.70 162.33 -15.01 16*0.5
11  1 1 1  1 1 1  1 1 1  1
BEGIN COMPLEX
/* PLACE THE FUEL PLATES EQUALLY SPACED INTO THE SLOT
/* BOX TYPE 3 FOR NORMAL HEIGHT
/* BOX TYPE 4 FOR PROTRUDED HEIGHT
COMPLEX  3  7    -4.12750    0.00  0.0    14  1  1  0.635000   0.00  0.0
/*14 PLATES
COMPLEX  4  8    -4.12750    0.00  0.0    14  1  1  0.635000   0.00  0.0
/*14 PLATES
/* PLACE FUEL ASSEMBLIES INTO CASK    NORMAL HEIGHT
COMPLEX  9  3   -22.860  -10.540  0.0  5  3  1  11.430  10.540  0.0
/*MIDDLE ROWS
COMPLEX  9  3   -11.430  -21.080  0.0  3  2  1  11.430  42.160  0.0
/*OUTER ROWS
/* PLACE FUEL ASSEMBLIES INTO CASK    EXTENDED HEIGHT
COMPLEX  10  4   -22.860  -10.540   0.00  5  3  1  11.430  10.540  0.0
/*MIDDLE ROWS
COMPLEX  10  4   -11.430  -21.080   0.00  3  2  1  11.430  42.160  0.0
/*OUTER ROWS
/* PLACE BORAL PLATES INTO CASK
COMPLEX  9  5   -17.145  -10.540  0.0  4  3  1  11.430  10.540  0.0
/*VERT PLATES
COMPLEX  9  6   -11.430  -15.810  0.0  3  4  1  11.430  10.540  0.0
/*HORIZ PLATES
```

```
/* PLACE LOWER SECTION (NORMAL HEIGHT) INTO THE BOX TYPE 1
COMPLEX  1  9  0.0   0.0   0.0   1  1  1   0.0  0.0  0.0
/* PLACE PROTRUDED SECTION (EXTENDED HEIGHT) INTO THE BOX TYPE 1
COMPLEX  1 10  0.0   0.0   125.2728   1  1  1   0.0  0.0  0.0
/* PLACE LOADED CASK INTO OVERALL PROBLEM BOX
COMPLEX  11  1  0.0     0.0    0.0   1 1 1   0.0    0.0    0.0
/* PLACE TOP INTO OVERALL PROBLEM BOX
COMPLEX  11  2  0.0     0.0    0.0   1 1 1   0.0    0.0    0.0
END GEOM
*END GEMER*
```

6.7.6.5.3 Number Density Calculations (MTR Type I Fuel)

6.7.6.5.3.1 FORTRAN Program

```
PROGRAM NUMBER
C
C   ASSUMPTIONS:
C   1. THE FUEL AND CLAD ARE MODELED HETEROGEOUSLY.
C   2. NBSR FUEL USED
C   3. 17 PLATES/ELEMENT
C   4. 2 ELEMENTS STACKED UP. WITH THE TOP ELEMENTS PROTRUDING.
C
        REAL NAL_CLAD,MAL
        REAL MU235,M238,MO16,MH2O,MH
        REAL MU,MUOLD
        REAL MU3O8
        REAL NELEMACT,NSLOT
        REAL N235,N238,N16,N131,N1
        REAL N235TOT
        DIMENSION HEIGHT(3)
        OPEN(6,FILE='NBSR.OUT',STATUS='UNKNOWN')
C
C    FOR U3O8 FUEL
C
C    NUMBER DENSITY PROGRAM FOR NBSR
C      3/23/98
C      AV = AVOGADRO'S NUMBER
C     RHO_WAT = WATER DENSITY (1 G/CC)
C
      DATA PI/3.14159265/
      RHO_WAT = 1.0
      AV=0.6022
      M235 =235.0439
      M238 =238.0508
      MAL = 26.98
      MO16 = 16.000
      MH2O=18.0
      MH=1.0
C
C    D  = ACTIVE FUEL LENGTH (IN)
C    E  = CLADDING THICKNESS (IN)
C    C  = PLATE LENGTH (IN)
C    G  = PLATE THICKNESS (IN)
C    F  = ACTIVE FUEL THICKNESS (IN)
C    RHOCLAD  = DENISTY OF AL CLAD (G/CC)
C    WF       = WEIGHT % OF U3O8  IN THE U3O8/AL MIXTURE
C    ENRICH   = FUEL ENRICHMENT
```

```
C     ELEMH     = EFFECTIVE ELEMENT HEIGHT IN INCHES (HEIGHT OF 2
ELEMENTS)
C     NELEMACT = NUMBER OF ACTIVE FUEL PLATES PER FUEL ASSEMBLY (17 PER
ASSEMBLY)
C
C       NBSR
C
        ELEMH=52.52
        D=2.415
        E=0.015
        C=2.625
        G=0.050
        F=0.020
C
C        ENRICH = U-235 ENRICHMENT
C     94 % ENRICHMENT
C
        ENRICH = 0.940
        WF=0.416
        U235MAS=710.0
C
C    NUMBER OF ACTIVE PLATES
C
        WRITE(6,*) ' ********************************'
        DO 1400 NN=1,17
        WRITE(6,*) '  '
        WRITE(6,*) ' ********************************'

        NELEMACT=FLOAT(NN)
        WRITE(6,*) ' NUMBER OF PLATES =',NELEMACT

C
C    AREASLOT = SLOT AREA PER ELEMENT (cm^2)
        AREASLOT=71.12889
C
        RHOH2O = 1.0
        RHOCLAD = 2.7
C
       WRITE(6,*) ' ************************************'
       WRITE(6,*) ' FUEL ELEMENT HEIGHT =',ELEMH*2.54,' CM'
       WRITE(6,*) '  NBSR CASE'
       WRITE(6,*) ' ELEMENT HEIGHT=',ELEMH
       WRITE(6,*) ' RHOH2O =',RHOH2O
       WRITE(6,*) ' ENRICH =',ENRICH
       WRITE(6,*)  ' WF =',WF
       WRITE(6,*) ' RHOCLAD=',RHOCLAD
C
        AELEMENT=C*G*2.54*2.54
        AMEAT=D*F*2.54*2.54
        ACLAD=AELEMENT-AMEAT
C
        WRITE(6,*) ' '
        WRITE(6,*) '  FOR EACH UNIT ELELEMT'
        WRITE(6,*) '   ACLAD   AMEAT   AELEMENT (CM2)'
        WRITE(6,*) ACLAD,AMEAT,AELEMENT
C
        U238MAS=U235MAS/ENRICH - U235MAS
C
        MU= 1.0/(ENRICH/M235 + (1.0-ENRICH)/M238)
        F2=3.0*MU/(3.0*MU + 8.0*MO16)
        U3O8MAS=(U235MAS+U238MAS)/F2
```

```
      O16MAS=U3O8MAS-(U235MAS+U238MAS)
      WRITE(6,*) ' O16(FUEL) MASS =',O16MAS
      WRITE(6,*) ' U238      MASS =',U238MAS
      WRITE(6,*) ' U235      MASS =',U235MAS
      WRITE(6,*) ' U3O8      MASS =',U3O8MAS
C
      ALFUEL=U3O8MAS/WF*(1.0-WF)
C
      WRITE(6,*) ' AL MASS IN FUEL =',ALFUEL
      TOTAL = U3O8MAS + ALFUEL
      WRITE(6,*) 'TOTAL MASS (FUEL) =',TOTAL
C
C    2 ELEMENTS STACKED UP
C
      FVOLUME=AMEAT*(ELEMH*2.54)*NELEMACT
      WRITE(6,*) '   TOTAL FUEL IN EACH SLOT =',FVOLUME,' CM^3'
      RHOF = TOTAL/FVOLUME
      WRITE(6,*) ' FUEL MIXTURE DENSITY =',RHOF
C
     N235 = U235MAS*AV/M235/FVOLUME

     N235TOT=N235*FVOLUME*21.0
     N238 = U238MAS*AV/M238/FVOLUME
     N16 = O16MAS*AV/MO16/FVOLUME
     N131= ALFUEL*AV/MAL/FVOLUME
C
     WRITE(6,*) '  '
     WRITE(6,*) '  N16  N131  N238  N235'
     WRITE(6,*) '     16',N16
     WRITE(6,*) '    131',N131
     WRITE(6,*) '   2381',N238
     WRITE(6,*) '   2351',N235
     WRITE(6,*) 'TOTAL',N16+N131+N238+N235
C*************************************************************
C    ESTIMATE THE AMOUNT OF WATER IN THE CASK
C
C     H_SLOT = SLOT HEIGHT IN CM
C     V_SLOT = VOLUME OF ALL SLOTS CM^3
C     H_CASK = HEIGHT OF CASK (CM)
C     R_CASK = RADIUS OF CASK (CM)
C     NSLOT = NUMBER OF SLOTS IN THE CASK
C
     H_SLOT= 125.2728
     H_CASK = 140.64
     R_CASK = 33.65
     NSLOT=21.0
C
C    V_CASK_TOP = CASK VOLUME ABOVE THE INGOT (CM^3)
C    V_SLOT = VOLUME OF WATER IN ALL SLOTS (CM^3)
C    V_FPLATES = VOLUME OF ALL FUEL PLATES (17X21 PLATES)
C    V_WATER = AMOUNT OF WATER VOLUME IN THE CASK (CM^3)
C
      V_SLOT=H_SLOT*AREASLOT*NSLOT
      V_CASK_TOP = PI*R_CASK*R_CASK*(H_CASK - H_SLOT)
      V_FPLATES = NELEMACT*AELEMENT*(ELEMH*2.54)*NSLOT
      V_WATER = V_CASK_TOP + V_SLOT - V_FPLATES
      WRITE(6,*)
      WRITE(6,*) ' VOLUME OF CASK TOP =',V_CASK_TOP,'CM^3'
      WRITE(6,*) ' VOLUME OF ALL SLOTS =',V_SLOT,'CM^3'
      WRITE(6,*) ' VOLUME OF ALL FUEL PLATES =',V_FPLATES,'CM^3'
      WRITE(6,*) ' VOLUME OF WATER =',V_WATER,'CM^3'
```

```
C
C
      WRITE(6,*) ' WEIGHT FRACTION     H/U (ALL VOLUME) '
      DO 3000 I=0,10
      WFWATER = 0.1*FLOAT(I)*RHO_WAT
      N1=2.0*WFWATER*AV/MH2O
      HURATIO=N1*V_WATER/(N235*FVOLUME*NSLOT)
      WRITE(6,*)  WFWATER,HURATIO
 3000 CONTINUE


C     WATER REFLECTOR CASE
C
      WRITE(6,*)
      WRITE(6,*) ' WATER REFLECTOR CASE'
      RAD_WR=48.56
      RAD_CASK=33.34
      HT_CASK=125.2728
      HT_WR=140.64+14.90
      RHO_WATER=1.0
      VOL_WR=PI*(RAD_WR-RAD_CASK)*(RAD_WR-RAD_CASK)*(HT_WR-HT_CASK)
      WRITE(6,*) ' VOLUME OF WATER REFLECTOR =',VOL_WR,' CM^3'
      NHTOT=2.0*RHO_WATER*AV/18.0*V_WATER
     *      + 2.0*RHO_WATER*AV/18.0*VOL_WR
      RATIO6=NHTOT/N235TOT
      WRITE(6,*) RHO_WATER,RATIO6
 1400 CONTINUE
      END
```

6.7.6.5.3.2 FORTRAN Output (MTR Type I Fuel)

```
*******************************

  ********************************
  NUMBER OF PLATES =   1.000000
  ************************************
  FUEL ELEMENT HEIGHT =   133.4008     CM
   NBSR CASE
  ELEMENT HEIGHT=   52.52000
  RHOH2O =   1.000000
  ENRICH =  0.9400000
  WF =  0.4160000
  RHOCLAD=   2.700000

   FOR EACH UNIT ELELEMT
    ACLAD   AMEAT   AELEMENT (CM2)
  0.5351602      0.3116122      0.8467725
  O16(FUEL) MASS =   137.0305
  U238      MASS =   45.31915
  U235      MASS =   710.0000
  U3O8      MASS =   892.3497
  AL MASS IN FUEL =   1252.722
 TOTAL MASS (FUEL) =   2145.071
    TOTAL FUEL IN EACH SLOT =   41.56932     CM^3
  FUEL MIXTURE DENSITY =   51.60226

   N16  N131  N238  N235
      16  0.1240695
     131  0.6726364
    2381  2.7579088E-03
```

```
   2351  4.3768156E-02
TOTAL  0.8432320

 VOLUME OF CASK TOP =   54665.70    CM^3
 VOLUME OF ALL SLOTS =   187120.8    CM^3
 VOLUME OF ALL FUEL PLATES =   2372.163    CM^3
 VOLUME OF WATER =   239414.4    CM^3
 WEIGHT FRACTION     H/U (ALL VOLUME)
 0.0000000E+00  0.0000000E+00
 0.1000000       41.92740
 0.2000000       83.85480
 0.3000000       125.7822
 0.4000000       167.7096
 0.5000000       209.6370
 0.6000000       251.5644
 0.7000000       293.4918
 0.8000000       335.4192
 0.9000000       377.3465
  1.000000       419.2740

 WATER REFLECTOR CASE
 VOLUME OF WATER REFLECTOR =   22026.80     CM^3
  1.000000       457.8400

 ********************************
 NUMBER OF PLATES =   2.000000
 ************************************
 FUEL ELEMENT HEIGHT =   133.4008     CM
  NBSR CASE
 ELEMENT HEIGHT=   52.52000
 RHOH2O =   1.000000
 ENRICH =  0.9400000
 WF =  0.4160000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELELEMT
   ACLAD   AMEAT   AELEMENT (CM2)
 0.5351602      0.3116122      0.8467725
 O16(FUEL) MASS =   137.0305
 U238      MASS =   45.31915
 U235      MASS =   710.0000
 U3O8      MASS =   892.3497
 AL MASS IN FUEL =   1252.722
TOTAL MASS (FUEL) =   2145.071
   TOTAL FUEL IN EACH SLOT =   83.13865     CM^3
 FUEL MIXTURE DENSITY =   25.80113

  N16  N131  N238  N235
     16  6.2034760E-02
    131  0.3363182
   2381  1.3789544E-03
   2351  2.1884078E-02
TOTAL  0.4216160

 VOLUME OF CASK TOP =   54665.70    CM^3
 VOLUME OF ALL SLOTS =   187120.8    CM^3
 VOLUME OF ALL FUEL PLATES =   4744.325    CM^3
 VOLUME OF WATER =   237042.2    CM^3
 WEIGHT FRACTION     H/U (ALL VOLUME)
 0.0000000E+00  0.0000000E+00
 0.1000000       41.51197
```

```
 0.2000000        83.02395
 0.3000000        124.5359
 0.4000000        166.0479
 0.5000000        207.5598
 0.6000000        249.0718
 0.7000000        290.5838
 0.8000000        332.0958
 0.9000000        373.6077
  1.000000        415.1197

 WATER REFLECTOR CASE
 VOLUME OF WATER REFLECTOR =   22026.80     CM^3
  1.000000        453.6786

 ********************************
 NUMBER OF PLATES =   3.000000
 ************************************
 FUEL ELEMENT HEIGHT =   133.4008     CM
  NBSR CASE
 ELEMENT HEIGHT=   52.52000
 RHOH2O =   1.000000
 ENRICH =  0.9400000
 WF =  0.4160000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELELEMT
   ACLAD   AMEAT   AELEMENT (CM2)
 0.5351602      0.3116122      0.8467725
 O16(FUEL) MASS =   137.0305
 U238      MASS =   45.31915
 U235      MASS =   710.0000
 U3O8      MASS =   892.3497
 AL MASS IN FUEL =   1252.722
TOTAL MASS (FUEL) =   2145.071
   TOTAL FUEL IN EACH SLOT =   124.7080     CM^3
 FUEL MIXTURE DENSITY =   17.20075

  N16  N131  N238  N235
     16  4.1356504E-02
    131  0.2242121
   2381  9.1930293E-04
   2351  1.4589385E-02
TOTAL  0.2810774

 VOLUME OF CASK TOP =   54665.70    CM^3
 VOLUME OF ALL SLOTS =   187120.8    CM^3
 VOLUME OF ALL FUEL PLATES =   7116.488    CM^3
 VOLUME OF WATER =   234670.0    CM^3
 WEIGHT FRACTION     H/U (ALL VOLUME)
 0.0000000E+00  0.0000000E+00
 0.1000000        41.09655
 0.2000000        82.19309
 0.3000000        123.2896
 0.4000000        164.3862
 0.5000000        205.4827
 0.6000000        246.5793
 0.7000000        287.6758
 0.8000000        328.7724
 0.9000000        369.8689
  1.000000        410.9655
```

```
 WATER REFLECTOR CASE
 VOLUME OF WATER REFLECTOR =   22026.80     CM^3
  1.000000       449.5171

 ********************************
 NUMBER OF PLATES =   4.000000
 ************************************
 FUEL ELEMENT HEIGHT =   133.4008     CM
  NBSR CASE
 ELEMENT HEIGHT=   52.52000
 RHOH2O =   1.000000
 ENRICH =  0.9400000
 WF =  0.4160000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELELEMT
   ACLAD   AMEAT   AELEMENT (CM2)
 0.5351602      0.3116122      0.8467725
 O16(FUEL) MASS =   137.0305
 U238      MASS =   45.31915
 U235      MASS =   710.0000
 U3O8      MASS =   892.3497
 AL MASS IN FUEL =   1252.722
TOTAL MASS (FUEL) =   2145.071
   TOTAL FUEL IN EACH SLOT =   166.2773     CM^3
 FUEL MIXTURE DENSITY =   12.90057

  N16  N131  N238  N235
     16  3.1017380E-02
    131  0.1681591
   2381  6.8947719E-04
   2351  1.0942039E-02
TOTAL  0.2108080

 VOLUME OF CASK TOP =   54665.70    CM^3
 VOLUME OF ALL SLOTS =   187120.8    CM^3
 VOLUME OF ALL FUEL PLATES =   9488.650    CM^3
 VOLUME OF WATER =   232297.9    CM^3
 WEIGHT FRACTION     H/U (ALL VOLUME)
 0.0000000E+00  0.0000000E+00
 0.1000000       40.68112
 0.2000000       81.36224
 0.3000000       122.0434
 0.4000000       162.7245
 0.5000000       203.4056
 0.6000000       244.0867
 0.7000000       284.7678
 0.8000000       325.4490
 0.9000000       366.1301
  1.000000       406.8112

 WATER REFLECTOR CASE
 VOLUME OF WATER REFLECTOR =   22026.80     CM^3
  1.000000       445.3818

 ********************************
 NUMBER OF PLATES =   5.000000
 ************************************
 FUEL ELEMENT HEIGHT =   133.4008     CM
  NBSR CASE
 ELEMENT HEIGHT=   52.52000
```

```
 RHOH2O =   1.000000
 ENRICH =  0.9400000
 WF =  0.4160000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELELEMT
   ACLAD   AMEAT   AELEMENT (CM2)
 0.5351602      0.3116122      0.8467725
 O16(FUEL) MASS =   137.0305
 U238      MASS =   45.31915
 U235      MASS =   710.0000
 U3O8      MASS =   892.3497
 AL MASS IN FUEL =   1252.722
TOTAL MASS (FUEL) =   2145.071
   TOTAL FUEL IN EACH SLOT =   207.8466     CM^3
 FUEL MIXTURE DENSITY =   10.32045

  N16  N131  N238  N235
     16  2.4813903E-02
    131  0.1345273
   2381  5.5158179E-04
   2351  8.7536313E-03
TOTAL  0.1686464

 VOLUME OF CASK TOP =   54665.70    CM^3
 VOLUME OF ALL SLOTS =   187120.8    CM^3
 VOLUME OF ALL FUEL PLATES =   11860.81    CM^3
 VOLUME OF WATER =   229925.7    CM^3
 WEIGHT FRACTION     H/U (ALL VOLUME)
 0.0000000E+00  0.0000000E+00
 0.1000000       40.26570
 0.2000000       80.53140
 0.3000000       120.7971
 0.4000000       161.0628
 0.5000000       201.3285
 0.6000000       241.5942
 0.7000000       281.8599
 0.8000000       322.1256
 0.9000000       362.3913
  1.000000       402.6570

 WATER REFLECTOR CASE
 VOLUME OF WATER REFLECTOR =   22026.80     CM^3
  1.000000       441.2203

 ********************************
 NUMBER OF PLATES =   6.000000
 ************************************
 FUEL ELEMENT HEIGHT =   133.4008     CM
  NBSR CASE
 ELEMENT HEIGHT=   52.52000
 RHOH2O =   1.000000
 ENRICH =  0.9400000
 WF =  0.4160000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELELEMT
   ACLAD   AMEAT   AELEMENT (CM2)
 0.5351602      0.3116122      0.8467725
 O16(FUEL) MASS =   137.0305
 U238      MASS =   45.31915
```

```
 U235       MASS =   710.0000
 U3O8       MASS =   892.3497
 AL MASS IN FUEL =   1252.722
TOTAL MASS (FUEL) =   2145.071
   TOTAL FUEL IN EACH SLOT =   249.4160     CM^3
 FUEL MIXTURE DENSITY =   8.600377

  N16  N131  N238  N235
     16  2.0678252E-02
    131  0.1121061
   2381  4.5965146E-04
   2351  7.2946926E-03
TOTAL  0.1405387

 VOLUME OF CASK TOP =   54665.70    CM^3
 VOLUME OF ALL SLOTS =   187120.8    CM^3
 VOLUME OF ALL FUEL PLATES =   14232.98    CM^3
 VOLUME OF WATER =   227553.5    CM^3
 WEIGHT FRACTION     H/U (ALL VOLUME)
 0.0000000E+00  0.0000000E+00
 0.1000000       39.85027
 0.2000000       79.70055
 0.3000000       119.5508
 0.4000000       159.4011
 0.5000000       199.2514
 0.6000000       239.1016
 0.7000000       278.9519
 0.8000000       318.8022
 0.9000000       358.6524
  1.000000       398.5027

 WATER REFLECTOR CASE
 VOLUME OF WATER REFLECTOR =   22026.80     CM^3
  1.000000       437.0589

 ********************************
 NUMBER OF PLATES =   7.000000
 ************************************
 FUEL ELEMENT HEIGHT =   133.4008     CM
  NBSR CASE
 ELEMENT HEIGHT=   52.52000
 RHOH2O =   1.000000
 ENRICH =  0.9400000
 WF =  0.4160000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELELEMT
   ACLAD   AMEAT   AELEMENT (CM2)
 0.5351602      0.3116122      0.8467725
 O16(FUEL) MASS =   137.0305
 U238      MASS =   45.31915
 U235      MASS =   710.0000
 U3O8      MASS =   892.3497
 AL MASS IN FUEL =   1252.722
TOTAL MASS (FUEL) =   2145.071
   TOTAL FUEL IN EACH SLOT =   290.9853     CM^3
 FUEL MIXTURE DENSITY =   7.371752

  N16  N131  N238  N235
     16  1.7724218E-02
    131  9.6090920E-02
```

```
   2381  3.9398699E-04
   2351  6.2525943E-03
TOTAL  0.1204617

 VOLUME OF CASK TOP =   54665.70    CM^3
 VOLUME OF ALL SLOTS =   187120.8    CM^3
 VOLUME OF ALL FUEL PLATES =   16605.14    CM^3
 VOLUME OF WATER =   225181.4    CM^3
 WEIGHT FRACTION     H/U (ALL VOLUME)
 0.0000000E+00  0.0000000E+00
 0.1000000       39.43485
 0.2000000       78.86970
 0.3000000       118.3045
 0.4000000       157.7394
 0.5000000       197.1742
 0.6000000       236.6091
 0.7000000       276.0439
 0.8000000       315.4788
 0.9000000       354.9136
  1.000000       394.3485

 WATER REFLECTOR CASE
 VOLUME OF WATER REFLECTOR =   22026.80     CM^3
  1.000000       432.8974

 ********************************
 NUMBER OF PLATES =   8.000000
 ************************************
 FUEL ELEMENT HEIGHT =   133.4008     CM
  NBSR CASE
 ELEMENT HEIGHT=   52.52000
 RHOH2O =   1.000000
 ENRICH =  0.9400000
 WF =  0.4160000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELELEMT
   ACLAD   AMEAT   AELEMENT (CM2)
 0.5351602      0.3116122      0.8467725
 O16(FUEL) MASS =   137.0305
 U238      MASS =   45.31915
 U235      MASS =   710.0000
 U3O8      MASS =   892.3497
 AL MASS IN FUEL =   1252.722
TOTAL MASS (FUEL) =   2145.071
   TOTAL FUEL IN EACH SLOT =   332.5546     CM^3
 FUEL MIXTURE DENSITY =   6.450283

  N16  N131  N238  N235
     16  1.5508690E-02
    131  8.4079556E-02
   2381  3.4473860E-04
   2351  5.4710195E-03
TOTAL  0.1054040

 VOLUME OF CASK TOP =   54665.70    CM^3
 VOLUME OF ALL SLOTS =   187120.8    CM^3
 VOLUME OF ALL FUEL PLATES =   18977.30    CM^3
 VOLUME OF WATER =   222809.2    CM^3
 WEIGHT FRACTION     H/U (ALL VOLUME)
 0.0000000E+00  0.0000000E+00
```

```
 0.1000000        39.01943
 0.2000000        78.03886
 0.3000000        117.0583
 0.4000000        156.0777
 0.5000000        195.0971
 0.6000000        234.1165
 0.7000000        273.1360
 0.8000000        312.1554
 0.9000000        351.1748
  1.000000        390.1942

 WATER REFLECTOR CASE
 VOLUME OF WATER REFLECTOR =   22026.80     CM^3
  1.000000        428.7621

 ********************************
 NUMBER OF PLATES =   9.000000
 ************************************
 FUEL ELEMENT HEIGHT =   133.4008     CM
  NBSR CASE
 ELEMENT HEIGHT=   52.52000
 RHOH2O =   1.000000
 ENRICH =  0.9400000
 WF =  0.4160000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELELEMT
   ACLAD   AMEAT   AELEMENT (CM2)
 0.5351602      0.3116122      0.8467725
 O16(FUEL) MASS =   137.0305
 U238      MASS =   45.31915
 U235      MASS =   710.0000
 U3O8      MASS =   892.3497
 AL MASS IN FUEL =   1252.722
TOTAL MASS (FUEL) =   2145.071
   TOTAL FUEL IN EACH SLOT =   374.1239     CM^3
 FUEL MIXTURE DENSITY =   5.733585

  N16  N131  N238  N235
     16  1.3785501E-02
    131  7.4737377E-02
   2381  3.0643432E-04
   2351  4.8631285E-03
TOTAL  9.3692444E-02

 VOLUME OF CASK TOP =   54665.70    CM^3
 VOLUME OF ALL SLOTS =   187120.8    CM^3
 VOLUME OF ALL FUEL PLATES =   21349.46    CM^3
 VOLUME OF WATER =   220437.0    CM^3
 WEIGHT FRACTION     H/U (ALL VOLUME)
 0.0000000E+00  0.0000000E+00
 0.1000000        38.60400
 0.2000000        77.20799
 0.3000000        115.8120
 0.4000000        154.4160
 0.5000000        193.0200
 0.6000000        231.6240
 0.7000000        270.2280
 0.8000000        308.8320
 0.9000000        347.4359
  1.000000        386.0400
```

```
 WATER REFLECTOR CASE
 VOLUME OF WATER REFLECTOR =   22026.80     CM^3
  1.000000       424.6006

 ********************************
 NUMBER OF PLATES =   10.00000
 ************************************
 FUEL ELEMENT HEIGHT =   133.4008     CM
  NBSR CASE
 ELEMENT HEIGHT=   52.52000
 RHOH2O =   1.000000
 ENRICH =  0.9400000
 WF =  0.4160000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELELEMT
   ACLAD   AMEAT   AELEMENT (CM2)
 0.5351602      0.3116122      0.8467725
 O16(FUEL) MASS =   137.0305
 U238      MASS =   45.31915
 U235      MASS =   710.0000
 U3O8      MASS =   892.3497
 AL MASS IN FUEL =   1252.722
TOTAL MASS (FUEL) =   2145.071
   TOTAL FUEL IN EACH SLOT =   415.6932     CM^3
 FUEL MIXTURE DENSITY =   5.160226

  N16  N131  N238  N235
     16  1.2406952E-02
    131  6.7263648E-02
   2381  2.7579090E-04
   2351  4.3768156E-03
TOTAL  8.4323205E-02

 VOLUME OF CASK TOP =   54665.70    CM^3
 VOLUME OF ALL SLOTS =   187120.8    CM^3
 VOLUME OF ALL FUEL PLATES =   23721.63    CM^3
 VOLUME OF WATER =   218064.9    CM^3
 WEIGHT FRACTION     H/U (ALL VOLUME)
 0.0000000E+00  0.0000000E+00
 0.1000000       38.18858
 0.2000000       76.37715
 0.3000000       114.5657
 0.4000000       152.7543
 0.5000000       190.9429
 0.6000000       229.1314
 0.7000000       267.3200
 0.8000000       305.5086
 0.9000000       343.6972
  1.000000       381.8857

 WATER REFLECTOR CASE
 VOLUME OF WATER REFLECTOR =   22026.80     CM^3
  1.000000       420.4391

 ********************************
 NUMBER OF PLATES =   11.00000
 ************************************
 FUEL ELEMENT HEIGHT =   133.4008     CM
  NBSR CASE
```

```
 ELEMENT HEIGHT=   52.52000
 RHOH2O =   1.000000
 ENRICH =  0.9400000
 WF =  0.4160000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELELEMT
   ACLAD   AMEAT   AELEMENT (CM2)
 0.5351602      0.3116122      0.8467725
 O16(FUEL) MASS =   137.0305
 U238      MASS =   45.31915
 U235      MASS =   710.0000
 U3O8      MASS =   892.3497
 AL MASS IN FUEL =   1252.722
TOTAL MASS (FUEL) =   2145.071
   TOTAL FUEL IN EACH SLOT =   457.2626     CM^3
 FUEL MIXTURE DENSITY =   4.691115

  N16  N131  N238  N235
     16  1.1279047E-02
    131  6.1148766E-02
   2381  2.5071899E-04
   2351  3.9789234E-03
TOTAL  7.6657459E-02

 VOLUME OF CASK TOP =   54665.70    CM^3
 VOLUME OF ALL SLOTS =   187120.8    CM^3
 VOLUME OF ALL FUEL PLATES =   26093.79    CM^3
 VOLUME OF WATER =   215692.7    CM^3
 WEIGHT FRACTION     H/U (ALL VOLUME)
 0.0000000E+00  0.0000000E+00
 0.1000000       37.77316
 0.2000000       75.54631
 0.3000000       113.3195
 0.4000000       151.0926
 0.5000000       188.8658
 0.6000000       226.6389
 0.7000000       264.4120
 0.8000000       302.1852
 0.9000000       339.9583
  1.000000       377.7315

 WATER REFLECTOR CASE
 VOLUME OF WATER REFLECTOR =   22026.80     CM^3
  1.000000       416.3039

 ********************************
 NUMBER OF PLATES =   12.00000
 ************************************
 FUEL ELEMENT HEIGHT =   133.4008     CM
  NBSR CASE
 ELEMENT HEIGHT=   52.52000
 RHOH2O =   1.000000
 ENRICH =  0.9400000
 WF =  0.4160000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELELEMT
   ACLAD   AMEAT   AELEMENT (CM2)
 0.5351602      0.3116122      0.8467725
 O16(FUEL) MASS =   137.0305
```

```
 U238       MASS =   45.31915
 U235       MASS =   710.0000
 U3O8       MASS =   892.3497
 AL MASS IN FUEL =   1252.722
TOTAL MASS (FUEL) =   2145.071
   TOTAL FUEL IN EACH SLOT =   498.8319     CM^3
 FUEL MIXTURE DENSITY =   4.300189

  N16  N131  N238  N235
     16  1.0339126E-02
    131  5.6053035E-02
   2381  2.2982573E-04
   2351  3.6473463E-03
TOTAL  7.0269339E-02

 VOLUME OF CASK TOP =   54665.70    CM^3
 VOLUME OF ALL SLOTS =   187120.8    CM^3
 VOLUME OF ALL FUEL PLATES =   28465.95    CM^3
 VOLUME OF WATER =   213320.6    CM^3
 WEIGHT FRACTION     H/U (ALL VOLUME)
 0.0000000E+00  0.0000000E+00
 0.1000000       37.35772
 0.2000000       74.71545
 0.3000000       112.0732
 0.4000000       149.4309
 0.5000000       186.7886
 0.6000000       224.1463
 0.7000000       261.5041
 0.8000000       298.8618
 0.9000000       336.2195
  1.000000       373.5772

 WATER REFLECTOR CASE
 VOLUME OF WATER REFLECTOR =   22026.80     CM^3
  1.000000       412.1424

 ********************************
 NUMBER OF PLATES =   13.00000
 ************************************
 FUEL ELEMENT HEIGHT =   133.4008     CM
  NBSR CASE
 ELEMENT HEIGHT=   52.52000
 RHOH2O =   1.000000
 ENRICH =  0.9400000
 WF =  0.4160000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELELEMT
   ACLAD   AMEAT   AELEMENT (CM2)
 0.5351602      0.3116122      0.8467725
 O16(FUEL) MASS =   137.0305
 U238       MASS =   45.31915
 U235       MASS =   710.0000
 U3O8       MASS =   892.3497
 AL MASS IN FUEL =   1252.722
TOTAL MASS (FUEL) =   2145.071
   TOTAL FUEL IN EACH SLOT =   540.4012     CM^3
 FUEL MIXTURE DENSITY =   3.969405

  N16  N131  N238  N235
     16  9.5438082E-03
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```
    131  5.1741261E-02
   2381  2.1214683E-04
   2351  3.3667812E-03
TOTAL  6.4864002E-02

 VOLUME OF CASK TOP =   54665.70    CM^3
 VOLUME OF ALL SLOTS =   187120.8    CM^3
 VOLUME OF ALL FUEL PLATES =   30838.12    CM^3
 VOLUME OF WATER =   210948.4    CM^3
 WEIGHT FRACTION     H/U (ALL VOLUME)
 0.0000000E+00  0.0000000E+00
 0.1000000       36.94230
 0.2000000       73.88461
 0.3000000       110.8269
 0.4000000       147.7692
 0.5000000       184.7115
 0.6000000       221.6538
 0.7000000       258.5961
 0.8000000       295.5384
 0.9000000       332.4807
  1.000000       369.4230

 WATER REFLECTOR CASE
 VOLUME OF WATER REFLECTOR =   22026.80     CM^3
  1.000000       407.9809

 ********************************
 NUMBER OF PLATES =   14.00000
 ************************************
 FUEL ELEMENT HEIGHT =   133.4008     CM
  NBSR CASE
 ELEMENT HEIGHT=   52.52000
 RHOH2O =   1.000000
 ENRICH =  0.9400000
 WF =  0.4160000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELELEMT
   ACLAD   AMEAT   AELEMENT (CM2)
 0.5351602      0.3116122      0.8467725
 O16(FUEL) MASS =   137.0305
 U238      MASS =   45.31915
 U235      MASS =   710.0000
 U3O8      MASS =   892.3497
 AL MASS IN FUEL =   1252.722
TOTAL MASS (FUEL) =   2145.071
   TOTAL FUEL IN EACH SLOT =   581.9705     CM^3
 FUEL MIXTURE DENSITY =   3.685876

  N16  N131  N238  N235
     16  8.8621089E-03
    131  4.8045460E-02
   2381  1.9699350E-04
   2351  3.1262971E-03
TOTAL  6.0230859E-02

 VOLUME OF CASK TOP =   54665.70    CM^3
 VOLUME OF ALL SLOTS =   187120.8    CM^3
 VOLUME OF ALL FUEL PLATES =   33210.28    CM^3
 VOLUME OF WATER =   208576.2    CM^3
 WEIGHT FRACTION     H/U (ALL VOLUME)
```

```
 0.0000000E+00  0.0000000E+00
 0.1000000       36.52688
 0.2000000       73.05376
 0.3000000       109.5806
 0.4000000       146.1075
 0.5000000       182.6344
 0.6000000       219.1612
 0.7000000       255.6881
 0.8000000       292.2150
 0.9000000       328.7419
  1.000000       365.2688

 WATER REFLECTOR CASE
 VOLUME OF WATER REFLECTOR =   22026.80     CM^3
  1.000000       403.8195

 ********************************
 NUMBER OF PLATES =   15.00000
 ************************************
 FUEL ELEMENT HEIGHT =   133.4008     CM
  NBSR CASE
 ELEMENT HEIGHT=   52.52000
 RHOH2O =   1.000000
 ENRICH =  0.9400000
 WF =  0.4160000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELELEMT
   ACLAD   AMEAT   AELEMENT (CM2)
 0.5351602      0.3116122      0.8467725
 O16(FUEL) MASS =   137.0305
 U238      MASS =   45.31915
 U235      MASS =   710.0000
 U3O8      MASS =   892.3497
 AL MASS IN FUEL =   1252.722
TOTAL MASS (FUEL) =   2145.071
   TOTAL FUEL IN EACH SLOT =   623.5399     CM^3
 FUEL MIXTURE DENSITY =   3.440151

  N16  N131  N238  N235
     16  8.2713012E-03
    131  4.4842429E-02
   2381  1.8386060E-04
   2351  2.9178772E-03
TOTAL  5.6215473E-02

 VOLUME OF CASK TOP =   54665.70    CM^3
 VOLUME OF ALL SLOTS =   187120.8    CM^3
 VOLUME OF ALL FUEL PLATES =   35582.44    CM^3
 VOLUME OF WATER =   206204.1    CM^3
 WEIGHT FRACTION     H/U (ALL VOLUME)
 0.0000000E+00  0.0000000E+00
 0.1000000       36.11145
 0.2000000       72.22290
 0.3000000       108.3344
 0.4000000       144.4458
 0.5000000       180.5573
 0.6000000       216.6687
 0.7000000       252.7801
 0.8000000       288.8916
 0.9000000       325.0031
```

```
 1.000000        361.1145

WATER REFLECTOR CASE
VOLUME OF WATER REFLECTOR =   22026.80      CM^3
 1.000000        399.6842

*******************************
NUMBER OF PLATES =   16.00000
************************************
FUEL ELEMENT HEIGHT =   133.4008      CM
 NBSR CASE
ELEMENT HEIGHT=   52.52000
RHOH2O =   1.000000
ENRICH =  0.9400000
WF =  0.4160000
RHOCLAD=   2.700000

 FOR EACH UNIT ELELEMT
  ACLAD   AMEAT   AELEMENT (CM2)
0.5351602      0.3116122      0.8467725
O16(FUEL) MASS =   137.0305
U238      MASS =   45.31915
U235      MASS =   710.0000
U3O8      MASS =   892.3497
AL MASS IN FUEL =   1252.722
TOTAL MASS (FUEL) =   2145.071
  TOTAL FUEL IN EACH SLOT =   665.1092      CM^3
FUEL MIXTURE DENSITY =   3.225142

 N16  N131  N238  N235
    16  7.7543450E-03
   131  4.2039778E-02
  2381  1.7236930E-04
  2351  2.7355098E-03
TOTAL  5.2702002E-02

VOLUME OF CASK TOP =   54665.70    CM^3
VOLUME OF ALL SLOTS =   187120.8    CM^3
VOLUME OF ALL FUEL PLATES =   37954.60    CM^3
VOLUME OF WATER =   203831.9    CM^3
WEIGHT FRACTION     H/U (ALL VOLUME)
0.0000000E+00  0.0000000E+00
0.1000000       35.69603
0.2000000       71.39206
0.3000000       107.0881
0.4000000       142.7841
0.5000000       178.4801
0.6000000       214.1762
0.7000000       249.8722
0.8000000       285.5682
0.9000000       321.2643
 1.000000       356.9603

WATER REFLECTOR CASE
VOLUME OF WATER REFLECTOR =   22026.80      CM^3
 1.000000        395.5227

*******************************
NUMBER OF PLATES =   17.00000
************************************
FUEL ELEMENT HEIGHT =   133.4008      CM
```

```
 NBSR CASE
ELEMENT HEIGHT=   52.52000
RHOH2O =   1.000000
ENRICH =  0.9400000
WF =  0.4160000
RHOCLAD=   2.700000

 FOR EACH UNIT ELELEMT
  ACLAD   AMEAT   AELEMENT (CM2)
0.5351602      0.3116122      0.8467725
O16(FUEL) MASS =   137.0305
U238      MASS =   45.31915
U235      MASS =   710.0000
U3O8      MASS =   892.3497
AL MASS IN FUEL =   1252.722
TOTAL MASS (FUEL) =   2145.071
   TOTAL FUEL IN EACH SLOT =   706.6785     CM^3
FUEL MIXTURE DENSITY =   3.035427

 N16  N131  N238  N235
    16  7.2982069E-03
   131  3.9566848E-02
  2381  1.6222993E-04
  2351  2.5745975E-03
TOTAL  4.9601883E-02

VOLUME OF CASK TOP =   54665.70    CM^3
VOLUME OF ALL SLOTS =   187120.8    CM^3
VOLUME OF ALL FUEL PLATES =   40326.77    CM^3
VOLUME OF WATER =   201459.8    CM^3
WEIGHT FRACTION     H/U (ALL VOLUME)
0.0000000E+00  0.0000000E+00
0.1000000       35.28061
0.2000000       70.56121
0.3000000       105.8418
0.4000000       141.1224
0.5000000       176.4030
0.6000000       211.6836
0.7000000       246.9642
0.8000000       282.2448
0.9000000       317.5254
 1.000000       352.8060

WATER REFLECTOR CASE
VOLUME OF WATER REFLECTOR =   22026.80     CM^3
 1.000000       391.3612
```

6.7.6.5.4 Geometrical Plots of the MTR Type I Fuel — Side and Sectional Views

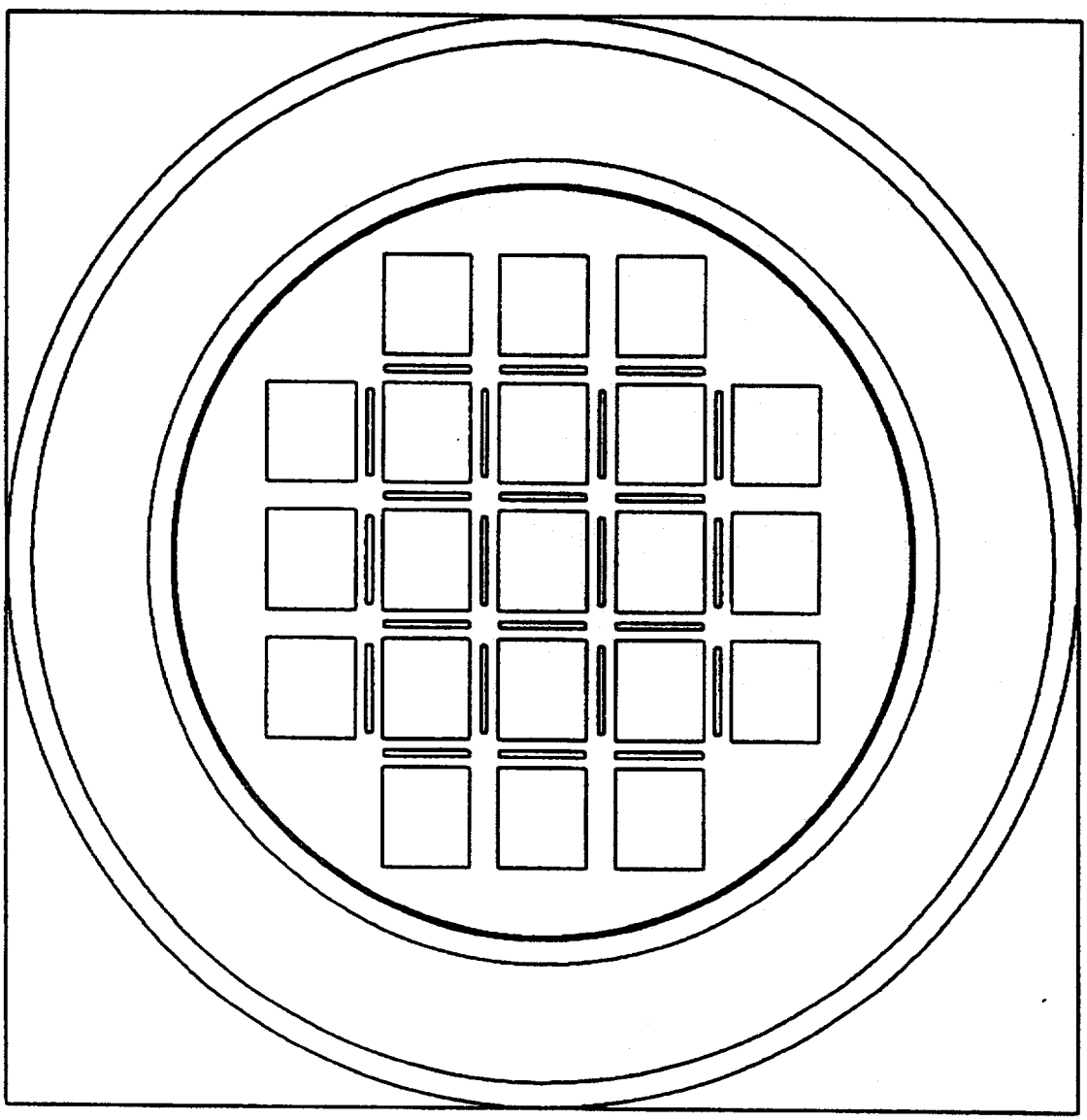


Figure 6.67. Sectional View (Z = 5 cm) for MTR Type I Fuel

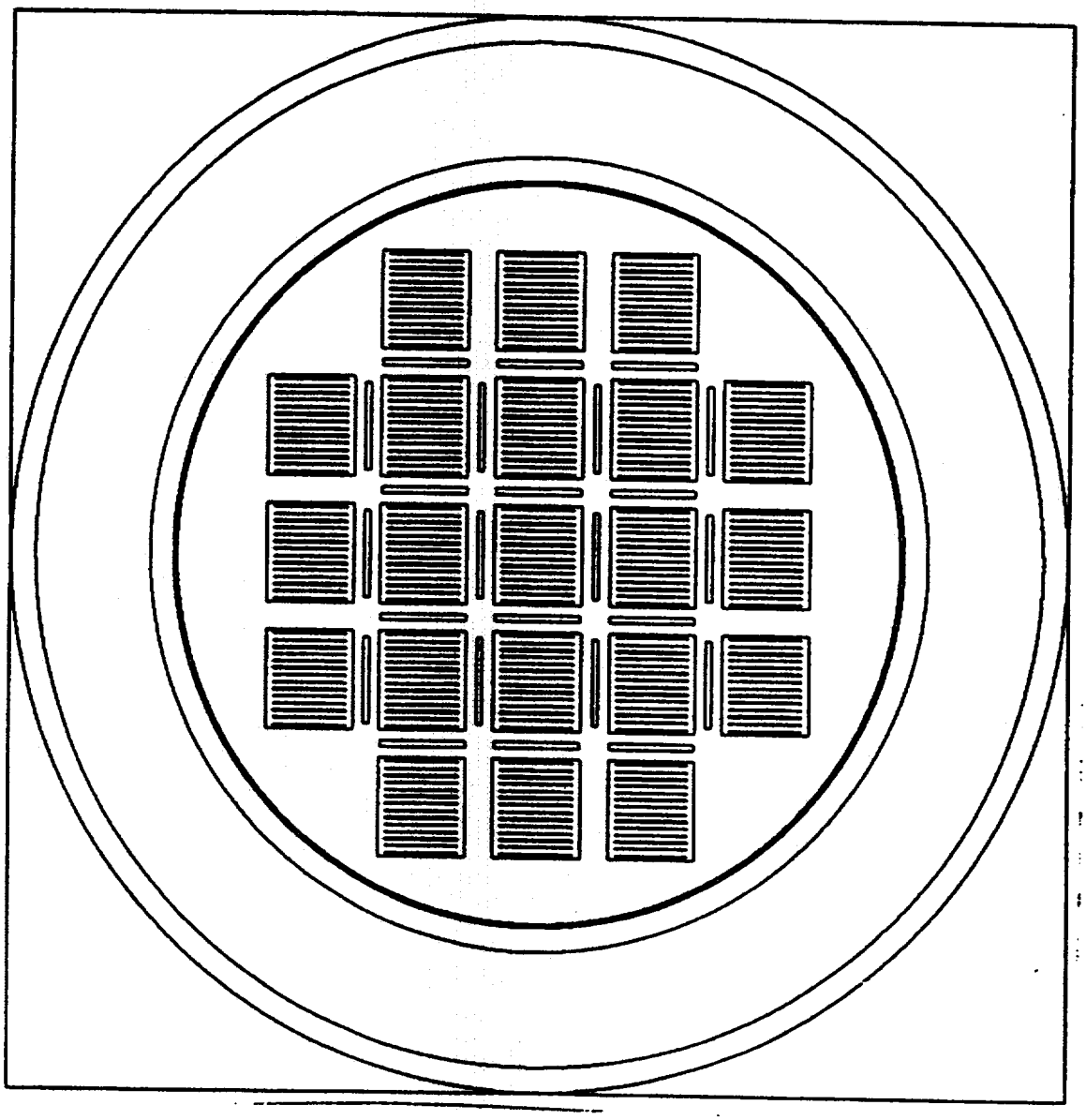


Figure 6.68. Sectional View (Z = 60 cm) for MTR Type I Fuel

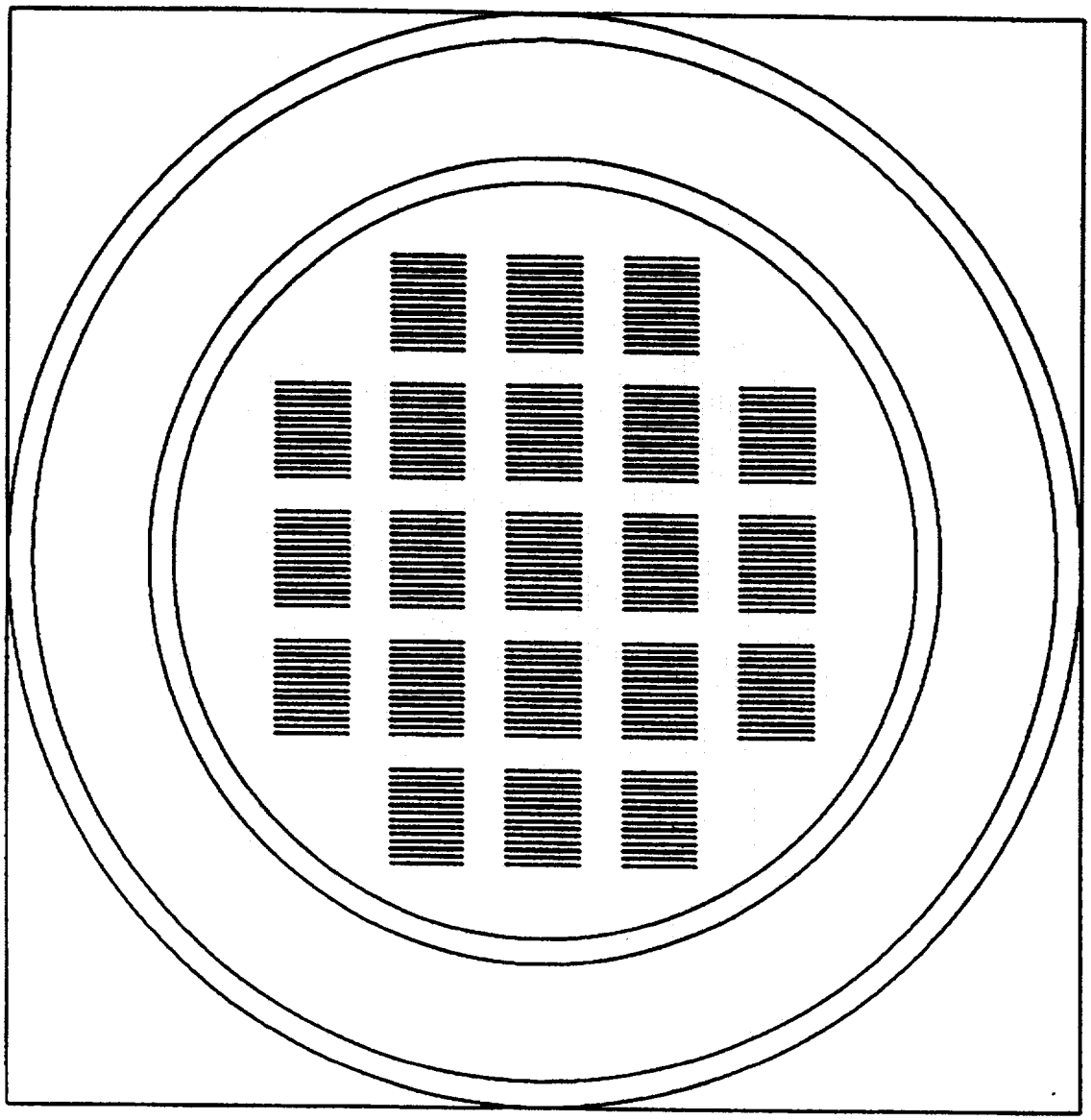


Figure 6.69. Sectional View (Z = 130 cm) for MTR Type I Fuel

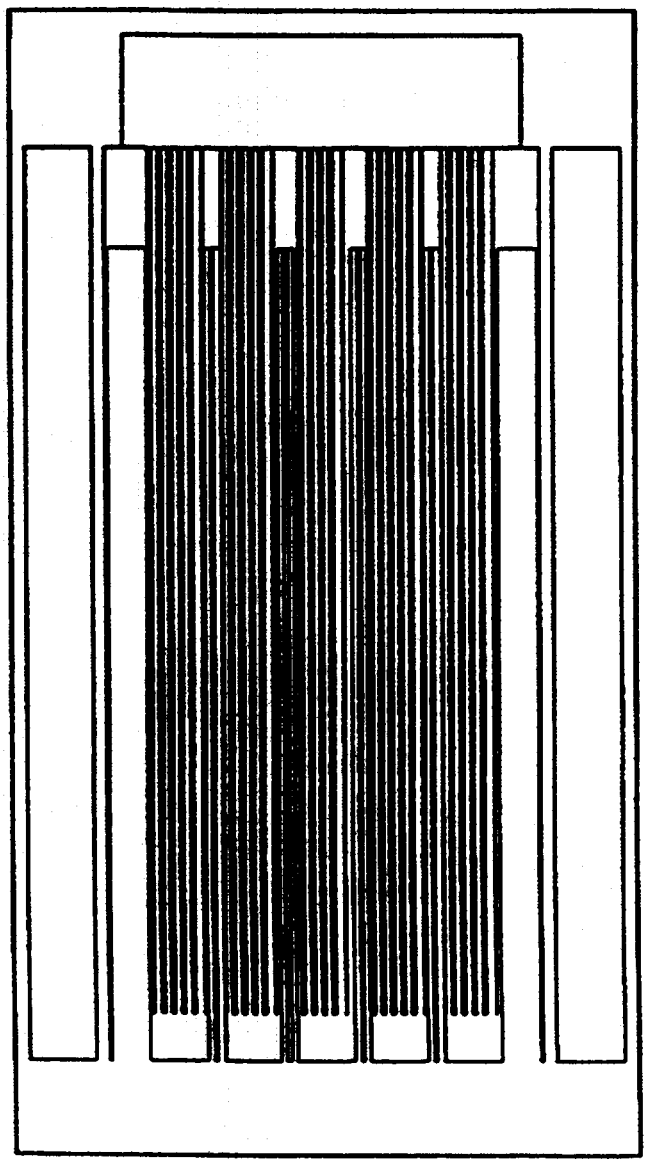


Figure 6.70. Side View for MTR Type I Fuel

6.7.6.5.5 GEMER Input Decks for MTR Type II Fuel

This section includes GEMER geometrical plots and input listings for the infinite array. Each NBSR basedeck contains a "header" with fuel material and geometry information.

6.7.6.5.6 Infinite Case (20.0% Enriched Fuel) for MTR Type II Fuel

```
ORR FUEL/ IF2000/21 ELEMENTS, SS+Pb SHIELDING. MASS U235 IN EACH
ELEM=694G
   105 /* # BATCHES
  1000  /* # NEUTRONS PER BATCH
     5  /* # BATCHES TO SKIP
 2123469/* INITIAL "SEED" (IF NON-ZERO)
     0  /* "IDUMP"
     0  /* "NRSTRT"
     0  /* "NBTED" (NON-ZERO IS PRINT EDITS)
     0  /* "KRED" (NUMBER OF COMBINED REGIONS IN EDITS)
     0  293   19  7
      4  293 0  0 U(20.0)3SI2  RHOMIX= 6.362267 g/cc     MAT 1
     14  7.9770721E-03
    131  2.8401462E-02
   2381  9.5476955E-03
   2351  2.4179113E-03
      3  293 0 0 Boral 0.25" Plate (75% Boron Loading)  MAT 2
     10    4.15822E-03
     11    8.48616E-05
    131    5.8001E-02
      2  293 0 0  MODERATOR IN CASK (100.00%)                    MAT 3
      1   6.69111121E-02
     16   3.34555566E-02
      1  293 0 0 LEAD SHIELDING                        MAT 4
     82   3.29890E-02
      7  293 0 0 304 STAINLESS STEEL                   MAT 5
     12   6.82690E-05
     14   8.53360E-04
     24   1.53600E-02
     26   6.04950E-02
     28   6.82690E-03
     55   1.70670E-03
   1316   2.56010E-05
      2  293 0 0 FULL DENSITY WATER (100%)             MAT 6
      1    6.69111121E-02
     16    3.34555566E-02
      1  293 0 0 AL CLADDING             MAT 7
    131    6.026464E-02
KENO GEOM
     19  /* "KREFM"
     11  /* "NBOX"
      1  /* "NBXMAX"
      1  /* "NBYMAX"
      1  /* "NBZMAX"
      1  /* "NXX"
      0  /* "NTYPST"
      1  /* "NEMBRG"
      0  /* "NGMCHK"
 -1.0  -1.0  -1.0  -1.0  -1.0  -1.0
BOX TYPE     1 /*MODEL 2000 CASK & STAINLESS SUPPORT STRUCTURE
```

```
CYLINDER      6  33.65      140.64      0.0     16*0.5
CYLINDER      5  35.85      140.64      0.0     16*0.5
CYLINDER      4  46.34      140.64      0.0     16*0.5
CYLINDER      5  48.56      140.64    -14.90    16*0.5
BOX TYPE      2 /* CASK TOP
CYLINDER      4  30.96      158.42     140.64  16*0.5
CYLINDER      5  48.56      162.23     140.64  16*0.5
BOX TYPE      3 /* 21 SLOTS FILLED WITH WATER  125.2778 CM HIGH
CUBOID        6  4.4450 -4.4450  4.0005  -4.0005  125.2728  0.0   16*0.5
BOX TYPE      4 /* 21 SLOTS FILLED WITH WATER      ***   EXTENDED HEIGHT
CUBOID        6  4.4450 -4.4450  4.0005  -4.0005  15.35  0.00  16*0.5
BOX TYPE      5 /* BORAL PLATE (VERT)  125.2728 CM (49.32")
CUBOID        2  0.2667  -0.2667  3.937  -3.937  125.2728  0.0   16*0.5
BOX TYPE      6 /* BORAL PLATE (HORIZ) MODELED AS 3.1" X 0.21" X 49.32"
MIN DIMENSIONS
CUBOID        2  3.937  -3.937  0.2667  -0.2667  125.2728  0.0   16*0.5
BOX TYPE      7  /* FUEL PLATES        119.93626 CM TOTAL H
CUBOID        1  0.0254 -0.0254  3.175   -3.175  125.2728  20.68654
16*0.5  /* *** FUEL
CUBOID        7  0.0635 -0.0635  3.556   -3.556  125.2728  20.68654
16*0.5  /* *** CLAD
BOX TYPE      8  /* FUEL PLATES        119.93626 CM TOTAL
CUBOID        1  0.0254 -0.0254  3.175   -3.175  15.350  0.00   16*0.5
/*  *** FUEL
CUBOID        7  0.0635 -0.0635  3.556   -3.556  15.350  0.00   16*0.5
/*  *** CLAD
BOX TYPE      9
CYLINDER      5  33.34      125.2728      0.0     16*0.5
BOX TYPE     10  /*          ***
CYLINDER      6  33.34      15.350      0.0     16*0.5
BOX TYPE     11  /* OVERALL BOX FOR THE PROBLEM
CUBOID        6  48.60    -48.60   48.60 -48.60 162.23 -14.91 16*0.5
CORE          0  48.60    -48.60   48.60 -48.60 162.23 -14.91 16*0.5
CUBOID        6  48.70    -48.70   48.70 -48.70 162.33 -15.01 16*0.5
11  1 1 1  1 1 1  1 1 1  1
BEGIN COMPLEX
/* PLACE THE FUEL PLATES INTO THE SLOT 4.445-0.0254
/* BOX TYPE 3 FOR NORMAL HEIGHT
/* BOX TYPE 4 FOR PROTRUDED HEIGHT
COMPLEX  3  7    -4.05765    0.00  0.0    19  1  1  0.45085   0.00  0.0
/*19 PLATES
COMPLEX  4  8    -4.05765    0.00  0.0    19  1  1  0.45085   0.00  0.0
/*19 PLATES
/* PLACE FUEL ASSEMBLIES INTO CASK    NORMAL HEIGHT
COMPLEX  9  3   -22.860  -10.540  0.0  5  3  1  11.430  10.540  0.0
/*MIDDLE ROWS
COMPLEX  9  3   -11.430  -21.080  0.0  3  2  1  11.430  42.160  0.0
/*OUTER ROWS
/* PLACE FUEL ASSEMBLIES INTO CASK    EXTENDED HEIGHT
COMPLEX  10  4   -22.860  -10.540   0.00  5  3  1  11.430  10.540  0.0
/*MIDDLE ROWS
COMPLEX  10  4   -11.430  -21.080   0.00  3  2  1  11.430  42.160  0.0
/*OUTER ROWS
/* PLACE BORAL PLATES INTO CASK
COMPLEX  9  5   -17.145  -10.540  0.0  4  3  1  11.430  10.540  0.0
/*VERT PLATES
COMPLEX  9  6   -11.430  -15.810  0.0  3  4  1  11.430  10.540  0.0
/*HORIZ PLATES
/* PLACE LOWER SECTION (NORMAL HEIGHT) INTO THE BOX TYPE 1
COMPLEX  1  9  0.0   0.0   0.0   1  1  1   0.0  0.0  0.0
/* PLACE PROTRUDED SECTION (EXTENDED HEIGHT) INTO THE BOX TYPE 1
```

```
COMPLEX  1 10  0.0   0.0   125.2728   1  1  1   0.0  0.0  0.0
/* PLACE LOADED CASK INTO OVERALL PROBLEM BOX
COMPLEX  11  1  0.0     0.0    0.0   1 1 1   0.0    0.0    0.0
/* PLACE TOP INTO OVERALL PROBLEM BOX
COMPLEX  11  2  0.0     0.0    0.0   1 1 1   0.0    0.0    0.0
END GEOM
*END GEMER*
```

6.7.6.5.7 Number Density Calculations for MTR Type II Fuel

6.7.6.5.7.1 FORTRAN Program

```
PROGRAM NUMBER
C
C   ASSUMPTIONS:
C   1. THE FUEL AND CLAD ARE MODELED HETEROGEOUSLY.
C   2. ORR FUEL USED
C   3. 19 PLATES/ELEMENT
C   4. 2 ELEMENTS STACKED UP. WITH THE TOP ELEMENTS PROTRUDING.
C
       REAL NAL_CLAD
       REAL MU235,M238,MO16,MH2O,MH,MSI,MAL
       REAL MU,MUOLD
       REAL MU3O8
       REAL NELEMACT,NSLOT
       REAL N235,N238,N16,N131,N1,N14
       REAL N235TOT
       DIMENSION HEIGHT(3)
       OPEN(6,FILE='ORR.OUT',STATUS='UNKNOWN')
C
C    FOR U3SI2 FUEL
C
C    NUMBER DENSITY PROGRAM FOR ORR
C      3/23/98
C      AV = AVOGADRO'S NUMBER
C     RHO_WAT = WATER DENSITY (1 G/CC)
C
      DATA PI/3.14159265/
      RHO_WAT = 1.0
      AV=0.6022
      M235 =235.0439
      M238 =238.0508
      MAL = 26.98
      MO16 = 16.000
      MH2O=18.0

      MSI=28.0855
      MAL=26.98
      MH=1.0

C
C    D  = ACTIVE FUEL LENGTH (IN)
C    E  = CLADDING THICKNESS (IN)
C    C  = PLATE LENGTH (IN)
C    G  = PLATE THICKNESS (IN)
C    F  = ACTIVE FUEL THICKNESS (IN)
C    RHOCLAD  = DENISTY OF AL CLAD (G/CC)
C    WF       = WEIGHT % OF U3SI2  IN THE U3SI2/AL MIXTURE
C    ENRICH   = FUEL ENRICHMENT
```

```
C     ELEMH     = EFFECTIVE ELEMENT HEIGHT IN INCHES (HEIGHT OF 2
ELEMENTS)
C     NELEMACT = NUMBER OF ACTIVE FUEL PLATES PER FUEL ASSEMBLY (19 PER
ASSEMBLY)
C
C       ORR
C
        ELEMH=23.6095*2.0
C
        D=2.500
        E=0.015
        C=2.800
        G=0.050
        F=0.020
C
C        ENRICH = U-235 ENRICHMENT
C     20 % ENRICHMENT
C
        DO 1400 NJ=1,19


        ENRICH = 0.20
        WF=0.80
        U235MAS=693.6


        NELEMACT=FLOAT(NJ)
       WRITE(6,*)
       WRITE(6,*)
       WRITE(6,*) ' ******************************'
       WRITE(6,*) '  NUMBER OF PLATES =',NELEMACT
C
C    AREASLOT = SLOT AREA PER ELEMENT (cm^2)
        AREASLOT=71.12889
C
        RHOH2O = 1.0
        RHOCLAD = 2.7
C
       WRITE(6,*) ' ************************************'
       WRITE(6,*) ' FUEL ELEMENT HEIGHT =',ELEMH*2.54,' CM'
       WRITE(6,*) '  ORR CASE'
       WRITE(6,*) ' ELEMENT HEIGHT=',ELEMH
       WRITE(6,*) ' ENRICH =',ENRICH
       WRITE(6,*)  ' WF =',WF
       WRITE(6,*) ' RHOCLAD=',RHOCLAD
C
        AELEMENT=C*G*2.54*2.54
        AMEAT=D*F*2.54*2.54
        ACLAD=AELEMENT-AMEAT
C
        WRITE(6,*) ' '
        WRITE(6,*) '  FOR EACH UNIT ELELEMT'
        WRITE(6,*) '   ACLAD   AMEAT   AELEMENT (CM2)'
        WRITE(6,*) ACLAD,AMEAT,AELEMENT
C
        U238MAS=U235MAS/ENRICH - U235MAS
C
        MU= 1.0/(ENRICH/M235 + (1.0-ENRICH)/M238)
C
        F2=3.0*MU/(3.0*MU + 2.0*MSI)
        U3SI2MAS=(U235MAS+U238MAS)/F2
```

```
      SIMAS=U3SI2MAS-(U235MAS+U238MAS)
      WRITE(6,*) ' SI        MASS =',SIMAS
      WRITE(6,*) ' U238      MASS =',U238MAS
      WRITE(6,*) ' U235      MASS =',U235MAS
      WRITE(6,*) ' U3SI2      MASS =',U3SI2MAS
C
      ALFUEL=U3SI2MAS/WF*(1.0-WF)
C
      WRITE(6,*) ' AL MASS IN FUEL =',ALFUEL
C
      TOTAL = U3SI2MAS + ALFUEL
      WRITE(6,*) 'TOTAL MASS (FUEL) =',TOTAL
C
C    2 ELEMENTS STACKED UP
C
      FVOLUME=AMEAT*(ELEMH*2.54)*NELEMACT
      WRITE(6,*) '   TOTAL FUEL IN EACH SLOT =',FVOLUME,' CM^3'
      RHOF = TOTAL/FVOLUME
      WRITE(6,*) ' FUEL MIXTURE DENSITY =',RHOF
C
     N235 = U235MAS*AV/M235/FVOLUME
     N235TOT=N235*FVOLUME*21.0
     N238 = U238MAS*AV/M238/FVOLUME
     N131= ALFUEL*AV/MAL/FVOLUME
     N14=2.0/3.0*(N235+N238)
C
     WRITE(6,*) '  '
     WRITE(6,*) '  N16  N131  N238  N235'
     WRITE(6,*) '     14',N14
     WRITE(6,*) '    131',N131
     WRITE(6,*) '   2381',N238
     WRITE(6,*) '   2351',N235
     WRITE(6,*) 'TOTAL',N14+N131+N238+N235
C
C*************************************************************
C    ESTIMATE THE AMOUNT OF WATER IN THE CASK
C
C     H_SLOT = SLOT HEIGHT IN CM
C     V_SLOT = VOLUME OF ALL SLOTS CM^3
C     H_CASK = HEIGHT OF CASK (CM)
C     R_CASK = RADIUS OF CASK (CM)
C     NSLOT = NUMBER OF SLOTS IN THE CASK
C
     H_SLOT= 125.2728
     H_CASK = 140.64
     R_CASK = 33.65
     NSLOT=21.0
C
C    V_CASK_TOP = CASK VOLUME ABOVE THE INGOT (CM^3)
C    V_SLOT = VOLUME OF WATER IN ALL SLOTS (CM^3)
C    V_FPLATES = VOLUME OF ALL FUEL PLATES (17X21 PLATES)
C    V_WATER = AMOUNT OF WATER VOLUME IN THE CASK (CM^3)
C
      V_SLOT=H_SLOT*AREASLOT*NSLOT
      V_CASK_TOP = PI*R_CASK*R_CASK*(H_CASK - H_SLOT)
      V_FPLATES = NELEMACT*AELEMENT*(ELEMH*2.54)*NSLOT
      V_WATER = V_CASK_TOP + V_SLOT - V_FPLATES
      WRITE(6,*)
      WRITE(6,*) ' VOLUME OF CASK TOP =',V_CASK_TOP,'CM^3'
      WRITE(6,*) ' VOLUME OF ALL SLOTS =',V_SLOT,'CM^3'
      WRITE(6,*) ' VOLUME OF ALL FUEL PLATES =',V_FPLATES,'CM^3'
```

```
      WRITE(6,*) ' VOLUME OF WATER =',V_WATER,'CM^3'
C
C
      WRITE(6,*) ' WEIGHT FRACTION     H/U (ALL VOLUME) '
      DO 3000 I=0,10
      WFWATER = 0.1*FLOAT(I)*RHO_WAT
      N1=2.0*WFWATER*AV/MH2O
      HURATIO=N1*V_WATER/(N235*FVOLUME*NSLOT)
      WRITE(6,*)  WFWATER,HURATIO
 3000 CONTINUE
C

C     WATER REFLECTOR CASE
C
      WRITE(6,*)
      WRITE(6,*) ' WATER REFLECTOR CASE'
      RAD_WR=48.56
      RAD_CASK=33.34
      HT_CASK=125.2728
      HT_WR=140.64+14.90
      RHO_WATER=1.0
      VOL_WR=PI*(RAD_WR-RAD_CASK)*(RAD_WR-RAD_CASK)*(HT_WR-HT_CASK)
      WRITE(6,*) ' VOLUME OF WATER REFLECTOR =',VOL_WR,' CM^3'
C      NHTOT=RHO_WATER*AV/18.0*WATER_TOTAL + NH*NPIN*21.0*FVOLUME
      NHTOT=2.0*RHO_WATER*AV/18.0*V_WATER
     *      + 2.0*RHO_WATER*AV/18.0*VOL_WR
      RATIO6=NHTOT/N235TOT
      WRITE(6,*) RHO_WATER,RATIO6
 1400 CONTINUE
      END
```

6.7.6.5.7.2 FORTRAN Output for MTR Type II Fuel

```
*****************************
   NUMBER OF PLATES =   19.00000
  ************************************
  FUEL ELEMENT HEIGHT =   119.9363     CM
   ORR CASE
  ELEMENT HEIGHT=   47.21900
  ENRICH =  0.2000000
  WF =  0.8000000
  RHOCLAD=   2.700000

   FOR EACH UNIT ELELEMT
    ACLAD   AMEAT   AELEMENT (CM2)
  0.5806440      0.3225800      0.9032240
  SI        MASS =   273.4807
  U238      MASS =   2774.400
  U235      MASS =   693.6000
  U3SI2      MASS =   3741.481
  AL MASS IN FUEL =   935.3701
 TOTAL MASS (FUEL) =   4676.851
    TOTAL FUEL IN EACH SLOT =   735.0918     CM^3
  FUEL MIXTURE DENSITY =   6.362267

   N16  N131  N238  N235
      14  7.9770721E-03
     131  2.8401462E-02
    2381  9.5476955E-03
    2351  2.4179113E-03
 TOTAL  4.8344143E-02

  VOLUME OF CASK TOP =   54665.70    CM^3
  VOLUME OF ALL SLOTS =   187120.8    CM^3
  VOLUME OF ALL FUEL PLATES =   43223.40    CM^3
  VOLUME OF WATER =   198563.1    CM^3
  WEIGHT FRACTION     H/U (ALL VOLUME)
  0.0000000E+00  0.0000000E+00
  0.1000000       35.59554
  0.2000000       71.19108
  0.3000000       106.7866
  0.4000000       142.3822
  0.5000000       177.9777
  0.6000000       213.5732
  0.7000000       249.1688
  0.8000000       284.7643
  0.9000000       320.3599
   1.000000       355.9554

  WATER REFLECTOR CASE
  VOLUME OF WATER REFLECTOR =   22026.80     CM^3
   1.000000       395.4173
```

6.7.6.5.8 Geometrical Plots of the MTR Type II Fuel — Side and Sectional Views

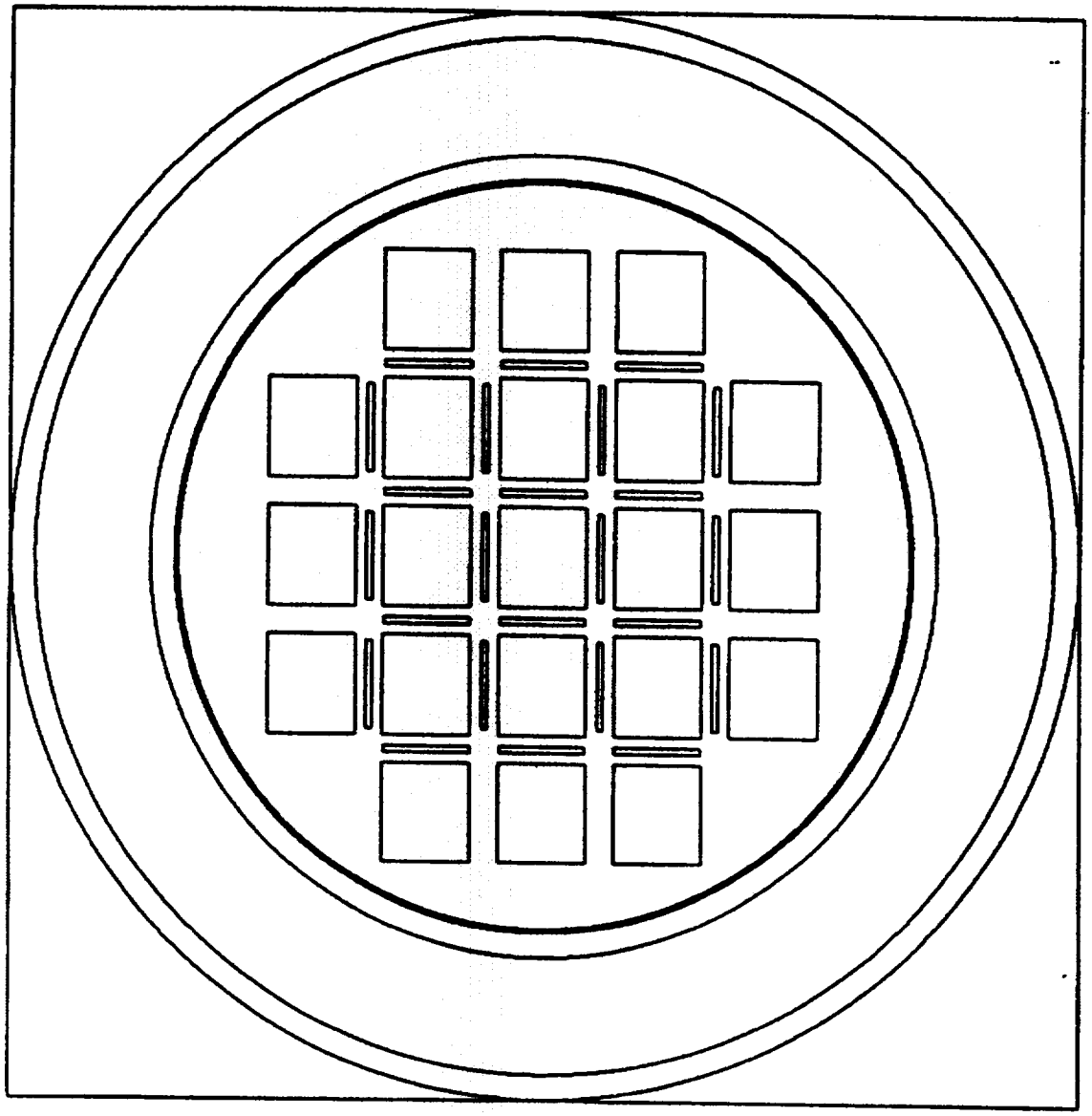


Figure 6.71. Sectional View (Z = 5 cm) for MTR Type II Fuel

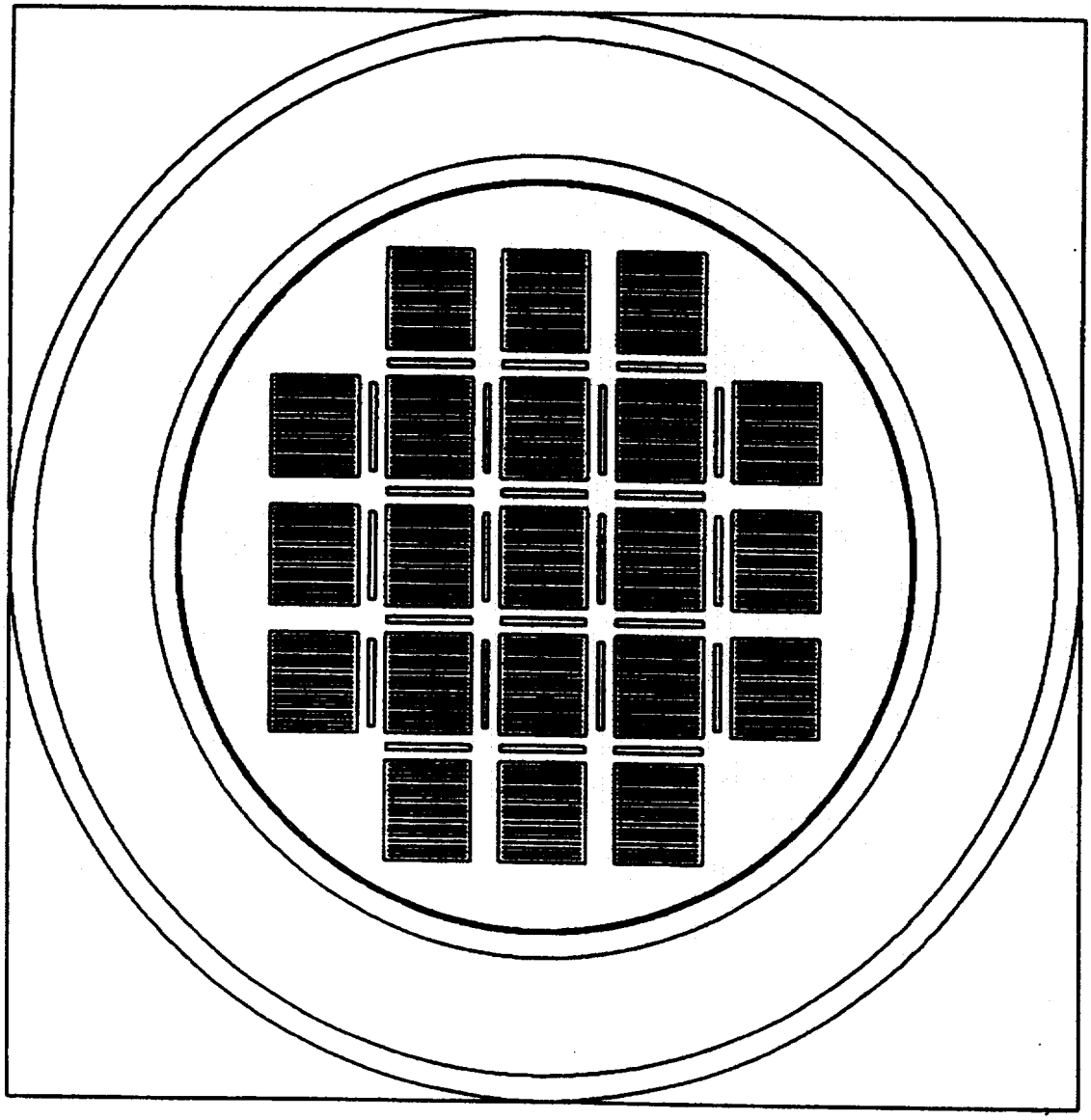


Figure 6.72. Sectional View (Z = 60 cm) for MTR Type II Fuel

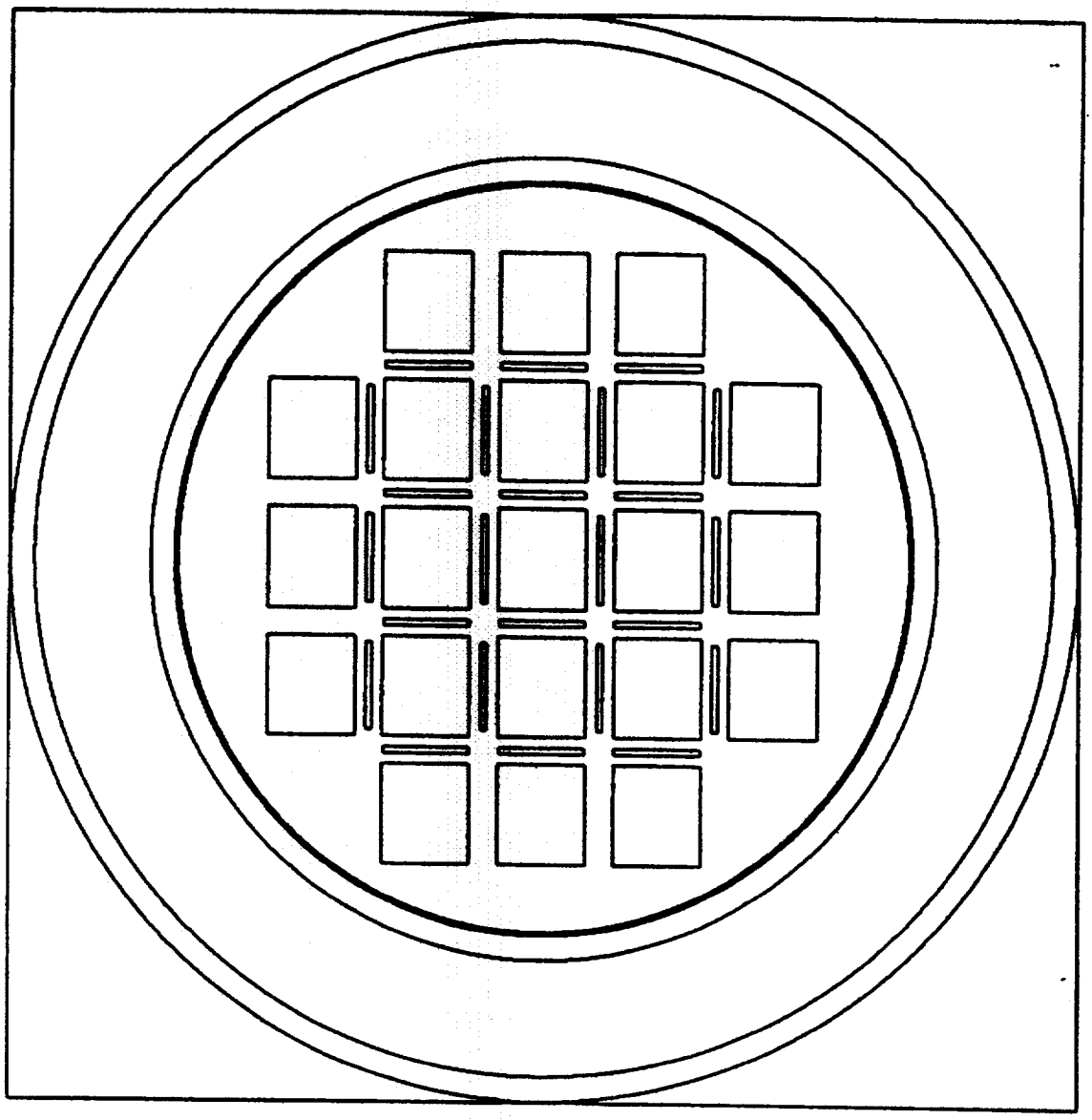


Figure 6.73. Sectional View (Z = 130 cm) for MTR Type II Fuel

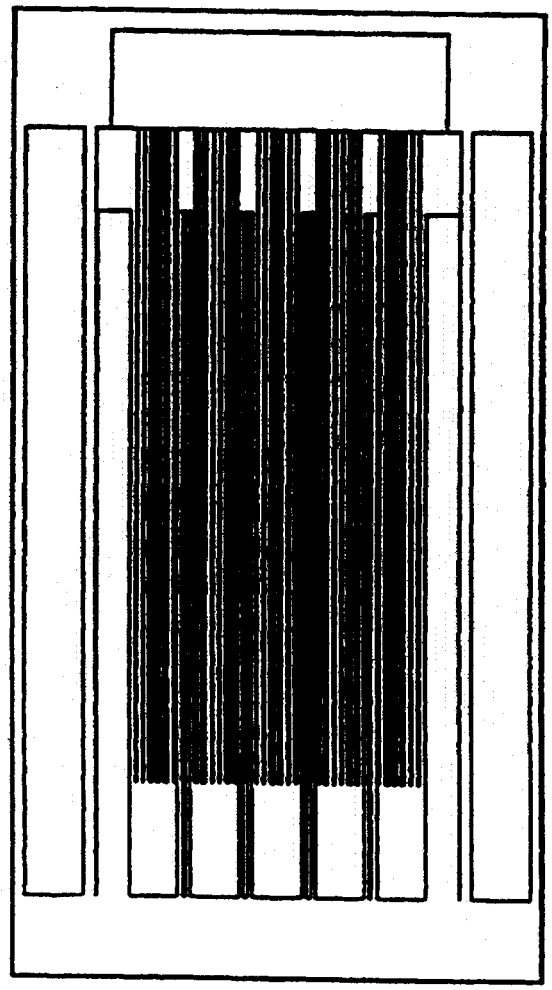


Figure 6.74. Side View for MTR Type II Fuel

6.7.6.5.9 GEMER Input Decks for MTR Type III Fuel

This section includes GEMER geometrical plots and input listings for the infinite array. Each NBSR basedeck contains a "header" with fuel material and geometry information.

6.7.6.5.10 Infinite Case (94.0% Enriched Fuel) for MTR Type III Fuel

```
SAPHIR FUEL/ IF2000/21 ELEMENTS, SS+Pb SHIELDING. MASS U235 IN EACH
ELEM=580.0 G
   105 /* # BATCHES
  1000  /* # NEUTRONS PER BATCH
     5  /* # BATCHES TO SKIP
 2123469/* INITIAL "SEED" (IF NON-ZERO)
     0  /* "IDUMP"
     0  /* "NRSTRT"
     0  /* "NBTED" (NON-ZERO IS PRINT EDITS)
     0  /* "KRED" (NUMBER OF COMBINED REGIONS IN EDITS)
     0  293   19  7
      3  293 0  0 U(94.0)AL/AL 2 FUEL ELEMENTS     MAT 1
    131  7.4334987E-02
   2381  1.2783392E-04
   2351  2.0287295E-03
      3  293 0 0 Boral 0.25" Plate (75% Boron Loading)  MAT 2
   10    4.15822E-03
   11    8.48616E-05
  131    5.8001E-02
      2  293 0 0  MODERATOR IN CASK (100.00%)                    MAT 3
    1   6.69111121E-02
   16   3.34555566E-02
      1  293 0 0 LEAD SHIELDING                        MAT 4
   82   3.29890E-02
      7  293 0 0 304 STAINLESS STEEL                   MAT 5
   12   6.82690E-05
   14   8.53360E-04
   24   1.53600E-02
   26   6.04950E-02
   28   6.82690E-03
   55   1.70670E-03
 1316   2.56010E-05
      2  293 0 0 FULL DENSITY WATER (100%)             MAT 6
    1    6.69111121E-02
   16    3.34555566E-02
    1  293 0 0 AL CLADDING             MAT 7
  131    6.026464E-02
KENO GEOM
   19  /* "KREFM"
   11  /* "NBOX"
    1  /* "NBXMAX"
    1  /* "NBYMAX"
    1  /* "NBZMAX"
    1  /* "NXX"
    0  /* "NTYPST"
    1  /* "NEMBRG"
    0  /* "NGMCHK"
 -1.0  -1.0  -1.0  -1.0  -1.0  -1.0
```

```
BOX TYPE      1 /*MODEL 2000 CASK & STAINLESS SUPPORT STRUCTURE
CYLINDER      6  33.65      140.64      0.0     16*0.5
CYLINDER      5  35.85      140.64      0.0     16*0.5
CYLINDER      4  46.34      140.64      0.0     16*0.5
CYLINDER      5  48.56      140.64    -14.90    16*0.5
BOX TYPE      2 /* CASK TOP
CYLINDER      4  30.96      158.42     140.64  16*0.5
CYLINDER      5  48.56      162.23     140.64  16*0.5
BOX TYPE      3 /* 21 SLOTS FILLED WITH WATER  125.2778 CM HIGH
CUBOID        6  4.4450 -4.4450  4.0005  -4.0005  125.2728  0.0   16*0.5
BOX TYPE      4 /* 21 SLOTS FILLED WITH WATER      ***   EXTENDED HEIGHT
CUBOID        6  4.4450 -4.4450  4.0005  -4.0005  15.35  0.00  16*0.5
BOX TYPE      5 /* BORAL PLATE (VERT)  125.2728 CM (49.32")
CUBOID        2  0.2667  -0.2667  3.937  -3.937  125.2728  0.0   16*0.5
BOX TYPE      6 /* BORAL PLATE (HORIZ) MODELED AS 3.1" X 0.21" X 49.32"
MIN DIMENSIONS
CUBOID        2  3.937  -3.937  0.2667  -0.2667  125.2728  0.0   16*0.5
BOX TYPE      7  /* FUEL PLATES        119.5324 CM TOTAL H
CUBOID        1  0.02540 -0.02540  3.175   -3.175  125.2728  21.0904
16*0.5  /* *** FUEL
CUBOID        7  0.06477 -0.06477  3.556   -3.556  125.2728  21.0904
16*0.5  /* *** CLAD
BOX TYPE      8  /* FUEL PLATES        119.5324 CM TOTAL
CUBOID        1  0.02540 -0.02540  3.175   -3.175  15.350  0.00   16*0.5
/*  *** FUEL
CUBOID        7  0.06477 -0.06477  3.556   -3.556  15.350  0.00   16*0.5
/*  *** CLAD
BOX TYPE      9
CYLINDER      5  33.34      125.2728      0.0     16*0.5
BOX TYPE     10  /*           ***
CYLINDER      6  33.34      15.350      0.0     16*0.5
BOX TYPE     11  /* OVERALL BOX FOR THE PROBLEM
CUBOID        6  48.60     -48.60    48.60 -48.60 162.23 -14.91 16*0.5
CORE          0  48.60     -48.60    48.60 -48.60 162.23 -14.91 16*0.5
CUBOID        6  48.70     -48.70    48.70 -48.70 162.33 -15.01 16*0.5
11  1 1 1  1 1 1  1 1 1  1
BEGIN COMPLEX
/* PLACE THE FUEL PLATES INTO THE SLOT 4.445-0.0254
/* BOX TYPE 3 FOR NORMAL HEIGHT
/* BOX TYPE 4 FOR PROTRUDED HEIGHT
COMPLEX  3  7    -4.4196    0.00  0.0  19  1  1  0.491067   0.00  0.0
/*19 PLATES
COMPLEX  4  8    -4.4196    0.00  0.0  19  1  1  0.491067   0.00  0.0
/*19 PLATES
/* PLACE FUEL ASSEMBLIES INTO CASK    NORMAL HEIGHT
COMPLEX  9  3   -22.860  -10.540  0.0  5  3  1  11.430  10.540  0.0
/*MIDDLE ROWS
COMPLEX  9  3   -11.430  -21.080  0.0  3  2  1  11.430  42.160  0.0
/*OUTER ROWS
/* PLACE FUEL ASSEMBLIES INTO CASK    EXTENDED HEIGHT
COMPLEX  10  4   -22.860  -10.540   0.00  5  3  1  11.430  10.540  0.0
/*MIDDLE ROWS
COMPLEX  10  4   -11.430  -21.080   0.00  3  2  1  11.430  42.160  0.0
/*OUTER ROWS
/* PLACE BORAL PLATES INTO CASK
COMPLEX  9  5   -17.145  -10.540  0.0  4  3  1  11.430  10.540  0.0
/*VERT PLATES
COMPLEX  9  6   -11.430  -15.810  0.0  3  4  1  11.430  10.540  0.0
/*HORIZ PLATES
/* PLACE LOWER SECTION (NORMAL HEIGHT) INTO THE BOX TYPE 1
COMPLEX  1  9  0.0   0.0   0.0   1  1  1   0.0  0.0  0.0
```

```
/* PLACE PROTRUDED SECTION (EXTENDED HEIGHT) INTO THE BOX TYPE 1
COMPLEX  1 10  0.0   0.0   125.2728   1  1  1   0.0  0.0  0.0
/* PLACE LOADED CASK INTO OVERALL PROBLEM BOX
COMPLEX  11  1  0.0     0.0    0.0   1 1 1   0.0    0.0    0.0
/* PLACE TOP INTO OVERALL PROBLEM BOX
COMPLEX  11  2  0.0     0.0    0.0   1 1 1   0.0    0.0    0.0
END GEOM
*END GEMER*
```

6.7.6.5.11 Number Density Calculations for MTR Type III Fuel

6.7.6.5.11.1 FORTRAN Program

```
PROGRAM NUMBER
C
C   ASSUMPTIONS:
C   1. THE FUEL AND CLAD ARE MODELED HETEROGEOUSLY.
C   2. SAPHIR FUEL USED
C   3. 19 PLATES/ELEMENT
C   4. 2 ELEMENTS STACKED UP. WITH THE TOP ELEMENTS PROTRUDING.
C
       REAL NAL_CLAD
       REAL MU235,M238,MO16,MH2O,MH,MSI,MAL
       REAL MU,MUOLD
       REAL MU3O8
       REAL NELEMACT,NSLOT
       REAL N235,N238,N16,N131,N1,N14
       REAL N235TOT
       DIMENSION HEIGHT(3)
       OPEN(6,FILE='SAPHIR.OUT',STATUS='UNKNOWN')
C
C    FOR UAL FUEL
C
C    NUMBER DENSITY PROGRAM FOR SAPHIR
C      3/23/98
C      AV = AVOGADRO'S NUMBER
C     RHO_WAT = WATER DENSITY (1 G/CC)
C
      DATA PI/3.14159265/
      RHO_WAT = 1.0
      AV=0.6022
      M235 =235.0439
      M238 =238.0508
      MAL = 26.98
      MO16 = 16.000
      MH2O=18.0
      MSI=28.0855
      MAL=26.98
      MH=1.0

C
C    D  = ACTIVE FUEL LENGTH (IN)
C    E  = CLADDING THICKNESS (IN)
C    C  = PLATE LENGTH (IN)
C    G  = PLATE THICKNESS (IN)
C    F  = ACTIVE FUEL THICKNESS (IN)
C    RHOCLAD  = DENISTY OF AL CLAD (G/CC)
C    WF       = WEIGHT % OF UAL  IN THE UAL/AL MIXTURE
C    ENRICH   = FUEL ENRICHMENT
```

```
C    ELEMH     = EFFECTIVE ELEMENT HEIGHT IN INCHES (HEIGHT OF 2
ELEMENTS)
C    NELEMACT = NUMBER OF ACTIVE FUEL PLATES PER FUEL ASSEMBLY (19 PER
ASSEMBLY)
C
C      SAPHIR
C
       ELEMH=23.53*2.0
C
       D=2.500
       E=0.015
       C=2.799
       G=0.051
       F=0.020
C
C       ENRICH = U-235 ENRICHMENT
C    94 % ENRICHMENT
C
       ENRICH = 0.94
       WF=0.225

C       U235MAS=230.0*2.0
C      5 ELEMENTS AS BEFORE
C
C   5 FAS       U235MAS=1112.45
C   4 FAS               890.0
C   2 FAS               460.0
C
C       U235MAS=460.0
       U235MAS=580.0
C
       NELEMACT=19.0
C
C   AREASLOT = SLOT AREA PER ELEMENT (cm^2)
       AREASLOT=71.12889
C
       RHOH2O = 1.0
       RHOCLAD = 2.7
C
      WRITE(6,*) ' ************************************'
      WRITE(6,*) ' FUEL ELEMENT HEIGHT =',ELEMH*2.54,' CM'
      WRITE(6,*) '  SAPHIR CASE'
      WRITE(6,*) ' ELEMENT HEIGHT=',ELEMH
      WRITE(6,*) ' RHOH2O =',RHOH2O
      WRITE(6,*) ' ENRICH =',ENRICH
      WRITE(6,*)  ' WF =',WF
      WRITE(6,*) ' RHOCLAD=',RHOCLAD
C
       AELEMENT=C*G*2.54*2.54
       AMEAT=D*F*2.54*2.54
       ACLAD=AELEMENT-AMEAT
C
       WRITE(6,*) ' '
       WRITE(6,*) '  FOR EACH UNIT ELELEMT'
       WRITE(6,*) '   ACLAD   AMEAT   AELEMENT (CM2)'
       WRITE(6,*) ACLAD,AMEAT,AELEMENT
C
       U238MAS=U235MAS/ENRICH - U235MAS
C
       MU= 1.0/(ENRICH/M235 + (1.0-ENRICH)/M238)
C
```

```
C
C       ALMAS = ALUMIUM MASS IN THE UAL FUEL.
        F2=MU/(MU+MAL)
        UALMAS=(U235MAS+U238MAS)/F2
        ALMAS=UALMAS-(U235MAS+U238MAS)
        WRITE(6,*) ' FOR ALL PLATES AND FUEL ELEMENTS CONSIDERED:'
        WRITE(6,*) ' AL (FUEL) MASS =',ALMAS
        WRITE(6,*) ' U238      MASS =',U238MAS
        WRITE(6,*) ' U235      MASS =',U235MAS
        WRITE(6,*) ' UAL      MASS =',UALMAS
C
C       ALPLATE = ALUMINIUM IN THE FUEL PLATE (NON UAL PORTION)
C       (THE FUEL CONSISTS OF UAL AND AL MIXTURE)
C
       ALPLATE=UALMAS/WF*(1.0-WF)
C
C
       ALFUEL=ALPLATE + ALMAS
C
C
C
        WRITE(6,*) ' AL MASS IN FUEL =',ALFUEL
C
C       TOTAL = TOTAL MASS OF FUEL (UAL + AL)
        TOTAL = U238MAS + U235MAS + ALFUEL
        WRITE(6,*) 'TOTAL MASS (FUEL) =',TOTAL
C
C     2 ELEMENTS STACKED UP
C
        FVOLUME=AMEAT*(ELEMH*2.54)*NELEMACT
        WRITE(6,*) '   TOTAL FUEL IN EACH SLOT =',FVOLUME,' CM^3'
        RHOF = TOTAL/FVOLUME
        WRITE(6,*) ' FUEL MIXTURE DENSITY =',RHOF
C
       N235 = U235MAS*AV/M235/FVOLUME
       N235TOT=N235*FVOLUME*21.0
       N238 = U238MAS*AV/M238/FVOLUME
       N131= ALFUEL*AV/MAL/FVOLUME
C
       WRITE(6,*) '  '
       WRITE(6,*) '  N131  N238  N235'
       WRITE(6,*) '    131',N131
       WRITE(6,*) '   2381',N238
       WRITE(6,*) '   2351',N235
       WRITE(6,*) 'TOTAL',N131+N238+N235
C
C*************************************************************
C      ESTIMATE THE AMOUNT OF WATER IN THE CASK
C
C       H_SLOT = SLOT HEIGHT IN CM
C       V_SLOT = VOLUME OF ALL SLOTS CM^3
C       H_CASK = HEIGHT OF CASK (CM)
C       R_CASK = RADIUS OF CASK (CM)
C       NSLOT = NUMBER OF SLOTS IN THE CASK
C
       H_SLOT= 125.2728
       H_CASK = 140.64
       R_CASK = 33.65
       NSLOT=21.0
C
C      V_CASK_TOP = CASK VOLUME ABOVE THE INGOT (CM^3)
```

```
C       V_SLOT = VOLUME OF WATER IN ALL SLOTS (CM^3)
C       V_FPLATES = VOLUME OF ALL FUEL PLATES (17X21 PLATES)
C       V_WATER = AMOUNT OF WATER VOLUME IN THE CASK (CM^3)
C
        V_SLOT=H_SLOT*AREASLOT*NSLOT
        V_CASK_TOP = PI*R_CASK*R_CASK*(H_CASK - H_SLOT)
        V_FPLATES = NELEMACT*AELEMENT*(ELEMH*2.54)*NSLOT
        V_WATER = V_CASK_TOP + V_SLOT - V_FPLATES
        WRITE(6,*)
        WRITE(6,*) ' VOLUME OF CASK TOP =',V_CASK_TOP,'CM^3'
        WRITE(6,*) ' VOLUME OF ALL SLOTS =',V_SLOT,'CM^3'
        WRITE(6,*) ' VOLUME OF ALL FUEL PLATES =',V_FPLATES,'CM^3'
        WRITE(6,*) ' VOLUME OF WATER =',V_WATER,'CM^3'
C
C
        WRITE(6,*) ' WEIGHT FRACTION     H/U (ALL VOLUME) '
        DO 3000 I=0,20
        WFWATER = 0.05*FLOAT(I)*RHO_WAT
        N1=2.0*WFWATER*AV/MH2O
        HURATIO=N1*V_WATER/(N235*FVOLUME*NSLOT)
        WRITE(6,*)  WFWATER,HURATIO
 3000   CONTINUE

C       WATER REFLECTOR CASE
C
        WRITE(6,*)
        WRITE(6,*) ' WATER REFLECTOR CASE'
        RAD_WR=48.56
        RAD_CASK=33.34
        HT_CASK=125.2728
        HT_WR=140.64+14.90
        RHO_WATER=1.0
        VOL_WR=PI*(RAD_WR-RAD_CASK)*(RAD_WR-RAD_CASK)*(HT_WR-HT_CASK)
        WRITE(6,*) ' VOLUME OF WATER REFLECTOR =',VOL_WR,' CM^3'
C        NHTOT=RHO_WATER*AV/18.0*WATER_TOTAL + NH*NPIN*21.0*FVOLUME
        NHTOT=2.0*RHO_WATER*AV/18.0*V_WATER
     *       + 2.0*RHO_WATER*AV/18.0*VOL_WR
        RATIO6=NHTOT/N235TOT
        WRITE(6,*) RHO_WATER,RATIO6

        END
```

6.7.6.5.11.2 FORTRAN Output for MTR Type III Fuel

```
*************************************
 FUEL ELEMENT HEIGHT =   119.5324     CM
  SAPHIR CASE
 ELEMENT HEIGHT=   47.06000
 RHOH2O =   1.000000
 ENRICH =  0.9400000
 WF =  0.2250000
 RHOCLAD=   2.700000

  FOR EACH UNIT ELELEMT
   ACLAD   AMEAT   AELEMENT (CM2)
 0.5983794      0.3225800      0.9209594
 FOR ALL PLATES AND FUEL ELEMENTS CONSIDERED:
 AL (FUEL) MASS =   70.78485
 U238      MASS =   37.02130
 U235      MASS =   580.0000
```

```
 UAL       MASS =    687.8062
 AL MASS IN FUEL =    2439.895
TOTAL MASS (FUEL) =    3056.916
   TOTAL FUEL IN EACH SLOT =    732.6165      CM^3
 FUEL MIXTURE DENSITY =    4.172601

  N131  N238  N235
    131  7.4334987E-02
   2381  1.2783392E-04
   2351  2.0287295E-03
TOTAL  7.6491550E-02

 VOLUME OF CASK TOP =    54665.70     CM^3
 VOLUME OF ALL SLOTS =    187120.8     CM^3
 VOLUME OF ALL FUEL PLATES =    43923.71     CM^3
 VOLUME OF WATER =    197862.8     CM^3
 WEIGHT FRACTION      H/U (ALL VOLUME)
 0.0000000E+00  0.0000000E+00
 5.0000001E-02   21.20861
 0.1000000       42.41723
 0.1500000       63.62584
 0.2000000       84.83446
 0.2500000       106.0431
 0.3000000       127.2517
 0.3500000       148.4603
 0.4000000       169.6689
 0.4500000       190.8775
 0.5000000       212.0861
 0.5500000       233.2948
 0.6000000       254.5033
 0.6500000       275.7120
 0.7000000       296.9206
 0.7500000       318.1292
 0.8000000       339.3378
 0.8500000       360.5464
 0.9000000       381.7550
 0.9500000       402.9637
  1.000000       424.1722

 WATER REFLECTOR CASE
 VOLUME OF WATER REFLECTOR =    22026.80      CM^3
  1.000000       471.3908
```

6.7.6.5.12 Geometrical Plots of the MTR Type III Fuel — Side and Sectional Views

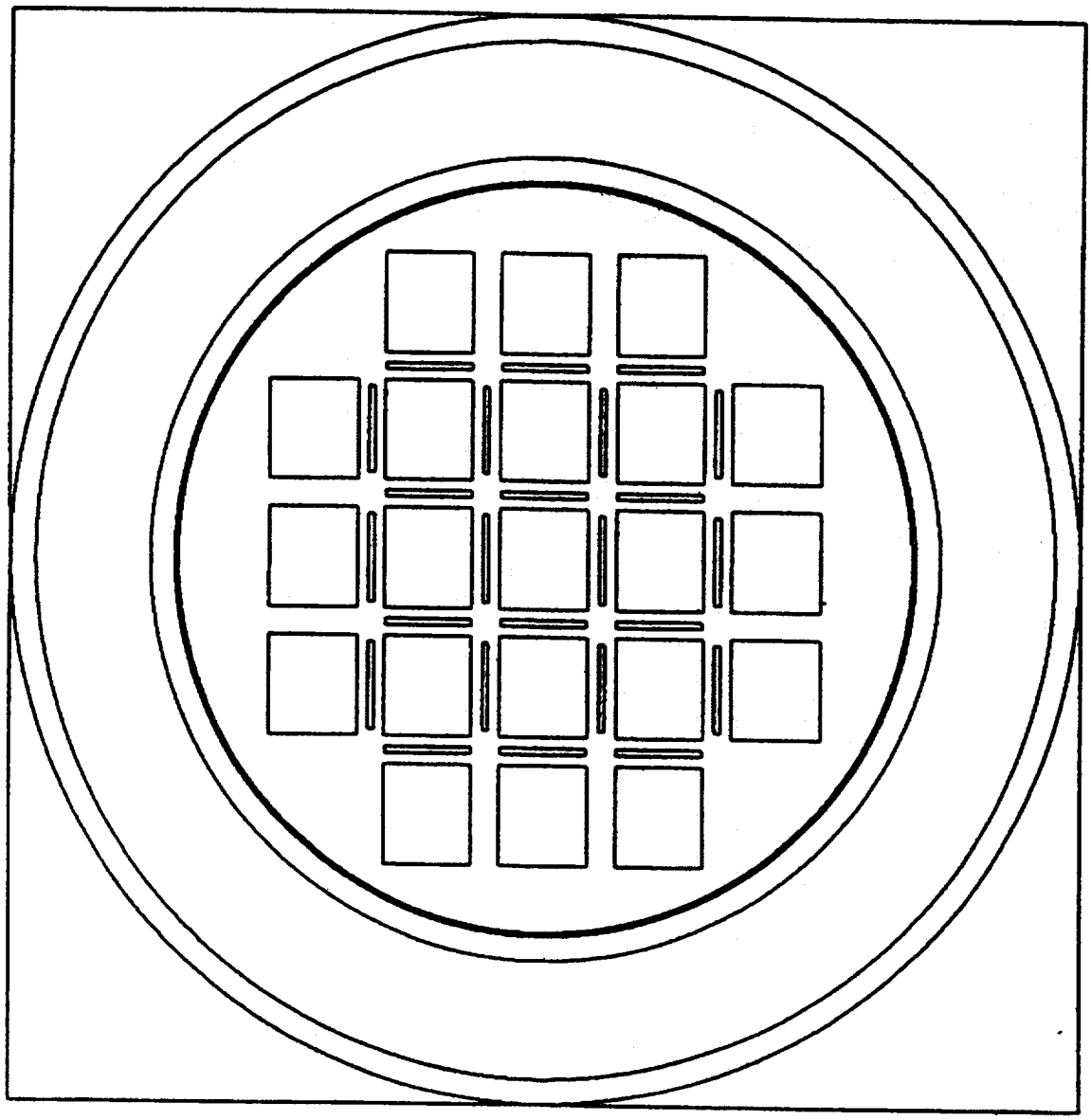


Figure 6.75. Sectional View (Z = 5 cm) for MTR Type III Fuel

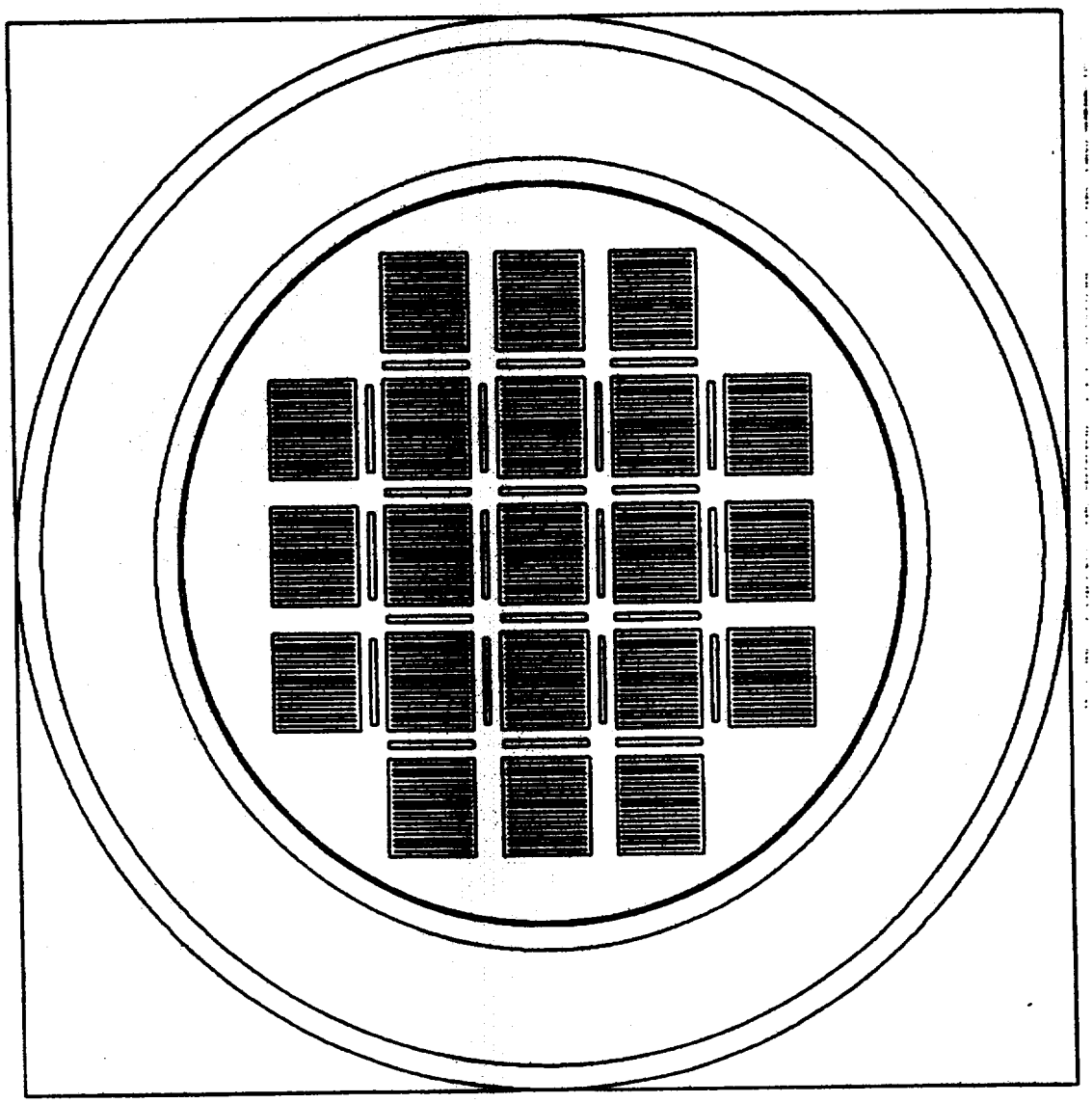


Figure 6.76. Sectional View (Z = 60 cm) for MTR Type III Fuel

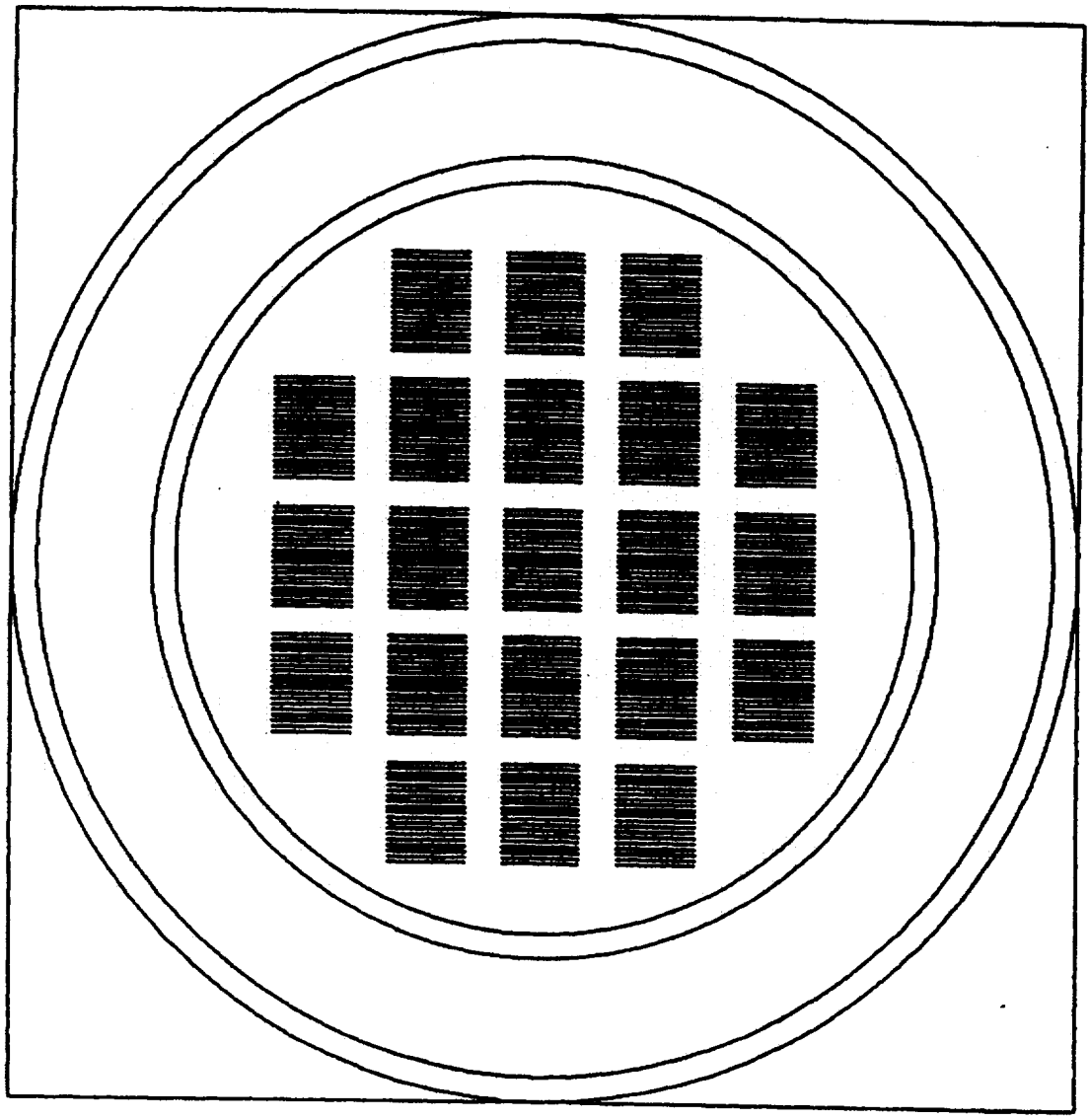


Figure 6.77. Sectional View (Z = 130 cm) for MTR Type III Fuel

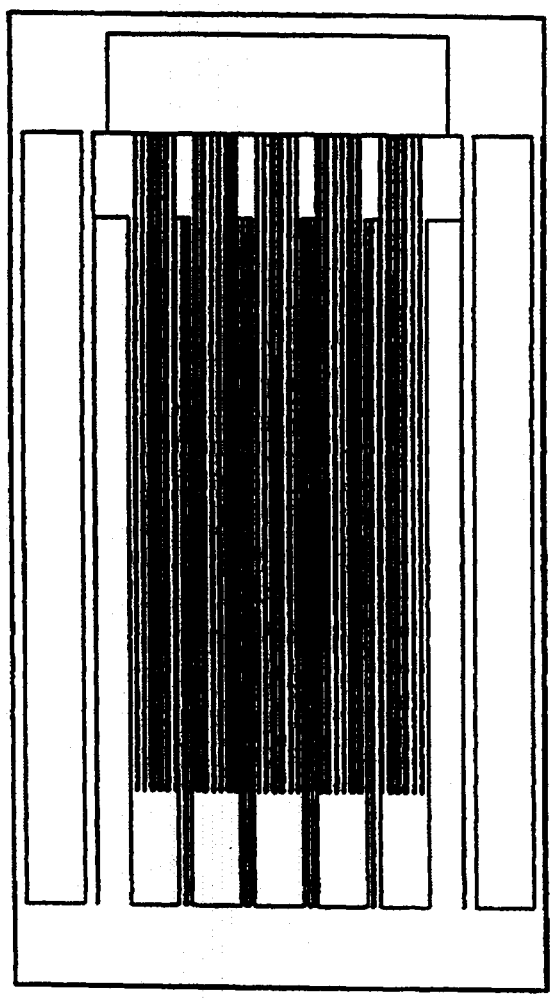


Figure 6.78. Side View for MTR Type III Fuel

6.7.6.5.13 GEMER Input Decks for MTR Type IV Fuel

This section includes GEMER geometrical plots and input listings for the infinite array. Each NBSR basedeck contains a "header" with fuel material and geometry information.

6.7.6.5.14 Infinite Case (95.0% Enriched Fuel) for MTR Type IV Fuel

```
UMETAL FUEL/ IF2000/21 ELEMENTS, SS+Pb SHIELDING. MASS U235 IN 2
ELEMS=220 G
   105 /* # BATCHES
  1000  /* # NEUTRONS PER BATCH
     5  /* # BATCHES TO SKIP
 2123469/* INITIAL "SEED" (IF NON-ZERO)
     0  /* "IDUMP"
     0  /* "NRSTRT"
```

```
     0  /* "NBTED" (NON-ZERO IS PRINT EDITS)
     0  /* "KRED" (NUMBER OF COMBINED REGIONS IN EDITS)
     0  293   19  7
      2  293 0  0 U(95.0) 2 FUEL ELEMENTS SIMILAR TO SAPHIR     MAT 1
    2381  3.9981911E-05
    2351  7.6951814E-04
      3  293 0 0 Boral 0.25" Plate (75% Boron Loading)  MAT 2
    10    4.15822E-03
    11    8.48616E-05
   131    5.8001E-02
      2  293 0 0  MODERATOR IN CASK (100.00%)                    MAT 3
     1   6.69111121E-02
    16   3.34555566E-02
      1  293 0 0 LEAD SHIELDING                        MAT 4
    82   3.29890E-02
      7  293 0 0 304 STAINLESS STEEL                   MAT 5
    12   6.82690E-05
    14   8.53360E-04
    24   1.53600E-02
    26   6.04950E-02
    28   6.82690E-03
    55   1.70670E-03
  1316   2.56010E-05
     2  293 0 0 FULL DENSITY WATER (100%)             MAT 6
     1    6.69111121E-02
    16    3.34555566E-02
     1  293 0 0 AL CLADDING             MAT 7
   131    6.026464E-02
KENO GEOM
    19  /* "KREFM"
    11  /* "NBOX"
     1  /* "NBXMAX"
     1  /* "NBYMAX"
     1  /* "NBZMAX"
     1  /* "NXX"
     0  /* "NTYPST"
     1  /* "NEMBRG"
     0  /* "NGMCHK"
 -1.0  -1.0  -1.0  -1.0  -1.0  -1.0
BOX TYPE     1 /*MODEL 2000 CASK & STAINLESS SUPPORT STRUCTURE
CYLINDER     6  33.65     140.64     0.0    16*0.5
CYLINDER     5  35.85     140.64     0.0    16*0.5
CYLINDER     4  46.34     140.64     0.0    16*0.5
CYLINDER     5  48.56     140.64   -14.90   16*0.5
BOX TYPE     2 /* CASK TOP
CYLINDER     4  30.96     158.42    140.64  16*0.5
CYLINDER     5  48.56     162.23    140.64  16*0.5
BOX TYPE     3 /* 21 SLOTS FILLED WITH WATER  125.2778 CM HIGH
CUBOID       6  4.4450 -4.4450  4.0005  -4.0005  125.2728  0.0   16*0.5
BOX TYPE     4 /* 21 SLOTS FILLED WITH WATER      ***   EXTENDED HEIGHT
CUBOID       6  4.4450 -4.4450  4.0005  -4.0005  15.35  0.00  16*0.5
BOX TYPE     5 /* BORAL PLATE (VERT)  125.2728 CM (49.32")
CUBOID       2  0.2667  -0.2667  3.937  -3.937  125.2728  0.0   16*0.5
BOX TYPE     6 /* BORAL PLATE (HORIZ) MODELED AS 3.1" X 0.21" X 49.32"
MIN DIMENSIONS
CUBOID       2  3.937  -3.937  0.2667  -0.2667  125.2728  0.0   16*0.5
BOX TYPE     7  /* FUEL PLATES        119.5324 CM TOTAL H
CUBOID       1  0.02540 -0.02540  3.175   -3.175  125.2728  21.0904
16*0.5  /* *** FUEL
CUBOID       7  0.06477 -0.06477  3.556   -3.556  125.2728  21.0904
16*0.5  /* *** CLAD
```

```
BOX TYPE      8  /* FUEL PLATES        119.5324 CM TOTAL
CUBOID        1  0.02540 -0.02540  3.175   -3.175  15.350  0.00   16*0.5
/*  *** FUEL
CUBOID        7  0.06477 -0.06477  3.556   -3.556  15.350  0.00   16*0.5
/*  *** CLAD
BOX TYPE      9
CYLINDER      5  33.34     125.2728     0.0    16*0.5
BOX TYPE     10  /*          ***
CYLINDER      6  33.34     15.350     0.0    16*0.5
BOX TYPE     11  /* OVERALL BOX FOR THE PROBLEM
CUBOID        6  48.60    -48.60   48.60 -48.60 162.23 -14.91 16*0.5
CORE          0  48.60    -48.60   48.60 -48.60 162.23 -14.91 16*0.5
CUBOID        6  48.70    -48.70   48.70 -48.70 162.33 -15.01 16*0.5
11  1 1 1  1 1 1  1 1 1  1
BEGIN COMPLEX
/* PLACE THE FUEL PLATES INTO THE SLOT 4.445-0.0254
/* BOX TYPE 3 FOR NORMAL HEIGHT
/* BOX TYPE 4 FOR PROTRUDED HEIGHT
COMPLEX  3  7    -4.058796    0.00  0.0    19  1  1  0.45085   0.00  0.0
/*19 PLATES
COMPLEX  4  8    -4.058796    0.00  0.0    19  1  1  0.45085   0.00  0.0
/*19 PLATES
/* PLACE FUEL ASSEMBLIES INTO CASK    NORMAL HEIGHT
COMPLEX  9  3   -22.860  -10.540  0.0  5  3  1  11.430  10.540  0.0
/*MIDDLE ROWS
COMPLEX  9  3   -11.430  -21.080  0.0  3  2  1  11.430  42.160  0.0
/*OUTER ROWS
/* PLACE FUEL ASSEMBLIES INTO CASK    EXTENDED HEIGHT
COMPLEX  10  4   -22.860  -10.540   0.00  5  3  1  11.430  10.540  0.0
/*MIDDLE ROWS
COMPLEX  10  4   -11.430  -21.080   0.00  3  2  1  11.430  42.160  0.0
/*OUTER ROWS
/* PLACE BORAL PLATES INTO CASK
COMPLEX  9  5   -17.145  -10.540  0.0  4  3  1  11.430  10.540  0.0
/*VERT PLATES
COMPLEX  9  6   -11.430  -15.810  0.0  3  4  1  11.430  10.540  0.0
/*HORIZ PLATES
/* PLACE LOWER SECTION (NORMAL HEIGHT) INTO THE BOX TYPE 1
COMPLEX  1  9  0.0   0.0   0.0   1  1  1   0.0  0.0  0.0
/* PLACE PROTRUDED SECTION (EXTENDED HEIGHT) INTO THE BOX TYPE 1
COMPLEX  1 10  0.0   0.0   125.2728   1  1  1   0.0  0.0  0.0
/* PLACE LOADED CASK INTO OVERALL PROBLEM BOX
COMPLEX  11  1  0.0     0.0     0.0   1 1 1   0.0    0.0    0.0
/* PLACE TOP INTO OVERALL PROBLEM BOX
COMPLEX  11  2  0.0     0.0     0.0   1 1 1   0.0    0.0    0.0
END GEOM
*END GEMER*
```

6.7.6.5.15 Number Density Calculations for MTR Type IV Fuel

6.7.6.5.15.1 FORTRAN Program

```
PROGRAM NUMBER
C
C   ASSUMPTIONS:
C   1. THE FUEL AND CLAD ARE MODELED HETEROGEOUSLY.
C   2. SIMILAR TO THE SAPHIR FUEL. HOWEVER, NO AL USED.
C   3. 19 PLATES/ELEMENT
C   4. 2 ELEMENTS STACKED UP. WITH THE TOP ELEMENTS PROTRUDING.
C
        REAL NAL_CLAD
        REAL MU235,M238,MO16,MH2O,MH,MSI,MAL
        REAL MU,MUOLD
        REAL MU3O8
        REAL NELEMACT,NSLOT
        REAL N235,N238,N16,N1,N14
        REAL N235TOT
        DIMENSION HEIGHT(3)
        OPEN(6,FILE='UMETAL.OUT',STATUS='UNKNOWN')
C
C    FOR U METAL FUEL
C
C    NUMBER DENSITY PROGRAM FOR SAPHIR
C      3/23/98
C      AV = AVOGADRO'S NUMBER
C     RHO_WAT = WATER DENSITY (1 G/CC)
C
      DATA PI/3.14159265/
      RHO_WAT = 1.0
      AV=0.6022
      M235 =235.0439
      M238 =238.0508
      MAL = 0.0
      MO16 = 16.000
      MH2O=18.0
      MSI=28.0855
      MH=1.0
C
C
C    D  = ACTIVE FUEL LENGTH (IN)
C    E  = CLADDING THICKNESS (IN)
C    C  = PLATE LENGTH (IN)
C    G  = PLATE THICKNESS (IN)
C    F  = ACTIVE FUEL THICKNESS (IN)
C    RHOCLAD  = DENISTY OF AL CLAD (G/CC)
C    WF       = WEIGHT % OF UAL  IN THE UAL/AL MIXTURE
C    ENRICH   = FUEL ENRICHMENT
C    ELEMH    = EFFECTIVE ELEMENT HEIGHT IN INCHES (HEIGHT OF 2
ELEMENTS)
C    NELEMACT = NUMBER OF ACTIVE FUEL PLATES PER FUEL ASSEMBLY (19 PER
ASSEMBLY)
C
C      PURE UMETAL CASE
C
       ELEMH=23.53*2.0
C
```

```
      D=2.500
      E=0.015
      C=2.799
      G=0.051
      F=0.020
C
C      ENRICH = U-235 ENRICHMENT
C    95 % ENRICHMENT
C
      ENRICH = 0.95
C      WF=0.225
      WF=1.00
C
C
C   SAME AS HOMOGENOUS CASE
C
      U235MAS=220.0
C      U235MAS=400.0
C
      NELEMACT=19.0
C
C   AREASLOT = SLOT AREA PER ELEMENT (cm^2)
      AREASLOT=71.12889
C
      RHOH2O = 1.0
      RHOCLAD = 2.7
C
     WRITE(6,*) ' ************************************'
     WRITE(6,*) ' FUEL ELEMENT HEIGHT =',ELEMH*2.54,' CM'
     WRITE(6,*) '  SAPHIR CASE'
     WRITE(6,*) ' ELEMENT HEIGHT=',ELEMH
     WRITE(6,*) ' RHOH2O =',RHOH2O
     WRITE(6,*) ' ENRICH =',ENRICH
     WRITE(6,*)  ' WF =',WF
     WRITE(6,*) ' RHOCLAD=',RHOCLAD
C
      AELEMENT=C*G*2.54*2.54
      AMEAT=D*F*2.54*2.54
      ACLAD=AELEMENT-AMEAT
C
      ACLAD=0.0
C
      WRITE(6,*) ' '
      WRITE(6,*) '  FOR EACH UNIT ELELEMT'
      WRITE(6,*) '   ACLAD   AMEAT   AELEMENT (CM2)'
      WRITE(6,*) ACLAD,AMEAT,AELEMENT
C
      U238MAS=U235MAS/ENRICH - U235MAS
C
      MU= 1.0/(ENRICH/M235 + (1.0-ENRICH)/M238)
C
C
C     ALMAS = ALUMIUM MASS IN THE UAL FUEL.
      F2=MU/(MU+MAL)
      UALMAS=(U235MAS+U238MAS)/F2
      ALMAS=UALMAS-(U235MAS+U238MAS)
      WRITE(6,*) ' FOR ALL PLATES AND FUEL ELEMENTS CONSIDERED:'
      WRITE(6,*) ' AL (FUEL) MASS =',ALMAS
      WRITE(6,*) ' U238      MASS =',U238MAS
      WRITE(6,*) ' U235      MASS =',U235MAS
      WRITE(6,*) ' UAL      MASS =',UALMAS
```

```
C
C       ALPLATE = ALUMINIUM IN THE FUEL PLATE (NON UAL PORTION)
C       (THE FUEL CONSISTS OF UAL AND AL MIXTURE)
C
      ALPLATE=UALMAS/WF*(1.0-WF)
C
C
      ALFUEL=ALPLATE + ALMAS
C
C
C
       WRITE(6,*) ' AL MASS IN FUEL =',ALFUEL
C
C      TOTAL = TOTAL MASS OF FUEL (UAL + AL)
       TOTAL = U238MAS + U235MAS + ALFUEL
       WRITE(6,*) 'TOTAL MASS (FUEL) =',TOTAL
C
C    2 ELEMENTS STACKED UP
C
       FVOLUME=AMEAT*(ELEMH*2.54)*NELEMACT
       WRITE(6,*) '   TOTAL FUEL IN EACH SLOT =',FVOLUME,' CM^3'
       RHOF = TOTAL/FVOLUME
       WRITE(6,*) ' FUEL MIXTURE DENSITY =',RHOF
C
      N235 = U235MAS*AV/M235/FVOLUME
      N235TOT=N235*FVOLUME*21.0
      N238 = U238MAS*AV/M238/FVOLUME
C      N131= ALFUEL*AV/MAL/FVOLUME
C
      WRITE(6,*) '  '
      WRITE(6,*) '  N131  N238  N235'
C      WRITE(6,*) '    131',N131
      WRITE(6,*) '   2381',N238
      WRITE(6,*) '   2351',N235
      WRITE(6,*) 'TOTAL',N238+N235
C
C*************************************************************
C     ESTIMATE THE AMOUNT OF WATER IN THE CASK
C
C      H_SLOT = SLOT HEIGHT IN CM
C      V_SLOT = VOLUME OF ALL SLOTS CM^3
C      H_CASK = HEIGHT OF CASK (CM)
C      R_CASK = RADIUS OF CASK (CM)
C      NSLOT = NUMBER OF SLOTS IN THE CASK
C
      H_SLOT= 125.2728
      H_CASK = 140.64
      R_CASK = 33.65
      NSLOT=21.0
C
C     V_CASK_TOP = CASK VOLUME ABOVE THE INGOT (CM^3)
C     V_SLOT = VOLUME OF WATER IN ALL SLOTS (CM^3)
C     V_FPLATES = VOLUME OF ALL FUEL PLATES (17X21 PLATES)
C     V_WATER = AMOUNT OF WATER VOLUME IN THE CASK (CM^3)
C
       V_SLOT=H_SLOT*AREASLOT*NSLOT
       V_CASK_TOP = PI*R_CASK*R_CASK*(H_CASK - H_SLOT)
       V_FPLATES = NELEMACT*AELEMENT*(ELEMH*2.54)*NSLOT
       V_WATER = V_CASK_TOP + V_SLOT - V_FPLATES
       WRITE(6,*)
       WRITE(6,*) ' VOLUME OF CASK TOP =',V_CASK_TOP,'CM^3'
```

```
      WRITE(6,*) ' VOLUME OF ALL SLOTS =',V_SLOT,'CM^3'
      WRITE(6,*) ' VOLUME OF ALL FUEL PLATES =',V_FPLATES,'CM^3'
      WRITE(6,*) ' VOLUME OF WATER =',V_WATER,'CM^3'
C
C
      WRITE(6,*) ' WEIGHT FRACTION     H/U (ALL VOLUME) '
      DO 3000 I=0,20
      WFWATER = 0.05*FLOAT(I)*RHO_WAT
      N1=2.0*WFWATER*AV/MH2O
      HURATIO=N1*V_WATER/(N235*FVOLUME*NSLOT)
      WRITE(6,*)  WFWATER,HURATIO
 3000 CONTINUE

C     WATER REFLECTOR CASE
C
      WRITE(6,*)
      WRITE(6,*) ' WATER REFLECTOR CASE'
      RAD_WR=48.56
      RAD_CASK=33.34
      HT_CASK=125.2728
      HT_WR=140.64+14.90
      RHO_WATER=1.0
      VOL_WR=PI*(RAD_WR-RAD_CASK)*(RAD_WR-RAD_CASK)*(HT_WR-HT_CASK)
      WRITE(6,*) ' VOLUME OF WATER REFLECTOR =',VOL_WR,' CM^3'
C      NHTOT=RHO_WATER*AV/18.0*WATER_TOTAL + NH*NPIN*21.0*FVOLUME
      NHTOT=2.0*RHO_WATER*AV/18.0*V_WATER
     *      + 2.0*RHO_WATER*AV/18.0*VOL_WR
      RATIO6=NHTOT/N235TOT
      WRITE(6,*) RHO_WATER,RATIO6
      END
```

6.7.6.5.15.2 FORTRAN Output for MTR Type IV Fuel

```
*************************************
  FUEL ELEMENT HEIGHT =   119.5324     CM
   SAPHIR CASE
  ELEMENT HEIGHT=   47.06000
  RHOH2O =   1.000000
  ENRICH =  0.9500000
  WF =   1.000000
  RHOCLAD=   2.700000

   FOR EACH UNIT ELELEMT
    ACLAD   AMEAT   AELEMENT (CM2)
  0.0000000E+00  0.3225800      0.9209594
  FOR ALL PLATES AND FUEL ELEMENTS CONSIDERED:
  AL (FUEL) MASS =  0.0000000E+00
  U238      MASS =   11.57895
  U235      MASS =   220.0000
  UAL      MASS =   231.5789
  AL MASS IN FUEL =  0.0000000E+00
 TOTAL MASS (FUEL) =   231.5789
    TOTAL FUEL IN EACH SLOT =   732.6165     CM^3
  FUEL MIXTURE DENSITY =  0.3160985

   N131  N238  N235
    2381  3.9981911E-05
    2351  7.6951814E-04
 TOTAL  8.0950005E-04

  VOLUME OF CASK TOP =   54665.70    CM^3
  VOLUME OF ALL SLOTS =   187120.8    CM^3
  VOLUME OF ALL FUEL PLATES =   43923.71    CM^3
  VOLUME OF WATER =   197862.8    CM^3
  WEIGHT FRACTION     H/U (ALL VOLUME)
  0.0000000E+00  0.0000000E+00
  5.0000001E-02   55.91362
  0.1000000       111.8272
  0.1500000       167.7408
  0.2000000       223.6545
  0.2500000       279.5681
  0.3000000       335.4817
  0.3500000       391.3953
  0.4000000       447.3090
  0.4500000       503.2225
  0.5000000       559.1361
  0.5500000       615.0498
  0.6000000       670.9634
  0.6500000       726.8770
  0.7000000       782.7905
  0.7500000       838.7042
  0.8000000       894.6179
  0.8500000       950.5314
  0.9000000       1006.445
  0.9500000       1062.359
   1.000000       1118.272

  WATER REFLECTOR CASE
  VOLUME OF WATER REFLECTOR =   22026.80     CM^3
   1.000000       1242.758
```

6.7.6.5.16 Geometrical Plots of the MTR Type IV Fuel — Side and Sectional Views

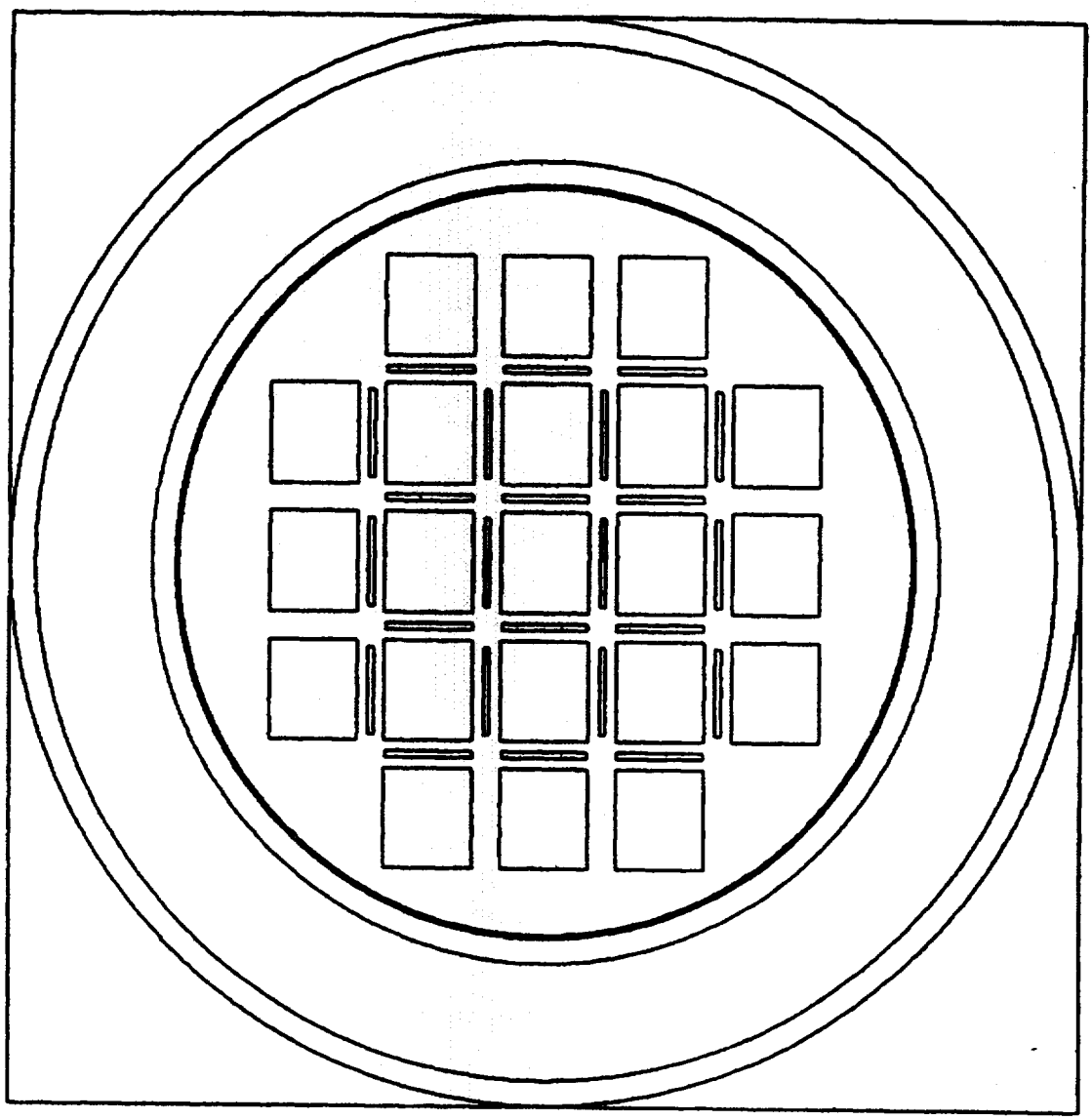


Figure 6.79. Sectional View (Z = 5 cm) for MTR Type IV Fuel

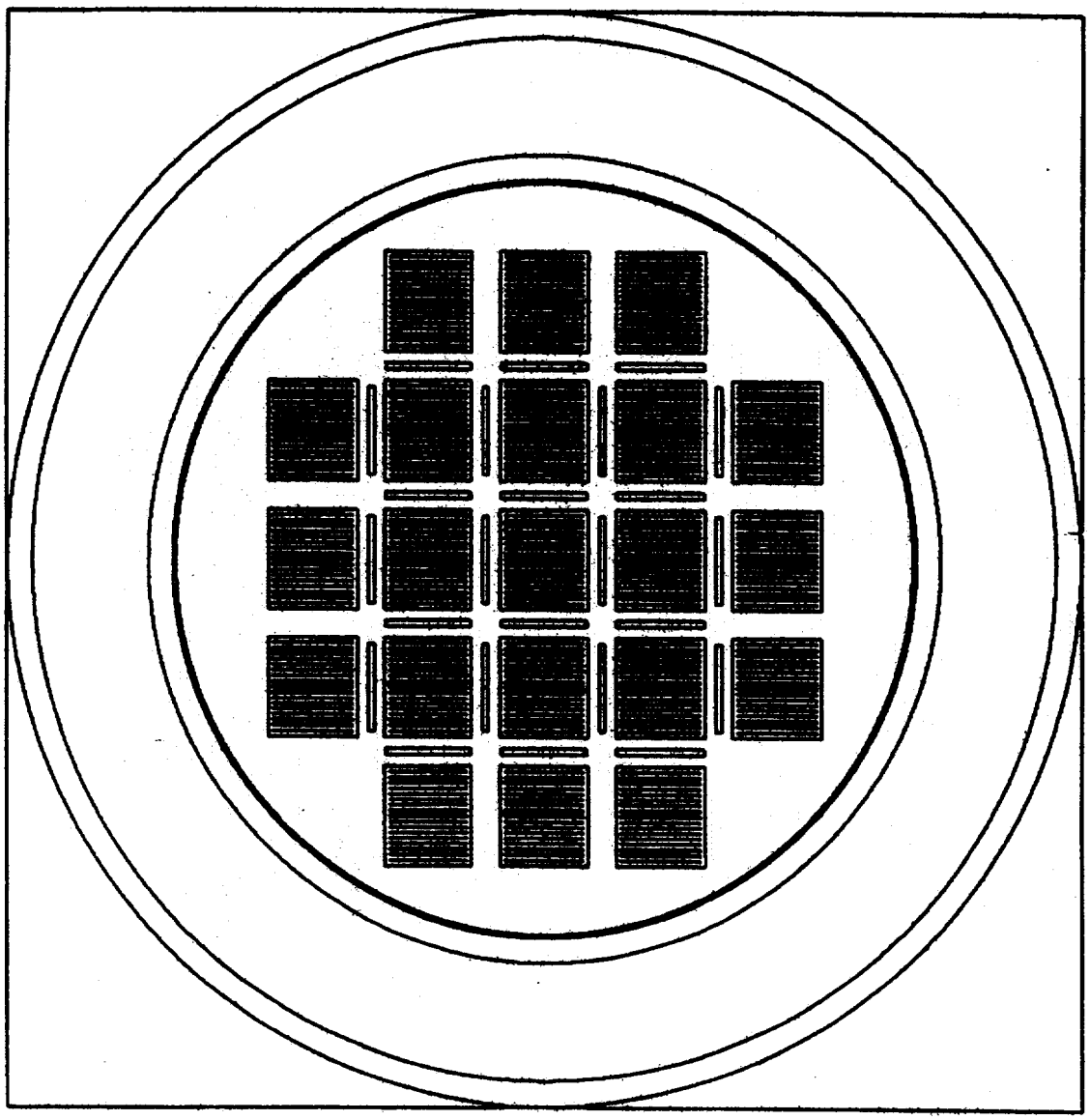


Figure 6.80. Sectional View (Z = 60 cm) for MTR Type IV Fuel

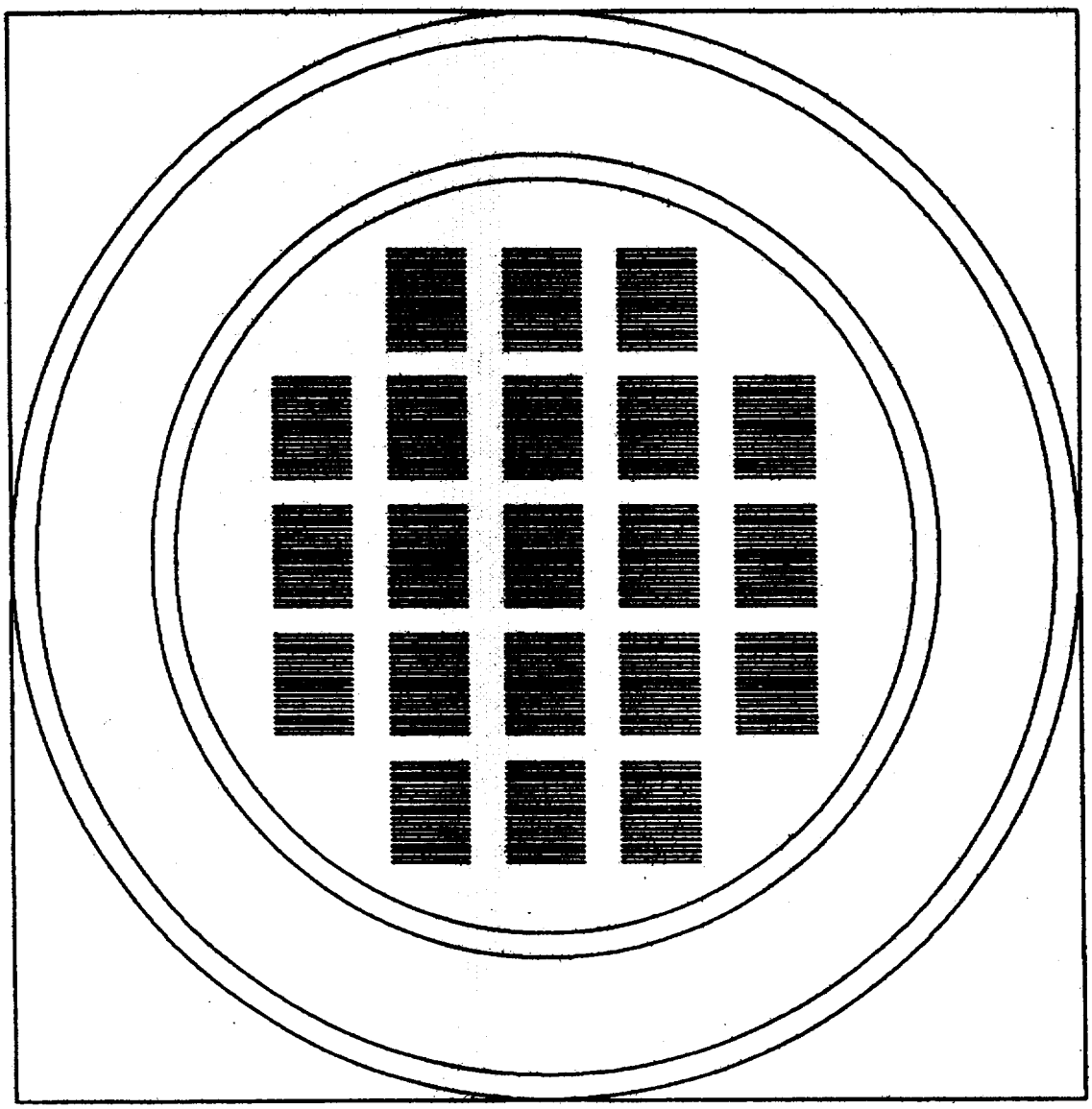


Figure 6.81. Sectional View (Z = 130 cm) for MTR Type IV Fuel

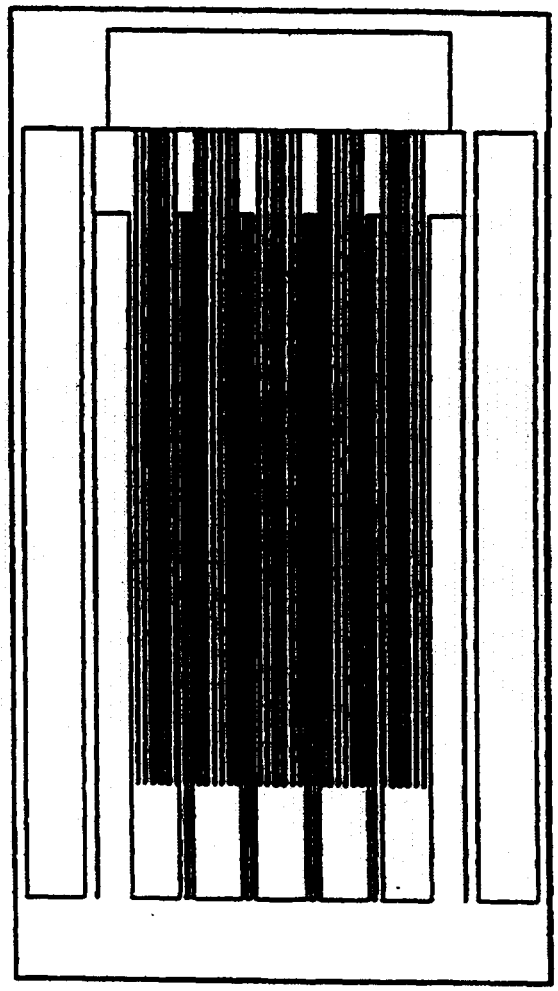


Figure 6.82. Side View for MTR Type IV Fuel

6.7.7 Criticality Evaluation (Discrete Model) for TRIGA-Fuel Divider SN 01

6.7.7.1 Discussion and Results

6.7.7.1.1 General

The Model 2000 cask, as discussed earlier in Subsection 6.1.2, is a cylindrical cask with lead shielding. The cask has a cavity that is 26.5 inches inside diameter and 54 inches high for holding nuclear radioactive material, including special nuclear material.

This application serves two purposes:

First, this application applies the discrete fuel modeling approach to the TRIGA Case V, VIII, and XVII fuels. This represents a more realistic approach in modeling the TRIGA Case V, VIII, and XVII fuels and is different from the homogenous fuel model discussed earlier in Section 6.4.3.

Second, the steel ingot and boral plates are shorter than the previous application (boral plates are 125.27 cm versus the previous submittal of 136.64 cm). Since the TRIGA fuels are not double stacked, they do not protrude from the steel ingot into the top cask space. This application shows that even with this dimensional change, the criticality safety analysis demonstrates that for the TRIGA Case V, VIII, and XVII fuels, the worst-case discrete fuel modeling k-effective are all below the subcriticality limit of 0.95.

6.7.7.1.2 Applicable Regulatory Criteria

The applicable regulatory criteria for the TRIGA fuel shipment remain the same as discussed earlier in Subsection 6.1.1.1 and will not be elaborated further here.

6.7.7.1.3 Container Description

The Model 2000 cask has been discussed earlier in Subsection 6.1.2. The cask remains the same internally and externally.

6.7.7.1.4 Calculational Methods

The GEMER01V code is used to demonstrate the subcriticality of the Model 2000 cask with the TRIGA fuel assemblies loaded in the cask. Critical benchmark experiments using GEMER01V confirm the accuracy of the calculational method chosen for the present analysis and provide the basis for calculational bias.

The key assumptions used in the criticality analysis of TRIGA Case V, VIII, and XVII fuels are as follows:

1. The borated aluminum plates used for reactivity control are conservatively modeled. Only 75% of the boron atoms are accounted for in the calculations.
2. The borated aluminum plates, typically 3.25 inches (8.255 cm) x 0.25 inches (0.635 cm) x 49.32 inches (125.2728 cm), are conservatively treated as 3.1 inches (7,874 cm) x 0.21inches (0.5334 cm) x 49.32 inches (125.2728 cm).
3. The fission products in the TRIGA Case V, VIII, and XVII fuels will be ignored in this analysis. This is a conservative assumption.
4. All TRIGA Case V, VIII, and XVII fuels are analyzed in fresh fuel condition. All burnable poisons will be zeroed out in the fresh fuel. This is a conservative assumption.
5. The TRIGA fuel pins are not protruding from the 21 slots and are modeled as discrete fuel pins within each divider slot.

Table 6.118 provides dimensions and nuclear data for several TRIGA-type fuels to which this analysis applies.

Table 6.118. TRIGA Fuel Data

TRIGA Case	Fuel Pin	Cladding	Zirconium Rod	U-238 Mass (g)	U-235 Mass (g)	Uranium Weight %	Enrichment (%)	Zirconium Mass (g)	Element Length (in)	Fuel Length (in)	Fuel OD (in)	Cladding Thickness (in)	H/Zr in the Fuel
I		SS	Yes		<137	8.5	20		28.5	15	1.435	0.020	1.6
II		SS	Yes		<137	8.5	20		28.5	15	1.371	0.020	1.6
III		SS	Yes		<137	8.5	70		28.5	15	1.435	0.020	1.6
IV		SS	Yes		<137	8.5	70		28.5	15	1.371	0.020	1.6
V		**SS**	**Yes**	**13.08**	**174.1**	**8.5**	**94**	**1981**	**28.5**	**15**	**1.435**	**0.020**	**1.6**
VI		Al	No		< 174.1	8.5	93		30.0	15	1.415	0.030	1.6
VII		SS	Yes		<137	12.0	20		28.5	15	1.435	0.020	1.6
VIII		**Incoloy**	**No**	**3.10**	**41.16**	**10.0**	**94**	**391**	**30.0**	**22**	**0.510**	**0.016**	**1.6**
IX		SS	Yes		<137	20.0	20		28.5	15	1.435	0.020	1.6
X		SS	Yes		<137	30.0	20		28.5	15	1.435	0.020	1.6
XI		Incoloy	No	219	55	30.0	20		30.0	22	0.510	0.016	1.6
XII		Incoloy	No	219	55	45.0	20		30.0	22	0.510	0.016	1.6
XIII	14"	Al	No	144	36	8.0	20	2070					1.0
XIV	15"		No	144	36	8.0	20	2070					1.0
XV	Std. (prior 11/64)	SS	Yes	156	39	8.0	20	2088					1.0
XVI	Std. (after 11/64)		Yes	156	39	8.5	20	2088					1.7
XVII	**FLIP**	**SS**	**Yes**	**59**	**137**	**8.5**	**70**	**2070**	**28.5**	**15**	**1.435**	**0.02**	**1.6**
XVIII	FLIP-LEU-I		Yes	403	101	20.0	20	1988		15			1.6

Table 6.118. TRIGA Fuel Data (Continued)

TRIGA Case	Fuel Pin	Cladding	Zirconium Rod	U-238 Mass (g)	U-235 Mass (g)	Uranium Weight %	Enrichment (%)	Zirconium Mass (g)	Element Length (in)	Fuel Length (in)	Fuel OD (in)	Cladding Thickness (in)	H/Zr in the Fuel
XIX	FLIP-LEU-II		Yes	659	165	30.0	20	1886		15			1.6
XX	ACPR		Yes	215	54	12.0	20	1962					1.7
XXI		Incoloy 800	No	219	55	45.0	20	327			0.510	0.016	1.6
XXII	Fuel Follower Control Rod		Yes	150	38	8.5	20	2004					1.6
XXIII	FLIP-LEU-I		Yes	387	97	8.5	20	1908					1.6

FLIP = Fuel Life Improvement Program

LEU = Low Enriched Uranium

ACPR = Annular Core Pulsed Reactor

6.7.7.1.5 TRIGA Case XVII Fuel

The GEMER model for the TRIGA Case XVII fuel consists of 4 fuel pins loaded into each TRIGA divider position. A total of 560 grams of 70% enriched U-235 per divider position in the TRIGA type fuel divider is modeled in this criticality analysis. The corresponding masses of U-238, Zr and H can be estimated. Subsection 6.7.7.5.3 shows the simple FORTRAN program used to calculate the fuel number densities (U-235, U-238, Zr, and H) for the case of TRIGA Case XVII fuel pins and the associated FORTRAN output.

6.7.7.1.6 TRIGA Case V Fuel

The GEMER model for the TRIGA Case V fuel consists of 660 grams of 94% enriched U-235 per divider position in the TRIGA type fuel divider. This represents 4 TRIGA fuel pins each with 165 grams of U-235 or 3 TRIGA fuel pins each with 220 grams loaded into each divider position. Based on the U-235 mass (165 grams per fuel pin for the four pin case, and 220 grams per fuel pin for the three pin case), the corresponding masses of U-238, Zr, and H, and cladding material can be estimated. The detailed calculations of these number densities are shown in Subsection 6.7.2.2.2.

6.7.7.1.7 TRIGA Case VIII Fuel

The GEMER model for the TRIGA Case VIII fuel consists of 660 grams of 94% enriched U-235 per divider position in the TRIGA type fuel divider. This represents 20 or 15 fuel pins per divider position. Based on the ^{235}U mass (44.0 grams x 15 fuel pins or 33 grams x 20 fuel pins), the corresponding masses of ^{238}U, Zr and H, and cladding material can be estimated. The detailed calculations of these number densities are shown in Subsection 6.7.2.3.2.

6.7.7.1.8 Summary of Results

Tables 6.119 through 6.121 summarize the results of the criticality evaluations for the TRIGA Case XVII, V, and VIII fuel, respectively, for the case of infinite cask arrays.

Table 6.119. Summary of Results for the Infinite Cask Scenario for TRIGA Case XVII Fuel (70% Enrichment) — Discrete Fuel Model

Condition/Parameter	Quantity/Comment
Number of Containers in Demonstration	Infinite Array
Optimum Hydrogenous Moderation	1.0 Weight Fraction H_2O
Maximum Multiplication Factor $k_{eff} + 2\sigma$ + Bias	**0.92617**

Table 6.120. Summary of Results for the Infinite Cask Scenario for TRIGA Case V Fuel (94% Enrichment) — Discrete Fuel Model

Condition/Parameter	Quantity/Comment
Number of Containers in Demonstration	Infinite Array
Optimum Hydrogenous Moderation	1.0 Weight Fraction H_2O
Maximum Multiplication Factor $k_{eff} + 2\sigma$ + Bias	**0.93826**

Table 6.121. Summary of Results for the Infinite Cask Scenario for TRIGA Case VIII Fuel (94% Enrichment) — Discrete Fuel Model

Condition/Parameter	Quantity/Comment
Number of Containers in Demonstration	Infinite Array
Optimum Hydrogenous Moderation	1.0 Weight Fraction H_2O
Maximum Multiplication Factor $k_{eff} + 2\sigma$ + Bias	**0.94062**

6.7.7.2 Package Fuel Loading

Tables 6.122 through 6.124 summarize the maximum fuel load (mass), as well as some significant constraints for the form of the TRIGA Case XVII, V, and VIII fuel, respectively. The loading specified in Tables 6.122 through 6.124 described herein qualifies as an infinite (N=∞) Fissile Class III package with a zero transport index under the provisions of 10CFR71.61 based on the infinite cask analysis. This loading also meets the IAEA Safety Standards for an infinite shipment (N=∞) with a zero Transport Index for criticality safety.

Table 6.122. Package Parameters for the Model 2000 Cask with TRIGA Case XVII Type of Fuel (70% Enriched)

Parameter	Quantity/Comment
Fuel Construction	Cylinders
Fuel Material	$UZrH_{1.6}$ (8.5 wt% U)
Cladding Material	Stainless Steel
Total ^{235}U mass per divider position	560 grams
Maximum Fuel Enrichment	70.0%
^{238}U mass per divider position	240 grams
Minimum Fuel Burnup	N/A
Burnable Poison Materials*	20 to 36 grams per fuel pin (Not Modelled)
Nominal Stainless Steel Density	7.827 g/cc

Table 6.123. Package Parameters for the Model 2000 Cask with TRIGA Case V Type of Fuel (94% Enriched)

Parameter	Quantity/Comment
Fuel Construction	Cylinders
Fuel Material	$UZrH_{1.6}$ (8.5 wt% U)
Cladding Material	Stainless Steel
Total ^{235}U mass per divider position	660 grams (4 pins x 165 grams or 3 pins x 220 grams)
Maximum Fuel Enrichment	94.0%
^{238}U mass per divider position	44.46 grams
Minimum Fuel Burnup	N/A
Burnable Poison Materials	None
Nominal Stainless Steel Density	7.827 g/cc

Table 6.124. Package Parameters for the Model 2000 Cask with TRIGA Case VIII Type of Fuel (94% Enriched)

Parameter	Quantity/Comment
Fuel Construction	Cylinders
Fuel Material	$UzrH_{1.6}$ (10 wt% U)
Cladding Material	Inconel
Total ^{235}U mass per divider position	660 grams (15 pins x 44 grams or 20 pins x 33 grams)
Maximum Fuel Enrichment	94.0%
^{238}U mass per divider position	42.1 grams
Minimum Fuel Burnup	N/A
Burnable Poison Materials	2.8 wt% Natural Erbium (Not Modelled)
Nominal Incoloy Density	8.01 g/cc

6.7.7.3 Model Specification

6.7.7.3.1 Description of Calulational Models

The model assumes fresh, undepleted fuel in the active fuel region, neglecting any as-built poisons or fission products. The model also omits the overpack from consideration, which brings the water reflector closer to the fissile material and adds an extra degree of conservatism to the analysis.

The Model 2000 cask is modeled in three dimensions. Only the cask (without the overpack) and fuel are modeled. The cask is cylindrical with an interior cavity. This cavity is 26.5 inches (67.31 cm) in diameter and 54 inches (137.16 cm) in height. The cask outside diameter is 38.5 inches (97.79 cm). The total cask radial wall and bottom plate thickness is 6.0 inches (15.24 cm). The Model 2000 cask consists of a layered radial wall design composed of 1.0 inch (2.54 cm) of 304 stainless steel, 4.0 inches (10.16 cm) of lead, and then another 1.0 inch of 304 stainless steel. The cask bottom consists of 6 inches (15.24 cm) of 304 stainless steel. The top of the cask was modeled as having a 1.5 inch (3.81 cm) thick 304 stainless steel plate inside the cask at the top, then 4.5 inches (11.43 cm) of lead, and then a 1.75 inch (4.45 cm) thick 304 stainless steel plate on the top of the cask. For conservatism, the model reduces the wall thickness of stainless steel portions of the cask in areas where neutron absorption in the stainless steel reduces the neutron multiplication (i.e., cask walls and cask top).

The TRIGA fuel pins are modeled in a most conservative but credible position. As the TRIGA fuel pins are not double stacked, they do not protrude from the 21 slots. Subsection 6.7.7.5.4 shows the sectional and side views of the GEMER geometrical model.

The three cases of TRIGA fuels are treated discretely as follows:

1. The TRIGA Case XVII fuel consists of 4 or fewer fueled pins. The fuel pins are modeled in GEMER as cylinders as shown in Table 6.125.
2. The TRIGA Case V fuel consists of 4 or fewer fueled pins. The fuel pins are modeled in GEMER as cylinders as shown in Table 6.126.
3. The TRIGA Case VIII fuel consists of 20 or fewer fueled pins. The fuel pins are modeled in GEMER as cylinders as shown in Table 6.127.

Table 6.125. TRIGA Case XVII Fuel Pin Discrete Model

Description	Inner Radius (cm)	Outer Radius (cm)	Top height (cm)	Bottom Height
Central Zr Rod	0	0.3175	19.05	57.15
Active Fuel	0.3175	1.77165	19.05	57.15
SS Clad	1.77165	1.82245	19.05	57.15
Graphite Reflector #1	0	1.82245	57.15	65.786
Graphite Reflector #2	0	1.82245	10.414	19.05
Top End Fitting	0	1.82245	65.786	76.20
Bottom End Fitting	0	1.82245	0.00	10.414

Table 6.126. TRIGA Case V Fuel Pin Discrete Model

Description	Inner Radius (cm)	Outer Radius (cm)	Top height (cm)	Bottom Height
Central Zr Rod	0	0.3175	19.05	57.15
Active Fuel	0.3175	1.77165	19.05	57.15
SS Clad	1.77165	1.82245	19.05	57.15
Graphite Reflector #1	0	1.82245	57.15	65.786
Graphite Reflector #2	0	1.82245	10.414	19.05
Top End Fitting	0	1.82245	65.786	76.20
Bottom End Fitting	0	1.82245	0.00	10.414

Table 6.127. TRIGA Case VIII Fuel Pin Discrete Model

Description	Inner Radius (cm)	Outer Radius (cm)	Top height (cm)	Bottom Height
Active Fuel	0.0000	0.64770	66.04	10.16
Incoloy Clad	0.64770	0.68834	66.04	10.16
Top End Fitting (Incoloy)	0.0000	0.68834	68.58	66.04
Bottom End Fitting (Incoloy)	0.0000	0.68834	10.16	0.00

The stainless ingot is 125.27 cm high and the boral plates extend to a height of 125.27 cm.

6.7.7.3.2 Package Regional Densities

The fuel assembly model assumes the maximum possible fissile mass of ^{235}U per fuel assembly with a maximum enrichment of 94.% for TRIGA Case V and Case VIII fuel, and 70% for TRIGA Case XVII fuel. Subsection 6.7.7.5.3 lists the FORTRAN program used to calculate the fuel densities used in this analysis.

Material densities and corresponding number densities are based on standard material specifications. These materials have been calculated earlier (Subsection 6.3.2). Tables 6.128 and 6.129 present the material densities and number densities for substances (materials) in the criticality model. Substances composed of more than one element are broken into their elemental number densities in the number density column.

Table 6.128. Material Densities Used in the Model 2000 for the TRIGA Type of Fuel

Region	Material	Component Density (gm/cm^3)	Number Density (atom/barn-cm)
Cladding/End Fitting	Incoloy	8.01	1.94815E-02 (Cr) 8.78012E-05 (Mn) 3.97312E-02 (Fe) 2.63002E-02 (Ni)
304 Stainless Steel	SS304	7.800	6.82690E-05 (C-12) 8.53360E-04 (Si) 1.53600E-02 (Cr) 6.04950E-02 (Fe) 6.82690E-03 (Ni) 1.70670E-03 (Mn) 2.56010E-05 (S-16)
Lead Shielding	Pb	11.35	3.2989E-02 (Pb)
Water (Reflector)	H_2O	1.00	6.691E-02 (H) 3.345E-03 (O)

Table 6.129. Material Densities of Borated Aluminum

Nuclide	Number Density (atom/bn-cm) (Used in GEMER Analysis*)	Number Density (atom/bn-cm) (Actual Design Requirement)
B-10*	4.15822E-03	5.5443E-03
B-11*	8.48616E-05	1.1315E-04
Al*	5.8001E-02	5.8001E-02

Notes: * The B-10, B-11 and Al number densities are calculated as follows:

N(B-10) = 98% B-10 * 3.5 weight percent of Boron * 2.693 g/cm^3 in the mixture

* Avogardo's number / Boron Atomic Weight * (75% reduction factor)

= .98 * .035 * 2.693 * 6.022E23 *.75 / (.98*10.01294 + .02*11.00931)

= 4.15822×10^{21} number/cm^3

N(B-11) = 0.02/.98 * N(B-10)

= 8.48616×10^{19} number/cm^3

N(Al) = 0.965 * 2.693 * 6.022E23/26.98153

= 5.8001×10^{22} number/cm^3.

6.7.7.4 Criticality Calculation

6.7.7.4.1 Calculational Method

The computational tool used in this evaluation is the GE MERit code (GEMER).

6.7.7.4.2 Fuel Loading Optimization

Fuel assemblies are held within the basket structure during both normal conditions of transport and during hypothetical accident, so the geometry to be analyzed is well defined. Like other light water reactor fuels, the fuels considered here are substantially subcritical when placed in air due to a lack of neutron moderation. Increasing the moderation within an assembly by adding water to it results in an increase in k_{eff}.

The boundary condition around the cask in all criticality calculations is a leakage-proof boundary condition with perfect reflection surrounding all sides of the arrays. This corresponds to an infinite array of casks in their most reactive array configuration with full reflection.

6.7.7.4.3 GEMER Results

6.7.7.4.3.1 TRIGA Case XVII Fuel

Table 6.130 summarizes the GEMER results for the infinite cask scenario for TRIGA Case XVII for the Discrete Model.

Table 6.131 and Figure 6.83 show the variation of the k-effectives as the number of fuel pins is varied from 1 to 4, maintaining the same fissile content within each fuel pin (i.e., 140 grams of U-235 per fuel pin) and at full-density water.

In addition, the fuel pins are assumed to be equally spaced within the divider slot. The optimum number of fuel pins is found to be 4, and the 4-pin case is expanded to include full range of water moderation (i.e., varying H/U^{235} ratios). These results are shown in Table 6.132 and Figure 6.84. In addition, the 3-pin case is also studied for the full range of water density (Table 6.133 and Figure 6.84).

The water reflection (WR) case denotes the case when the surrounding materials outside of the fuel basket is replaced by full-density water and the perfectly reflecting boundary conditions are applied on all sides and the top and bottom.

The 4-pin case is also studied with a varying pitch in the x-direction (the pins are nearly touching in the y-direction and there is no much room for movement) and the results are shown in Table 6.134 and Figure 6.63.

The pitch sensitivity case shows that the system tends to be under-moderated and hence increasing the fuel plate pitch tends to increase the k-effective. The equally-spaced pitch used in the base model represents a condition very close to the worst configuration.

The maximum k_{eff} for TRIGA Case XVII Fuel is 0.92167 for the discrete case after accounting for uncertainty and bias. These values are below the subcriticality limit of 0.95.

Table 6.130. Summary of Results — Infinite Cask Scenario for TRIGA Case XVII Fuel

Condition/Parameter	Quantity/Comment
Number of Containers in Demonstration	Infinite Array
Optimum Hydrogenous Moderation	1.00 Weight Fraction H_2O
Maximum Multiplication Factor $k_{eff} + 2\sigma$ + Bias	**0.92167**

Table 6.131. GEMER Results — Infinite Cask Scenario for TRIGA Case XVII Fuel (Discrete Model, Fuel Pin Sensitivity)

H_2O Density Weight %	Number of Fuel Pins	$H/^{235}U$ Ratio	K_{eff}	± σ	Bias	k+2σ +Bias
100	1	2061.764	0.42887	0.00220	0.00000	0.43327
100	2	987.870	0.60271	0.00239	0.00940	0.61689
100	3	629.906	0.79150	0.00235	0.00803	0.80423
100	4	450.924	0.91058	0.00235	0.00639	0.92167

Table 6.132. GEMER Results — Infinite Cask Scenario for TRIGA Case XVII Fuel (Discrete Model, Water Density Sensitivity, 4 out of 4 Pins Case)

H_2O Density Weight %	Number of Fuel Pins	$H/^{235}U$ Ratio	K_{eff}	± σ	Bias	k+2σ +Bias
0	4	62.259	0.78620	0.00245	0.00061	0.79171
10	4	101.158	0.78997	0.00236	0.00132	0.79601
20	4	140.021	0.80160	0.00192	0.00200	0.80744
30	4	178.884	0.82149	0.00244	0.00266	0.82903
40	4	217.746	0.83973	0.00263	0.00328	0.84827
50	4	256.609	0.85120	0.00249	0.00387	0.86005
60	4	295.472	0.86700	0.00224	0.00444	0.87592
70	4	334.335	0.88254	0.00259	0.00497	0.89269
80	4	373.198	0.89045	0.00235	0.00547	0.90062
90	4	412.061	0.90736	0.00246	0.00594	0.91822
100	**4**	**450.924**	**0.91058**	**0.00235**	**0.00639**	**0.92167**
WR	4	499.840	0.88781	0.00271	0.00690	0.90013

Table 6.133. GEMER Results — Infinite Cask Scenario for TRIGA Case XVII Fuel (Discrete Model, Water Density Sensitivity, 3 out of 4 Pins Case)

H_2O Density Weight %	Number of Fuel Pins	$H/^{235}U$ Ratio	K_{eff}	± σ	Bias	k+2σ +Bias
0	3	62.295	0.64667	0.00203	0.00061	0.65134
10	3	119.056	0.64784	0.00225	0.00164	0.65398
20	3	175.817	0.67385	0.00218	0.00261	0.68082
30	3	232.578	0.69626	0.00223	0.00351	0.70423
40	3	289.339	0.71367	0.00247	0.00435	0.72296
50	3	346.100	0.73450	0.00237	0.00512	0.74436
60	3	402.862	0.74484	0.00265	0.00583	0.75597
70	3	459.623	0.75831	0.00224	0.00648	0.76927
80	3	516.384	0.77318	0.00232	0.00706	0.78488
90	3	573.145	0.78014	0.00266	0.00758	0.79304
100	3	629.906	0.79150	0.00275	0.00803	0.80503
WR	3	695.127	0.76933	0.00275	0.00847	0.78330

Table 6.134. GEMER Results — Infinite Cask Scenario for TRIGA Case XVII Fuel (Discrete Model, Fuel Pitch Sensitivity for the 4 x 140 Grams Limit Case)

H_2O Density Weight %	$H/^{235}U$ Ratio	Fuel Pin Pitch (cm)	K_{eff}	± σ	Bias	k+2σ +Bias
100	450.924	1.002744	0.88617	0.00267	0.00639	0.89790
100	450.924	1.137178	0.90461	0.00268	0.00639	0.91636
100	450.924	1.219512	0.90736	0.00246	0.00639	0.91867
100	450.924	1.324042	0.91058	0.00235	0.00639	0.92167

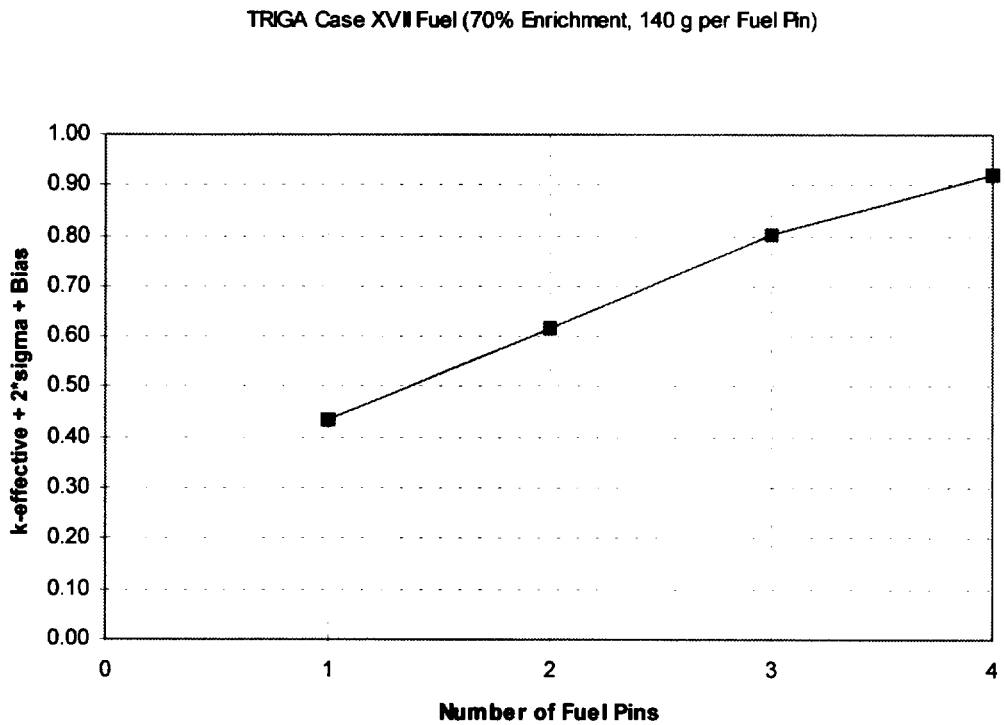


Figure 6.83. GEMER Results — Infinite Cask Scenario for TRIGA Case XVII Fuel (Discrete Model, Fuel Pin Sensitivity)

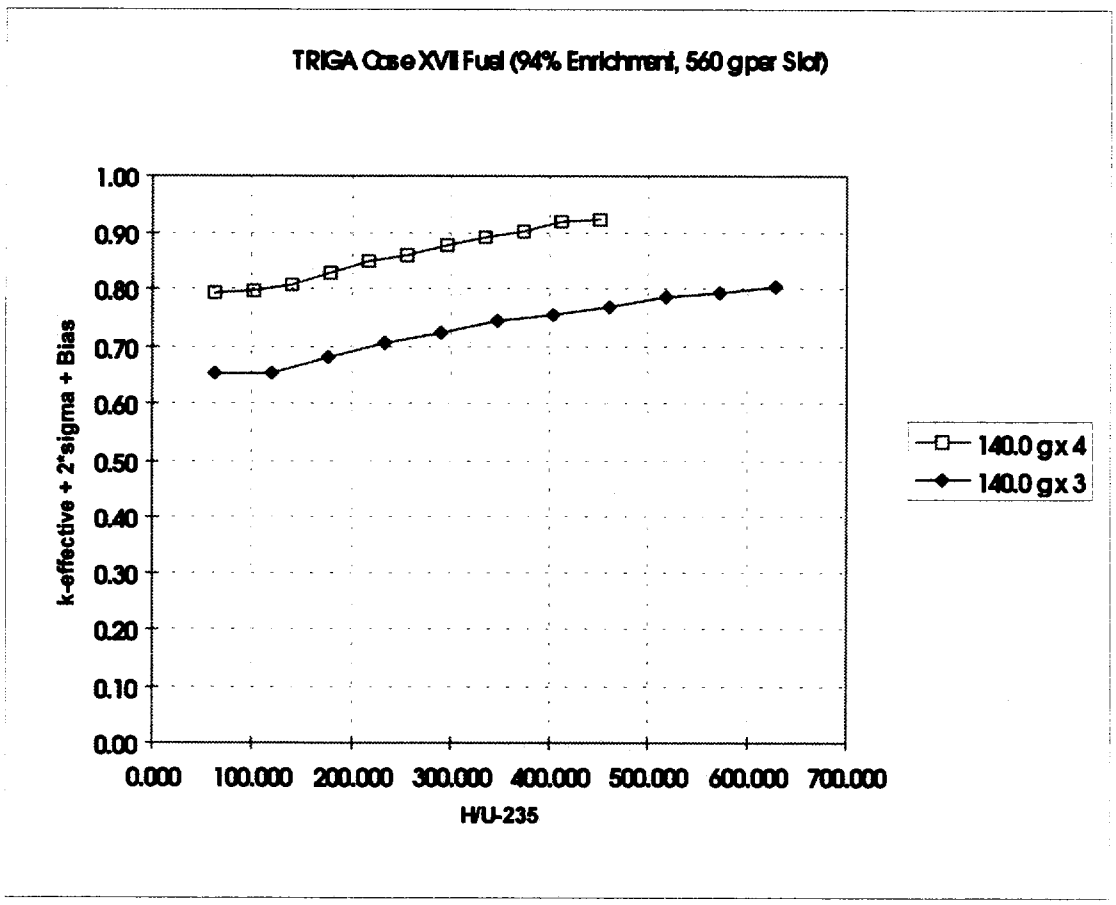


Figure 6.84. TRIGA Case XVII Fuel, Infinite Cask Array, Water Variation for the 4 out of 4 Pins and 3 out of 4 Pins Cases

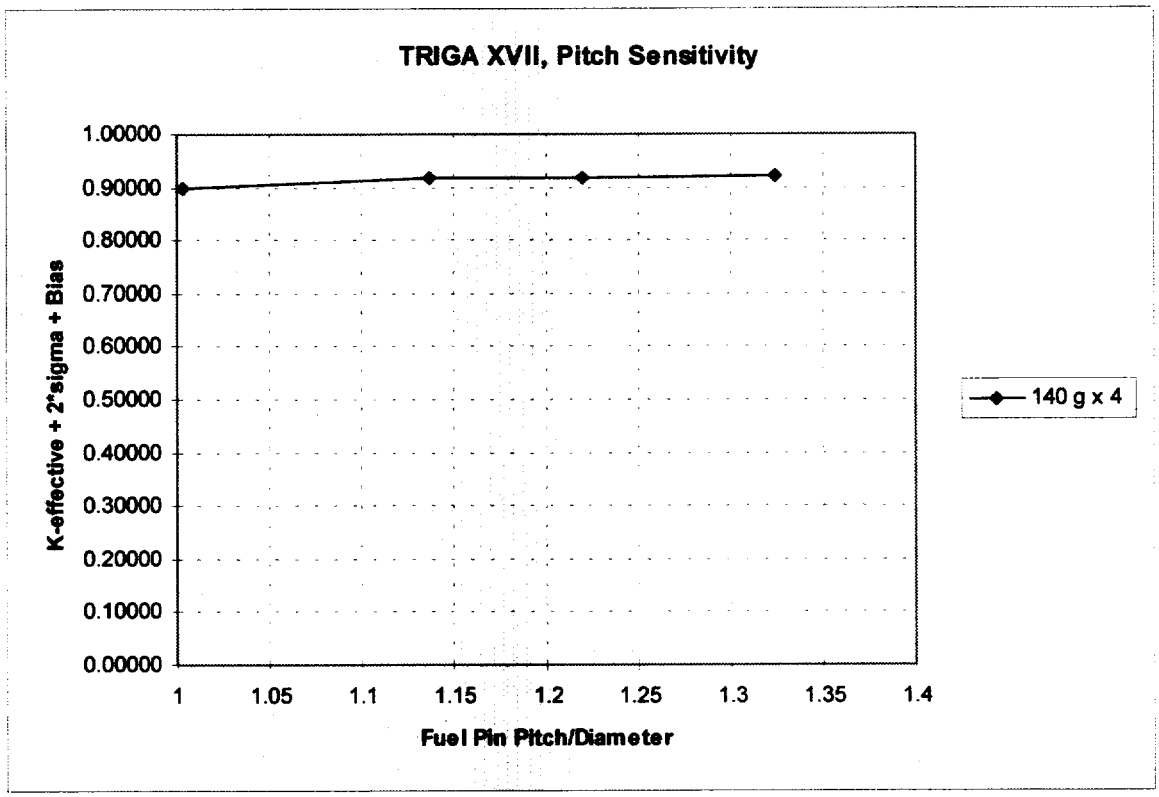


Figure 6.85. TRIGA Case XVII Fuel, Infinite Cask Array, Pitch Sensitivity Variation for the 4 out of 4 Pins Cases

6.7.7.4.3.2 TRIGA Case V Fuel

Table 6.135 summarizes the GEMER results for the infinite cask scenario for TRIGA Case V for the Discrete Model.

Table 6.136 and Figure 6.86 show the variation of the k-effectives as the number of fuel pins is varied from 1 to 4, maintaining the same fissile content within each fuel pin (i.e., 140 grams of U-235 per fuel pin for the 4-pin case, and 220 grams per U-235 fuel pin for the 3-pin case) and at full-density water.

To maximize the reactivity within the 3-pin case, the pins are analyzed in a triangular arrangement, instead of just pulling out a pin from the 2x2 cell. The closer triangular pin arrangement tends to have a higher reactivity than a rectangular design with a missing fuel pin.

In addition, the fuel pins are assumed to be equally spaced within the divider slot.

For the 4 pins x 165 grams case, the optimum number of fuel pins is found to be 4, and the 4-pin case is expanded to include full range of water moderation (i.e., varying H/U^{235} ratios). These results are shown in Table 6.137 and Figure 6.87. In addition, the 3-pin case is also studied for the full range of water density (Table 6.137 and Figure 6.87).

For the 3 pins x 220 grams case, the optimum number of fuel pins is found to be 3, and the 3-pin case is expanded to include full range of water moderation (i.e., varying H/U^{235} ratios). These results are shown in Table 6.138 and Figure 6.87. In addition, the 2-pin case is also studied for the full range of water density (Table 6.138 and Figure 6.87).

The water reflection (WR) case denotes the case when the surrounding materials outside of the fuel basket is replaced by full-density water and the perfectly reflecting boundary conditions are applied on all sides and the top and bottom.

The 4 pins x 165 grams cases and the 3 pins x 220 grams cases are also studied with varying pitches in the x- and y-directions and the results are shown in Table 6.139 and Figure 6.68.

The pitch sensitivity case shows that the system tends to be under-moderated and hence increasing the fuel plate pitch tends to increase the k-effective. The equally-spaced pitch used in the base model represents a condition very close to the worst configuration.

The maximum k_{eff} for TRIGA Case V Fuel is 0.93826 for the discrete case after accounting for uncertainty and bias. These values are below the subcriticality limit of 0.95.

Table 6.135. Summary of Results — Infinite Cask Scenario for TRIGA Case V Fuel

Condition/Parameter	Quantity/Comment
Number of Containers in Demonstration	Infinite Array
Optimum Hydrogenous Moderation	1.00 Weight Fraction H_2O
Maximum Multiplication Factor $k_{eff} + 2\sigma$ + Bias	**0.93826**

Table 6.136. GEMER Results — Infinite Cask Scenario for TRIGA Case V Fuel (Discrete Model, Fuel Pin Sensitivity)

H_2O Density Weight %	Number of Fuel Pins	$H/^{235}U$ Ratio	K_{eff}	$\pm\sigma$	Bias	$k+2\sigma$ +Bias
4 Pins x 165 Gram Case						
100	1	1742.909	0.43966	0.00224	0.00388	0.44802
100	2	831.727	0.61163	0.00253	0.00912	0.62581
100	3	527.999	0.79475	0.00289	0.00717	0.80770
100	4	376.135	0.92739	0.00268	0.00551	0.93826
3 Pins x220 Grams Case						
100	1	1318.779	0.49650	0.00223	0.00838	0.50934
100	2	635.392	0.69551	0.00224	0.00807	0.70806
100	3	407.597	0.89971	0.00266	0.00589	0.91092

Table 6.137. GEMER Results — Infinite Cask Scenario for TRIGA Case V Fuel (Discrete Model, Water Density Sensitivity, 4 Pins x 165 Grams Case)

H_2O Density Weight %	Number of Fuel Plates	$H/^{235}U$ Ratio	K_{eff}	$\pm\sigma$	Bias	$k+2\sigma$ +Bias
4 Pins x 165 Grams Case						
0	4	46.390	0.79371	0.00232	0.00031	0.79866
10	4	79.364	0.78645	0.00260	0.00092	0.79257
20	4	112.339	0.80408	0.00236	0.00152	0.81032
30	4	145.314	0.82063	0.00227	0.00210	0.82727
40	4	178.288	0.84215	0.00257	0.00265	0.84994
50	4	211.263	0.86285	0.00263	0.00318	0.87129
60	4	244.337	0.88099	0.00270	0.00369	0.89008
70	4	277.212	0.88994	0.00270	0.00418	0.89952
80	4	310.186	0.90373	0.00285	0.00464	0.91407
90	4	343.161	0.91300	0.00251	0.00509	0.92311
100	**4**	**376.135**	**0.92739**	**0.00268**	**0.00551**	**0.93826**
WR	4	417.640	0.89526	0.00265	0.00601	0.90657

Table 6.137. GEMER Results — Infinite Cask Scenario for TRIGA Case V Fuel (Discrete Model, Water Density Sensitivity, 4 Pins x 165 Grams Case) (Continued)

H_2O Density Weight %	Number of Fuel Plates	$H/^{235}U$ Ratio	K_{eff}	$\pm\sigma$	Bias	$k+2\sigma$ +Bias
3 Pins x 220 Grams Case						
0	3	46.390	0.64586	0.00240	0.00000	0.65066
10	3	94.551	0.64894	0.00214	0.00120	0.65442
20	3	142.712	0.66940	0.00254	0.00205	0.67653
30	3	190.873	0.69414	0.00199	0.00285	0.70097
40	3	239.034	0.71923	0.00236	0.00361	0.72756
50	3	287.195	0.73527	0.00253	0.00432	0.74465
60	3	335.355	0.74984	0.00263	0.00498	0.76008
70	3	383.516	0.76835	0.00275	0.00560	0.77945
80	3	431.677	0.77995	0.00259	0.00617	0.79130
90	3	479.838	0.79217	0.00283	0.00669	0.80452
100	3	527.999	0.79475	0.00289	0.00717	0.80770
WR	3	583.338	0.77184	0.00289	0.00766	0.78528

Table 6.138. GEMER Results — Infinite Cask Scenario for TRIGA Case V Fuel (Discrete Model, Water Density Sensitivity, 3 Pins x 220 Grams Case)

H_2O Density Weight %	Number of Fuel Plates	$H/^{235}U$ Ratio	K_{eff}	$\pm\sigma$	Bias	$k+2\sigma$ +Bias
3 Pins x 220 Grams Case						
0	3	46.390	0.81308	0.00240	0.00031	0.81819
10	3	82.511	0.80940	0.00256	0.00098	0.81550
20	3	118.631	0.81640	0.00221	0.00163	0.82245
30	3	154.752	0.83297	0.00276	0.00226	0.84075
40	3	190.873	0.85252	0.00259	0.00285	0.86055
50	3	226.993	0.86562	0.00246	0.00342	0.87396
60	3	263.113	0.87291	0.00278	0.00397	0.88244
70	3	299.235	0.88714	0.00258	0.00449	0.89679
80	3	335.355	0.89383	0.00269	0.00498	0.90419
90	3	371.476	0.89376	0.00282	0.00545	0.90485
100	3	407.597	0.89971	0.00266	0.00589	0.91092
WR	3	449.101	0.88610	0.00284	0.00637	0.89815

Table 6.138. GEMER Results — Infinite Cask Scenario for TRIGA Case V Fuel (Discrete Model, Water Density Sensitivity, 3 Pins x 220 Grams Case) (Continued)

H_2O Density Weight %	Number of Fuel Plates	$H/^{235}U$ Ratio	K_{eff}	$\pm\sigma$	Bias	$k+2\sigma$ +Bias
2 Pins x 220 Grams Case						
0	2	46.390	0.61507	0.00214	0.00000	0.61935
10	2	105.290	0.60752	0.00220	0.00139	0.61331
20	2	164.190	0.62628	0.00234	0.00241	0.63337
30	2	223.091	0.65152	0.00249	0.00336	0.65986
40	2	281.991	0.66613	0.00246	0.00424	0.67529
50	2	340.891	0.67360	0.00248	0.00506	0.68362
60	2	399.791	0.68654	0.00257	0.00580	0.69748
70	2	458.692	0.70157	0.00232	0.00647	0.71268
80	2	517.592	0.69739	0.00293	0.00707	0.71032
90	2	576.492	0.70076	0.00260	0.00761	0.71357
100	2	635.392	0.69551	0.00224	0.00807	0.70806
WR	2	697.649	0.68063	0.00267	0.00849	0.69446

Table 6.139. GEMER Results — Infinite Cask Scenario for TRIGA Case V Fuel (Discrete Model, Fuel Pitch Sensitivity for the 4 Pins x 165 Grams Case and the 3 Pins x 220 Grams Case)

H_2O Density Weight %	Fuel Pin X-Pitch (cm)	Fuel Pin Y-Pitch (cm)	$H/^{235}U$ Ratio	K_{eff}	$\pm\sigma$	Bias	$k+2\sigma$ +Bias
4 Pins x 165 Grams Case							
100	3.6549	3.81	376.135	0.89633	0.00272	0.00000	0.90177
100	4.1449	3.81	376.135	0.90878	0.00276	0.00551	0.91981
100	4.445	3.81	376.135	0.91645	0.00264	0.00551	0.92724
100	**4.826**	**3.81**	**376.135**	**0.92739**	**0.00268**	**0.00551**	**0.93826**
100	4.826	3.9949	376.135	0.92577	0.00256	0.00551	0.93640
3 Pins x 220 Grams Case							
100	3.6549	3.81	407.957	0.87734	0.00248	0.00000	0.88230
100	4.1449	3.81	407.957	0.89549	0.00268	0.00589	0.90674
100	4.445	3.81	407.957	0.89329	0.00246	0.00589	0.90410
100	4.826	3.81	407.957	0.89971	0.00266	0.00589	0.91092
100	4.826	3.6549	407.957	0.89798	0.00268	0.00589	0.90923
100	4.826	3.7449	407.957	0.89700	0.00268	0.00589	0.90825
100	4.826	3.9949	407.957	0.90088	0.00284	0.00589	0.91245

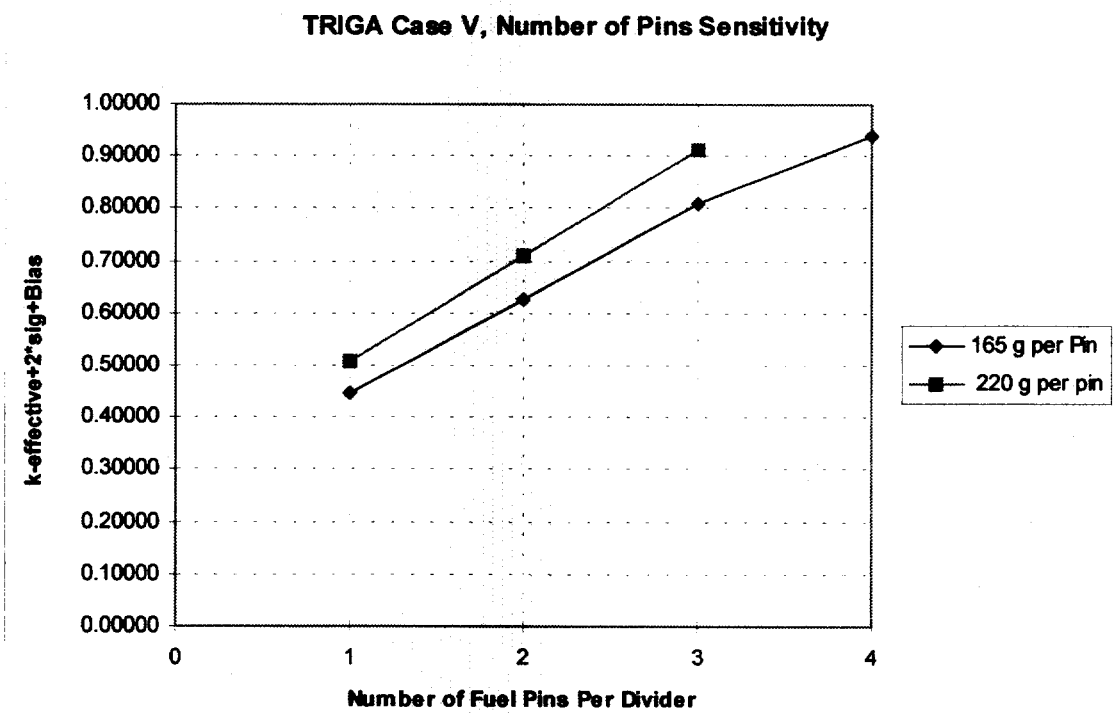


Figure 6.86. GEMER Results — Infinite Cask Scenario for TRIGA Case V Fuel (Discrete Model, Fuel Pin Sensitivity)

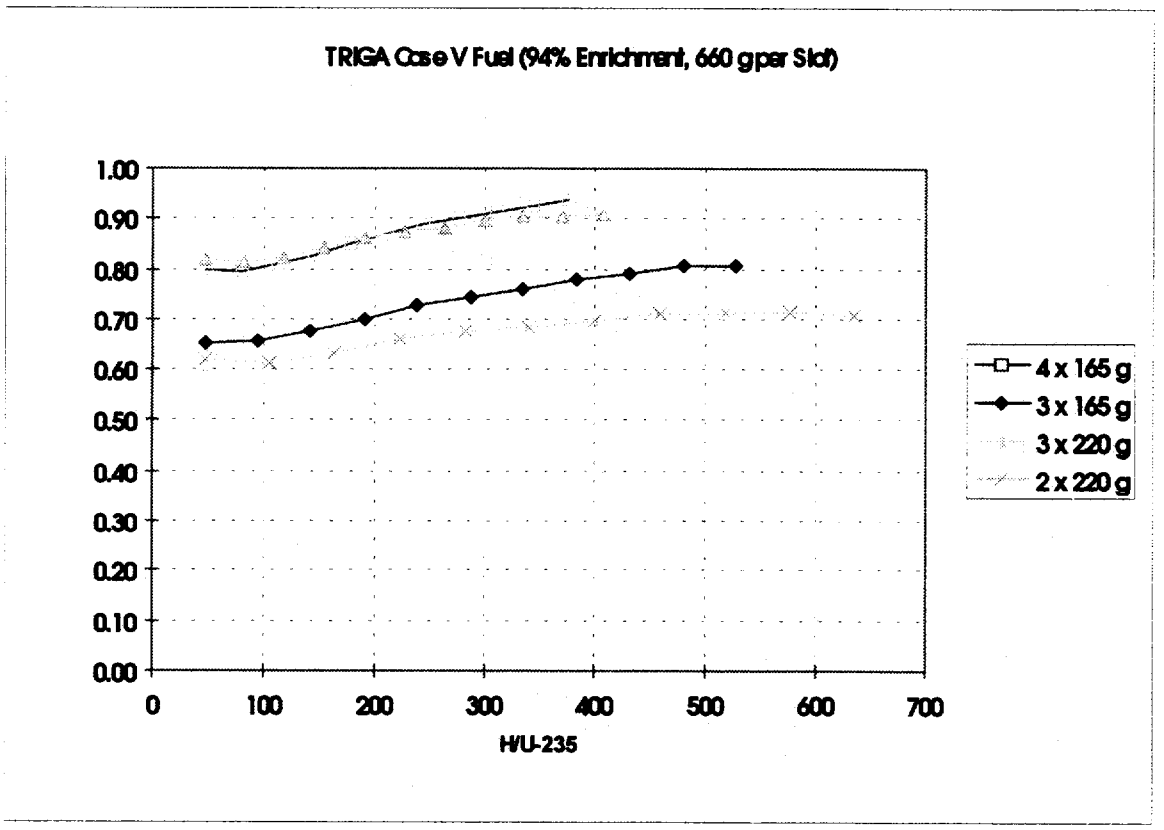


Figure 6.87. TRIGA Case V Fuel, Infinite Cask Array, Water

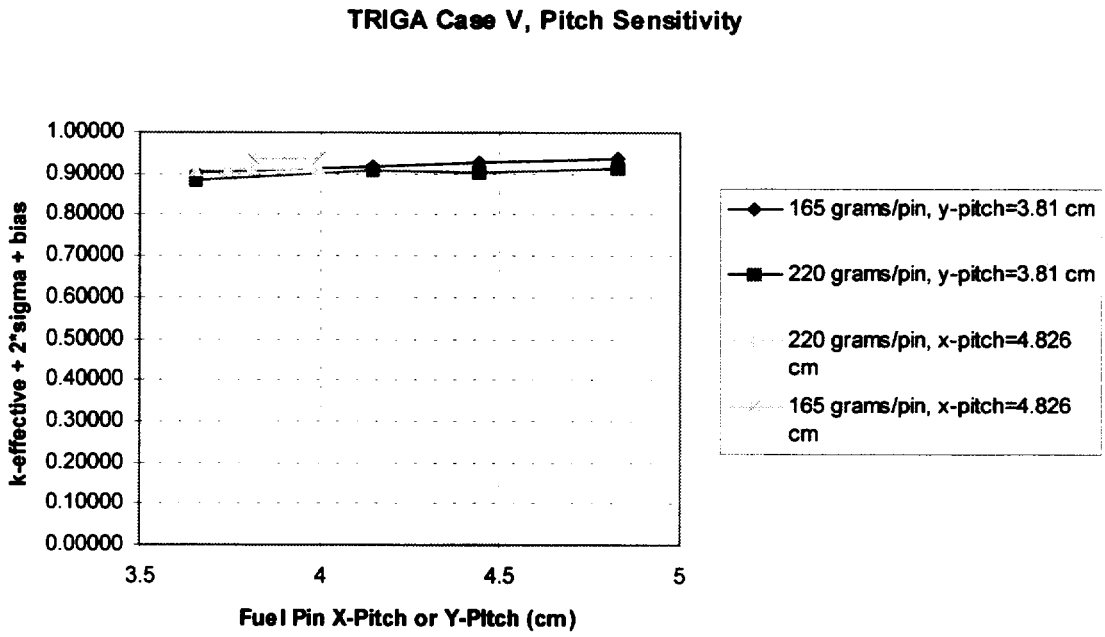


Figure 6.88. TRIGA Case V Fuel, Infinite Cask Array, Pitch Sensitivity

6.7.7.4.3.3 TRIGA Case VIII Fuel

Table 6.140 summarizes the GEMER results for the infinite cask scenario for TRIGA Case VIII for the Discrete Model.

The 20 pin cases are modeled in a 5 x 4 fuel pin loading design. The 15 pin cases are modeled in a 5 x 3 fuel pin loading design and in a 4 x 4 - 1 fuel pin loading design (with one rod missing in the 4 x 4 arrangement).

Tables 6.141 and 6.142 and Figure 6.89 show the variation of the k-effectives as the number of fuel pins is varied from 1 to 15 or 20, maintaining the same fissile content within each fuel pin (i.e., 44 or 33 grams of U-235 per fuel pin) and at full-density water. These fuel pins are assumed to be equally spaced within the divider slot in both the x- and y-directions.

The optimum number of fuel pins is found to be 15 or 20, and the 15-pin and 20-pin cases are expanded to include full range of water moderation (i.e., varying H/U^{235} ratios). These results are shown in Tables 6.143 and 6.144 and in Figure 6.90. In addition, the 14-pin case and 19-pin cases are also studied for the full range of water density (Tables 6.145 and 6.146 and Figure 6.90).

The water reflection (WR) case denotes the case when the surrounding materials outside of the fuel basket is replaced by full-density water and the perfectly reflecting boundary conditions are applied on all sides and the top and bottom.

The 15 pins x 44 grams cases and 20 pins x 33 grams cases are also studied with varying pitches in the x-direction and y-direction and the results are shown in Table 6.147 and Figure 6.91.

The pitch sensitivity case shows that the system tends to be under-moderated and hence increasing the fuel plate pitch tends to increase the k-effective. The equally-spaced pitch used in the base model represents a condition very close to the worst configuration.

The 4 x 4 -1 fuel pin loading design cases are also shown in Table 6.148. Of the three fuel designs (5 x 4 with 33 grams per pin, 5 x 3 with 44 grams per pin, and 4 x 4 -1 with 44 grams per pin), the 4 x 4 -1 design is found to be the most limiting.

The maximum k_{eff} for TRIGA Case VIII Fuel is 0.94062 for the discrete case after accounting for uncertainty and bias. These values are below the subcriticality limit of 0.95.

Table 6.140. Summary of Results — Infinite Cask Scenario for TRIGA Case VIII Fuel

Condition/Parameter	Quantity/Comment
Number of Containers in Demonstration	Infinite Array
Optimum Hydrogenous Moderation	1.00 Weight Fraction H_2O
Maximum Multiplication Factor $k_{eff} + 2\sigma$ + Bias	**0.94062**

Table 6.141. GEMER Results — Infinite Cask Scenario for TRIGA Case VIII Fuel (Discrete Model, Fuel Pin Sensitivity for the 20 x 33 Grams Limit Case)

H_2O Density Weight %	Number of Fuel Pins	$H/^{235}U$ Ratio	K_{eff}	$\pm\sigma$	Bias	$k+2\sigma$ +Bias
100	8	1086.892	0.63614	0.00233	0.00932	0.65012
100	12	707.232	0.77221	0.00244	0.00854	0.78563
100	14	598.758	0.81494	0.00232	0.00779	0.82737
100	15	555.369	0.82915	0.00256	0.00742	0.84169
100	16	517.403	0.85936	0.00255	0.00707	0.87153
100	17	483.903	0.87246	0.00246	0.00674	0.88412
100	18	454.126	0.88590	0.00240	0.00642	0.89712
100	19	427.483	0.89701	0.00277	0.00612	0.90867
100	20	403.505	0.90738	0.00249	0.00584	0.91820

Table 6.142. GEMER Results — Infinite Cask Scenario for TRIGA Case VIII Fuel (Discrete Model, Fuel Pin Sensitivity for the 15 x 44 Grams Limit Case)

H_2O Density Weight %	Number of Fuel Pins	$H/^{235}U$ Ratio	K_{eff}	$\pm\sigma$	Bias	$k+2\sigma$ +Bias
100	8	824.865	0.69845	0.00272	0.00909	0.71298
100	12	540.121	0.85762	0.00258	0.00729	0.87007
100	14	458.765	0.90256	0.00259	0.00647	0.91421
100	15	426.223	0.92230	0.00259	0.00611	0.93359

Table 6.143. GEMER Results — Infinite Cask Scenario for TRIGA Case VIII Fuel (Discrete Model, Water Density Sensitivity, 20 pins x 33 grams Case)

H_2O Density Weight %	Number of Fuel Pins	$H/^{235}U$ Ratio	K_{eff}	$\pm\sigma$	Bias	$k+2\sigma$ +Bias
0	20	38.785	0.56440	0.00173	0.00016	0.56802
10	20	75.257	0.58280	0.00195	0.00085	0.58755
20	20	111.729	0.63251	0.00197	0.00151	0.63796
30	20	148.201	0.67748	0.00196	0.00214	0.68354
40	20	184.673	0.72153	0.00221	0.00275	0.72870
50	20	221.145	0.76143	0.00208	0.00333	0.76892
60	20	257.617	0.79904	0.00224	0.00389	0.80741
70	20	294.089	0.82991	0.00233	0.00442	0.83899
80	20	330.561	0.85626	0.00224	0.00492	0.86566
90	20	367.033	0.88161	0.00245	0.00539	0.89190
100	20	403.505	0.90738	0.00249	0.00584	0.91820
WR	20	445.009	0.87666	0.00266	0.00632	0.88830

Table 6.144. GEMER Results — Infinite Cask Scenario for TRIGA Case VIII Fuel (Discrete Model, Water Density Sensitivity, 15 pins x 44 grams Case)

H_2O Density Weight %	Number of Fuel Pins	$H/^{235}U$ Ratio	K_{eff}	$\pm\sigma$	Bias	$k+2\sigma$ +Bias
0	15	33.785	0.57002	0.00197	0.00006	0.57402
10	15	77.529	0.59761	0.00169	0.00089	0.60188
20	15	116.273	0.64716	0.00186	0.00159	0.65247
30	15	155.016	0.69514	0.00231	0.00226	0.70202
40	15	193.760	0.74500	0.00229	0.00290	0.75248
50	15	232.504	0.78524	0.00244	0.00351	0.79363
60	15	271.248	0.82027	0.00224	0.00409	0.82884
70	15	309.991	0.85023	0.00254	0.00464	0.85995
80	15	348.735	0.88110	0.00221	0.00516	0.89068
90	15	387.479	0.90234	0.00245	0.00565	0.91289
100	15	426.223	0.92230	0.00264	0.00611	0.93369
WR	15	467.727	0.88985	0.00264	0.00657	0.90170

Table 6.145. GEMER Results — Infinite Cask Scenario for TRIGA Case VIII Fuel (Discrete Model, Water Density Sensitivity, 19 pins x 33 grams Case)

H_2O Density Weight %	Number of Fuel Pins	$H/^{235}U$ Ratio	K_{eff}	$\pm\sigma$	Bias	$k+2\sigma$ +Bias
0	19	38.785	0.53324	0.00180	0.00016	0.53700
10	19	77.655	0.55840	0.00201	0.00089	0.56331
20	19	116.525	0.61214	0.00219	0.00159	0.61811
30	19	155.395	0.65969	0.00203	0.00227	0.66602
40	19	194.264	0.70393	0.00250	0.00291	0.71184
50	19	233.134	0.74851	0.00255	0.00352	0.75713
60	19	272.004	0.78819	0.00228	0.00410	0.79685
70	19	310.874	0.81651	0.00238	0.00465	0.82592
80	19	349.744	0.84826	0.00250	0.00517	0.85843
90	19	388.614	0.87524	0.00240	0.00566	0.88570
100	19	427.483	0.89701	0.00277	0.00612	0.90867
WR	19	471.172	0.87416	0.00240	0.00660	0.88556

Table 6.146. GEMER Results — Infinite Cask Scenario for TRIGA Case VIII Fuel (Discrete Model, Water Density Sensitivity, 14 pins x 44 grams Case)

H_2O Density Weight %	Number of Fuel Pins	$H/^{235}U$ Ratio	K_{eff}	$\pm\sigma$	Bias	$k+2\sigma$ +Bias
0	14	38.785	0.53191	0.00154	0.00016	0.53515
10	14	80.783	0.56065	0.00210	0.00095	0.56580
20	14	122.781	0.61785	0.00229	0.00170	0.62413
30	14	164.779	0.67188	0.00224	0.00242	0.67878
40	14	206.777	0.72044	0.00238	0.00311	0.72831
50	14	248.775	0.76387	0.00227	0.00376	0.77217
60	14	290.773	0.80055	0.00235	0.00437	0.80962
70	14	332.771	0.83323	0.00208	0.00495	0.84234
80	14	374.769	0.86175	0.00248	0.00549	0.87220
90	14	416.767	0.88282	0.00263	0.00600	0.89408
100	14	458.765	0.90256	0.00259	0.00647	0.91421
WR	14	503.234	0.87873	0.00224	0.00693	0.89014

Table 6.147. GEMER Results — Infinite Cask Scenario for TRIGA Case VIII Fuel (Fuel Pitch Sensitivity for the 15 x 44 Grams and 20 Pins x 33 Grams Cases)

H_2O Density Weight %	Fuel Pin X-Pitch/ Diameter	Fuel Pin Y-Pitch/ Diameter	$H/^{235}U$ Ratio	K_{eff}	$\pm\sigma$	Bias	$k+2\sigma$ +Bias
20 Pins x 33 Grams per Fuel Pin [5 x 4 Design]							
100	1.0073	1.4530	403.505	0.84828	0.00253	0.00584	0.85918
100	1.1453	1.4530	403.505	0.88473	0.00242	0.00584	0.89541
100	1.2179	1.4530	403.505	0.89461	0.00259	0.00584	0.90563
100	1.2915	1.4530	403.505	0.90738	0.00249	0.00584	0.91820
100	1.2915	1.0073	403.505	0.82142	0.00224	0.00584	0.83174
100	1.2915	1.1453	403.505	0.85738	0.00250	0.00584	0.86822
100	1.2915	1.2906	403.505	0.89087	0.00258	0.00584	0.90187
100	1.2915	1.3995	403.505	0.90306	0.00226	0.00584	0.91342
15 Pins x 44 Grams per Pin [5 x 3 Design]							
100	1.0073	1.9373	426.223	0.87542	0.00256	0.00611	0.88665
100	1.1453	1.9373	426.223	0.90161	0.00270	0.00611	0.91312
100	1.2179	1.9373	426.223	0.91215	0.00245	0.00611	0.92316
100	1.2915	1.9373	426.223	0.92230	0.00259	0.00611	0.93359
100	1.2915	1.0073	426.223	0.79654	0.00249	0.00611	0.80763
100	1.2915	1.2906	426.223	0.85842	0.00256	0.00611	0.86965
100	1.2915	1.5811	426.223	0.89954	0.00292	0.00611	0.91149
100	1.2915	1.7264	426.223	0.90715	0.00270	0.00611	0.91866
100	1.2915	1.8717	426.223	0.91432	0.00257	0.00611	0.92557

Table 6.148. GEMER Results — Infinite Cask Scenario for TRIGA Case VIII Fuel (Fuel Pin Loading Sensitivity for the 15 Pins x 44 Grams Cases)

	H_2O Density Weight %	Fuel Pin X-Pitch/ Diameter	Fuel Pin Y-Pitch/ Diameter	$H/^{235}U$ Ratio	K_{eff}	$\pm\sigma$	Bias	$k+2\sigma$ +Bias
5 x3 Design								
	100	1.2915	1.9373	426.223	0.92230	0.00259	0.00611	0.93359
Missing Rod	**4 x 4 - 1 Design**							
Corner	100	1.6144	1.4530	426.223	0.91793	0.00255	0.00611	0.92914
Side Central	100	1.6144	1.4530	426.223	0.91755	0.00257	0.00611	0.92880
Central	**100**	**1.6144**	**1.4530**	**426.223**	**0.92991**	**0.00230**	**0.00611**	**0.94062**
Central	WR	1.6144	1.4530	467.727	0.89962	0.00255	0.00657	0.91129

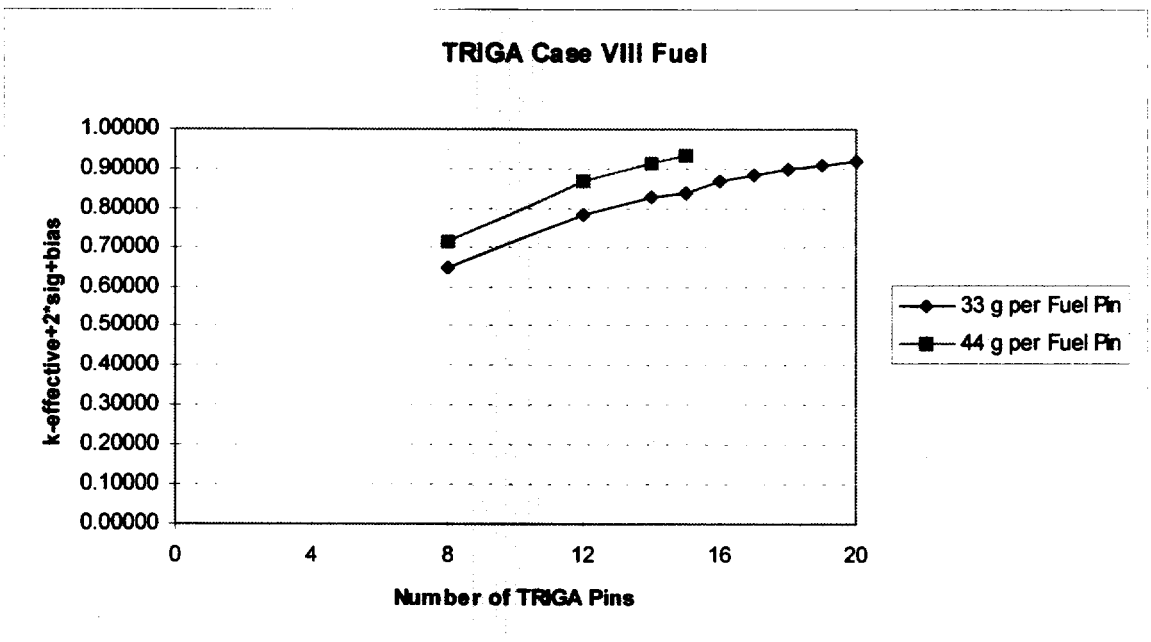


Figure 6.89. GEMER Results — Infinite Cask Scenario for TRIGA Case VIII Fuel (Discrete Model, Fuel Pin Number Sensitivity)

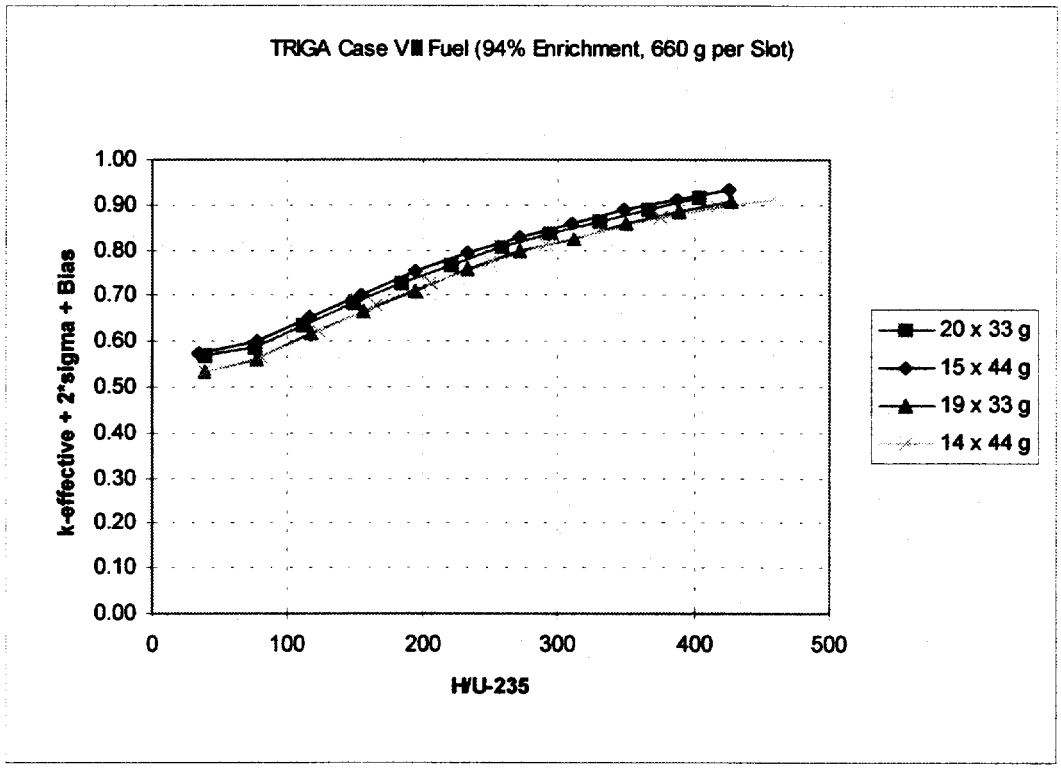


Figure 6.90. GEMER Results — Infinite Cask Scenario for TRIGA Case VIII Fuel, Water Density Variation for the 19/20 out of 20 Pins and 15/16 out of 16 Pins Sensitivity)

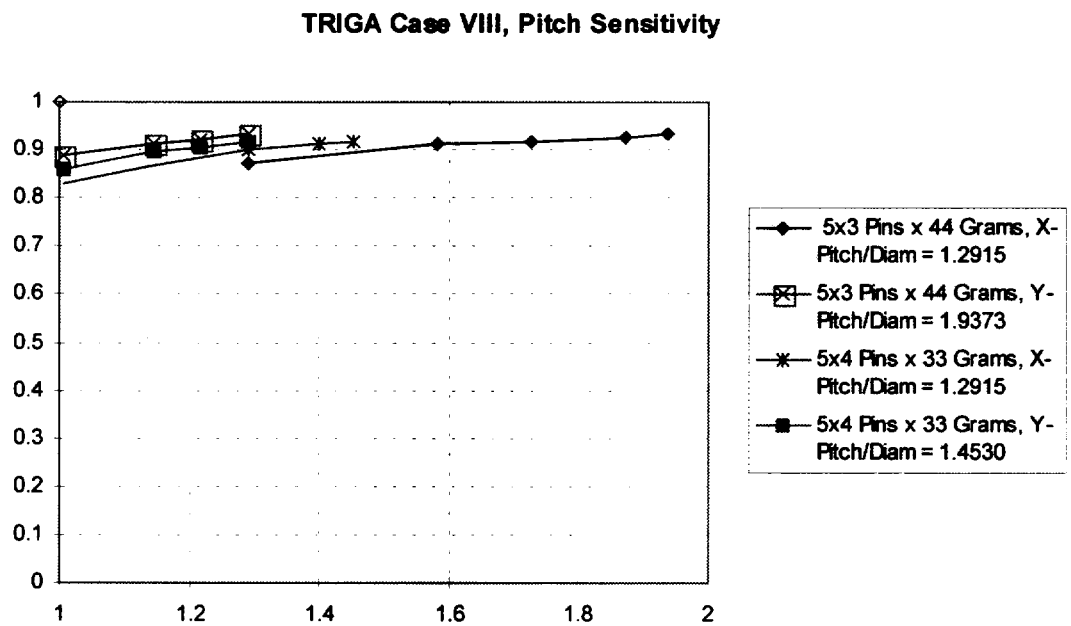


Figure 6.91. TRIGA Case XVIII Fuel, Infinite Cask Array, Pitch Sensitivity for the 15 Pins x 44 Grams and 20 Pins x 33 Grams Cases

6.7.7.4.4 Conclusions

All results, including the conservative accident condition cases, are subcritical. The maximum k-effectives for the worst TRIGA Case XVII, V, and VIII cases, after accounting for uncertainty and bias, are 0.92167, 0.93826, and 0.94062, respectively. The effective multiplication factors are all less than 0.95. It is usually true that the discrete model will tend to have lower k-effective than the homogenous model because the worst case homogenous model tends to be optimally moderated.

The system will be subcritical under all conceivable and realistic accident scenarios. This conclusion is reached based on the requirement that the borated aluminum poison structure is maintained under all credible accident conditions. This meets all NRC requirements for the subcriticality safety analysis and the TRIGA Case XVII, V, and VIII fuel can be safely transported using the Model 2000 cask.

6.7.7.5 Input/Output — TRIGA Case V, VIII, and XVII Fuels

6.7.7.5.1 GEMER Input Decks (TRIGA Case XVII Fuel)

This section includes GEMER geometrical plots and input listings for the infinite array. Each NBSR basedeck contains a "header" with fuel material and geometry information.

6.7.7.5.2 Infinite TRIGA Case XVII Case (70.0% Enriched Fuel)

```
TRIGA17 FUEL/ IF2000/21 SLOTS, SS+Pb SHIELDING. MASS U235 IN EACH ELEM
   105 /* # BATCHES
  1000  /* # NEUTRONS PER BATCH
     5  /* # BATCHES TO SKIP
 2123469/* INITIAL "SEED" (IF NON-ZERO)
     0  /* "IDUMP"
     0  /* "NRSTRT"
     0  /* "NBTED" (NON-ZERO IS PRINT EDITS)
     0  /* "KRED" (NUMBER OF COMBINED REGIONS IN EDITS)
     0  293   20  11
      4  293 0  0  U(70%)ZRH1.6   140 GRAM/FA MAT 1
       1  6.1449654E-02
     401  3.8406037E-02
    2381  4.1741561E-04
    2351  9.8642963E-04
      3  293 0 0 Boral 0.25" Plate (75% Boron Loading)  MAT 2
    10    4.15822E-03
    11    8.48616E-05
   131    5.8001E-02
     2  293 0 0  MODERATOR IN CASK (100.00%)           MAT 3
     1   6.69111121E-02
    16   3.34555566E-02
      1  293 0 0 LEAD SHIELDING                        MAT 4
    82   3.29890E-02
      7  293 0 0 304 STAINLESS STEEL                   MAT 5
    12   6.82690E-05
    14   8.53360E-04
    24   1.53600E-02
    26   6.04950E-02
    28   6.82690E-03
    55   1.70670E-03
  1316   2.56010E-05
     2  293 0 0 FULL DENSITY WATER (100%)             MAT 6
     1    6.69111121E-02
    16    3.34555566E-02
     1  293 0 0 AL CLADDING                           MAT 7
   131    6.026464E-02
    2  293 0 0 FULL DENSITY WATER (VOID)              MAT 8
     1    6.69111121E-09
    16    3.34555566E-09
     1  293 0 0 GRAPHITE                              MAT 9
    12    0.1366692
     1  293 0 0 ZIRCOLOY-2                            MAT 10
   401    0.0432825
      4  293 0  0  U(70%)ZRH1.6 DENSITY =  4.306340 G/CC 137 GRAM/FA MAT
11
```

```
       1  3.9424587E-02
     401  2.4640365E-02
    2381  3.8531370E-04
    2351  9.1056689E-04
KENO GEOM
    20  /* "KREFM"
     9  /* "NBOX"
     1  /* "NBXMAX"
     1  /* "NBYMAX"
     1  /* "NBZMAX"
     1  /* "NXX"
     0  /* "NTYPST"
     1  /* "NEMBRG"
     0  /* "NGMCHK"
 -1.0  -1.0  -1.0  -1.0  -1.0  -1.0
BOX TYPE     1 /*MODEL 2000 CASK & STAINLESS SUPPORT STRUCTURE
CYLINDER     6  33.65     140.64     0.0    16*0.5
CYLINDER     5  35.85     140.64     0.0    16*0.5
CYLINDER     4  46.34     140.64     0.0    16*0.5
CYLINDER     5  48.56     140.64   -14.90   16*0.5
BOX TYPE     2 /* CASK TOP
CYLINDER     4  30.96     158.42    140.64  16*0.5
CYLINDER     5  48.56     162.23    140.64  16*0.5
BOX TYPE     3 /* 21 SLOTS FILLED WITH WATER  125.2778 CM HIGH
CUBOID       6  4.4450 -4.4450  4.0005  -4.0005  125.2728  0.0   16*0.5
BOX TYPE     4 /* 21 SLOTS FILLED WITH WATER      ***   EXTENDED HEIGHT
CUBOID       6  4.4450 -4.4450  4.0005  -4.0005  15.35  0.00  16*0.5
BOX TYPE     5 /* BORAL PLATE (VERT)  125.2728 CM (49.32")
CUBOID       2  0.2667  -0.2667  3.937  -3.937  125.2728  0.0   16*0.5
BOX TYPE     6 /* BORAL PLATE (HORIZ) MODELED AS 3.1" X 0.21" X 49.32"
MIN DIMENSIONS
CUBOID       2  3.937  -3.937  0.2667  -0.2667  125.2728  0.0   16*0.5
BOX TYPE     7 /* TRIGA FUEL PIN
CYLINDER    10  0.3175     57.150    19.05   16*0.5  /* ZR ROD
(R=0.125")
CYLINDER     1  1.77165    57.150    19.05   16*0.5  /* FUEL (R=1.435-
0.02*2")
CYLINDER     5  1.82245    57.150    19.05   16*0.5  /* SS CLAD
(R=1.435/2")
CYLINDER     9  1.82245    65.786    10.414  16*0.5  /* GRAHITE
REFLECTORS
CYLINDER     5  1.82245    76.20    0.000   16*0.5  /* ZR ENDFIT 30-15-
2*3.4"=10.414 CM
CUBOID       6  1.82245  -1.82245  1.82245 -1.82245 80.0  0.0 16*0.5 /*
WATER
BOX TYPE     8  /* SS IN THE CAVITY
CYLINDER     5  33.34     125.2728     0.0    16*0.5
BOX TYPE     9  /* OVERALL BOX FOR THE PROBLEM
CUBOID       6  48.60    -48.60   48.60 -48.60 162.23 -14.91 16*0.5
CORE         0  48.60    -48.60   48.60 -48.60 162.23 -14.91 16*0.5
CUBOID       6  48.70    -48.70   48.70 -48.70 162.33 -15.01 16*0.5
9  1 1 1  1 1 1  1 1 1  1
BEGIN COMPLEX
/* PLACE THE FUEL PLATES INTO THE SLOT
/*                                  PX=   PITCH (X) = 1.9" = 4.826 CM
/*                                  PY=   PITCH (Y) = 1.5" = 3.810 CM
/* BOX TYPE 3 FOR NORMAL HEIGHT
/*     (-0.5 PX,-0.5PY)
COMPLEX  3  7  -2.413  -1.905  0.0  2  2  1  4.826  3.810  0.0  /*2X2
FUEL PINS
/* PLACE FUEL ASSEMBLIES INTO CASK    NORMAL HEIGHT
```

```
COMPLEX  8  3   -22.860  -10.540  0.0  5  3  1  11.430  10.540  0.0
/*MIDDLE ROWS
COMPLEX  8  3   -11.430  -21.080  0.0  3  2  1  11.430  42.160  0.0
/*OUTER ROWS
/* PLACE BORAL PLATES INTO CASK
COMPLEX  8  5   -17.145  -10.540  0.0  4  3  1  11.430  10.540  0.0
/*VERT PLATES
COMPLEX  8  6   -11.430  -15.810  0.0  3  4  1  11.430  10.540  0.0
/*HORIZ PLATES
/* PLACE LOWER SECTION (NORMAL HEIGHT) INTO THE BOX TYPE 1
COMPLEX  1  8  0.0   0.0   0.0   1  1  1   0.0  0.0  0.0
/* PLACE PROTRUDED SECTION (EXTENDED HEIGHT) INTO THE BOX TYPE 1
/* COMPLEX  1 10  0.0   0.0   125.2728   1  1  1   0.0  0.0  0.0
/* PLACE LOADED CASK INTO OVERALL PROBLEM BOX
COMPLEX  9  1  0.0     0.0    0.0   1 1 1   0.0    0.0    0.0
/* PLACE TOP INTO OVERALL PROBLEM BOX
COMPLEX  9  2  0.0     0.0    0.0   1 1 1   0.0    0.0    0.0
END GEOM
*END GEMER*
```

6.7.7.5.3 Number Density Calculations (TRIGA Case XVII Fuel)

6.7.7.5.3.1 FORTRAN Program

```
PROGRAM NUMBER
C
C   PRODUCTION RUN
C   9/18/96
C                        AKC
C    U-235 (94% ENRICHMENT CASE)
C    STAINLESS STEEL CLAD (FLIP TYPE OF TRIGA FUEL)
C    15" ACTIVE FUEL LENGTH, 1.475" O.D. FUEL ELEMENT,
C                            1.435" O.D. FUEL
C                            0.020" CLADDING THICKNESS
C     CENTRAL ZR ROD
C
      REAL NPIN,N235TOT,NHTOT

      REAL M235,M238
      REAL U235MAS,U238MAS
      REAL MZR,MU,MH,MH16,MH20
      REAL N235,N238,NH,NZR,NZR1,NHFUEL
      REAL MNI,MCR,MMN,MFE,MC12,MSI
      REAL FEMAS,CRMAS,NIMAC,MNMAS
      REAL NNI,NMN,NFE,NCR,NSI,NC12
      REAL LREFL
      REAL N24,N55,N26,N28
C
      DATA PI/3.14159265/
C
      OPEN(6,FILE='P.OUT',STATUS='UNKNOWN')
      AV=0.6022
      M235 =235.0439
      M238 =238.0508
      MZR=91.224
      MH=1.00794
      MH16=1.6*MH
      MH2O=18.0153
C
```

```
C
C       INCONEL
C
        MCR=51.9961
        MMN=54.938
        MFE=55.847
        MNI=58.690
C
C
C    CALCULATE THE INCONEL DENSITY
        RHOINC=8.01
        N24=RHOINC*0.21*AV/MCR
        N55=RHOINC*0.01*AV/MMN
        N26=RHOINC*0.46*AV/MFE
        N28=RHOINC*0.32*AV/MNI
C
        WRITE(6,*)
        WRITE(6,*) ' INCONEL NUMBER DENSITY'
        WRITE(6,*) '   24',N24
        WRITE(6,*) '   55',N55
        WRITE(6,*) '   26',N26
        WRITE(6,*) '   28',N28
C
       WRITE(6,*)  '  *************** GA SAR CASE TYPE 5 FUEL ******'
C
C        *****INPUTS********
C      WT_U = WEIGHT OF URANIUM
C      WT_U IS CALCULATED BASED ON A UZRH MASS OF 2360 G
C       SEE NUCL. TECH. VOL 105, 1/94, PAGE 42, PAPER BY MELE ETC.
C      BACK CALCULATE WT_U TO BE 0.188446   12/14/98
C
       WT_U=0.085
C
C      RHOZR=ZR DENSITY (G/CC)
C      RHOREFL = REFLECTOR (GRAPHITE) DENSITY IN G/CC
       RHOZR=6.50
       RHOREFL = 1.60
C      U235GRAM = U235 WEIGHT PER ELEMENT IN GRAMS
C      ER-167 MASS IGNORED.
C
C      WEIGHT OF U-235 PER FUEL ELEMENT
C       U235GRAM=175.0
C
C       U235GRAM=137.0
        U235GRAM=140.0
        NPIN=4.0
        ENRICH=0.70
C
C
C
       U235MAS=U235GRAM
       WRITE(6,*) ' U235 MASS PER ELEMENT =',U235MAS,' GRAMS'
       WRITE(6,*) ' TOTAL U235 MASS=',U235MAS,' GRAMS'
       WRITE(6,*) ' NUMBER OF FUEL PINS =',NPIN
C
C     RHOSS = STAINLESS STEEL DENSITY (G/CC)
       RHOSS=7.8266
C     RFUEL = FUEL OUTER RADIUS (CM)
C     RCLAD = CLAD OUTER RADIUS (CM)
       RZRROD=0.25*2.54/2.0
       RFUEL=1.395*2.54/2.0
```

```
      RCLAD=1.475*2.54/2.0
C
C   FLENGTH = FUEL ACTIVE LENGTH IN CM
C   FCLENGTH = CLAD LENGTH + ACTIVE FUEL LENGTH IN CM
C
      FLENGTH=15.0*2.54
      FCLENGTH=(3.40+3.40)*2.54 + FLENGTH
      WRITE(6,*) ' FUEL OUTER RADIUS =',RFUEL,'CM   OR ',
     * RFUEL/2.54,' INCHES'
      WRITE(6,*) ' CLAD OUTER RADIUS =',RCLAD,'CM  OR ',
     *             RCLAD/2.54,' INCHES'
      WRITE(6,*) ' FUEL ELEMENT LENGTH =',FLENGTH,'CM OR ',
     *            FLENGTH/2.54,' INCHES'
      WRITE(6,*) ' TOTAL CLAD LENGTH =',FCLENGTH,'CM OR ',
     *            FCLENGTH/2.54,' INCHES'
C
C     VOL_ENDFIT= 118*1.224/8.01
C               = 18.01   (PREVIOUS DESIGN)
C    CLADDING IS STAINLESS STEEL-304
C    CLAD = FUEL CLAD + END FITS + CLAD OVER GRAPHITE REFLECTORS
C
C     VOL_ENDFIT = 69.153 CC (FROM S. JAIN  8/5/96)
C
      VOL_ENDFIT = 0.0
      CVOLUME = PI*(RCLAD*RCLAD-RFUEL*RFUEL)*FCLENGTH
     *         + VOL_ENDFIT

C
C      NEXT THE CENTRAL ZR ROD:
C
C      RZRROD=0.25*2.54/2.0
C     ZRVOUME = VOULUME OF ZR RODS IN THE CENTER
C
      ZRVOLUME = PI*RZRROD*RZRROD*FLENGTH
      ZRRODMAS = ZRVOLUME*RHOZR
C
C     RREFL = GRAPHITE END REFLECTOR RADIUS (CM)
C     REFLVOLUME= REFLECTOR VOLUME (CC)
C     LREFL = TOTAL LENGTH OF BOTH REFLECTORS (CM)
C     REFLMAS = REFLECTOR MASS (G)
C
      RREFL = 1.40*2.54/2.0
      LREFL = (3.4+3.4)*2.54
      REFLVOLUME =PI*RREFL*RREFL*LREFL
      ZRVOLUME = PI*RZRROD*RZRROD*FLENGTH
      REFLMAS= REFLVOLUME*RHOREFL
C
      FVOLUME=PI*(RFUEL*RFUEL-RZRROD*RZRROD)*FLENGTH
      FCVOLUME=FVOLUME+CVOLUME
C
C    CALCULATING THE CLAD MASSES
C
      WTMN=0.020013
      WTCR=0.180116
      WTNI=0.080145
      WTFE=0.70892
      WTC12=0.0008
      WTSI=0.010006
C
      MNMAS = RHOSS*CVOLUME*WTMN
      CRMAS = RHOSS*CVOLUME*WTCR
```

```
      NIMAS = RHOSS*CVOLUME*WTNI
      FEMAS = RHOSS*CVOLUME*WTFE
      SIMAS = RHOSS*CVOLUME*WTSI
      C12MAS = RHOSS*CVOLUME*WTC12
C
      CLADMAS=MNMAS+CRMAS+NIMAS+FEMAS+C12MAS+SIMAS
C
       U238MAS=U235MAS/ENRICH - U235MAS
       UMAS=U238MAS +U235MAS
       ZRHMAS=UMAS/WT_U - UMAS
       ZRMAS = ZRHMAS*MZR/(MZR+MH16)
       H16MAS = ZRHMAS*MH16/(MZR+MH16)
      TOTAL1= (ZRMAS + H16MAS + U238MAS +U235MAS)
      TOTAL = TOTAL1
      VOLTOT= FVOLUME
       WRITE(6,*) '    '
C
C
       WRITE(6,*) ' FUEL DENSITY =',
     *   (ZRMAS + H16MAS + U238MAS +U235MAS)/FVOLUME,' G.CC'
C
C     WRITING OUT THE SUMMARY TABLE
C
      WRITE(6,1005)
 1005 FORMAT(23X, ' VOLUME(CC)        MASS(G)',5X,'DENSITY (G/CC)')
      WRITE(6,1006) ZRVOLUME,ZRRODMAS,ZRRODMAS/ZRVOLUME
      WRITE(6,1007) REFLVOLUME,REFLMAS,REFLMAS/REFLVOLUME
      WRITE(6,1010) FVOLUME,H16MAS+U238MAS +U235MAS + ZRMAS,
     *              (H16MAS+U238MAS +U235MAS + ZRMAS)/FVOLUME
      WRITE(6,*) '    '
      WRITE(6,1024) U235MAS
      WRITE(6,1025) U238MAS
      WRITE(6,1026) U238MAS+U235MAS
      WRITE(6,1021) ZRMAS
      WRITE(6,1022) H16MAS
      WRITE(6,1023) ZRHMAS
      WRITE(6,*) '    '
 1021 FORMAT(1X,'      ZR MASS (FUEL)',14X,F14.3)
 1023 FORMAT(1X,'    ZRH MASS (FUEL) ',14X,F14.3)
 1022 FORMAT(1X,'     H16 MASS (FUEL)',14X,F14.3)
 1024 FORMAT(1X,'    U235 MASS (FUEL)',14X,F14.3)
 1025 FORMAT(1X,'    U238 MASS (FUEL)',14X,F14.3)
 1026 FORMAT(1X,' U235 + U238 (FUEL)',14X,F14.3)
C
      WRITE(6,1008) CVOLUME,CLADMAS,CLADMAS/CVOLUME
      WRITE(6,1013) VOLTOT,TOTAL,TOTAL/VOLTOT
 1006 FORMAT(1X,'  CENTRAL ZR ROD    ',3F14.3)
 1007 FORMAT(1X,'  END REFLECTORS    ',3F14.3)
 1008 FORMAT(1X,'  CLAD + END FITS   ',3F14.3)
 1009 FORMAT(1X,'  WATER ONLY        ',3F14.3)
 1010 FORMAT(1X,'  UZRH FUEL         ',3F14.3)
 1013 FORMAT(/,1X,'  TOTAL(FUEL+WATER)',3F14.3,/)
C
      N235 = U235MAS*AV/M235/VOLTOT
      N238 = U238MAS*AV/M238/VOLTOT
      NH = H16MAS*AV/MH/VOLTOT
      NHFUEL = H16MAS*AV/MH/VOLTOT
      NZR = ZRMAS*AV/MZR/VOLTOT
      NZR1 = ZRMAS*AV/MZR/VOLTOT
C
      WRITE(6,*) ' FUEL NUMBER DENSITY'
```

```
      WRITE(6,*) '       1',NH
      WRITE(6,*) '     401',NZR
      WRITE(6,*) '    2381',N238
      WRITE(6,*) '    2351',N235
C
      RATIO1 = NHFUEL/NZR1
      WRITE(6,*) ' H/ZR (NUMBER DENSITIES IN FUEL) = ',RATIO1
C
C ********** CALCULATE THE N(H)/N(U235)
C
       WRITE(6,*) '    '
       WRITE(6,*) ' DENSITY   NH/NU-235'
       DO 100 ITER=0,10,1
       RHO_WATER=0.1*FLOAT(ITER)
       N235TOT=N235*NPIN*21.0*FVOLUME
C
       CASK_RADIUS=33.65
       CASK_HEIGHT=140.64
       SLOT_HEIGHT=125.2728
       FA_HEIGHT=76.2
       FA_RADIUS=1.82245
       UNCOVERED_HEIGHT=CASK_HEIGHT - SLOT_HEIGHT
       WATER_TOP = PI*UNCOVERED_HEIGHT*CASK_RADIUS*CASK_RADIUS
       FA_VOLUME=NPIN*PI*FA_HEIGHT*FA_RADIUS*FA_RADIUS
       WATER_ONE_DIVIDER=71.12889*SLOT_HEIGHT - FA_VOLUME
       WATER_TOTAL = WATER_TOP + WATER_ONE_DIVIDER*21.0

C       NHTOT=RHO_WATER*AV/18.0*WATER_TOTAL + NH*NPIN*21.0*FVOLUME
C       NH HAS THE 1.6 FACTOR
       NHTOT=2.0*RHO_WATER*AV/18.0*WATER_TOTAL + NH*NPIN*21.0*FVOLUME
       RATIO6=NHTOT/N235TOT
       WRITE(6,*) RHO_WATER,RATIO6
 100   CONTINUE


       WRITE(6,*) ' TOTAL WATER VOLUME =',WATER_TOTAL,'CM^3'
C
C      WATER REFLECTOR CASE
C
       WRITE(6,*)
       WRITE(6,*) ' WATER REFLECTOR CASE'
       RAD_WR=48.56
       RAD_CASK=33.34
       HT_CASK=125.2728
       HT_WR=140.64+14.90
       VOL_WR=PI*(RAD_WR-RAD_CASK)*(RAD_WR-RAD_CASK)*(HT_WR-HT_CASK)
       WRITE(6,*) ' VOLUME OF WATER REFLECTOR =',VOL_WR,' CM^3'
C   NH HAS THE 1.6 FACTOR
       NHTOT=2.0*RHO_WATER*AV/18.0*WATER_TOTAL + NH*NPIN*21.0*FVOLUME
     *      + 2.0*RHO_WATER*AV/18.0*VOL_WR
       RATIO6=NHTOT/N235TOT
       WRITE(6,*) RHO_WATER,RATIO6

       END
```

6.7.7.5.3.2 FORTRAN Output (TRIGA Case XVII Fuel)

```
INCONEL NUMBER DENSITY
    24  1.9481471E-02
    55  8.7801192E-04
    26  3.9731160E-02
    28  2.6300205E-02
   *************** GA SAR CASE TYPE 5 FUEL ******
  U235 MASS PER ELEMENT =   140.0000     GRAMS
  TOTAL U235 MASS=   140.0000     GRAMS
  NUMBER OF FUEL PINS =   4.000000
  FUEL OUTER RADIUS =   1.771650    CM   OR   0.6975000     INCHES
  CLAD OUTER RADIUS =   1.873250    CM  OR   0.7375000     INCHES
  FUEL ELEMENT LENGTH =   38.10000    CM OR    15.00000     INCHES
  TOTAL CLAD LENGTH =   55.37200    CM OR    21.80000     INCHES

  FUEL DENSITY =   6.470792     G.CC
                        VOLUME(CC)        MASS(G)     DENSITY (G/CC)
   CENTRAL ZR ROD           12.066        78.429         6.500
   END REFLECTORS          171.536       274.458         1.600
   UZRH FUEL               363.625      2352.941         6.471

    U235 MASS (FUEL)                     140.000
    U238 MASS (FUEL)                      60.000
  U235 + U238 (FUEL)                     200.000
      ZR MASS (FUEL)                    2115.542
    H16 MASS (FUEL)                       37.400
    ZRH MASS (FUEL)                     2152.941

   CLAD + END FITS          64.420       503.780         7.820

   TOTAL(FUEL+WATER)       363.625      2352.941         6.471

  FUEL NUMBER DENSITY
       1  6.1449654E-02
     401  3.8406037E-02
    2381  4.1741561E-04
    2351  9.8642963E-04
  H/ZR (NUMBER DENSITIES IN FUEL) =    1.600000

  DENSITY   NH/NU-235
  0.0000000E+00   62.29502
  0.1000000       101.1579
  0.2000000       140.0207
  0.3000000       178.8836
  0.4000000       217.7464
  0.5000000       256.6093
  0.6000000       295.4721
  0.7000000       334.3350
  0.8000000       373.1978
  0.9000000       412.0607
   1.000000       450.9236
  TOTAL WATER VOLUME =   174999.0    CM^3

  WATER REFLECTOR CASE
  VOLUME OF WATER REFLECTOR =   22026.80     CM^3
   1.000000       499.8395
```

6.7.7.5.4 Geometrical Plots of the TRIGA Case XVII Fuel — Side and Sectional Views

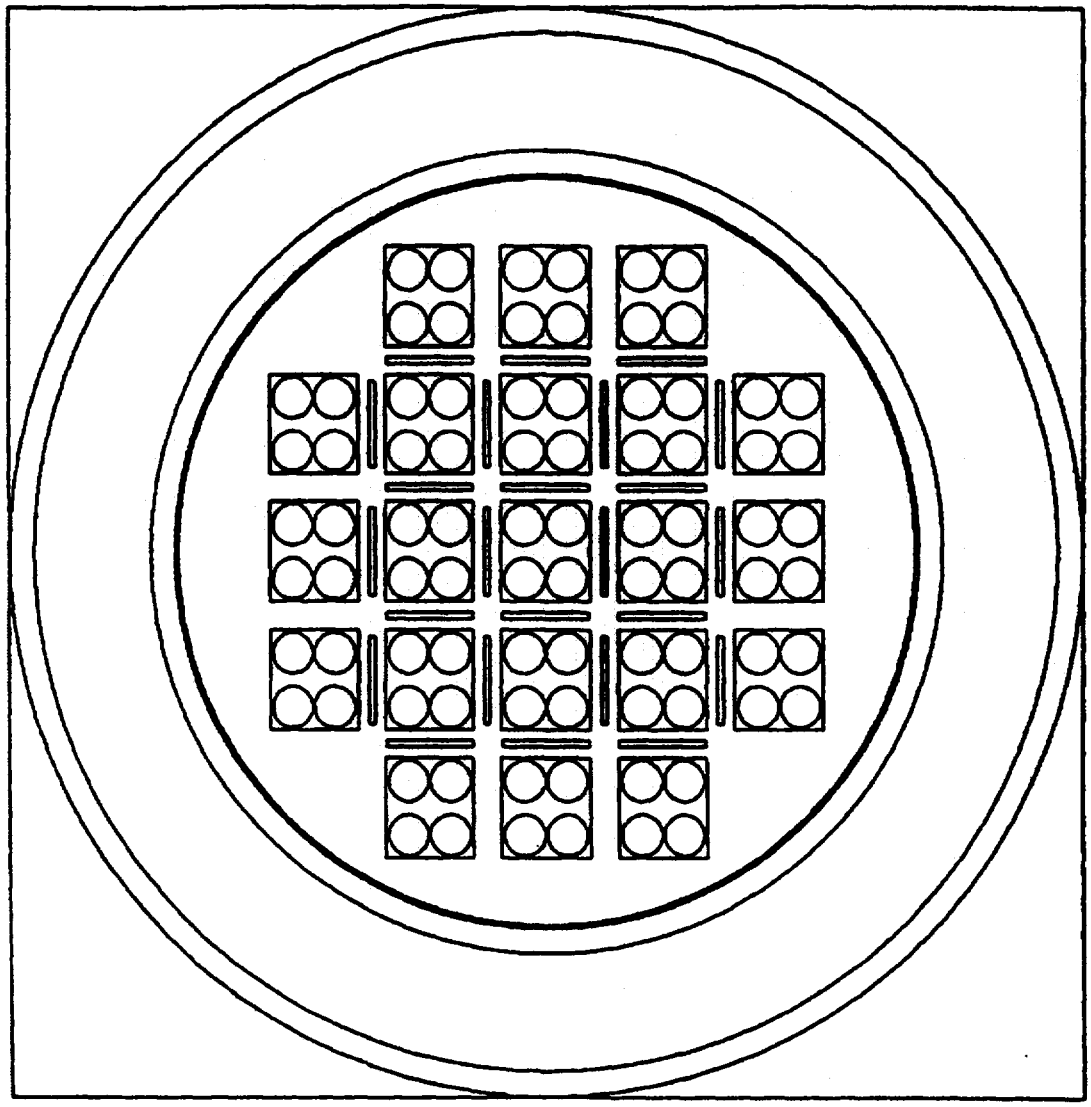


Figure 6.92. Sectional View (Z = 5 cm) for TRIGA Case XVII Fuel

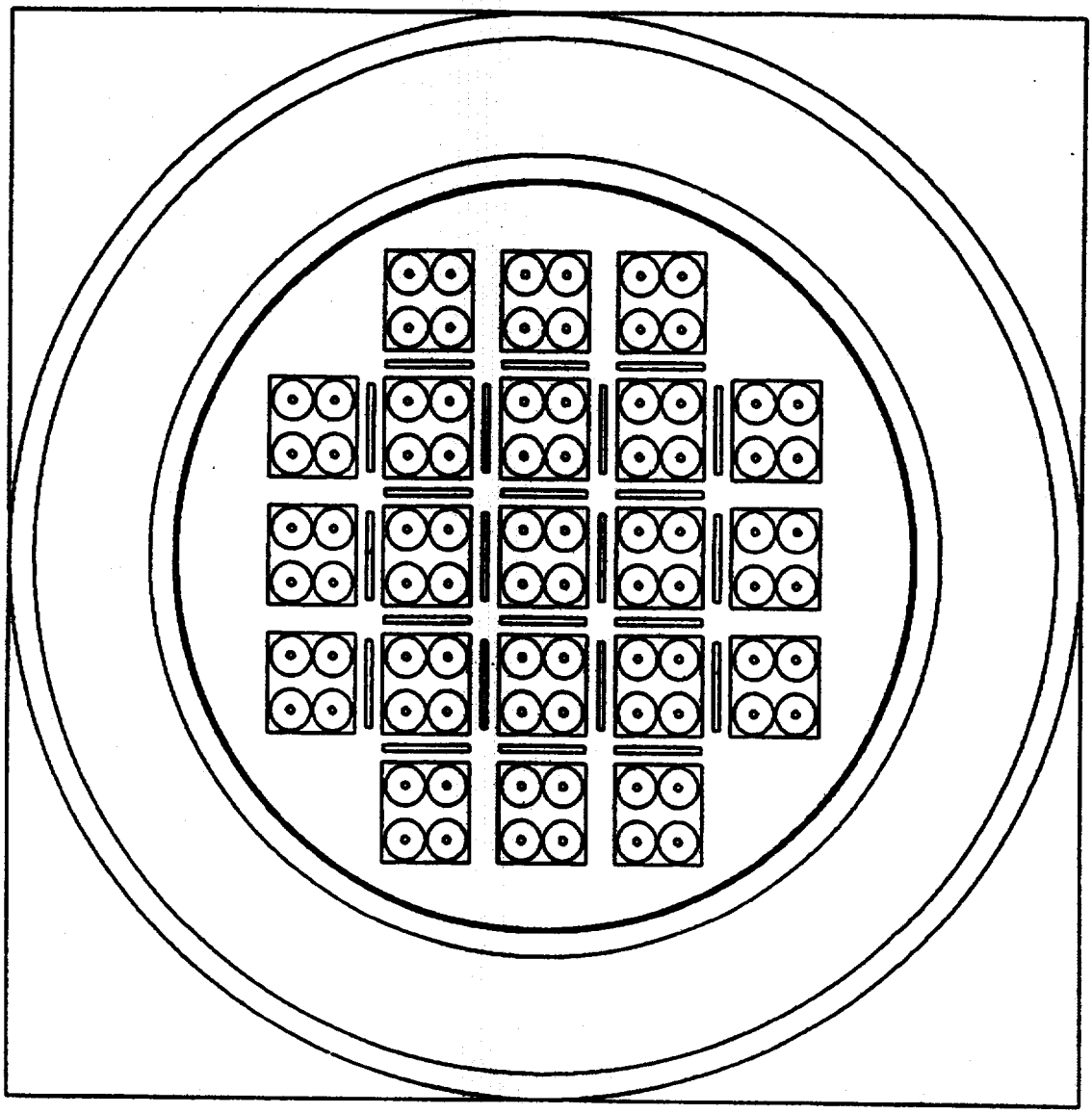


Figure 6.93. Sectional View (Z = 40 cm) for TRIGA Case XVII Fuel

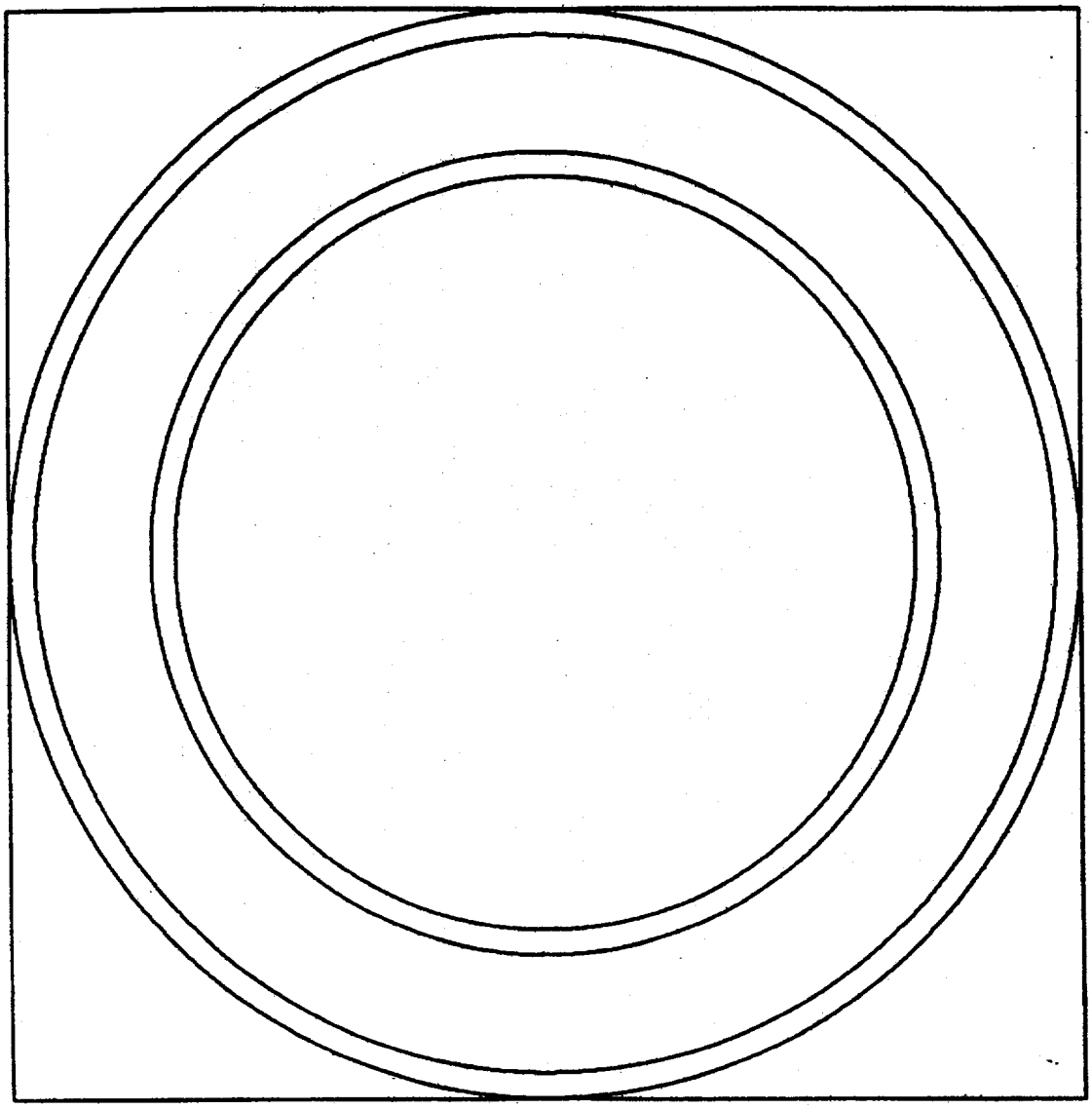


Figure 6.94. Sectional View (Z = 130 cm) for TRIGA Case XVII Fuel

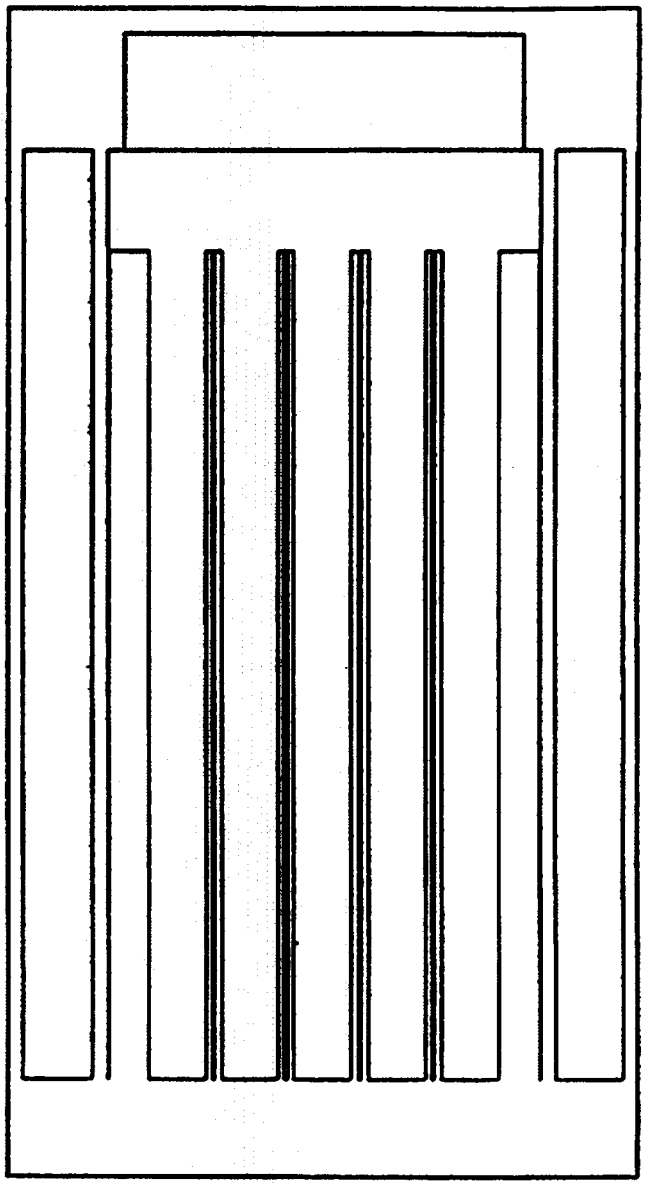


Figure 6.95. Side View for TRIGA Case XVII Fuel

6.7.7.5.5 GEMER Input Decks for TRIGA Case V Fuel

This section includes GEMER geometrical plots and input listings for the infinite array. Each NBSR basedeck contains a "header" with fuel material and geometry information.

6.7.7.5.6 Infinite Case (94.0% Enriched Fuel) for TRIGA Case V Fuel

```
TRIGA5 FUEL/ IF2000/21 SLOTS, SS+Pb SHIELDING. MASS U235 IN EACH ELEM
   105 /* # BATCHES
  1000  /* # NEUTRONS PER BATCH
     5  /* # BATCHES TO SKIP
 2123469/* INITIAL "SEED" (IF NON-ZERO)
     0  /* "IDUMP"
     0  /* "NRSTRT"
     0  /* "NBTED" (NON-ZERO IS PRINT EDITS)
     0  /* "KRED" (NUMBER OF COMBINED REGIONS IN EDITS)
     0  293   20  11
      4  293 0  0  U(94%)ZRH1.6   165.0 GRAM/FA MAT 1
      1  5.3931881E-02
    401  3.3707429E-02
   2381  7.3269803E-05
   2351  1.1625778E-03
      3  293 0 0 Boral 0.25" Plate (75% Boron Loading)  MAT 2
     10   4.15822E-03
     11   8.48616E-05
    131   5.8001E-02
      2  293 0 0  MODERATOR IN CASK (100.00%)          MAT 3
      1  6.69111121E-02
     16  3.34555566E-02
      1  293 0 0 LEAD SHIELDING                        MAT 4
     82  3.29890E-02
      7  293 0 0 304 STAINLESS STEEL                   MAT 5
     12  6.82690E-05
     14  8.53360E-04
     24  1.53600E-02
     26  6.04950E-02
     28  6.82690E-03
     55  1.70670E-03
   1316  2.56010E-05
      2  293 0 0 FULL DENSITY WATER (100%)             MAT 6
      1   6.69111121E-02
     16   3.34555566E-02
      1  293 0 0 AL CLADDING                           MAT 7
    131   6.026464E-02
      2  293 0 0 FULL DENSITY WATER (VOID)             MAT 8
      1   6.69111121E-09
     16   3.34555566E-09
      1  293 0 0 GRAPHITE                              MAT 9
     12   0.1366692
      1  293 0 0 ZIRCOLOY-2                            MAT 10
    401   0.0432825
      4  293 0  0  U(70%)ZRH1.6 DENSITY =  4.306340 G/CC 137 GRAM/FA MAT
11
      1  3.9424587E-02
    401  2.4640365E-02
   2381  3.8531370E-04
   2351  9.1056689E-04
```

```
KENO GEOM
    20  /* "KREFM"
     9  /* "NBOX"
     1  /* "NBXMAX"
     1  /* "NBYMAX"
     1  /* "NBZMAX"
     1  /* "NXX"
     0  /* "NTYPST"
     1  /* "NEMBRG"
     0  /* "NGMCHK"
 -1.0  -1.0  -1.0  -1.0  -1.0  -1.0
BOX TYPE     1 /*MODEL 2000 CASK & STAINLESS SUPPORT STRUCTURE
CYLINDER     6  33.65     140.64     0.0    16*0.5
CYLINDER     5  35.85     140.64     0.0    16*0.5
CYLINDER     4  46.34     140.64     0.0    16*0.5
CYLINDER     5  48.56     140.64   -14.90   16*0.5
BOX TYPE     2 /* CASK TOP
CYLINDER     4  30.96     158.42    140.64  16*0.5
CYLINDER     5  48.56     162.23    140.64  16*0.5
BOX TYPE     3 /* 21 SLOTS FILLED WITH WATER  125.2778 CM HIGH
CUBOID       6  4.4450 -4.4450  4.0005  -4.0005  125.2728  0.0   16*0.5
BOX TYPE     4 /* 21 SLOTS FILLED WITH WATER      ***   EXTENDED HEIGHT
CUBOID       6  4.4450 -4.4450  4.0005  -4.0005  15.35  0.00  16*0.5
BOX TYPE     5 /* BORAL PLATE (VERT)  125.2728 CM (49.32")
CUBOID       2  0.2667  -0.2667  3.937  -3.937  125.2728  0.0   16*0.5
BOX TYPE     6 /* BORAL PLATE (HORIZ) MODELED AS 3.1" X 0.21" X 49.32"
MIN DIMENSIONS
CUBOID       2  3.937  -3.937  0.2667  -0.2667  125.2728  0.0   16*0.5
BOX TYPE     7 /* TRIGA FUEL PIN
CYLINDER    10  0.3175     57.150    19.05   16*0.5  /* ZR ROD
(R=0.125")
CYLINDER     1  1.77165    57.150    19.05   16*0.5  /* FUEL (R=1.435-
0.02*2")
CYLINDER     5  1.82245    57.150    19.05   16*0.5  /* SS CLAD
(R=1.435/2")
CYLINDER     9  1.82245    65.786    10.414  16*0.5  /* GRAHITE
REFLECTORS
CYLINDER     5  1.82245    76.20    0.000   16*0.5  /* ZR ENDFIT 30-15-
2*3.4"=10.414 CM
CUBOID       6  1.82245  -1.82245  1.82245 -1.82245 80.0  0.0 16*0.5 /*
WATER
BOX TYPE     8  /* SS IN THE CAVITY
CYLINDER     5  33.34     125.2728     0.0    16*0.5
BOX TYPE     9  /* OVERALL BOX FOR THE PROBLEM
CUBOID       6  48.60    -48.60   48.60 -48.60 162.23 -14.91 16*0.5
CORE         0  48.60    -48.60   48.60 -48.60 162.23 -14.91 16*0.5
CUBOID       6  48.70    -48.70   48.70 -48.70 162.33 -15.01 16*0.5
9  1 1 1  1 1 1  1 1 1  1
BEGIN COMPLEX
/* PLACE THE FUEL PLATES INTO THE SLOT
/*                                  PX=   PITCH (X) = 1.9" = 4.826 CM
/*                                  PY=   PITCH (Y) = 1.5" = 3.810 CM
/* BOX TYPE 3 FOR NORMAL HEIGHT
/*     (-0.5 PX,-0.5PY)
COMPLEX  3  7  -2.413  -1.905  0.0  2  2  1  4.826  3.810  0.0  /*2X2
FUEL PINS
/* PLACE FUEL ASSEMBLIES INTO CASK    NORMAL HEIGHT
COMPLEX  8  3   -22.860  -10.540  0.0  5  3  1  11.430  10.540  0.0
/*MIDDLE ROWS
COMPLEX  8  3   -11.430  -21.080  0.0  3  2  1  11.430  42.160  0.0
/*OUTER ROWS
```

```
/* PLACE BORAL PLATES INTO CASK
COMPLEX  8  5   -17.145  -10.540  0.0  4  3  1  11.430  10.540  0.0
/*VERT PLATES
COMPLEX  8  6   -11.430  -15.810  0.0  3  4  1  11.430  10.540  0.0
/*HORIZ PLATES
/* PLACE LOWER SECTION (NORMAL HEIGHT) INTO THE BOX TYPE 1
COMPLEX  1  8  0.0   0.0   0.0   1  1  1   0.0  0.0  0.0
/* PLACE PROTRUDED SECTION (EXTENDED HEIGHT) INTO THE BOX TYPE 1
/* COMPLEX  1 10  0.0   0.0   125.2728   1  1  1   0.0  0.0  0.0
/* PLACE LOADED CASK INTO OVERALL PROBLEM BOX
COMPLEX  9  1  0.0     0.0    0.0   1 1 1   0.0    0.0    0.0
/* PLACE TOP INTO OVERALL PROBLEM BOX
COMPLEX  9  2  0.0     0.0    0.0   1 1 1   0.0    0.0    0.0
END GEOM
*END GEMER*
```

6.7.7.5.7 Number Density Calculations for TRIGA Case V Fuel

6.7.7.5.7.1 FORTRAN Program

```
PROGRAM NUMBER
C
C   PRODUCTION RUN
C   9/18/96
C                        AKC
C    U-235 (94% ENRICHMENT CASE)
C    STAINLESS STEEL CLAD (FLIP TYPE OF TRIGA FUEL)
C    15" ACTIVE FUEL LENGTH, 1.475" O.D. FUEL ELEMENT,
C                            1.435" O.D. FUEL
C                            0.020" CLADDING THICKNESS
C     CENTRAL ZR ROD
C
      REAL NPIN,N235TOT,NHTOT

      REAL M235,M238
      REAL U235MAS,U238MAS
      REAL MZR,MU,MH,MH16,MH20
      REAL N235,N238,NH,NZR,NZR1,NHFUEL
      REAL MNI,MCR,MMN,MFE,MC12,MSI
      REAL FEMAS,CRMAS,NIMAC,MNMAS
      REAL NNI,NMN,NFE,NCR,NSI,NC12
      REAL LREFL
      REAL N24,N55,N26,N28
C
      DATA PI/3.14159265/
C
      OPEN(6,FILE='P.OUT',STATUS='UNKNOWN')
      AV=0.6022
      M235 =235.0439
      M238 =238.0508
      MZR=91.224
      MH=1.00794
      MH16=1.6*MH
      MH2O=18.0153
C
C
C      INCONEL
C
       MCR=51.9961
```

```
      MMN=54.938
      MFE=55.847
      MNI=58.690
C
C
C   CALCULATE THE INCONEL DENSITY
      RHOINC=8.01
      N24=RHOINC*0.21*AV/MCR
      N55=RHOINC*0.01*AV/MMN
      N26=RHOINC*0.46*AV/MFE
      N28=RHOINC*0.32*AV/MNI
C
      WRITE(6,*)
      WRITE(6,*) ' INCONEL NUMBER DENSITY'
      WRITE(6,*) '   24',N24
      WRITE(6,*) '   55',N55
      WRITE(6,*) '   26',N26
      WRITE(6,*) '   28',N28
C
     WRITE(6,*)  '  *************** GA SAR CASE TYPE 5 FUEL ******'
C
C      *****INPUTS********
C    WT_U = WEIGHT OF URANIUM
C    WT_U IS CALCULATED BASED ON A UZRH MASS OF 2360 G
C     SEE NUCL. TECH. VOL 105, 1/94, PAGE 42, PAPER BY MELE ETC.
C    BACK CALCULATE WT_U TO BE 0.188446   12/14/98
C
     WT_U=0.085
C
C    RHOZR=ZR DENSITY (G/CC)
C    RHOREFL = REFLECTOR (GRAPHITE) DENSITY IN G/CC
     RHOZR=6.50
     RHOREFL = 1.60
C    U235GRAM = U235 WEIGHT PER ELEMENT IN GRAMS
C    ER-167 MASS IGNORED.
C
C    WEIGHT OF U-235 PER FUEL ELEMENT
C     U235GRAM=175.0
C
C     U235GRAM=137.0
C
C    TOTAL = 660 GRAMS = 165 X 4
C
      U235GRAM=165.0
      NPIN=4.0
      ENRICH=0.94
C
C
C
     U235MAS=U235GRAM
     WRITE(6,*) ' U235 MASS PER ELEMENT =',U235MAS,' GRAMS'
     WRITE(6,*) ' TOTAL U235 MASS=',U235MAS,' GRAMS'
     WRITE(6,*) ' NUMBER OF FUEL PINS =',NPIN
C
C   RHOSS = STAINLESS STEEL DENSITY (G/CC)
     RHOSS=7.8266
C   RFUEL = FUEL OUTER RADIUS (CM)
C   RCLAD = CLAD OUTER RADIUS (CM)
     RZRROD=0.25*2.54/2.0
     RFUEL=1.395*2.54/2.0
     RCLAD=1.475*2.54/2.0
```

```
C
C    FLENGTH = FUEL ACTIVE LENGTH IN CM
C    FCLENGTH = CLAD LENGTH + ACTIVE FUEL LENGTH IN CM
C
      FLENGTH=15.0*2.54
      FCLENGTH=(3.40+3.40)*2.54 + FLENGTH
      WRITE(6,*) ' FUEL OUTER RADIUS =',RFUEL,'CM   OR ',
     * RFUEL/2.54,' INCHES'
      WRITE(6,*) ' CLAD OUTER RADIUS =',RCLAD,'CM  OR ',
     *             RCLAD/2.54,' INCHES'
      WRITE(6,*) ' FUEL ELEMENT LENGTH =',FLENGTH,'CM OR ',
     *            FLENGTH/2.54,' INCHES'
      WRITE(6,*) ' TOTAL CLAD LENGTH =',FCLENGTH,'CM OR ',
     *            FCLENGTH/2.54,' INCHES'
C
C     VOL_ENDFIT= 118*1.224/8.01
C               = 18.01   (PREVIOUS DESIGN)
C    CLADDING IS STAINLESS STEEL-304
C    CLAD = FUEL CLAD + END FITS + CLAD OVER GRAPHITE REFLECTORS
C
C     VOL_ENDFIT = 69.153 CC (FROM S. JAIN  8/5/96)
C
      VOL_ENDFIT = 0.0
      CVOLUME = PI*(RCLAD*RCLAD-RFUEL*RFUEL)*FCLENGTH
     *         + VOL_ENDFIT

C
C      NEXT THE CENTRAL ZR ROD:
C
C      RZRROD=0.25*2.54/2.0
C     ZRVOUME = VOULUME OF ZR RODS IN THE CENTER
C
      ZRVOLUME = PI*RZRROD*RZRROD*FLENGTH
      ZRRODMAS = ZRVOLUME*RHOZR
C
C     RREFL = GRAPHITE END REFLECTOR RADIUS (CM)
C     REFLVOLUME= REFLECTOR VOLUME (CC)
C     LREFL = TOTAL LENGTH OF BOTH REFLECTORS (CM)
C     REFLMAS = REFLECTOR MASS (G)
C
      RREFL = 1.40*2.54/2.0
      LREFL = (3.4+3.4)*2.54
      REFLVOLUME =PI*RREFL*RREFL*LREFL
      ZRVOLUME = PI*RZRROD*RZRROD*FLENGTH
      REFLMAS= REFLVOLUME*RHOREFL
C
      FVOLUME=PI*(RFUEL*RFUEL-RZRROD*RZRROD)*FLENGTH
      FCVOLUME=FVOLUME+CVOLUME
C
C    CALCULATING THE CLAD MASSES
C
      WTMN=0.020013
      WTCR=0.180116
      WTNI=0.080145
      WTFE=0.70892
      WTC12=0.0008
      WTSI=0.010006
C
      MNMAS = RHOSS*CVOLUME*WTMN
      CRMAS = RHOSS*CVOLUME*WTCR
      NIMAS = RHOSS*CVOLUME*WTNI
```

```
      FEMAS = RHOSS*CVOLUME*WTFE
      SIMAS = RHOSS*CVOLUME*WTSI
      C12MAS = RHOSS*CVOLUME*WTC12
C
      CLADMAS=MNMAS+CRMAS+NIMAS+FEMAS+C12MAS+SIMAS
C
       U238MAS=U235MAS/ENRICH - U235MAS
       UMAS=U238MAS +U235MAS
       ZRHMAS=UMAS/WT_U - UMAS
       ZRMAS = ZRHMAS*MZR/(MZR+MH16)
       H16MAS = ZRHMAS*MH16/(MZR+MH16)
      TOTAL1= (ZRMAS + H16MAS + U238MAS +U235MAS)
      TOTAL = TOTAL1
      VOLTOT= FVOLUME
       WRITE(6,*) '    '
C
C
       WRITE(6,*) ' FUEL DENSITY =',
     *   (ZRMAS + H16MAS + U238MAS +U235MAS)/FVOLUME,' G.CC'
C
C     WRITING OUT THE SUMMARY TABLE
C
      WRITE(6,1005)
 1005 FORMAT(23X, ' VOLUME(CC)        MASS(G)',5X,'DENSITY (G/CC)')
      WRITE(6,1006) ZRVOLUME,ZRRODMAS,ZRRODMAS/ZRVOLUME
      WRITE(6,1007) REFLVOLUME,REFLMAS,REFLMAS/REFLVOLUME
      WRITE(6,1010) FVOLUME,H16MAS+U238MAS +U235MAS + ZRMAS,
     *              (H16MAS+U238MAS +U235MAS + ZRMAS)/FVOLUME
      WRITE(6,*) '    '
      WRITE(6,1024) U235MAS
      WRITE(6,1025) U238MAS
      WRITE(6,1026) U238MAS+U235MAS
      WRITE(6,1021) ZRMAS
      WRITE(6,1022) H16MAS
      WRITE(6,1023) ZRHMAS
      WRITE(6,*) '    '
 1021 FORMAT(1X,'      ZR MASS (FUEL)',14X,F14.3)
 1023 FORMAT(1X,'    ZRH MASS (FUEL) ',14X,F14.3)
 1022 FORMAT(1X,'     H16 MASS (FUEL)',14X,F14.3)
 1024 FORMAT(1X,'    U235 MASS (FUEL)',14X,F14.3)
 1025 FORMAT(1X,'    U238 MASS (FUEL)',14X,F14.3)
 1026 FORMAT(1X,' U235 + U238 (FUEL)',14X,F14.3)
C
      WRITE(6,1008) CVOLUME,CLADMAS,CLADMAS/CVOLUME
      WRITE(6,1013) VOLTOT,TOTAL,TOTAL/VOLTOT
 1006 FORMAT(1X,'  CENTRAL ZR ROD    ',3F14.3)
 1007 FORMAT(1X,'  END REFLECTORS    ',3F14.3)
 1008 FORMAT(1X,'  CLAD + END FITS   ',3F14.3)
 1009 FORMAT(1X,'  WATER ONLY        ',3F14.3)
 1010 FORMAT(1X,'  UZRH FUEL         ',3F14.3)
 1013 FORMAT(/,1X,'  TOTAL(FUEL+WATER)',3F14.3,/)
C
      N235 = U235MAS*AV/M235/VOLTOT
      N238 = U238MAS*AV/M238/VOLTOT
      NH = H16MAS*AV/MH/VOLTOT
      NHFUEL = H16MAS*AV/MH/VOLTOT
      NZR = ZRMAS*AV/MZR/VOLTOT
      NZR1 = ZRMAS*AV/MZR/VOLTOT
C
      WRITE(6,*) ' FUEL NUMBER DENSITY'
      WRITE(6,*) '       1',NH
```

```
      WRITE(6,*) '    401',NZR
      WRITE(6,*) '   2381',N238
      WRITE(6,*) '   2351',N235
C
      RATIO1 = NHFUEL/NZR1
      WRITE(6,*) ' H/ZR (NUMBER DENSITIES IN FUEL) = ',RATIO1
C
C ********** CALCULATE THE N(H)/N(U235)
C
       WRITE(6,*) '    '
       WRITE(6,*) ' DENSITY   NH/NU-235'
       DO 100 ITER=0,10,1
       RHO_WATER=0.1*FLOAT(ITER)
       N235TOT=N235*NPIN*21.0*FVOLUME
C
       CASK_RADIUS=33.65
       CASK_HEIGHT=140.64
       SLOT_HEIGHT=125.2728
       FA_HEIGHT=76.2
       FA_RADIUS=1.82245
       UNCOVERED_HEIGHT=CASK_HEIGHT - SLOT_HEIGHT
       WATER_TOP = PI*UNCOVERED_HEIGHT*CASK_RADIUS*CASK_RADIUS
       FA_VOLUME=NPIN*PI*FA_HEIGHT*FA_RADIUS*FA_RADIUS
       WATER_ONE_DIVIDER=71.12889*SLOT_HEIGHT - FA_VOLUME
       WATER_TOTAL = WATER_TOP + WATER_ONE_DIVIDER*21.0

       NHTOT=2.0*RHO_WATER*AV/18.0*WATER_TOTAL + NH*NPIN*21.0*FVOLUME
       RATIO6=NHTOT/N235TOT
       WRITE(6,*) RHO_WATER,RATIO6
 100   CONTINUE
       WRITE(6,*) ' TOTAL WATER VOLUME =',WATER_TOTAL,'CM^3'

C
C      WATER REFLECTOR CASE
C
       WRITE(6,*)
       WRITE(6,*) ' WATER REFLECTOR CASE'
       RAD_WR=48.56
       RAD_CASK=33.34
       HT_CASK=125.2728
       HT_WR=140.64+14.90
       VOL_WR=PI*(RAD_WR-RAD_CASK)*(RAD_WR-RAD_CASK)*(HT_WR-HT_CASK)
       WRITE(6,*) ' VOLUME OF WATER REFLECTOR =',VOL_WR,' CM^3'
       NHTOT=2.0*RHO_WATER*AV/18.0*WATER_TOTAL + NH*NPIN*21.0*FVOLUME
     *      + 2.0*RHO_WATER*AV/18.0*VOL_WR
       RATIO6=NHTOT/N235TOT
       WRITE(6,*) RHO_WATER,RATIO6
       END
```

6.7.7.5.7.2 FORTRAN Output for TRIGA Case V Fuel

```
INCONEL NUMBER DENSITY
    24  1.9481471E-02
    55  8.7801192E-04
    26  3.9731160E-02
    28  2.6300205E-02
   *************** GA SAR CASE TYPE 5 FUEL ******
  U235 MASS PER ELEMENT =   165.0000     GRAMS
  TOTAL U235 MASS=   165.0000     GRAMS
  NUMBER OF FUEL PINS =   4.000000
  FUEL OUTER RADIUS =   1.771650    CM   OR   0.6975000     INCHES
  CLAD OUTER RADIUS =   1.873250    CM  OR   0.7375000     INCHES
  FUEL ELEMENT LENGTH =   38.10000    CM OR    15.00000     INCHES
  TOTAL CLAD LENGTH =   55.37200    CM OR    21.80000     INCHES

  FUEL DENSITY =   5.679152     G.CC
                       VOLUME(CC)        MASS(G)     DENSITY (G/CC)
   CENTRAL ZR ROD          12.066        78.429         6.500
   END REFLECTORS         171.536       274.458         1.600
   UZRH FUEL              363.625      2065.081         5.679

    U235 MASS (FUEL)                     165.000
    U238 MASS (FUEL)                      10.532
  U235 + U238 (FUEL)                     175.532
      ZR MASS (FUEL)                    1856.725
    H16 MASS (FUEL)                      32.824
    ZRH MASS (FUEL)                    1889.549

   CLAD + END FITS          64.420       503.780         7.820

   TOTAL(FUEL+WATER)       363.625      2065.082         5.679

  FUEL NUMBER DENSITY
       1  5.3931881E-02
     401  3.3707429E-02
    2381  7.3269803E-05
    2351  1.1625778E-03
  H/ZR (NUMBER DENSITIES IN FUEL) =    1.600000

  DENSITY   NH/NU-235
  0.0000000E+00   46.38992
  0.1000000       79.36446
  0.2000000       112.3390
  0.3000000       145.3135
  0.4000000       178.2881
  0.5000000       211.2626
  0.6000000       244.2372
  0.7000000       277.2117
  0.8000000       310.1862
  0.9000000       343.1608
   1.000000       376.1353
  TOTAL WATER VOLUME =   174999.0    CM^3

  WATER REFLECTOR CASE
  VOLUME OF WATER REFLECTOR =   22026.80     CM^3
   1.000000       417.6398
```

6.7.7.5.8 Geometrical Plots of the TRIGA Case V Fuel — Side and Sectional Views

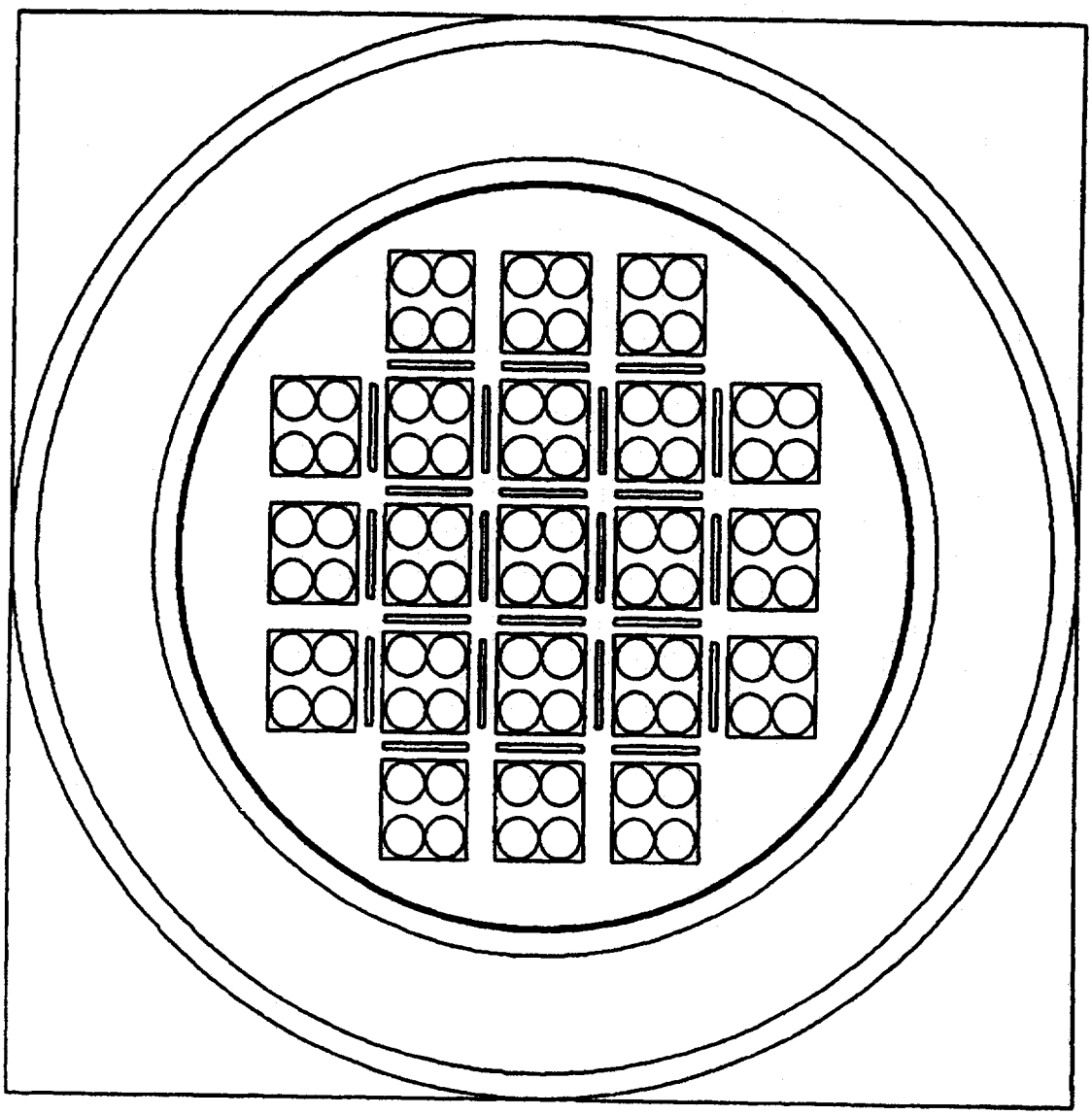


Figure 6.96. Sectional View (Z = 5 cm) for TRIGA Case V Fuel

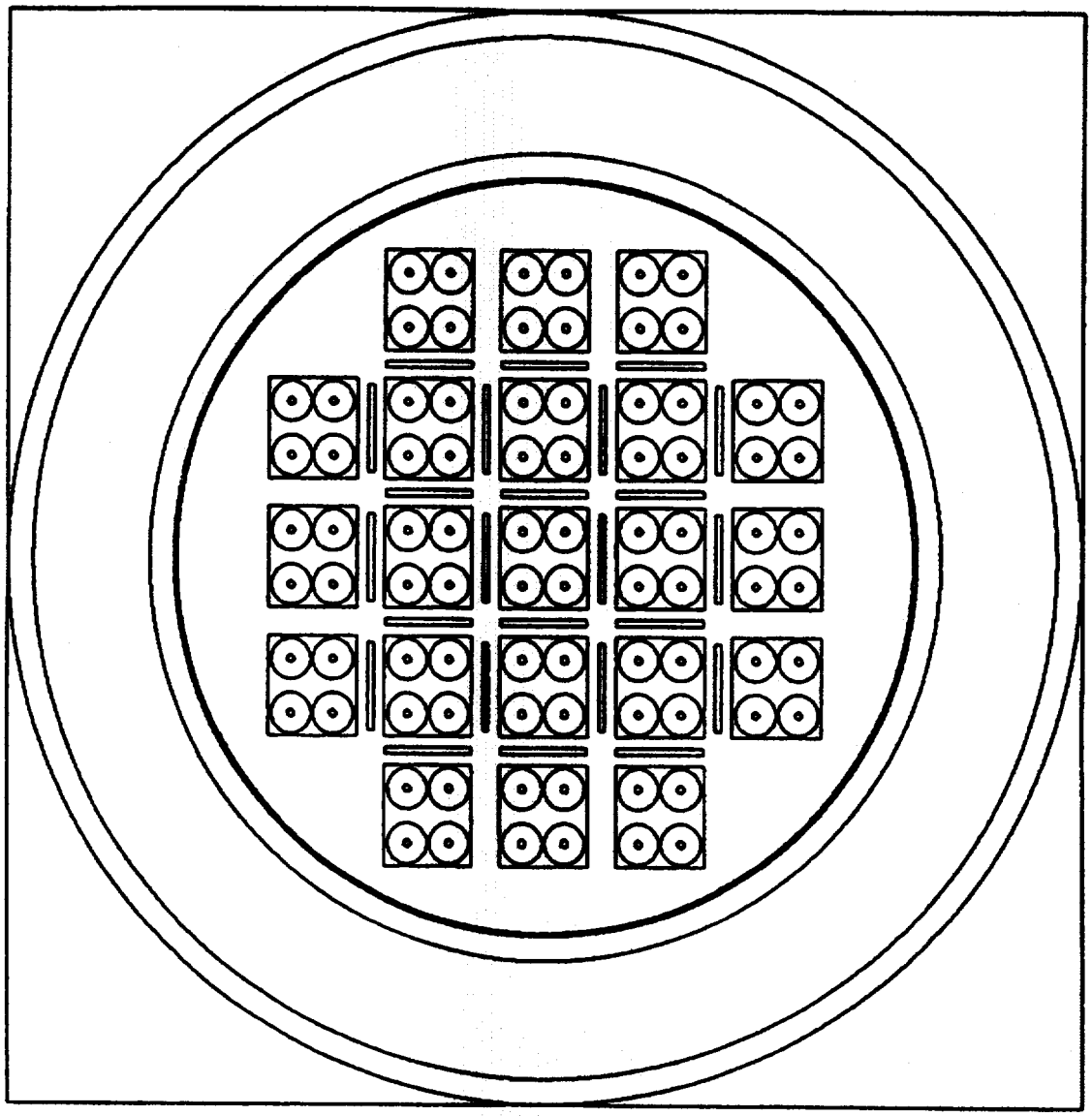


Figure 6.97. Sectional View (Z = 40 cm) for TRIGA Case V Fuel

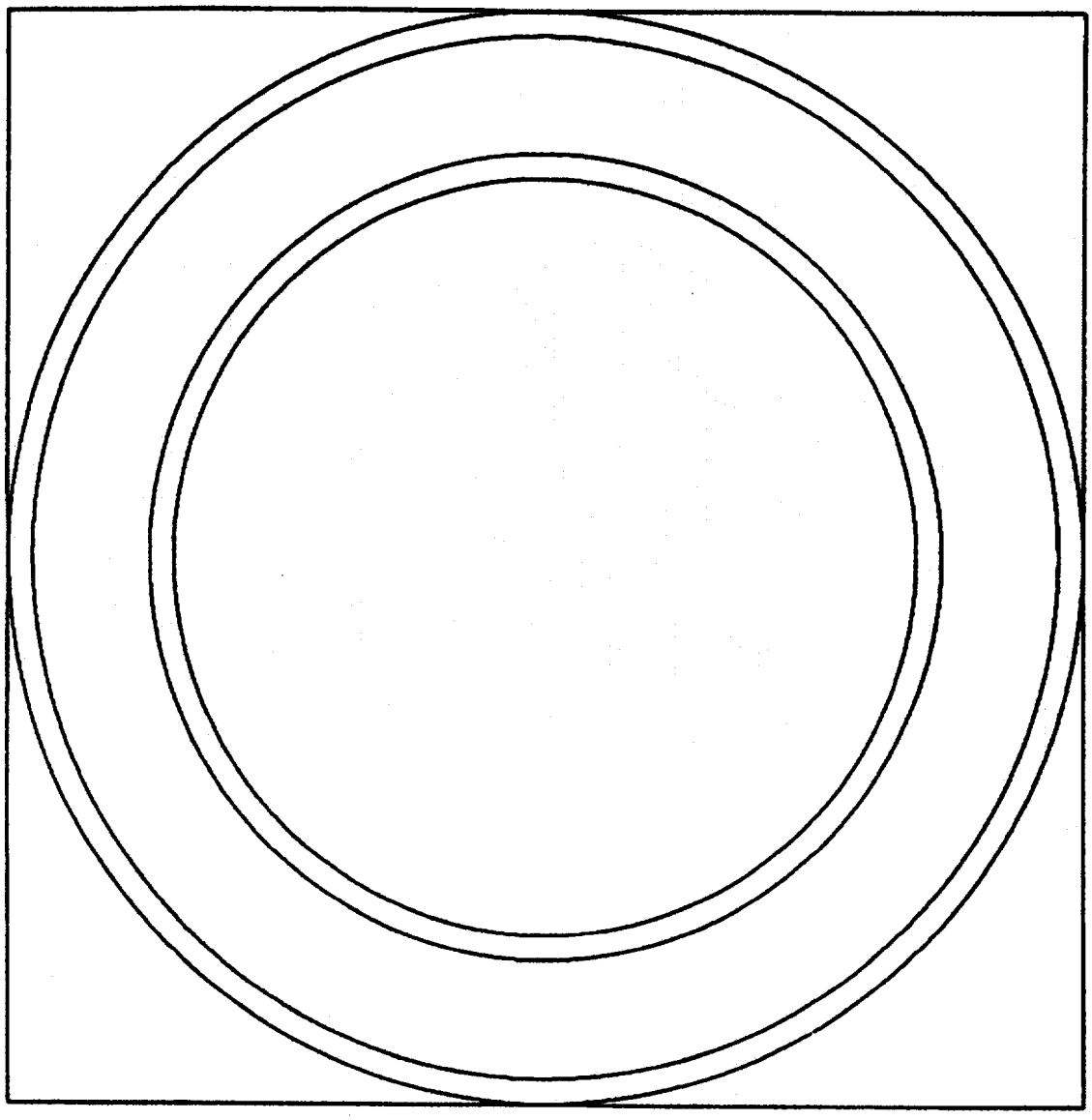


Figure 6.98. Sectional View (Z = 130 cm) for TRIGA Case V Fuel

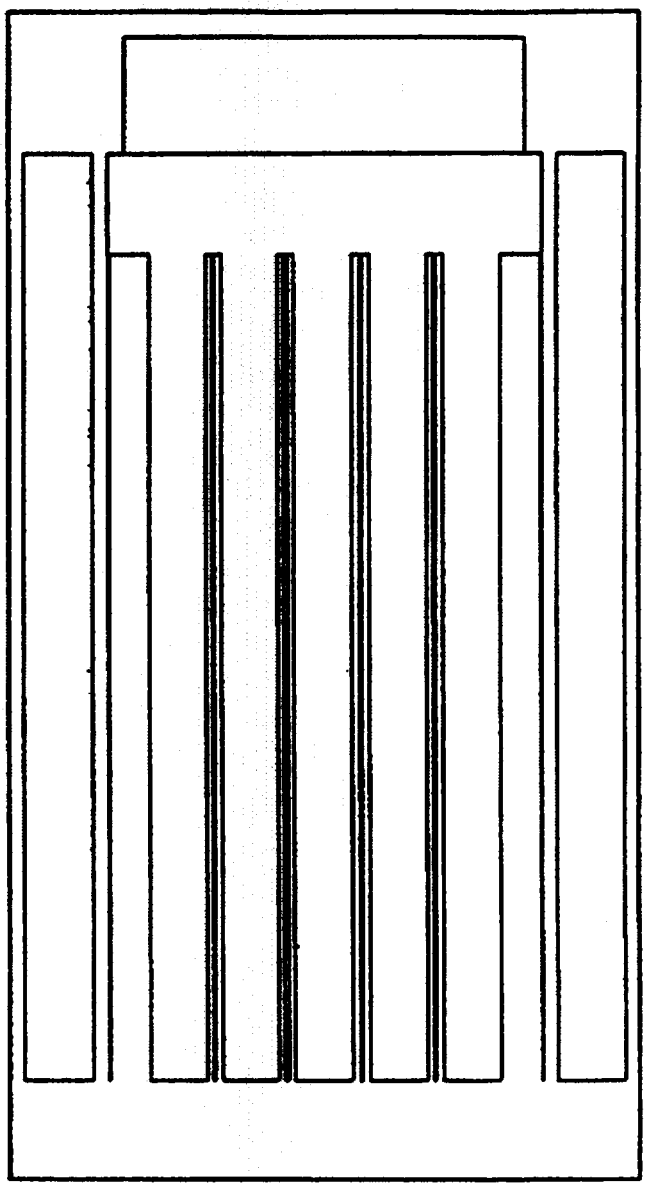


Figure 6.99. Side View for TRIGA Case V Fuel

6.7.7.5.9 GEMER Input Decks for TRIGA Case VIII Fuel

This section includes GEMER geometrical plots and input listings for the infinite array. Each NBSR basedeck contains a "header" with fuel material and geometry information.

6.7.7.5.10 Infinite Case (94.0% Enriched Fuel) for TRIGA Case VIII Fuel

```
TRIGA8 / IF2000/21 ELEMENTS, SS+Pb SHIELDING. 5x4 LOADING, U235 IN EACH
ELEM
   105 /* # BATCHES
  1000  /* # NEUTRONS PER BATCH
     5  /* # BATCHES TO SKIP
 2123469/* INITIAL "SEED" (IF NON-ZERO)
     0  /* "IDUMP"
     0  /* "NRSTRT"
     0  /* "NBTED" (NON-ZERO IS PRINT EDITS)
     0  /* "KRED" (NUMBER OF COMBINED REGIONS IN EDITS)
     0  293   18  11
      4  293 0  0  U(94%)ZRH1.6   33.0 GRAM/FA MAT 1
       1  4.4526186E-02
     401  2.7828865E-02
    2381  7.2352668E-05
    2351  1.1480256E-03
      3  293 0 0 Boral 0.25" Plate (75% Boron Loading)  MAT 2
    10    4.15822E-03
    11    8.48616E-05
   131    5.8001E-02
      2  293 0 0  MODERATOR IN CASK (100.00%)           MAT 3
     1   6.69111121E-02
    16   3.34555566E-02
      1  293 0 0 LEAD SHIELDING                        MAT 4
    82   3.29890E-02
      7  293 0 0 304 STAINLESS STEEL                   MAT 5
    12   6.82690E-05
    14   8.53360E-04
    24   1.53600E-02
    26   6.04950E-02
    28   6.82690E-03
    55   1.70670E-03
  1316   2.56010E-05
     2  293 0 0 FULL DENSITY WATER (100%)             MAT 6
     1    6.69111121E-02
    16    3.34555566E-02
     1  293 0 0 AL CLADDING                           MAT 7
   131    6.026464E-02
    2  293 0 0 FULL DENSITY WATER (VOID)             MAT 8
     1    6.69111121E-09
    16    3.34555566E-09
     1  293 0 0 GRAPHITE                              MAT 9
    12    0.1366692
     1  293 0 0 ZIRCOLOY-2                            MAT 10
   401    0.0432825
      4  293 0  0  INCOLOY 8.01 G/CC 21% CR 1% MN 46% FE  32% NI MAT 11
     24   1.9481473E-02
     55   8.78012E-05
     26   3.973116E-02
     28   2.630021E-02
```

```
KENO GEOM
    18  /* "KREFM"
     9  /* "NBOX"
     1  /* "NBXMAX"
     1  /* "NBYMAX"
     1  /* "NBZMAX"
     1  /* "NXX"
     0  /* "NTYPST"
     1  /* "NEMBRG"
     0  /* "NGMCHK"
 -1.0  -1.0  -1.0  -1.0  -1.0  -1.0
BOX TYPE     1 /*MODEL 2000 CASK & STAINLESS SUPPORT STRUCTURE
CYLINDER     6  33.65     140.64     0.0    16*0.5
CYLINDER     5  35.85     140.64     0.0    16*0.5
CYLINDER     4  46.34     140.64     0.0    16*0.5
CYLINDER     5  48.56     140.64   -14.90   16*0.5
BOX TYPE     2 /* CASK TOP
CYLINDER     4  30.96     158.42    140.64  16*0.5
CYLINDER     5  48.56     162.23    140.64  16*0.5
BOX TYPE     3 /* 21 SLOTS FILLED WITH WATER  125.2778 CM HIGH
CUBOID       6  4.4450 -4.4450  4.0005  -4.0005  125.2728  0.0   16*0.5
BOX TYPE     4 /* 21 SLOTS FILLED WITH WATER      ***   EXTENDED HEIGHT
CUBOID       6  4.4450 -4.4450  4.0005  -4.0005  15.35  0.00  16*0.5
BOX TYPE     5 /* BORAL PLATE (VERT)  125.2728 CM (49.32")
CUBOID       2  0.2667  -0.2667  3.937  -3.937  125.2728  0.0   16*0.5
BOX TYPE     6 /* BORAL PLATE (HORIZ) MODELED AS 3.1" X 0.21" X 49.32"
MIN DIMENSIONS
CUBOID       2  3.937  -3.937  0.2667  -0.2667  125.2728  0.0   16*0.5
BOX TYPE     7 /* TRIGA FUEL PIN           90 CM HIGH
CYLINDER     1  0.64770    66.04    10.16    16*0.5   /* FUEL R=0.255"
CYLINDER    11  0.68834    66.04    10.16    16*0.5   /* CLAD R=0.271"
CYLINDER    11  0.68834    68.58    0.000    16*0.5   /* 4" BOT. PLENUM,
1" TOP ENDPLUG
CUBOID       6  0.87376  -0.87376  0.87376 -0.87376  90.0 0.0 16*0.5
BOX TYPE     8
CYLINDER     5  33.34     125.2728     0.0    16*0.5
BOX TYPE     9  /* OVERALL BOX FOR THE PROBLEM
CUBOID       6  48.60    -48.60   48.60 -48.60 162.23 -14.91 16*0.5
CORE         0  48.60    -48.60   48.60 -48.60 162.23 -14.91 16*0.5
CUBOID       6  48.70    -48.70   48.70 -48.70 162.33 -15.01 16*0.5
9  1 1 1  1 1 1  1 1 1  1
BEGIN COMPLEX
/* PLACE THE FUEL PLATES INTO THE SLOT
/*                                  PX=   PITCH (X) = 1.778 CM
/*                                  PY=   PITCH (Y) = 1.8669 CM
/* BOX TYPE 3 FOR NORMAL HEIGHT
/*     (-2.0 PX,-1.5PY)
COMPLEX  3  7  -3.556  -3.00038  0.0  5  4  1  1.778  2.00025  0.0
/*5X4 FUEL PINS
/* PLACE FUEL ASSEMBLIES INTO CASK    NORMAL HEIGHT
COMPLEX  8  3   -22.860  -10.540  0.0  5  3  1  11.430  10.540  0.0
/*MIDDLE ROWS
COMPLEX  8  3   -11.430  -21.080  0.0  3  2  1  11.430  42.160  0.0
/*OUTER ROWS
/* PLACE BORAL PLATES INTO CASK
COMPLEX  8  5   -17.145  -10.540  0.0  4  3  1  11.430  10.540  0.0
/*VERT PLATES
COMPLEX  8  6   -11.430  -15.810  0.0  3  4  1  11.430  10.540  0.0
/*HORIZ PLATES
/* PLACE LOWER SECTION (NORMAL HEIGHT) INTO THE BOX TYPE 1
COMPLEX  1  8  0.0   0.0   0.0   1  1  1   0.0  0.0  0.0
```

```
/* PLACE PROTRUDED SECTION (EXTENDED HEIGHT) INTO THE BOX TYPE 1
/* COMPLEX  1 10  0.0   0.0   125.2728   1  1  1   0.0  0.0  0.0
/* PLACE LOADED CASK INTO OVERALL PROBLEM BOX
COMPLEX  9  1  0.0     0.0    0.0   1 1 1   0.0    0.0    0.0
/* PLACE TOP INTO OVERALL PROBLEM BOX
COMPLEX  9  2  0.0     0.0    0.0   1 1 1   0.0    0.0    0.0
END GEOM
*END GEMER*
```

6.7.7.5.11 Number Density Calculations for TRIGA Case VIII Fuel

6.7.7.5.11.1 FORTRAN Program

```
PROGRAM NUMBER
C
C   PRODUCTION RUN
C   9/18/96
C                          AKC
C    U-235 (94% ENRICHMENT CASE)
C
C                          AKC
C    U-235 (% ENRICHMENT CASE)
C    STAINLESS STEEL CLAD (FLIP TYPE OF TRIGA FUEL)
C    22" ACTIVE FUEL LENGTH, 0.542" O.D. FUEL ELEMENT,
C                            0.016" CLADDING THICKNESS
C
C   NO ZR ROD
C
      REAL NPIN,N235TOT,NHTOT

      REAL M235,M238
      REAL U235MAS,U238MAS
      REAL MZR,MU,MH,MH16,MH20
      REAL N235,N238,NH,NZR,NZR1,NHFUEL
      REAL MNI,MCR,MMN,MFE,MC12,MSI
      REAL FEMAS,CRMAS,NIMAC,MNMAS
      REAL NNI,NMN,NFE,NCR,NSI,NC12
      REAL LREFL
      REAL N24,N55,N26,N28
C
      DATA PI/3.14159265/
C
      OPEN(6,FILE='P.OUT',STATUS='UNKNOWN')
      AV=0.6022
      M235 =235.0439
      M238 =238.0508
      MZR=91.224
      MH=1.00794
      MH16=1.6*MH
      MH2O=18.0153
C
C
C      INCONEL
C
       MCR=51.9961
       MMN=54.938
       MFE=55.847
       MNI=58.690
C
C
C   CALCULATE THE INCONEL DENSITY
       RHOINC=8.01
       N24=RHOINC*0.21*AV/MCR
       N55=RHOINC*0.01*AV/MMN
       N26=RHOINC*0.46*AV/MFE
       N28=RHOINC*0.32*AV/MNI
C
```

```
      WRITE(6,*)
      WRITE(6,*) ' INCONEL NUMBER DENSITY'
      WRITE(6,*) '   24',N24
      WRITE(6,*) '   55',N55
      WRITE(6,*) '   26',N26
      WRITE(6,*) '   28',N28
C
     WRITE(6,*)  '  *************** TRIGA CASE VIII FUEL ******'
C
C      *****INPUTS********
C    WT_U = WEIGHT OF URANIUM
C    WT_U IS CALCULATED BASED ON A UZRH MASS OF 2360 G
C     SEE NUCL. TECH. VOL 105, 1/94, PAGE 42, PAPER BY MELE ETC.
C    BACK CALCULATE WT_U TO BE 0.188446   12/14/98
C
     WT_U=0.10
C
C    RHOZR=ZR DENSITY (G/CC)
C    RHOREFL = REFLECTOR (GRAPHITE) DENSITY IN G/CC
     RHOZR=6.50
     RHOREFL = 1.60
C    U235GRAM = U235 WEIGHT PER ELEMENT IN GRAMS
C    ER-167 MASS IGNORED.
C
C    WEIGHT OF U-235 PER FUEL ELEMENT
C
C
C      U235GRAM=35.0
C
      U235GRAM=33.0
      NPIN=20.0
      ENRICH=0.94
C
C
C
     U235MAS=U235GRAM
     WRITE(6,*) ' U235 MASS PER ELEMENT =',U235MAS,' GRAMS'
     WRITE(6,*) ' TOTAL U235 MASS=',U235MAS,' GRAMS'
     WRITE(6,*) ' NUMBER OF FUEL PINS =',NPIN
C
C   RHOSS = STAINLESS STEEL DENSITY (G/CC)
     RHOSS=7.8266
C   RFUEL = FUEL OUTER RADIUS (CM)
C   RCLAD = CLAD OUTER RADIUS (CM)
C     RZRROD=0.25*2.54/2.0
     RZRROD=0.00
C
C     RFUEL=1.395*2.54/2.0
C     RCLAD=1.475*2.54/2.0
C
C     RFUEL=(0.542/2.0-0.016)*2.54
     RFUEL=0.6477
     RCLAD=0.542/2.0*2.54
C
C
C  FLENGTH = FUEL ACTIVE LENGTH IN CM
C  FCLENGTH = CLAD LENGTH + ACTIVE FUEL LENGTH IN CM
C
     FLENGTH=22.0*2.54
     FCLENGTH=(4.0+1.0)*2.54 + FLENGTH
     WRITE(6,*) ' FUEL OUTER RADIUS =',RFUEL,'CM   OR ',
```

```
     * RFUEL/2.54,' INCHES'
      WRITE(6,*) ' CLAD OUTER RADIUS =',RCLAD,'CM  OR ',
     *            RCLAD/2.54,' INCHES'
      WRITE(6,*) ' FUEL ELEMENT LENGTH =',FLENGTH,'CM OR ',
     *           FLENGTH/2.54,' INCHES'
      WRITE(6,*) ' TOTAL CLAD LENGTH =',FCLENGTH,'CM OR ',
     *           FCLENGTH/2.54,' INCHES'
C
C     VOL_ENDFIT= 118*1.224/8.01
C               = 18.01   (PREVIOUS DESIGN)
C    CLADDING IS STAINLESS STEEL-304
C    CLAD = FUEL CLAD + END FITS + CLAD OVER GRAPHITE REFLECTORS
C
C     VOL_ENDFIT = 69.153 CC (FROM S. JAIN  8/5/96)
C
      VOL_ENDFIT = 0.0
      CVOLUME = PI*(RCLAD*RCLAD-RFUEL*RFUEL)*FCLENGTH
     *         + VOL_ENDFIT

C
C      NEXT THE CENTRAL ZR ROD:
C
C      RZRROD=0.25*2.54/2.0
C     ZRVOUME = VOULUME OF ZR RODS IN THE CENTER
C
C      ZRVOLUME = PI*RZRROD*RZRROD*FLENGTH
C      ZRRODMAS = ZRVOLUME*RHOZR
C
C     RREFL = GRAPHITE END REFLECTOR RADIUS (CM)
C     REFLVOLUME= REFLECTOR VOLUME (CC)
C     LREFL = TOTAL LENGTH OF BOTH REFLECTORS (CM)
C     REFLMAS = REFLECTOR MASS (G)
C
      RREFL = 1.40*2.54/2.0
      LREFL = (3.4+3.4)*2.54
      REFLVOLUME =PI*RREFL*RREFL*LREFL
C      ZRVOLUME = PI*RZRROD*RZRROD*FLENGTH
C      REFLMAS= REFLVOLUME*RHOREFL
C
      FVOLUME=PI*(RFUEL*RFUEL-RZRROD*RZRROD)*FLENGTH
C      FCVOLUME=FVOLUME+CVOLUME
C
C    CALCULATING THE CLAD MASSES
C
      WTMN=0.020013
      WTCR=0.180116
      WTNI=0.080145
      WTFE=0.70892
      WTC12=0.0008
      WTSI=0.010006
C
      MNMAS = RHOSS*CVOLUME*WTMN
      CRMAS = RHOSS*CVOLUME*WTCR
      NIMAS = RHOSS*CVOLUME*WTNI
      FEMAS = RHOSS*CVOLUME*WTFE
      SIMAS = RHOSS*CVOLUME*WTSI
      C12MAS = RHOSS*CVOLUME*WTC12
C
      CLADMAS=MNMAS+CRMAS+NIMAS+FEMAS+C12MAS+SIMAS
C
       U238MAS=U235MAS/ENRICH - U235MAS
```

```
       UMAS=U238MAS +U235MAS
       ZRHMAS=UMAS/WT_U - UMAS
       ZRMAS = ZRHMAS*MZR/(MZR+MH16)
       H16MAS = ZRHMAS*MH16/(MZR+MH16)
      TOTAL1= (ZRMAS + H16MAS + U238MAS +U235MAS)
      TOTAL = TOTAL1
      VOLTOT= FVOLUME
       WRITE(6,*) '    '
C
C
       WRITE(6,*) ' FUEL DENSITY =',
     *   (ZRMAS + H16MAS + U238MAS +U235MAS)/FVOLUME,' G.CC'
C
C     WRITING OUT THE SUMMARY TABLE
C
      WRITE(6,1005)
 1005 FORMAT(23X, ' VOLUME(CC)        MASS(G)',5X,'DENSITY (G/CC)')
C      WRITE(6,1006) ZRVOLUME,ZRRODMAS,ZRRODMAS/ZRVOLUME
C      WRITE(6,1007) REFLVOLUME,REFLMAS,REFLMAS/REFLVOLUME
      WRITE(6,1010) FVOLUME,H16MAS+U238MAS +U235MAS + ZRMAS,
     *              (H16MAS+U238MAS +U235MAS + ZRMAS)/FVOLUME
      WRITE(6,*) '    '
      WRITE(6,1024) U235MAS
      WRITE(6,1025) U238MAS
      WRITE(6,1026) U238MAS+U235MAS
      WRITE(6,1021) ZRMAS
      WRITE(6,1022) H16MAS
      WRITE(6,1023) ZRHMAS
      WRITE(6,*) '    '
 1021 FORMAT(1X,'      ZR MASS (FUEL)',14X,F14.3)
 1023 FORMAT(1X,'    ZRH MASS (FUEL) ',14X,F14.3)
 1022 FORMAT(1X,'     H16 MASS (FUEL)',14X,F14.3)
 1024 FORMAT(1X,'    U235 MASS (FUEL)',14X,F14.3)
 1025 FORMAT(1X,'    U238 MASS (FUEL)',14X,F14.3)
 1026 FORMAT(1X,' U235 + U238 (FUEL)',14X,F14.3)
C
      WRITE(6,1008) CVOLUME,CLADMAS,CLADMAS/CVOLUME
      WRITE(6,1013) VOLTOT,TOTAL,TOTAL/VOLTOT
 1006 FORMAT(1X,'  CENTRAL ZR ROD    ',3F14.3)
 1007 FORMAT(1X,'  END REFLECTORS    ',3F14.3)
 1008 FORMAT(1X,'  CLAD + END FITS   ',3F14.3)
 1009 FORMAT(1X,'  WATER ONLY        ',3F14.3)
 1010 FORMAT(1X,'  UZRH FUEL         ',3F14.3)
 1013 FORMAT(/,1X,'  TOTAL(FUEL+WATER)',3F14.3,/)
C
      N235 = U235MAS*AV/M235/VOLTOT
      N238 = U238MAS*AV/M238/VOLTOT
      NH = H16MAS*AV/MH/VOLTOT
      NHFUEL = H16MAS*AV/MH/VOLTOT
      NZR = ZRMAS*AV/MZR/VOLTOT
      NZR1 = ZRMAS*AV/MZR/VOLTOT
C
      WRITE(6,*) ' FUEL NUMBER DENSITY'
      WRITE(6,*) '       1',NH
      WRITE(6,*) '     401',NZR
      WRITE(6,*) '    2381',N238
      WRITE(6,*) '    2351',N235
C
      RATIO1 = NHFUEL/NZR1
      WRITE(6,*) ' H/ZR (NUMBER DENSITIES IN FUEL) = ',RATIO1
C
```

```
C ********** CALCULATE THE N(H)/N(U235)
C
      WRITE(6,*) '    '
      WRITE(6,*) ' DENSITY   NH/NU-235'
      DO 100 ITER=0,10,1
      RHO_WATER=0.1*FLOAT(ITER)
      N235TOT=N235*NPIN*21.0*FVOLUME
C
      CASK_RADIUS=33.65
      CASK_HEIGHT=140.64
      SLOT_HEIGHT=125.2728
C
      FA_HEIGHT=30.37*2.54
      FA_RADIUS=0.271*2.54
C
      UNCOVERED_HEIGHT=CASK_HEIGHT - SLOT_HEIGHT
      WATER_TOP = PI*UNCOVERED_HEIGHT*CASK_RADIUS*CASK_RADIUS
      FA_VOLUME=NPIN*PI*FA_HEIGHT*FA_RADIUS*FA_RADIUS
      WATER_ONE_DIVIDER=71.12889*SLOT_HEIGHT - FA_VOLUME
      WATER_TOTAL = WATER_TOP + WATER_ONE_DIVIDER*21.0

      NHTOT=2.0*RHO_WATER*AV/18.0*WATER_TOTAL + NH*NPIN*21.0*FVOLUME
C      NHTOT=RHO_WATER*AV/18.0*WATER_TOTAL
      RATIO6=NHTOT/N235TOT
      WRITE(6,*) RHO_WATER,RATIO6
 100  CONTINUE
      WRITE(6,*) ' TOTAL WATER VOLUME =',WATER_TOTAL,'CM^3'


C
C     WATER REFLECTOR CASE
C
      WRITE(6,*)
      WRITE(6,*) ' WATER REFLECTOR CASE'
      RAD_WR=48.56
      RAD_CASK=33.34
      HT_CASK=125.2728
      HT_WR=140.64+14.90
      VOL_WR=PI*(RAD_WR-RAD_CASK)*(RAD_WR-RAD_CASK)*(HT_WR-HT_CASK)
      WRITE(6,*) ' VOLUME OF WATER REFLECTOR =',VOL_WR,' CM^3'
      NHTOT=2.0*RHO_WATER*AV/18.0*WATER_TOTAL + NH*NPIN*21.0*FVOLUME
     *     + 2.0*RHO_WATER*AV/18.0*VOL_WR
      RATIO6=NHTOT/N235TOT
      WRITE(6,*) RHO_WATER,RATIO6

      END
```

6.7.7.5.11.2 FORTRAN Output for TRIGA Case VIII Fuel

```
INCONEL NUMBER DENSITY
    24  1.9481471E-02
    55  8.7801192E-04
    26  3.9731160E-02
    28  2.6300205E-02
   *************** TRIGA CASE VIII FUEL ******
  U235 MASS PER ELEMENT =   33.00000     GRAMS
  TOTAL U235 MASS=   33.00000     GRAMS
  NUMBER OF FUEL PINS =   20.00000
  FUEL OUTER RADIUS =  0.6477000    CM   OR   0.2550000     INCHES
  CLAD OUTER RADIUS =  0.6883400    CM  OR   0.2710000     INCHES
  FUEL ELEMENT LENGTH =   55.88000    CM OR    22.00000     INCHES
  TOTAL CLAD LENGTH =   68.58000    CM OR    27.00000     INCHES

  FUEL DENSITY =   4.766855     G.CC
                        VOLUME(CC)        MASS(G)     DENSITY (G/CC)
   UZRH FUEL                73.647       351.064         4.767

    U235 MASS (FUEL)                      33.000
    U238 MASS (FUEL)                       2.106
  U235 + U238 (FUEL)                      35.106
      ZR MASS (FUEL)                     310.469
     H16 MASS (FUEL)                       5.489
    ZRH MASS (FUEL)                     315.957

   CLAD + END FITS          11.698        91.220         7.798

   TOTAL(FUEL+WATER)        73.647       351.064         4.767

  FUEL NUMBER DENSITY
       1  4.4526186E-02
     401  2.7828865E-02
    2381  7.2352668E-05
    2351  1.1480256E-03
  H/ZR (NUMBER DENSITIES IN FUEL) =    1.600000

  DENSITY   NH/NU-235
  0.0000000E+00   38.78502
  0.1000000       75.25700
  0.2000000       111.7290
  0.3000000       148.2010
  0.4000000       184.6730
  0.5000000       221.1449
  0.6000000       257.6169
  0.7000000       294.0889
  0.8000000       330.5609
  0.9000000       367.0328
   1.000000       403.5049
  TOTAL WATER VOLUME =   193560.2    CM^3

  WATER REFLECTOR CASE
  VOLUME OF WATER REFLECTOR =   22026.80     CM^3
   1.000000       445.0093
```

6.7.7.5.12 Geometrical Plots of the TRIGA Case VIII Fuel — Side and Sectional Views

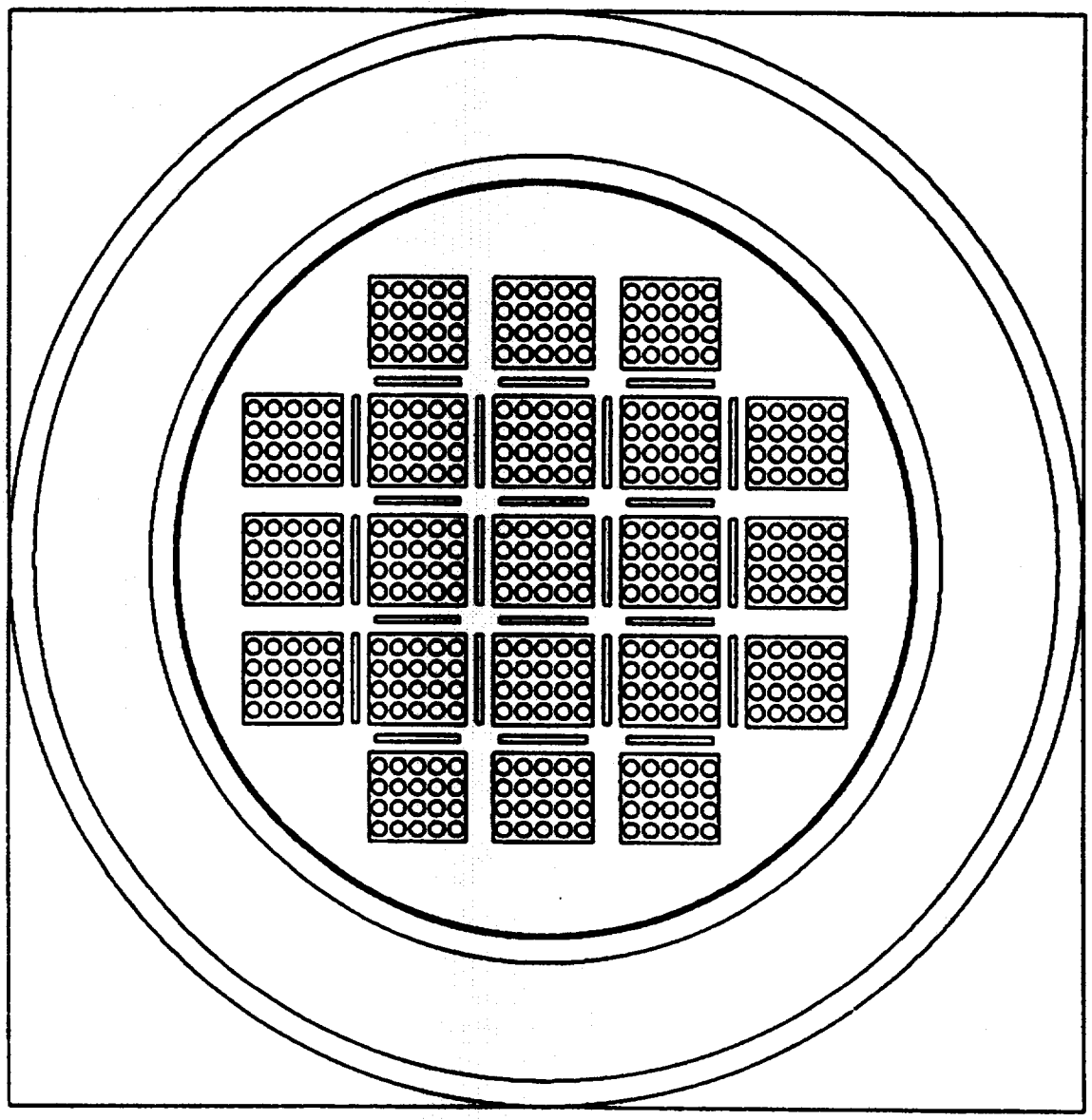


Figure 6.100. Sectional View (Z = 5 cm) for TRIGA Case VIII Fuel

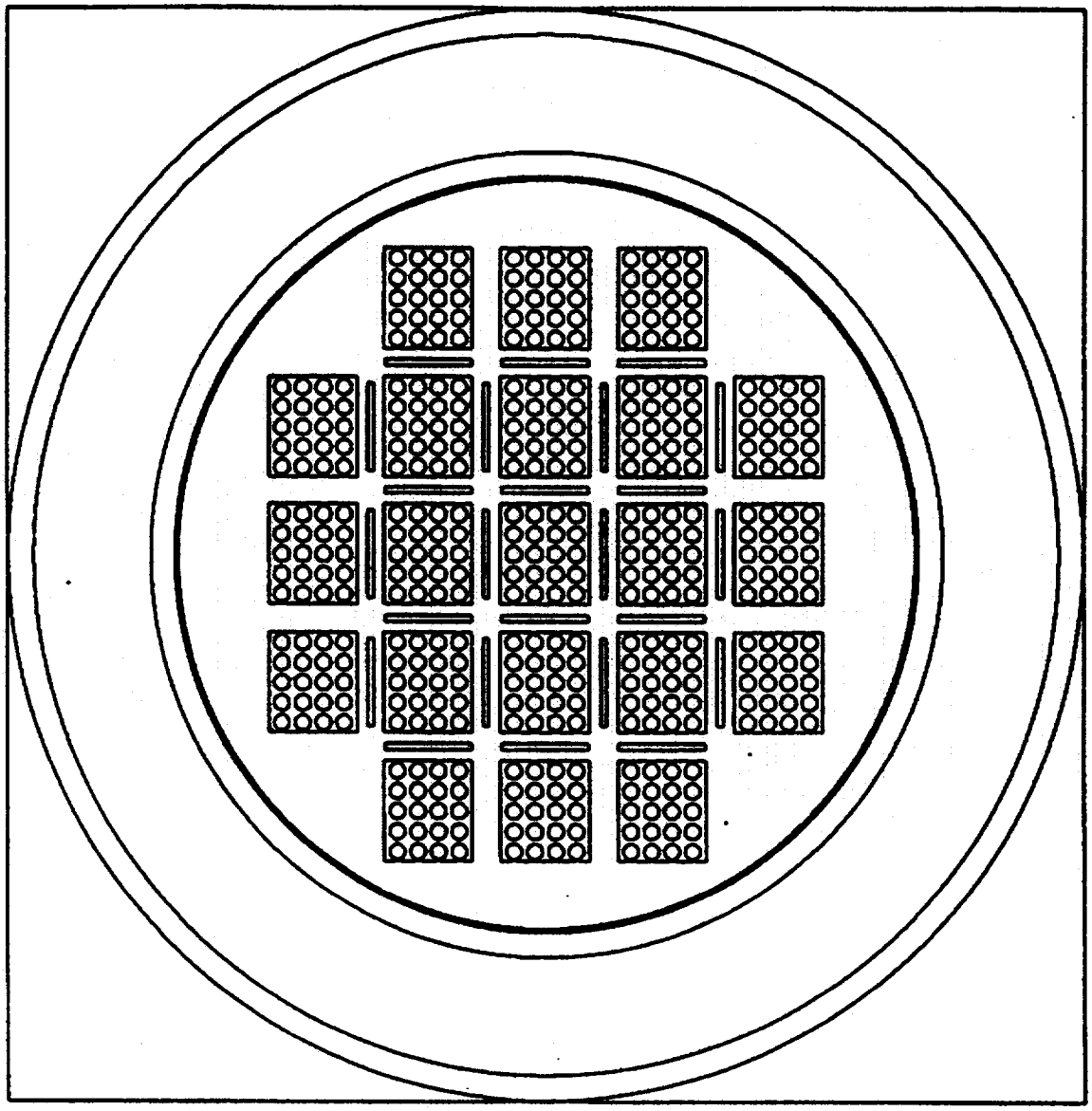


Figure 6.101. Sectional View (Z = 40 cm) for TRIGA Case VIII Fuel

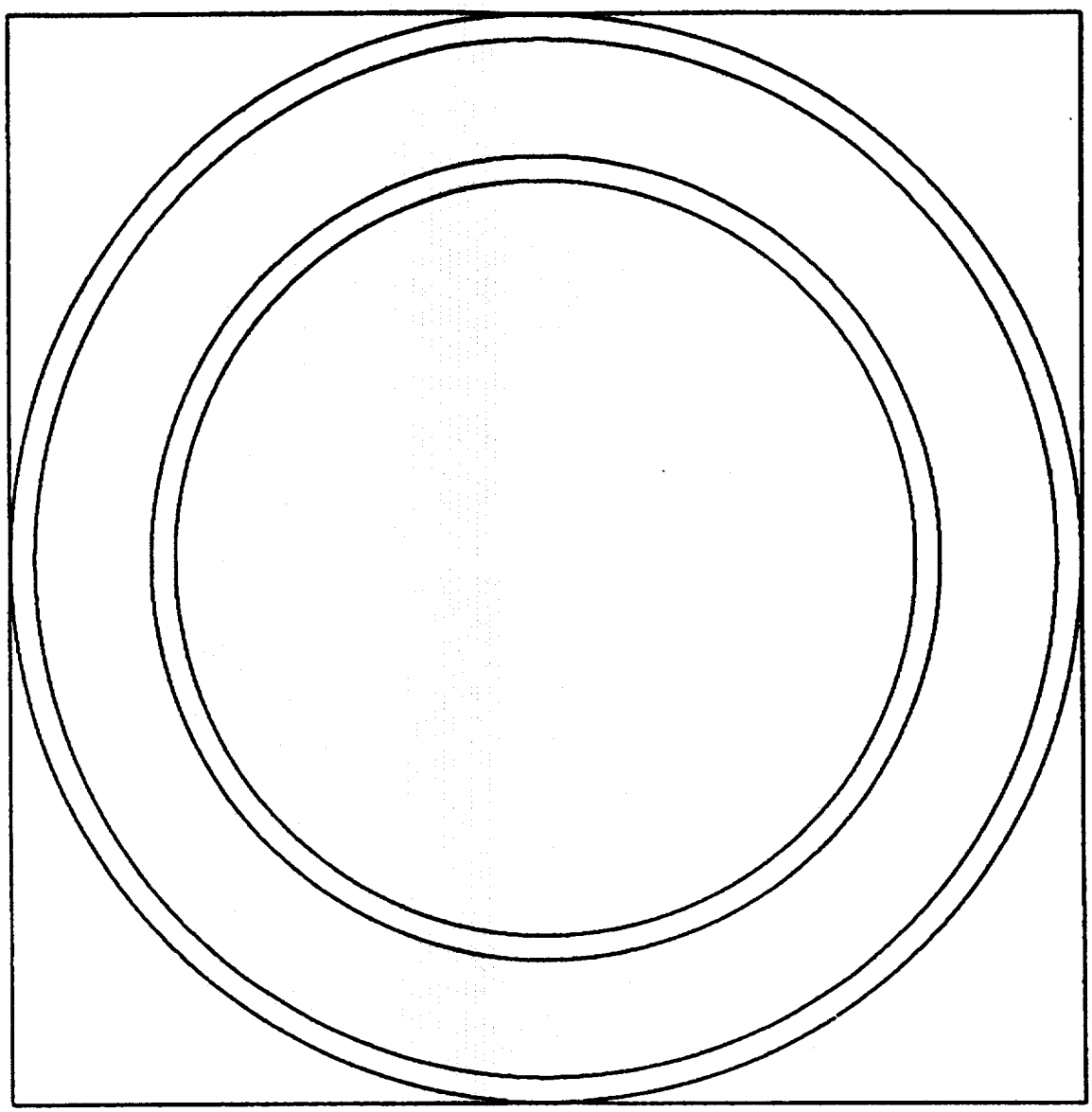


Figure 6.102. Sectional View (Z = 130 cm) for TRIGA Case VIII Fuel

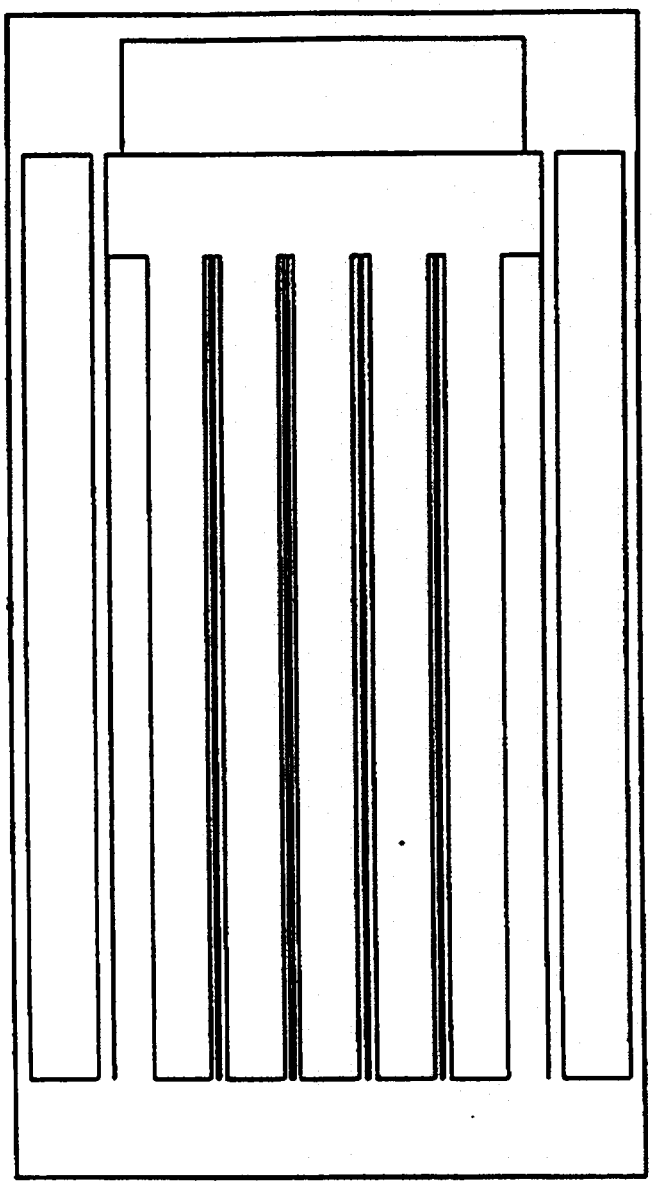


Figure 6.103. Side View for TRIGA Case VIII Fuel

6.7.8 Criticality Evaluation of VR-1 MTR Fuel

6.7.8.1 Introduction

The goal of the LTR submittal is to address the criticality safety of the Venezuelan fuel type. The Petten (PT) fuel bundle which consists of UAl_X alloy will be treated as a variant of the MTR Type III fuel. This MTR fuel type will be classified as MTR Type III-B fuel. This fuel differs from the MTR Type III fuel in the following:

The fuel loading is higher (460 grams of U-235 vs. xxx grams in Type III)

6.7.8.2 MTR Type III-B Fuel Key Criticality Assumptions

The key assumptions used in the criticality analysis of MTR Type III-B fuels are as follows:

1. The central divider slot is not used. It is filled with stainless steel. Hence, a total of 20 divider slots are used in this analysis.
2. The borated aluminum plates used for reactivity control are conservatively modeled. Only 75% of the boron atoms are accounted for in the calculations.
3. 3. The borated aluminum plates, typically 3.25 inches (8.255 cm) x 0.25 inches (0.635 cm) x 49.32 inches (125.2728 cm), are conservatively treated as 3.1 inches (7,874 cm) x 0.21 inches (0.5334 cm) x 49.32 inches (125.2728 cm).
4. All MTR Type III-B fuel is analyzed in fresh fuel condition. All burnable poisons will be zeroed out in the fresh fuel. This is a conservative assumption.
5. The MTR fuel elements are modelled in a most conservative but credible position, with all fuel elements protruding from the 21 slots to the maximum possible extent. This maximizes the reactivity in the system.
6. The fission products in the MTR Type III-B fuel will be ignored in this analysis. This is a conservative assumption.

For MTR Type III-B fuel, the maximum U-235 loading is 460x2 = 920 grams per divider position for two RV-1 fuel elements and the maximum U-235 enrichment is 19.92% (see Table 6.149). For conservatism purposes, the maximum loading analyzed for MTR Type III-B fuel is taken to be 300 grams and the U-235 enrichment is taken to be 20% enrichment.

6.7.8.3 MTR Type III-B Fuel (UAl) Description

Table 6.149 provides nominal dimensions and nuclear data for MTR Type III-B fuel (PT) to which this analysis applies. Fuel assemblies for these reactors are similarly constructed aluminum clad plates with UAl fuel material. The GEMER model for the MTR Type III-B fuel consists of two PT fuel elements loaded into each divider position. A total of 90 grams of 94% enriched U-235 per divider position in the fuel divider is modeled in this criticality analysis. Based on this mass, the corresponding masses of U-238 and cladding material can be estimated. Appendix A shows the simple FORTRAN program used to calculate the fuel number densities (U-235, U-238, and Al) for the case of MTR Type III-B fuel elements and its associated FORTRAN output.

Table 6.149 MTR Type I, II, III, and III-B Fuel Data

FUEL TYPE		GEOMETRY												NUCLEAR DATA					
REACTOR CLASS	Composition	TRIMMED LENGTH (IN)	FUEL DIMENSION (IN)											MAX. TOTAL g U-235	MAX. U-235 g per Plate	MAX. No. of Fuel Plate/Elem	Nominal Enrichment (%)	BURNUP (MWd)	BURNUP (%)
			a	b	t_{SP}	D	E	f	g	t_{WC}	L_{AF}	L_{EL}							
NBSR	U3O8-Al	13.313	3.000	3.368	0.187	2.500	0.015	0.020	0.050	0.116	11.00	13.39		350*2	10.3*2	17*2	93.0	170-200	65-73
OWR	U3O8-Al	n/a	3.031	3.303	0.187	2.547	0.015	0.020	0.050	0.116	23.54	42.625		235	12.2	19	93.0		50
HFBR	U3O8-Al	24.625	2.878	3.218	0.187	2.252	0.014	0.023	0.050	0.096	22.86	57.250		355	19.7	18	93.0		44-48
ORR #2	U3O8-Al	n/a	2.992	3.150	0.187	2.500	0.015	0.020	0.050	0.116	23.62	38.39		285	15.0	19	93.0		
ORR	U3Si2-Al	n/a	3.034	3.188	0.187	2.500	0.015	0.020	0.050	0.116	23.62	38.39		344	18.000	19	20.0	20-172	6-50
BSR	UAl-Al	n/a	2.996	3.313	0.187	2.500	0.015	0.020	0.051	0.116	23.53	37.125		223	11.7	19	93.0	88	40
SAPHIR	UAl-Al	n/a	2.996	2.968	0.177	2.469	0.015	0.020	0.050	0.088	23.61	34.39		287	12.5	23	93.0	155	71/64
ORR #1	UAl-Al	n/a	2.992	3.150	0.187	2.500	0.015	0.020	0.050	0.116	23.62	38.39		202	10.6	19	93.0		
GRR #1	UAl-Al	n/a	2.992	3.150	0.177	2.480	0.015	0.020	0.050	0.116	23.62	37.40		180.5	9.5	19	93.0		

Table 6.149 MTR Type I, II, III, and III-B Fuel Data (Continued)

FUEL TYPE		GEOMETRY											NUCLEAR DATA					
REACTOR CLASS	Composition	TRIMMED LENGTH (IN)	FUEL DIMENSION (IN)										MAX. TOTAL g U-235	MAX. U-235 g per Plate	MAX. No. of Fuel Plate/Elem	Nominal Enrichment (%)	BURNUP (MWd)	BURNUP (%)
			a	b	t_{SP}	D	E	f	g	t_{WC}	L_{AF}	L_{EL}						
GRR#2	UAl-Al	n/a	2.992	3.150	0.177	2.480	0.015	0.020	0.050	0.124	23.62	37.40	187.2	10.4	18	93.0		
GRR#3	UAl-Al	n/a	2.992	3.150	0.177	2.480	0.020	0.020	0.060	0.114	23.62	37.40	180.9	10.05	18	93.0		
ASTRA	UAl-Al	n/a	2.992	3.150	0.177	2.472	0.015	0.020	0.050	0.088	24.61	34.37	281	12.22	23	93.0		
PT	UAl-Al	n/a	2.992	3.150	0.177	2.472	**0.015**	**0.020**	0.050	0.088	24.61	34.37	**450**	12.22	23	93.0		
VR-1	UAl-Al	n/a	2.774		0.189	2.394	0.015	0.069	0.099		24.02	29.80	136.2	13.62	10	19.92		
TSR	MTR												8687				83.300	

Nomenclature:

a = Element width, inch

b = Assembly maximum depth, inch

t_{SP} = Side plate thickness, inch

d = Active fuel width, inch

e = Cladding thickness, inch

f = Active fuel thickness, inch

g = Plate thickness, inch

t_{WC} = Water channel thickness, inch

L_{AF} = Active fuel length, inch

L_{EL} = Element length, inch

ORR = Oak Ridge Research Reactor, Oak Ridge USA

NFBR = High Flux Beam Reactor, Brookhaven USA

OWR = Omega West Reactor, Los Alamos USA

BSR = Bulk Shielding Reactor, Oak Ridge USA

GRR = Greek Research Reactor, Greece

ASTRA = Adapter Schwimmbecken Tank Reaktor, Austria

SAPHIR = Reseach Reactor, Switzerland

VR = Venezuelan

PT = Petten

NBSR = National Institute of Standards Test Reactor, Washington D.C. USA

6.7.8.4 GEMER Model

The same GEMER analysis methodology used in the earlier submittal (NEDO-32408) will be used in the criticality analysis of MTR Type III-B fuel.

The MTR fuel elements will be modeled in a most conservative but credible position, with all fuel elements protruding from the 20 slots to the maximum possible extent. This maximizes the reactivity in the system.

The fuel is treated discretely as follows:

The MTR Type III-B fuel consists of 23 fueled plates. The nominal dimensions of the active fuel are 0.175 cm (68.9 mils) x 6.08 cm x 122.0 cm. The outer Aluminum clad dimensions are 0.2515 cm x 7.046 cm x 122.0 cm, with a nominal clad thickness of 15 mils.

To account for the variations in the fuel meat and cladding thickness, a number of sensitivity cases are performed. The active fuel meat thickness is varied from 0.0508 cm (20 mils) to 0.254 cm (100 mils) and the cladding thickness is varied 10 mils to 20 mils. The other dimensions remain constant.

A typical MTR III-B GEMER input is shown in Appendix A.

6.7.8.5 Package Fuel Loading

Table 6.150 summarizes the maximum fuel load (mass), as well as some significant constraints for the form of the MTR Type III-B fuel. The loading specified in Table 6.150 described herein qualifies as an infinite (N=∞) Fissile Class III-B package with a zero transport index under the provisions of 10CFR71.61 based on the infinite cask analysis. This loading also meets the IAEA Safety Standards for an infinite shipment (N=∞) with a zero Transport Index for criticality safety.

Table 6.150. Package Parameters for Model 2000 Cask with MTR Type III-B Fuel (UAl_x)

Parameters	Quantity/Comment
Fuel type	UAl/Al
^{235}U mass per plate	**20 grams**
Number of plates/fuel element	**23**
Number of fuel elements per divider position	**2**
Total ^{235}U mass per divider position	**920 grams**
^{235}U enrichment	93.0%
^{238}U mass per fuel plate	60.0 grams
Al mass (fuel) per fuel plate	159.434 grams
Al density	2.7 g/cc

6.7.8.6 Criticality Results for MTR Type III-B Fuel

Table 6.151 summarizes the GEMER results for the infinite cask scenario for MTR Type III-B for the Discrete Model.

Table 6.152 shows the variation in k-effective as a function of water density for the MTR Type III-B fuel with nominal dimensions (68.9 mils fuel meat thickness and 15 mils clad thickness). Figure 6.104 is a plot showing the discrete model k-effective under varying H/U^{235} ratios (from dry to fully moderated condition) for the MTR Type III-B fuel with nominal dimensions.

The water reflection (WR) case denotes the case when the surrounding materials outside of the fuel basket is replaced by full-density water and the perfectly reflecting boundary conditions are applied on all sides and the top and bottom.

Tables 6.153 through 6.155 show the variation in k-effective as a function of water density for the MTR Type III-B fuel with a 100-mil fuel meat thickness and clad thickness of 10, 15, and 20 mils, respectively. Figure 6.105 is a plot showing the discrete model k-effective under varying H/U^{235} ratios (from dry to fully moderated condition) for the MTR Type III-B fuel with a100-mil fuel meat thickness.

Tables 6.156 through 6.158 show the variation in k-effective as a function of water density for the MTR Type III-B fuel with a 20-mil fuel meat thickness and clad thickness of 10, 15, and 20 mils, respectively. Figure 6.106 is a plot showing the discrete model k-effective under varying H/U^{235} ratios (from dry to fully moderated condition) for the MTR Type III-B fuel with a 20-mil fuel meat thickness.

The maximum k_{eff} for MTR Type III-B fuel is 0.69740 for the discrete case after accounting for uncertainty and bias for a 20-mil fuel meat thickness and a 10-mil cladding thickness. These values are below the subcriticality limit of 0.95.

Additional pitch and fuel plate number sensitivity studies were not performed as the k-effective is much below 0.95.

Table 6.151. Summary of Results — Infinite Cask Scenario for MTR Type III-B Fuel (UAl_x)

Condition/Parameter	Quantity/Comment
Number of Containers in Demonstration	Infinite Array
Optimum Hydrogenous Moderation	1.00 Weight Fraction H_2O
Maximum Multiplication Factor $k_{eff} + 2\sigma$ + Bias	0.69740

Table 6.152. GEMER Results — Infinite Cask Scenario for MTR Type III-B Fuel (Discrete Model, Nominal Fuel Meat Thickness of 68.9 Mils and Clad Thickness of 15 Mils)

H_2O Density Weight %	$H/^{235}U$ Ratio	K_{eff}	$\pm\sigma$	Bias	$k+2\sigma$ +Bias
0	0.0000	0.08708	0.00028	0.00000	0.08764
10	81.4098	0.19000	0.00112	0.00096	0.19320
20	162.8196	0.32669	0.00167	0.00239	0.33242
30	244.2294	0.43104	0.00222	0.00369	0.43917
40	325.6392	0.51159	0.00238	0.00485	0.52120
50	407.0490	0.56407	0.00216	0.00588	0.57427
60	488.4588	0.60778	0.00205	0.00678	0.61866
70	569.8686	0.63274	0.00226	0.00755	0.64481
80	651.2784	0.64717	0.00251	0.00818	0.66037
90	732.6882	0.65756	0.00236	0.00869	0.67097
100	814.0980	0.65948	0.00246	0.00905	0.67345
WR	905.3923	0.65799	0.00249	0.00931	0.67228

Table 6.153. GEMER Results — Infinite Cask Scenario for MTR Type III-B Fuel (Discrete Model, Fuel Meat Thickness of 100 Mils and Clad Thickness of 10 Mils)

H_2O Density Weight %	$H/^{235}U$ Ratio	K_{eff}	$\pm\sigma$	Bias	$k+2\sigma$ +Bias
0	0.0000	0.08680	0.00029	0.00000	0.08738
10	77.4213	0.18607	0.00102	0.00089	0.18900
20	154.8425	0.31818	0.00169	0.00226	0.32382
30	232.2637	0.42118	0.00176	0.00351	0.42821
40	309.6850	0.49878	0.00243	0.00463	0.50827
50	387.1063	0.55174	0.00226	0.00564	0.56190
60	464.5275	0.59786	0.00195	0.00653	0.60829
70	541.9487	0.62028	0.00222	0.00730	0.63202
80	619.3701	0.64022	0.00238	0.00795	0.65293
90	696.7912	0.65079	0.00262	0.00848	0.66451
100	774.2125	0.65652	0.00264	0.00889	0.67069
WR	865.4941	0.64520	0.00226	0.00922	0.65894

Table 6.154. GEMER Results — Infinite Cask Scenario for MTR Type III-B Fuel (Discrete Model, Fuel Meat Thickness of 100 Mils and Clad Thickness of 15 Mils)

H_2O Density Weight %	$H/^{235}U$ Ratio	K_{eff}	$\pm\sigma$	Bias	$k+2\sigma$ +Bias
0	0.0000	0.08715	0.00028	0.00000	0.08771
10	75.4981	0.18368	0.00105	0.00085	0.18663
20	150.9961	0.31174	0.00183	0.00219	0.31759
30	226.4942	0.41266	0.00193	0.00342	0.41994
40	301.9923	0.49201	0.00235	0.00453	0.50124
50	377.4903	0.54909	0.00228	0.00552	0.55917
60	452.9884	0.58902	0.00209	0.00641	0.59961
70	528.4864	0.61527	0.00203	0.00718	0.62651
80	603.9846	0.63780	0.00262	0.00783	0.65087
90	679.4825	0.64655	0.00248	0.00837	0.65988
100	754.9807	0.64927	0.00258	0.00880	0.66323
WR	846.2884	0.64319	0.00218	0.00916	0.65671

Table 6.155. GEMER Results — Infinite Cask Scenario for MTR Type III-B Fuel (Discrete Model, Fuel Meat Thickness of 100 Mils and Clad Thickness of 20 Mils)

H_2O Density Weight %	$H/^{235}U$ Ratio	K_{eff}	$\pm\sigma$	Bias	$k+2\sigma$ +Bias
0	0.0000	0.08713	0.00027	0.00000	0.08767
10	73.6198	0.18304	0.00107	0.00082	0.18600
20	147.2396	0.30669	0.00151	0.00213	0.31184
30	220.8593	0.40801	0.00185	0.00333	0.41504
40	294.4791	0.48515	0.00201	0.00442	0.49359
50	368.0989	0.54336	0.00242	0.00541	0.55361
60	441.7187	0.58238	0.00211	0.00628	0.59288
70	515.3384	0.61205	0.00221	0.00705	0.62352
80	588.9583	0.62895	0.00233	0.00771	0.64132
90	662.5780	0.63848	0.00244	0.00826	0.65162
100	736.1978	0.64864	0.00308	0.00870	0.66350
WR	827.4545	0.63960	0.00245	0.00910	0.65360

Table 6.156. GEMER Results — Infinite Cask Scenario for MTR Type III-B Fuel (Discrete Model, Fuel Meat Thickness of 20 Mils and Clad Thickness of 10 Mils)

H_2O Density Weight %	$H/^{235}U$ Ratio	K_{eff}	± σ	Bias	k+2σ +Bias
0	0.0000	0.08631	0.00027	0.00000	0.08685
10	92.6271	0.20603	0.00130	0.00117	0.20980
20	185.2543	0.34908	0.00173	0.00276	0.35530
30	277.8814	0.46261	0.00204	0.00419	0.47088
40	370.5086	0.54542	0.00219	0.00544	0.55524
50	463.1357	0.59933	0.00201	0.00652	0.60987
60	555.7628	0.63729	0.00244	0.00743	0.64960
70	648.3899	0.65892	0.00244	0.00816	0.67196
80	741.0172	0.67351	0.00251	0.00873	0.68726
90	833.6442	0.68173	0.00250	0.00912	0.69585
100	926.2713	0.68327	0.00239	0.00935	0.69740
WR	1017.5290	0.67194	0.00271	0.00940	0.68676

Table 6.157. GEMER Results — Infinite Cask Scenario for MTR Type III-B Fuel (Discrete Model, Fuel Meat Thickness of 20 Mils and Clad Thickness of 15 Mils)

H_2O Density Weight %	$H/^{235}U$ Ratio	K_{eff}	$\pm\sigma$	Bias	$k+2\sigma$ +Bias
0	0.0000	0.08698	0.00031	0.00000	0.08760
10	90.7040	0.20188	0.00112	0.00113	0.20525
20	181.4079	0.34822	0.00184	0.00270	0.35460
30	272.1118	0.45604	0.00215	0.00410	0.46444
40	362.8158	0.53628	0.00253	0.00534	0.54668
50	453.5197	0.59299	0.00215	0.00641	0.60370
60	544.2236	0.63221	0.00222	0.00732	0.64397
70	634.9276	0.65444	0.00234	0.00807	0.66719
80	725.6316	0.66413	0.00233	0.00865	0.67744
90	816.3355	0.67070	0.00234	0.00906	0.68444
100	907.0395	0.67862	0.00226	0.00931	0.69245
WR	998.3231	0.66892	0.00237	0.00940	0.68306

Table 6.158. GEMER Results — Infinite Cask Scenario for MTR Type III-B Fuel (Discrete Model, Fuel Meat Thickness of 20 Mils and Clad Thickness of 20 Mils)

H_2O Density Weight %	$H/^{235}U$ Ratio	K_{eff}	$\pm\sigma$	Bias	$k+2\sigma$ +Bias
0	0.0000	0.08711	0.00027	0.00000	0.08765
10	88.8257	0.20403	0.00118	0.00110	0.20749
20	177.6513	0.34497	0.00193	0.00264	0.35147
30	266.4770	0.45667	0.00213	0.00402	0.46495
40	355.3027	0.52785	0.00223	0.00524	0.53755
50	444.1283	0.59116	0.00232	0.00631	0.60211
60	532.9540	0.61708	0.00236	0.00722	0.62902
70	621.7796	0.64217	0.00263	0.00797	0.65540
80	710.6053	0.66488	0.00234	0.00856	0.67812
90	799.4310	0.66480	0.00243	0.00900	0.67866
100	888.2567	0.66990	0.00284	0.00928	0.68486
WR	979.5511	0.66390	0.00279	0.00940	0.67888

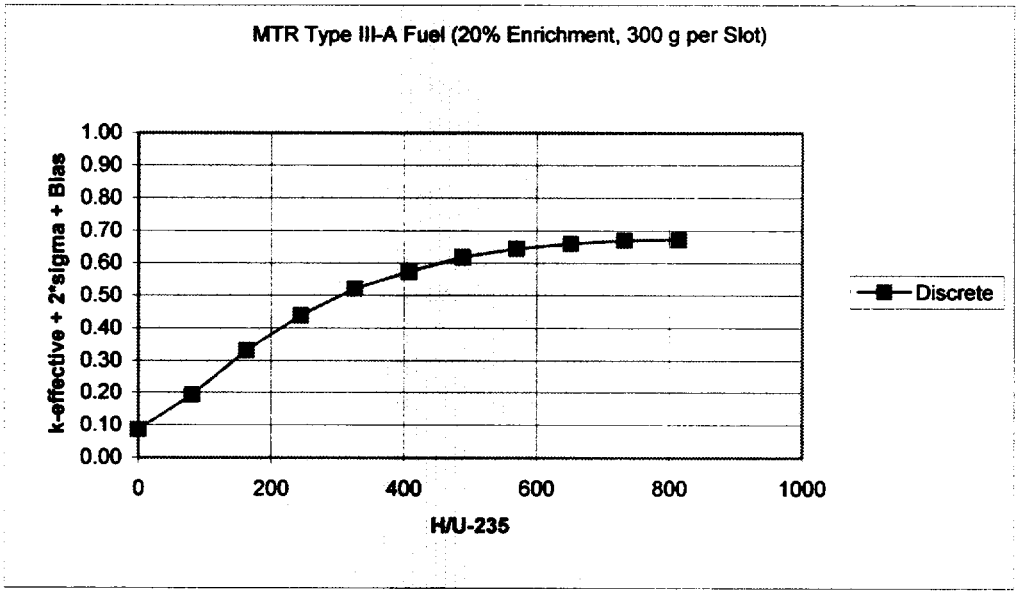


Figure 6.104. MTR Type III-B Fuel, Infinite Cask Array, 68.9-Mil Fuel Meat Thickness and 15-Mil Clad Thickness

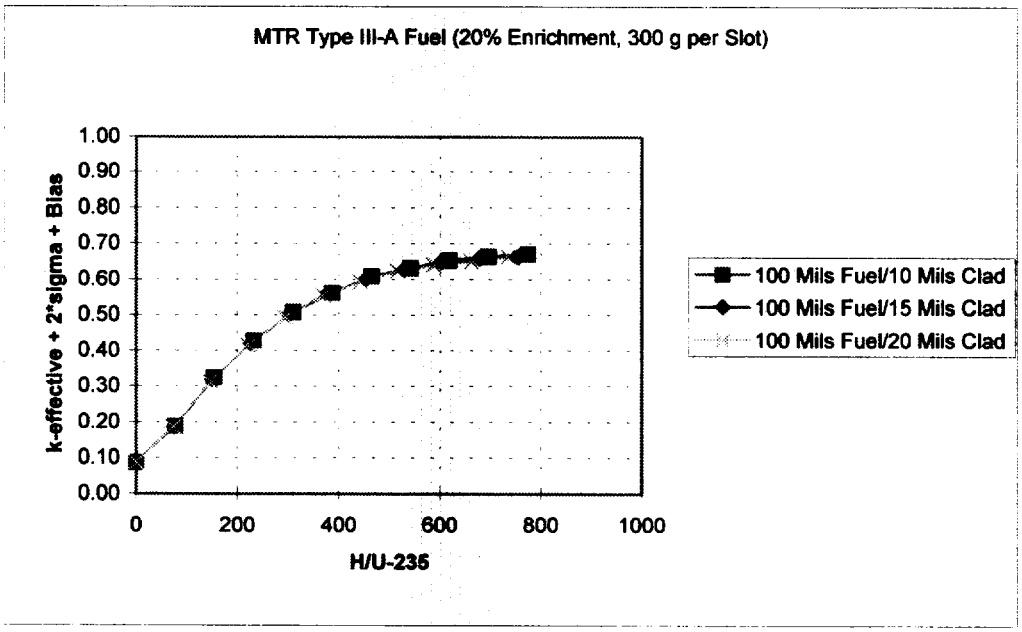


Figure 6.105. MTR Type III-B Fuel, Infinite Cask Array, 100-Mil Fuel Meat Thickness

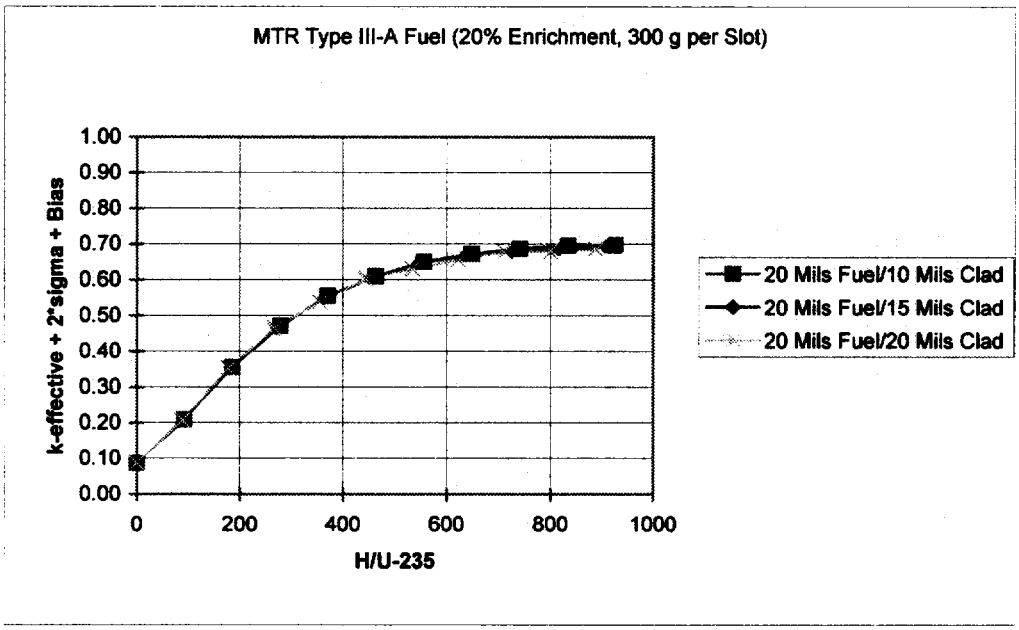


Figure 6.106. MTR Type III-B Fuel, Infinite Cask Array, 20-Mil Fuel Meat Thickness

6.7.8.7 Conclusions

All results, including the conservative accident condition cases, are subcritical. The maximum k-effective for the worst MTR Type III-B case, after accounting for uncertainty and bias, is 0.69740. The effective multiplication factor is much less than 0.95.

The system will be subcritical under all conceivable and realistic accident scenarios. This conclusion is reached based on the requirement that the borated aluminum poison structure is maintained under all credible accident conditions. This meets all NRC requirements for the subcriticality safety analysis and the MTR Type III-B fuel can be safely transported using the Model 2000 cask.

6.7.8.8 Appendix A: Input/Output — MTR Type III-B Fuel

A-1 GEMER Input Decks (MTR Type III-B Fuel)

This section includes GEMER geometrical plots and input listings for the infinite array. Each VR-1 basedeck contains a "header" with fuel material and geometry information.

A-2 Infinite MTR Type III-B Case (20.0% Enriched Fuel, Nominal Dimensions)

```
VR FUEL/ IF2000/21 ELEMENTS, SS+Pb SHIELDING. MASS U235 IN EACH ELEM=150.0 G
   105 /* # BATCHES
  1000  /* # NEUTRONS PER BATCH
     5  /* # BATCHES TO SKIP
 2123469/* INITIAL "SEED" (IF NON-ZERO)
     0  /* "IDUMP"
     0  /* "NRSTRT"
     0  /* "NBTED" (NON-ZERO IS PRINT EDITS)
     0  /* "KRED" (NUMBER OF COMBINED REGIONS IN EDITS)
     0  293   19  7
      3  293 0  0 U(20.0)AL/AL 2 FUEL ELEMENTS     MAT 1
     131  5.4828744E-02
    2381  2.3385726E-03
    2351  5.9212249E-04
      3  293 0 0 Boral 0.25" Plate (75% Boron Loading)  MAT 2
    10    4.15822E-03
    11    8.48616E-05
   131    5.8001E-02
      2  293 0 0  MODERATOR IN CASK (100.00%)                    MAT 3
     1   6.69111121E-02
    16   3.34555566E-02
      1  293 0 0 LEAD SHIELDING                        MAT 4
    82   3.29890E-02
      7  293 0 0 304 STAINLESS STEEL                   MAT 5
    12   6.82690E-05
    14   8.53360E-04
    24   1.53600E-02
    26   6.04950E-02
    28   6.82690E-03
    55   1.70670E-03
  1316   2.56010E-05
     2  293 0 0 FULL DENSITY WATER (100%)             MAT 6
     1    6.69111121E-02
    16    3.34555566E-02
     1  293 0 0 AL CLADDING             MAT 7
   131    6.026464E-02
KENO GEOM
    19  /* "KREFM"
    11  /* "NBOX"
     1  /* "NBXMAX"
     1  /* "NBYMAX"
     1  /* "NBZMAX"
     1  /* "NXX"
     0  /* "NTYPST"
     1  /* "NEMBRG"
     0  /* "NGMCHK"
 -1.0  -1.0  -1.0  -1.0  -1.0  -1.0
BOX TYPE     1 /*MODEL 2000 CASK & STAINLESS SUPPORT STRUCTURE
CYLINDER     6  33.65     140.64     0.0    16*0.5
CYLINDER     5  35.85     140.64     0.0    16*0.5
```

```
CYLINDER     4  46.34     140.64     0.0    16*0.5
CYLINDER     5  48.56     140.64   -14.90   16*0.5
BOX TYPE     2 /* CASK TOP
CYLINDER     4  30.96     158.42    140.64  16*0.5
CYLINDER     5  48.56     162.23    140.64  16*0.5
BOX TYPE     3 /* 21 SLOTS FILLED WITH WATER  125.2778 CM HIGH
CUBOID       6  4.4450 -4.4450  4.0005  -4.0005  125.2728  0.0   16*0.5
BOX TYPE     4 /* 21 SLOTS FILLED WITH WATER      ***   EXTENDED HEIGHT
CUBOID       6  4.4450 -4.4450  4.0005  -4.0005  15.35  0.00  16*0.5
BOX TYPE     5 /* BORAL PLATE (VERT)  125.2728 CM (49.32")
CUBOID       2  0.2667  -0.2667  3.937  -3.937  125.2728  0.0   16*0.5
BOX TYPE     6 /* BORAL PLATE (HORIZ) MODELED AS 3.1" X 0.21" X 49.32" MIN
DIMENSIONS
CUBOID       2  3.937  -3.937  0.2667  -0.2667  125.2728  0.0   16*0.5
BOX TYPE     7  /* FUEL PLATES        122.0 CM TOTAL H
CUBOID       1  0.08750 -0.08750  3.040   -3.040  125.2728  18.6228  16*0.5
/* *** FUEL
CUBOID       7  0.12575 -0.12575  3.523   -3.523  125.2728  18.6228  16*0.5
/* *** CLAD
BOX TYPE     8  /* FUEL PLATES        122.0 CM TOTAL
CUBOID       1  0.08750 -0.08750  3.040   -3.040  15.350  0.00   16*0.5  /*
*** FUEL
CUBOID       7  0.12575 -0.12575  3.523   -3.523  15.350  0.00   16*0.5  /*
*** CLAD
BOX TYPE     9
CYLINDER     5  33.34     125.2728     0.0    16*0.5
BOX TYPE    10  /*          ***
CYLINDER     6  33.34     15.350     0.0    16*0.5
BOX TYPE    11  /* OVERALL BOX FOR THE PROBLEM
CUBOID       6  48.60    -48.60   48.60 -48.60 162.23 -14.91 16*0.5
CORE         0  48.60    -48.60   48.60 -48.60 162.23 -14.91 16*0.5
CUBOID       6  48.70    -48.70   48.70 -48.70 162.33 -15.01 16*0.5
11  1 1 1  1 1 1  1 1 1  1
BEGIN COMPLEX
/* BOX TYPE 3 FOR NORMAL HEIGHT
/* BOX TYPE 4 FOR PROTRUDED HEIGHT
COMPLEX  3  7    -4.0050    0.00  0.0  10  1  1  0.8890   0.00  0.0  /*19
PLATES
COMPLEX  4  8    -4.0050    0.00  0.0  10  1  1  0.8890   0.00  0.0  /*19
PLATES
/* PLACE FUEL ASSEMBLIES INTO CASK    NORMAL HEIGHT
COMPLEX  9  3   -22.860  -10.540  0.0  5  3  1  11.430  10.540  0.0  /*MIDDLE
ROWS
COMPLEX  9  3   -11.430  -21.080  0.0  3  2  1  11.430  42.160  0.0  /*OUTER
ROWS
/* PLACE FUEL ASSEMBLIES INTO CASK    EXTENDED HEIGHT
COMPLEX  10  4   -22.860  -10.540   0.00  5  3  1  11.430  10.540  0.0
/*MIDDLE ROWS
COMPLEX  10  4   -11.430  -21.080   0.00  3  2  1  11.430  42.160  0.0
/*OUTER ROWS
/* PLACE BORAL PLATES INTO CASK
COMPLEX  9  5   -17.145  -10.540  0.0  4  3  1  11.430  10.540  0.0  /*VERT
PLATES
COMPLEX  9  6   -11.430  -15.810  0.0  3  4  1  11.430  10.540  0.0  /*HORIZ
PLATES
/* PLACE LOWER SECTION (NORMAL HEIGHT) INTO THE BOX TYPE 1
COMPLEX  1  9  0.0   0.0   0.0   1  1  1   0.0  0.0  0.0
/* PLACE PROTRUDED SECTION (EXTENDED HEIGHT) INTO THE BOX TYPE 1
COMPLEX  1 10  0.0   0.0   125.2728   1  1  1   0.0  0.0  0.0
/* PLACE LOADED CASK INTO OVERALL PROBLEM BOX
COMPLEX  11  1  0.0     0.0    0.0   1 1 1   0.0    0.0    0.0
```

```
/* PLACE TOP INTO OVERALL PROBLEM BOX
COMPLEX  11  2  0.0     0.0    0.0   1 1 1   0.0    0.0    0.0
END GEOM
*END GEMER*
```

A-3 Number Density Calculations (MTR Type III-B Fuel)

A-3.1 FORTRAN Program

```
PROGRAM NUMBER
C
C   ASSUMPTIONS:
C   1. THE FUEL AND CLAD ARE MODELED HETEROGEOUSLY.
C   2. VR-1 FUEL USED
C   3. 10 PLATES/ELEMENT
C   4. 2 ELEMENTS STACKED UP. WITH THE TOP ELEMENTS PROTRUDING.
C
      REAL NAL_CLAD
      REAL M235,M238,MO16,MH2O,MH,MSI,MAL
      REAL MU,MUOLD
      REAL MU3O8
      REAL NELEMACT,NSLOT
      REAL N235,N238,N16,N131,N1,N14
      REAL N235TOT
      DIMENSION HEIGHT(3)
      OPEN(6,FILE='N.OUT',STATUS='UNKNOWN')
C
C    FOR UAL FUEL
C
C    NUMBER DENSITY PROGRAM FOR VR-1
C      10/14/99
C      AV = AVOGADRO'S NUMBER
C     RHO_WAT = WATER DENSITY (1 G/CC)
C
      DATA PI/3.14159265/
      RHO_WAT = 1.0
      AV=0.6022
      M235 =235.0439
      M238 =238.0508
      MAL = 26.98
      MO16 = 16.000
      MH2O=18.0
      MSI=28.0855
      MAL=26.98
      MH=1.0
C
C    D  = ACTIVE FUEL LENGTH (IN)
C    E  = CLADDING THICKNESS (IN)
C    C  = PLATE LENGTH (IN)
C    G  = PLATE THICKNESS (IN)
C    F  = ACTIVE FUEL THICKNESS (IN)
C    RHOCLAD  = DENISTY OF AL CLAD (G/CC)
C    WF       = WEIGHT % OF UAL  IN THE UAL/AL MIXTURE
C    ENRICH   = FUEL ENRICHMENT
C    ELEMH    = EFFECTIVE ELEMENT HEIGHT IN INCHES (HEIGHT OF 2 ELEMENTS)
C    NELEMACT = NUMBER OF ACTIVE FUEL PLATES PER FUEL ASSEMBLY (10 PER
ASSEMBLY)
C
      E=0.015
```

```
      ELEMH=(2.0*61.0/2.54)
      D=6.08/2.54
      C=7.046/2.54
      G=0.2515/2.54
      F=0.175/2.54
C
C
C
C       ENRICH = U-235 ENRICHMENT
C
      ENRICH = 0.20
C
      U235MAS=150*2.0
C
      NELEMACT=10.0
C
C   AREASLOT = SLOT AREA PER ELEMENT (cm^2)
      AREASLOT=71.12889
C
      RHOH2O = 1.0
      RHOCLAD = 2.7
C
     WRITE(6,*) ' ************************************'
     WRITE(6,*) ' FUEL ELEMENT HEIGHT =',ELEMH*2.54,' CM'
     WRITE(6,*) '  VR-1 CASE'
     WRITE(6,*) ' ELEMENT HEIGHT=',ELEMH,' INCHES'
     WRITE(6,*) ' RHOH2O =',RHOH2O,' G/CC'
     WRITE(6,*) ' ENRICH =',ENRICH*100,' %'
     WRITE(6,*) ' RHOCLAD=',RHOCLAD,' G/CC'
C
      AELEMENT=C*G*2.54*2.54
      AMEAT=D*F*2.54*2.54
      ACLAD=AELEMENT-AMEAT
C
      WRITE(6,*) ' '
      WRITE(6,*) '  FOR EACH UNIT ELELEMT'
      WRITE(6,*) '   ACLAD          AMEAT    AELEMENT (CM2)'
      WRITE(6,*) ACLAD,AMEAT,AELEMENT
      WRITE(6,*) ' '
C
      U238MAS=U235MAS/ENRICH - U235MAS
C
C     ALFUEL = INPUT FROM THE FUEL SPECS SHEET
C
      ALFUEL=159.434*NELEMACT*2.0
      UALMAS=ALFUEL+U235MAS+U238MAS
      WRITE(6,*) ' FOR ALL PLATES AND FUEL ELEMENTS CONSIDERED:'
      WRITE(6,*) ' AL (FUEL) MASS =',ALFUEL
      WRITE(6,*) ' U238      MASS =',U238MAS
      WRITE(6,*) ' U235      MASS =',U235MAS
      WRITE(6,*) ' UAL      MASS =',UALMAS
      WRITE(6,*) ' '
C
C
C
C
C
C       WRITE(6,*) ' AL MASS IN FUEL =',ALFUEL
C
C     TOTAL = TOTAL MASS OF FUEL (UAL + AL)
      TOTAL = U238MAS + U235MAS + ALFUEL
```

```
      WRITE(6,*) 'TOTAL MASS (FUEL) =',TOTAL
C
C    2 ELEMENTS STACKED UP
C
      FVOLUME=AMEAT*(ELEMH*2.54)*NELEMACT
      WRITE(6,*) '   TOTAL FUEL IN EACH SLOT =',FVOLUME,' CM^3'
      RHOF = TOTAL/FVOLUME
      WRITE(6,*) ' FUEL MIXTURE DENSITY =',RHOF
C
C
      N235 = U235MAS*AV/M235/FVOLUME
      N235TOT=N235*FVOLUME*21.0
      N238 = U238MAS*AV/M238/FVOLUME
      N131= ALFUEL*AV/MAL/FVOLUME
C
      WRITE(6,*) '  '
      WRITE(6,*) '  N131  N238  N235'
      WRITE(6,*) '    131',N131
      WRITE(6,*) '   2381',N238
      WRITE(6,*) '   2351',N235
      WRITE(6,*) 'TOTAL',N131+N238+N235
C
C*************************************************************
C     ESTIMATE THE AMOUNT OF WATER IN THE CASK
C
C      H_SLOT = SLOT HEIGHT IN CM
C      V_SLOT = VOLUME OF ALL SLOTS CM^3
C      H_CASK = HEIGHT OF CASK (CM)
C      R_CASK = RADIUS OF CASK (CM)
C      NSLOT = NUMBER OF SLOTS IN THE CASK
C
      H_SLOT= 125.2728
      H_CASK = 140.64
      R_CASK = 33.65
      NSLOT=21.0
C
C     V_CASK_TOP = CASK VOLUME ABOVE THE INGOT (CM^3)
C     V_SLOT = VOLUME OF WATER IN ALL SLOTS (CM^3)
C     V_FPLATES = VOLUME OF ALL FUEL PLATES (17X21 PLATES)
C     V_WATER = AMOUNT OF WATER VOLUME IN THE CASK (CM^3)
C
      V_SLOT=H_SLOT*AREASLOT*NSLOT
      V_CASK_TOP = PI*R_CASK*R_CASK*(H_CASK - H_SLOT)
      V_FPLATES = NELEMACT*AELEMENT*(ELEMH*2.54)*NSLOT
      V_WATER = V_CASK_TOP + V_SLOT - V_FPLATES
      WRITE(6,*)
      WRITE(6,*) ' VOLUME OF CASK TOP =',V_CASK_TOP,'CM^3'
      WRITE(6,*) ' VOLUME OF ALL SLOTS =',V_SLOT,'CM^3'
      WRITE(6,*) ' VOLUME OF ALL FUEL PLATES =',V_FPLATES,'CM^3'
      WRITE(6,*) ' VOLUME OF WATER =',V_WATER,'CM^3'
C
C
      WRITE(6,*) ' WEIGHT FRACTION     H/U (ALL VOLUME) '
      DO 3000 I=0,20
      WFWATER = 0.05*FLOAT(I)*RHO_WAT
      N1=2.0*WFWATER*AV/MH2O
      HURATIO=N1*V_WATER/(N235*FVOLUME*NSLOT)
      WRITE(6,*)  WFWATER,HURATIO
 3000 CONTINUE

C     WATER REFLECTOR CASE
```

```
C
      WRITE(6,*)
      WRITE(6,*) ' WATER REFLECTOR CASE'
      RAD_WR=48.56
      RAD_CASK=33.34
      HT_CASK=125.2728
      HT_WR=140.64+14.90
      RHO_WATER=1.0
      VOL_WR=PI*(RAD_WR-RAD_CASK)*(RAD_WR-RAD_CASK)*(HT_WR-HT_CASK)
      WRITE(6,*) ' VOLUME OF WATER REFLECTOR =',VOL_WR,' CM^3'
C      NHTOT=RHO_WATER*AV/18.0*WATER_TOTAL + NH*NPIN*21.0*FVOLUME
      NHTOT=2.0*RHO_WATER*AV/18.0*V_WATER
     *      + 2.0*RHO_WATER*AV/18.0*VOL_WR
      RATIO6=NHTOT/N235TOT
      WRITE(6,*) RHO_WATER,RATIO6

      END
```

A-3.2 FORTRAN Output (MTR Type III-B Fuel)

```
************************************
  FUEL ELEMENT HEIGHT =   122.0000     CM
   VR-1 CASE
  ELEMENT HEIGHT=   48.03150     INCHES
  RHOH2O =   1.000000     G/CC
  ENRICH =   20.00000     %
  RHOCLAD=   2.700000     G/CC

   FOR EACH UNIT ELELEMT
    ACLAD          AMEAT    AELEMENT (CM2)
  0.7080690        1.064000       1.772069

  FOR ALL PLATES AND FUEL ELEMENTS CONSIDERED:
  AL (FUEL) MASS =   3188.680
  U238      MASS =   1200.000
  U235      MASS =   300.0000
  UAL      MASS =   4688.680

 TOTAL MASS (FUEL) =   4688.680
    TOTAL FUEL IN EACH SLOT =   1298.080     CM^3
  FUEL MIXTURE DENSITY =   3.612012

   N131  N238  N235
     131  5.4828744E-02
    2381  2.3385726E-03
    2351  5.9212249E-04
 TOTAL  5.7759441E-02

  VOLUME OF CASK TOP =   54665.70    CM^3
  VOLUME OF ALL SLOTS =   187120.8    CM^3
  VOLUME OF ALL FUEL PLATES =   45400.41    CM^3
  VOLUME OF WATER =   196386.1    CM^3
  WEIGHT FRACTION     H/U (ALL VOLUME)
  0.0000000E+00  0.0000000E+00
  5.0000001E-02   40.70490
  0.1000000       81.40981
  0.1500000       122.1147
  0.2000000       162.8196
  0.2500000       203.5245
  0.3000000       244.2294
```

```
0.3500000        284.9343
0.4000000        325.6392
0.4500000        366.3441
0.5000000        407.0490
0.5500000        447.7539
0.6000000        488.4588
0.6500000        529.1637
0.7000000        569.8686
0.7500000        610.5735
0.8000000        651.2784
0.8500000        691.9833
0.9000000        732.6882
0.9500000        773.3931
 1.000000        814.0980

WATER REFLECTOR CASE
VOLUME OF WATER REFLECTOR =    22026.80      CM^3
 1.000000        905.3923
```

A-4 Geometrical Plots of the MTR Type III-B Fuel — Side and Sectional Views

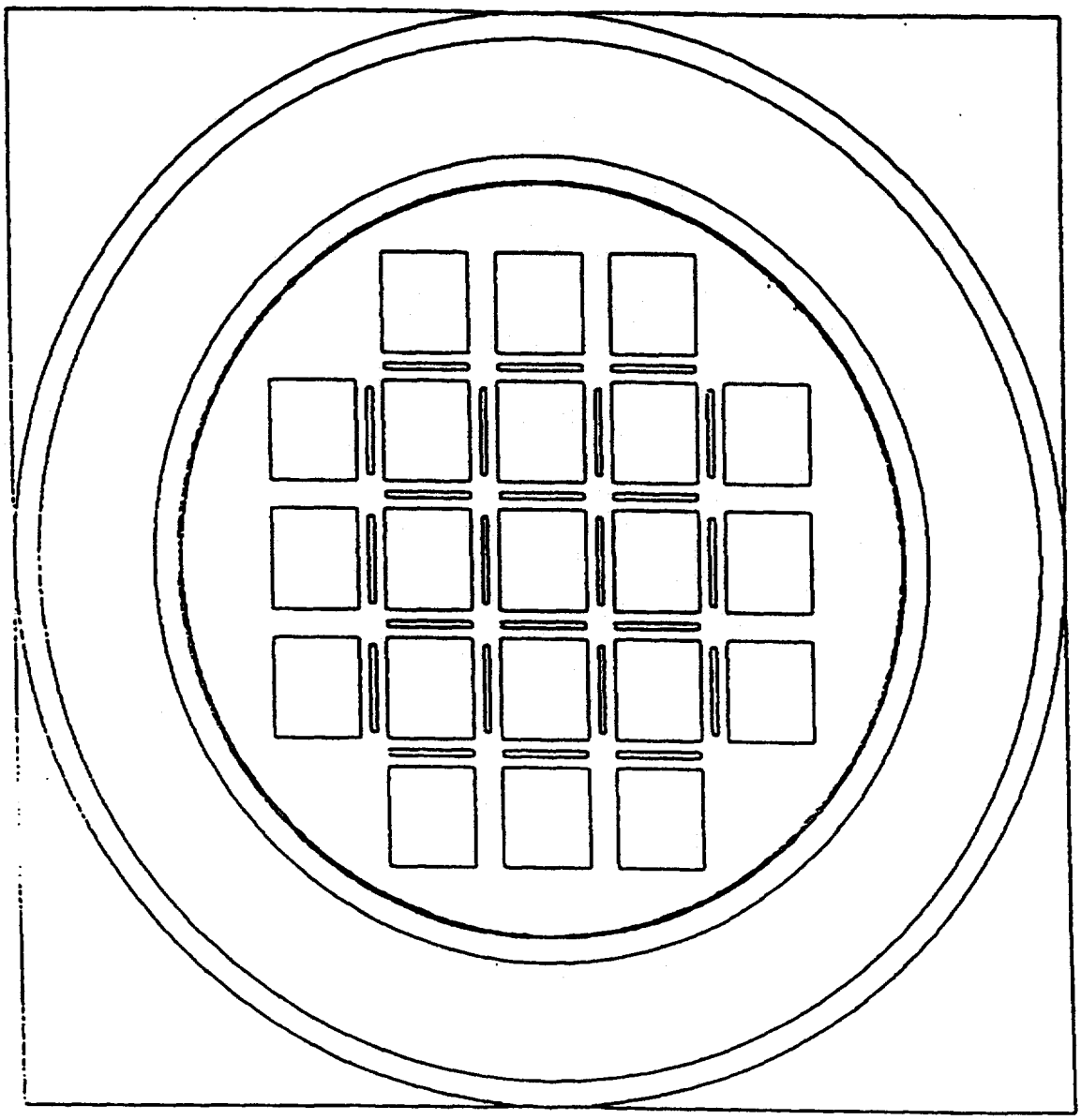


Figure A-1. Sectional View (Z = 5cm) for MTR Type III-B Fuel

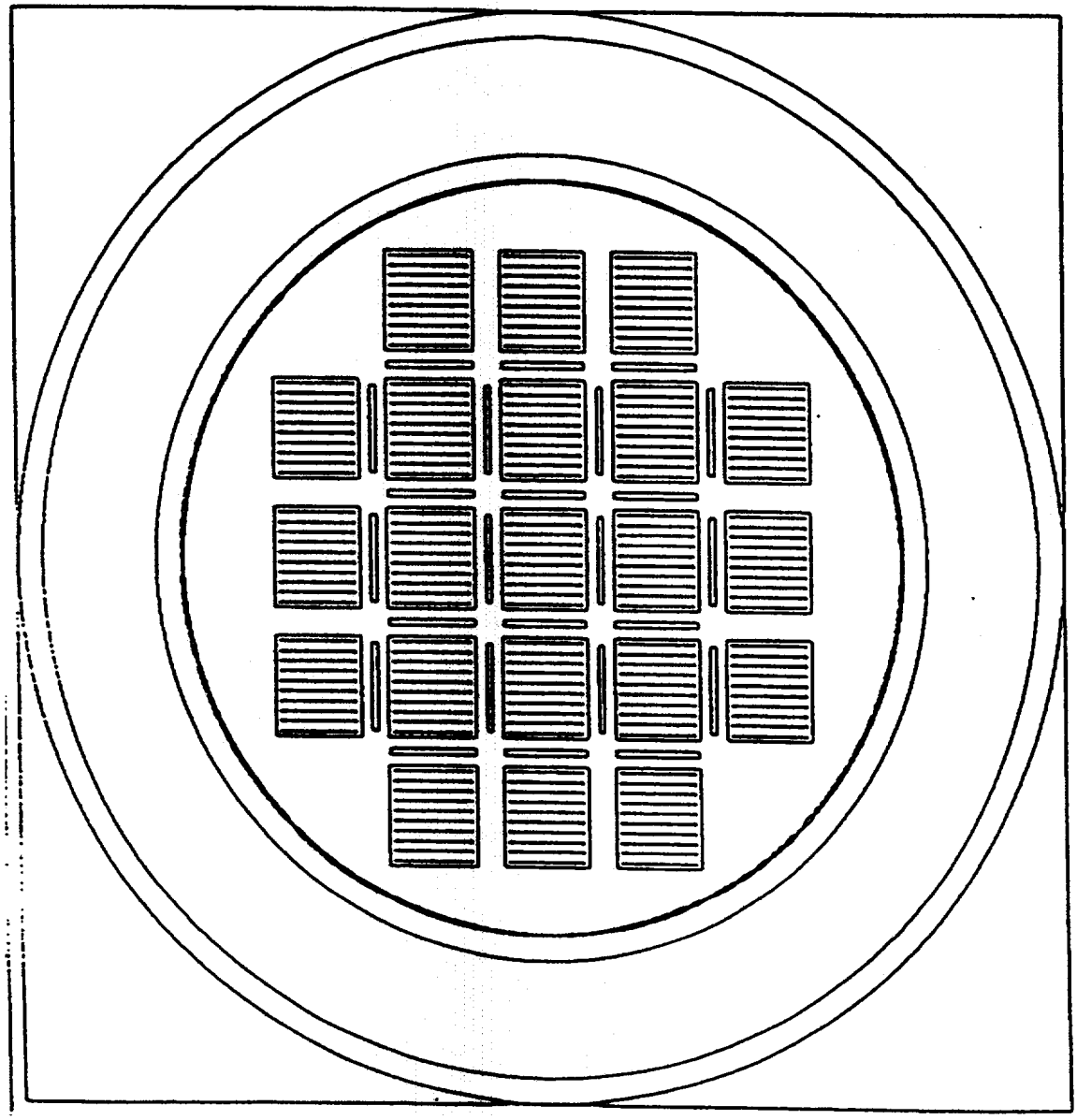


Figure A-2. Sectional View (Z = 60 cm) for MTR Type III-B Fuel

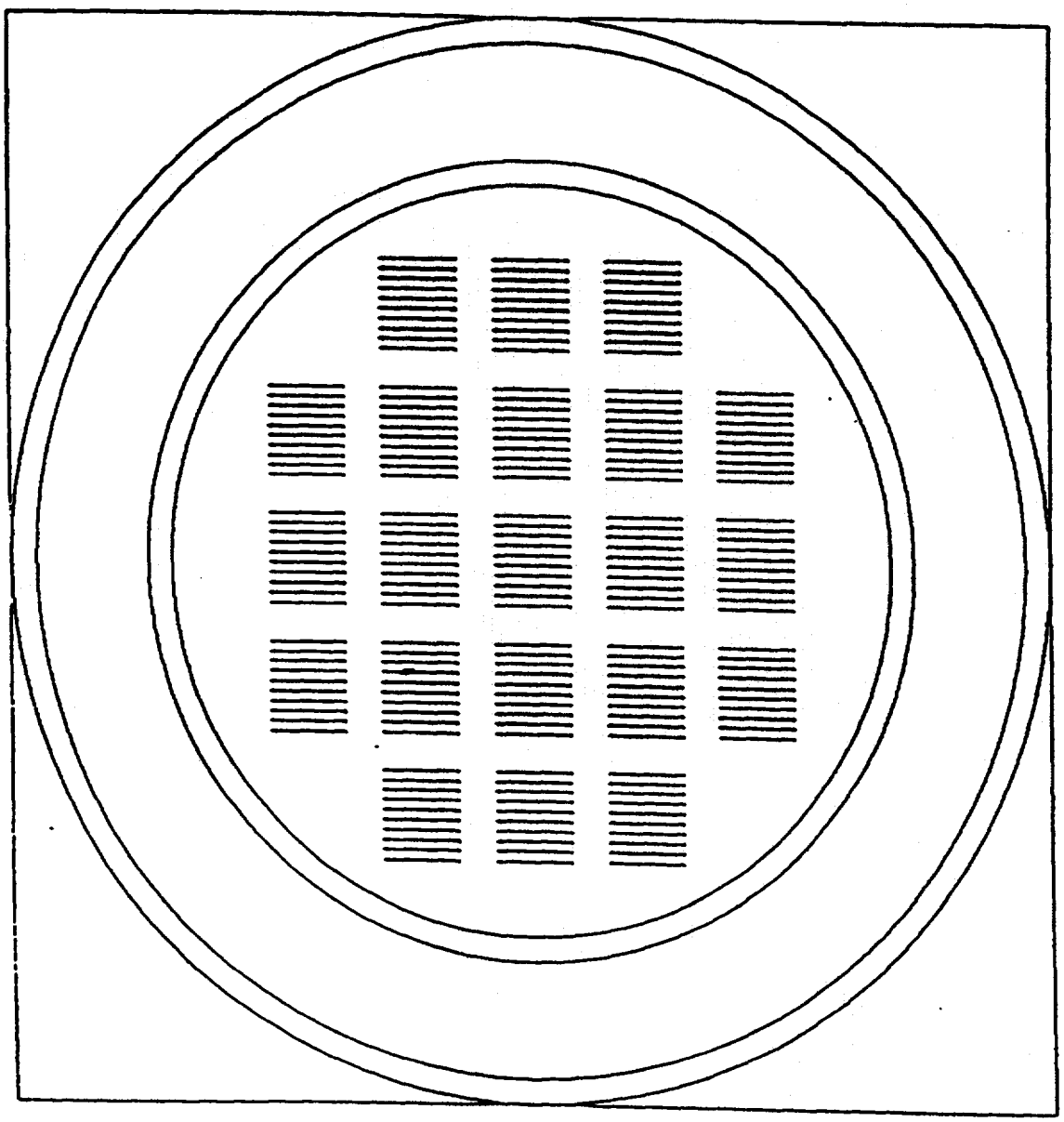


Figure A-3. Sectional View (Z = 130 cm) for MTR Type III-B Fuel

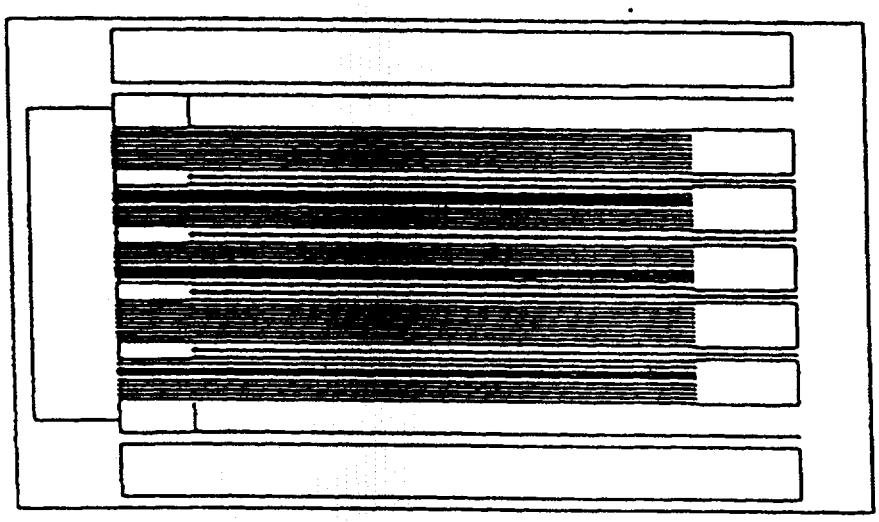


Figure A-4. Side View for MTR Type III-B Fuel

7. OPERATING PROCEDURES

Instructions for use of the Model 2000 Radioactive Transport Package are summarized below, beginning with Section 7.1. A more detailed description of these instructions is included in GE Specification 22A9380, *Operations and Maintenance of Model 2000 Transport Package* (O&M Manual). The transport package user follows the O&M Manual, but may expand it to include site-specific procedures. Some of the site-specific procedures in use at GE Vallecitos Nuclear Center are included in Appendix 7.4 of this Chapter for illustrative purposes only. During actual operation these procedures may be supplemented with engineering personnel, training classes, and/or site specific procedures as applicable.

Part of the Operating Procedure is a Pre-shipment Engineering Evaluation to ensure that the packaging with its proposed contents satisfies the applicable requirements of the package's license or certificate. This evaluation includes, but is not limited to, the review of:

- Proposed contents' isotopic composition, quantities, and decay heat;
- Proposed contents' form, weight, and geometry;
- Shielding requirements;
- Structural requirements;
- Thermal requirements;
- Shipping hardware (liners, racks, dividers, baskets, shoring device, etc.)

7.1 PROCEDURES FOR LOADING THE PACKAGE

Operations at the loading facility include the span of activities from receiving and inspecting the packaging to preparing the loaded package for shipment. Each loading facility must provide fully trained personnel and detailed operating procedures to cover all of the activities.

7.1.1 Package Receiving and Inspection

a. The Model 2000 transport vehicle is positioned for packaging inspection upon arrival.

b. A visual inspection for damage is made.

7.1.2 Removal of the Package from the Transport Vehicle

a. The transport vehicle is positioned under an overhead crane.

b. The packaging tie-downs are removed.

c. The Spreader Bar is positioned and the appropriate slings and shackles are connected.

d. Depending on site-specific issues, either the overpack top section is lifted off the overpack base and placed on the overpack stand or the entire packaging is lifted free from the transport vehicle and set down. The overpack top section is then lifted from the overpack base and placed on the overpack stand.

7.1.3 Preparing to Load the Cask

a. A visual inspection is performed. Any damage or unusual conditions are noted. If functionality of the part is impaired, repair or replacement will be effected as required.

b. The cask ears are installed. If a forklift is to be used to transport the cask, the standard lifting ears must be used. If the cask is to be lifted by crane, then either the standard or auxiliary ears may be used. If lifted by crane, the lifting slings shall not make an angle of greater than 30° measured from the vertical.

c. With proper radiological protection and monitoring, the closure lid is removed for visual inspection of the cavity.

d. The cask may be loaded either from a hot cell or storage basin.

e. The cask and lid sealing surfaces are visually inspected for damage or foreign material. Any damage is noted and repair or replacement is effected as required.

f. The cask seal is visually inspected for damage. Any gouges or cuts in the seal area are cause for replacement.

g. The seal is placed over the alignment pins on the top of the cask.

7.1.4 Loading Irradiated Fuel into the Cask

*** * * * CAUTION * * * ***

When loading MTR- or TRIGA-type fuels: The location of the fuel element within the Divider fuel cell shall depend on the decay heat content of the fuel in accordance with the following limits:

Decay Heat	**Location (see Figure 7.1)**
Decay heat ≤ 35 watts	Lower and upper regions
35 watts< decay heat ≤ 85 watts	Lower fuel cell region

For a maximum of 120 watts per fuel cell and 1500 watts per shipment

a. The list of irradiated fuel material (in the form of rod, elements, or assemblies), transfer procedure, and cask loading diagram are obtained.

b. Perform a visual inspection of the appropriate basket (basket, liner, rack, divider). Examine welds and materials for potential defects. Verify all design features are present and in good condition.

c. Install the appropriate basket in the cask as applicable.

d. Fuel material is moved one at a time to the appropriate location in the basket. Fuel material position should be verified.

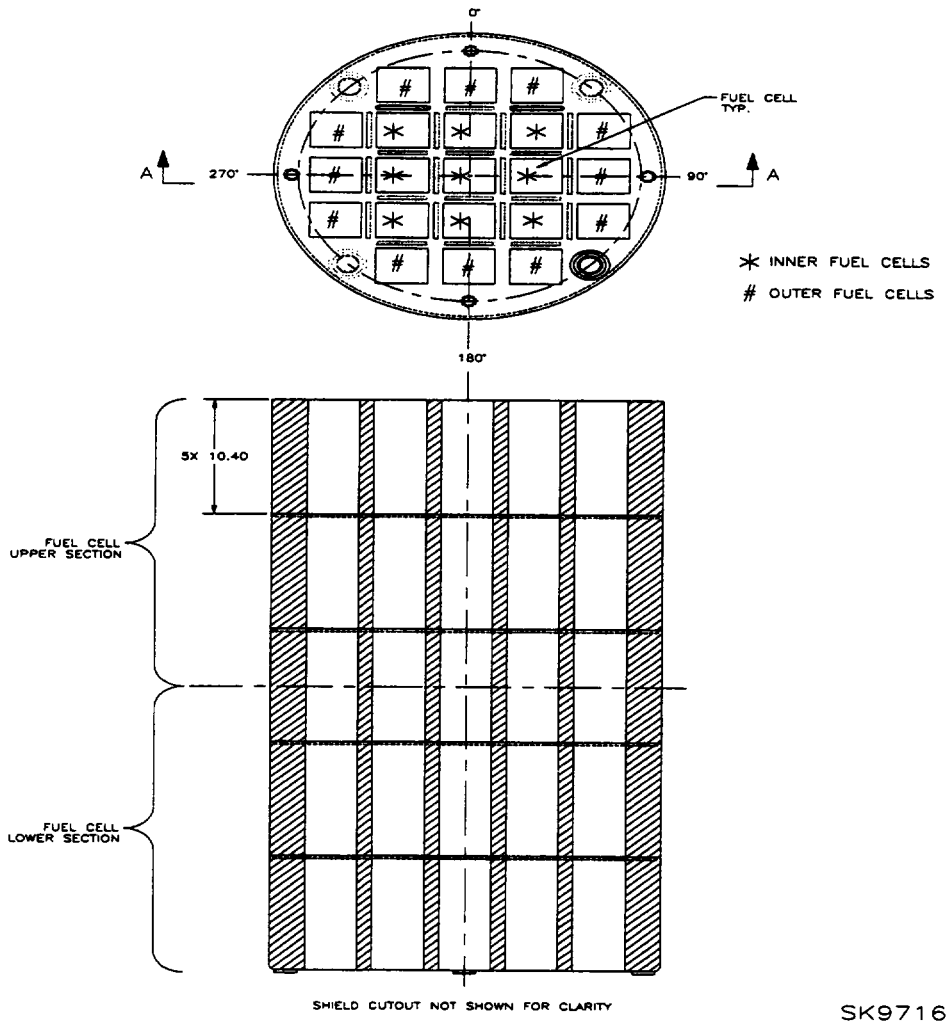


Figure 7.1. MTR Type Fuel Shipping Divider

7.1.5 Loading Irradiated Hardware or Other Contents

a. A basket for the hardware to be transported is placed in the cask.

b. The hardware is loaded into the basket using appropriate shoring as required.

7.1.6 Installing the Cask Closure Lid

a. With proper rigging, the lid is slowly lowered onto the cask over the guide pins. This operation is closely watched to ensure that the lid is properly aligned.

7.1.7 Removing the Cask from the Loading Area

a. The cask radiation levels are carefully measured while removing the cask from the storage basin or cell area.

b. The lid bolts are installed hand tight.

c. If the cask was loaded under water, it will be drained by removing the drain plug and the lid vent plug. After the water has drained, the cask cavity is vacuum-dried until 1 torr pressure is obtained. The pressure in the cavity must be maintained at or below 1 torr for at least 30 minutes. The discharged gas of the vacuum pump is filtered. Refer to Figure 7.2 for a typical vacuum drying set up and its equipment. If the vacuum pump used in this procedure is equipped with a "gas ballast" device, this device must be inoperative during the cask vacuum drying operation. The gas ballast device is used to drive off any moisture that may have been trapped in the vacuum pump oil. If needed to remove water vapor from the pump oil during the vacuum drying operation, the system shall be isolated. Turn on the gas ballast device until the oil is cleared up, turn off the gas ballast, and then place the system back on line.

d. The cask is decontaminated to a level consistent with 49CFR173.443 and 10CFR71.87.

7.1.8 Securing the Cask Lid

a. The lid bolts are torqued to 690 ft-lb. in a crisscross pattern to ensure equal compression of the seal.

b. The drain and vent plugs are installed following the drying operation as applicable. Pipe thread sealant is applied over thread area on plugs prior to installation.

7.1.9 Assembly Verification Leakage Testing

a. Leakage testing of the cask closure seal and vent and drain threaded pipe plugs is performed with a thermal conductivity sensing instrument (see Appendix 7.4.2). This type of instrument is sensitive to any gas stream having a thermal conductivity different from the ambient air in which the instrument is being used. The cask cavity is pressurized with 15 psi of Helium at the completion of the vacuum drying procedure. Helium is introduced using the "quick connect" fitting at the vent port. See Figure 7.2.

b. The test instrument is set up and used according to written procedures and the manufacturer's instructions.

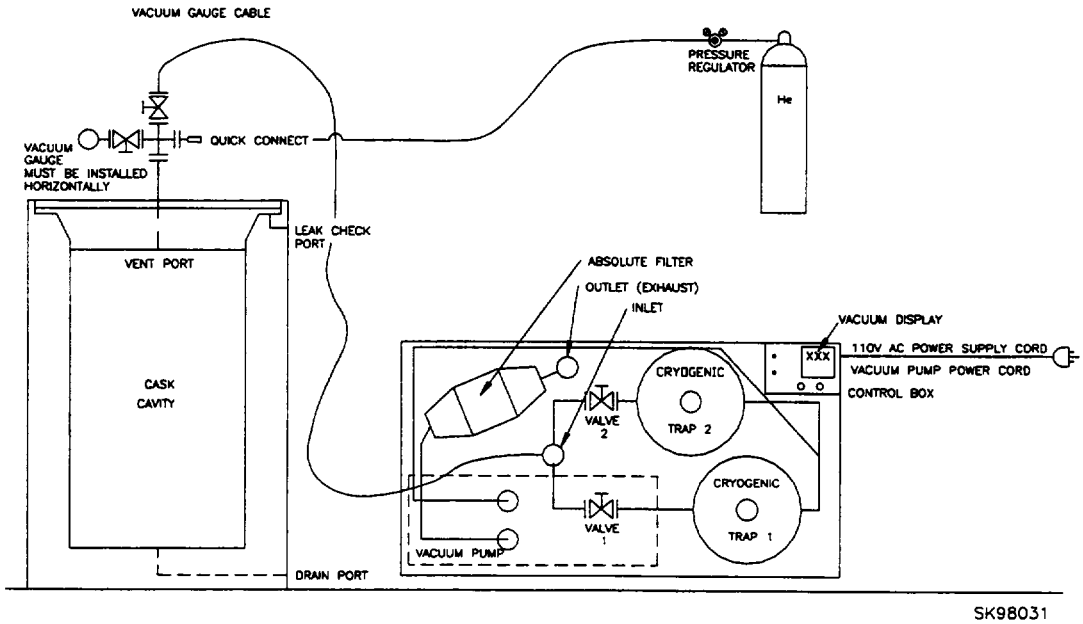


Figure 7.2. Typical Vacuum Drying System Set Up and Equipment

7.1.10 Preparing the Cask for Transport of Irradiated Fuel or Other Radioactive Material

NOTE: Transportation on the horizontal mode is limited to contents with 1500 watts of decay heat or less.

a. The cask is transported to and placed on the overpack base.

b. The cask lifting ears or redundant ears are removed from the cask.

c. The Spreader Bar is positioned over the overpack and the slings and shackles connected.

d. The overpack is slowly lowered over the cask with the locating pins aligned.

e. The overpack bolts are installed securing the top section to the base section. Note: An adhesive/sealant compound is applied to bolt threads prior to installation to prevent vibration loosening of bolts.

f. The package is positioned on the transport vehicle if required.

g. The shackle and slings are removed and the package is tied down to the transport vehicle. The Model 2000 does not have any parts or devices that would need to be rendered inoperable pursuant to 10CFR71.87(h).

h. The radiological survey of the package and transport vehicle consistent with 10CFR71.47, 71.87 and 10CFR173.441, 443 is completed. Note: A neutron radiation survey is performed in addition to a gamma radiation survey for irradiated fuel shipments.

i. The security seal is applied to the overpack.

7.2 PROCEDURES FOR UNLOADING THE PACKAGE

Operations at the unloading facility are largely the reverse of loading operations. Each unloading facility must provide fully trained personnel and will be supplied with detailed operating procedures to cover all activities as required by 10CFR71.89.

7.2.1 Package Receiving and Inspection

Steps 7.1.1.a and 7.1.1.b are repeated and a radiological survey (including neutron radiation for irradiated fuel shipments) is performed in accordance with the requirements of 10CFR20.205 or equivalent agreement state regulations.

7.2.2 Removal of the Package from the Transport Vehicle

a. The transport vehicle is positioned under an overhead crane.

b. The packaging tie-downs are removed.

c. The Spreader Bar is positioned and the appropriate slings and shackles are connected.

d. Depending on site-specific issues, either the overpack top section is lifted off the overpack base and placed on the overpack stand or the entire packaging is lifted free from the transport vehicle and set down, after which the overpack top section is lifted from the overpack base and placed on the overpack stand.

7.2.3 Preparing to Unload Irradiated Fuel

a. A visual inspection is performed. Any damage or unusual conditions are noted. If functionality of the part is impaired, repair or replacement will be effected as required. A radiological survey of the cask surface is performed, including neutron radiation.

b. The cask lifting ears or auxiliary ears (if applicable) are installed. The cask is transported to the unloading area.

c. With radiological monitoring and controlled ventilation in place, the vent plug and drain plugs are removed.

d. The lid bolts are removed for unloading in either a storage basin or hot cell.

e. The lid is removed following the placing of the cask within a hot cell or storage basin.

7.2.4 Preparing to Unload Irradiated Hardware or Other Contents

a. If the cask is to be unloaded underwater or in a hot cell, Steps 7.2.3.a through 7.2.3.e are followed.

b. If the cask is to be unloaded in air at a waste disposal site, the cask is prepared for unloading following a procedure developed by the burial site and reviewed by General Electric.

7.2.5 Unloading Irradiated Fuel from the Cask

a. The list identifying fuel rods to be unloaded is obtained.

b. The fuel rod identification and location in the cask are verified.

c. The fuel rods are transferred one at a time in accordance with the site's fuel transfer procedure.

7.2.6 Unloading Irradiated Hardware or Other Contents

a. Unloading of irradiated hardware in air at a disposal site will follow a disposal site procedure.

b. If the irradiated hardware is unloaded underwater or in a hot cell, the work is performed as specified by procedure.

7.2.7 Installing the Cask Closure Lid

a. With proper rigging, the lid is slowly lowered onto the cask over the guide pins. This operation is closely watched to assure that the lid is properly aligned.

7.2.8 Removing the Cask from the Unloading Area

a. The lid bolts are installed hand-tight.

b. The cask is removed to the storage area.

7.2.9 Securing the Cask Lid

Steps 7.1.8a and 7.1.8b are repeated.

7.3 PREARATION OF AN EMPTY CASK FOR TRANSPORT

The following operations are typically performed after transport of radioactive material.

7.3.1 Cask Cavity Inspection

a. The lid is removed from the empty cask.

b. A radiological survey of the cavity is made to determine extent of any contamination.

c. The cavity is decontaminated to the limits of 49CFR173.427 if the cask is shipped as an empty container as defined in the regulation.

d. The cavity is visually inspected to assure moisture has been removed.

7.3.2 Installation of the Cask Closure Lid

a. With proper rigging, the lid is slowly lowered onto the cask over the guide pins. This operation is closely watched to assure that the lid is properly aligned.

b. The head bolts are installed and torqued to 690 ft-lb. in a crisscross pattern to assure equal compression of the seal.

c. The cask is inspected to assure that all drain and vent plugs are properly installed.

7.3.3 Assembly Verification Leakage Testing

Leakage testing is not performed on the empty container.

7.3.4 Preparing the Empty Cask for Transport

The external surfaces of the cask are decontaminated to a level consistent with 490CFR173.427, "Empty Radioactive Materials Packaging".

7.4 APPENDICES

7.4.1 Typical Operating and Maintenance Procedures (For Illustrative Purposes Only)

7.4.2 Thermal Conductivity Sensing Instrument

Specifications

Detector:	Micro volume thermal conductivity cell.
Detects:	Any gas with a different thermal conductivity to reference ambient stream (air).
Response Time:	Less than 1 second.
Recovery Time:	1 second.
Audio:	Fixed volume, variable frequency audio; loudspeaker mounted in gun housing.
Diagnostic:	Battery low indication; detector cell failure alarm.

Sensitivity

The instrument is sensitive to a gas stream having a thermal conductivity different from the ambient air in which the instrument is being used. The sensitivity of the equipment is mainly dependent on the ratio of the thermal conductivity of the gas coming from the leak and the thermal conductivity of air. A table of typical responses of some of the more common gases is provided below.

Gas	Response Sense (Automatically Displayed)	Typical Leak Rate atm. cc/sec (Max. Resolution) With Outer Probe Removed
Hydrogen	Positive	8.3 x 10-6
Helium	Positive	1.0 x 10-5
Methane	Positive	2.6 x 10-5
Carbon Dioxide	Negative	3.5 x 10-5
Freon-R12	Negative	1.22 x 10-5

8. ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

The acceptance tests and maintenance program for the Model 2000 Transport Package included here, consolidated the information presented in the corresponding chapters of the various Model 2000 Safety Analysis Reports. Specifically, Chapter 8 of the Model 2000 (NEDO-31581) application has been combined with Chapter 8 of the HFIR (NEDO-32229) and Chapter 8 of the 2000 Watt (NEDO-32318) applications. The consolidated chapter has been further modified to address specific requirements of the MTR-Type Fuel divider and the TSR rack and is presented in this Safety Analysis Report.

The non-destructive examinations required during fabrication of the MTR Fuel Divider and TSR Fuel Basket are shown in Appendix 1.4. Routine inspection (prior to each loading) of the divider and basket consists of visual examination for physical damages of all surfaces. Periodic or once a year inspection includes visual examination of these devices and penetrant inspection of all safety-related welds.

8.1 ACCEPTANCE TEST

The inspection and acceptance tests are specified in the fabrication specifications and engineering drawings for the Model 2000 Transport Packaging and are governed by GE Quality Assurance Program QAP-1. QAP-1 has been approved by the NRC (Docket Number 71-0170).

8.1.1 Visual Inspection

Visual examinations of all welds and dimensions are conducted during fabrication. In addition, all welds within the cask containment boundary are liquid penetration tested (root and final passes); also, the welds forming the toroidal shell are 100% radiographed. These inspections are performed to insure no cracks, incomplete fusion or lack of penetration exist. Parts that do not meet the established criteria are repaired or replaced in accordance with written procedures. Nondestructive examination (NDE) procedures and acceptance standards are based on the ASME Code, Section III, Subsection NG. The above criteria applied to the fabrication of packaging serial number (S/N) 2001. All future fabrication will meet the requirements of the ASME code, Section III as follows:

<u>Cask assembly including ears;</u>

- Materials per NB-2000, Certification NCA-3800
- Fabrication per NB-4000
- NDE per NB-5000
- Pressure testing per NB-6000

The following components of the cask assembly will be excluded of the above requirements:

- Shielding lead and its installation
- Elastomers
- Seals and test port components
- Electro-polishing
- Miscellaneous equipment like name plate and its screws, honeycomb, and thread inserts

Overpack assembly;

- Materials per NF-2000
- Fabrication per NF-4000
- NDE per NF-5000

Support Structures for Criticality;

- Materials per NG-2000
- Neutron Absorbing Materials — Electron beam techniques and neutron radiography are performed to establish concentration and distribution of Boron-10 in the material to verify compliance with the criteria provided in Chapter 6
- Fabrication per NG-4000
- NDE per NG-5000

8.1.2 Structural and Pressure

The inner and outer cylinder welds of the cask are leak tested with a helium Mass Spectrometer Leak Detector (MSLD) by surrounding the cask with He and evacuating the plenum or by pressurizing the lead region of the cask and sniff all cask body welds. These test methods have a minimum sensitivity level of 10^{-6} atm cm^3/s. If any helium is detected above the minimum sensitivity, the failed weld area will be located, repaired, and reinspected.

In addition to the above test, the cask cavity is hydrostatically tested, to ensure that it is tight, per the requirements of NB6200, Subsection NB, Section III of the ASME Code. The test pressure is 45 psia.

8.1.3 Leak Tests

The assembled cask is leak tested by pressurizing the cavity to 15 psig with helium. Leak testing of the vent and drain plugs as well as the lid seal is performed using a MSLD with a sensitivity of $<1 \times 10^{-9}$ atm cc/sec. The lid seal is tested by connecting the test probe to a test port between the two seal rings of the seal and determining the leak rate. A leak-tightness criterion of 10^{-7} atm cm^3/s or less based on dry air at 25°C and for a pressure differential of 1 atm is used. If the leak-tightness criterion is not met, a new seal will be tested.

8.1.4 Component Tests

8.1.4.1 Valves, Rupture Discs, and Fluid Transport Devices

Component tests of valves, rupture discs and/or fluid transport devices are not applicable, since these parts do not exist in the Model 2000 packaging design.

8.1.4.2 Seal Testing

The procedure for testing the seals is based on ANSI 14.5-1977, "Standard for Leakage Tests on Packages for Shipment of Radioactive Materials". The seal material is tested under normal, high and low temperature environments. The temperatures are 70°F, 400°F, and -40°F, respectively. The seal material is mounted in a test flange and leak tested with a MSLD. Seal material exceeding the allowable leak rate is rejected. The test seal/flange joint used for the tests is scaled by matching the force per inch on the seal, and the flange stiffness so they are the same as for the actual joint. Results of the initial seal qualification tests are presented in Subsection 4.4.1.

8.1.4.3 Honeycomb Testing

The honeycomb energy absorber is tested in accordance with military specification MIL-STD-401B, Sandwich Constructions and Core Materials, General Test Methods.

The test procedure determines the compressive properties of the honeycomb material in the direction normal to the plane of facings. The test produces a load deformation curve, and from this curve the compressive stress at proportional limit load is computed. If the honeycomb material does not meet the required crush strength, the material will be rejected.

8.1.5 Shielding Integrity Test

The lead shielding is inspected for integrity by placing a cobalt source inside the cask and surveying the outside of the cask with a gamma detection instrument. The cask outside surface is divided by radial lines 12 degrees apart and by equally spaced circumferential lines along the vertical axis. Dose rate readings are taken over each of the 420 rectangular regions (~4 in. square); see Figure 8.1. If an area of void is detected, radiographic film is placed over this area to determine the size and location of the void. The criterion used to evaluate the effect of the void is that the dose rate may not exceed one and one-half times the mean dose rate. Any void area that does not meet the criteria will be repoured with lead.

8.1.6 Thermal Acceptance Tests

A thermal test is performed on the first unit built of the Model 2000 packaging to determine the thermal performance of the system versus what is predicted by the analysis. Corrective measures will be taken to prevent the temperature of the seal area from exceeding 400°F and/or the temperature of the lead body from exceeding 600°F.

8.1.6.1 Discussion of Test Setup

Two thermal tests are conducted, one each with 600- and 2000-watt heat source. The heat source is installed concentrically within the cask cavity. Thermocouples are strategically placed within the cavity and the external portions of the cask and overpack surfaces as schematically shown in Figure 8.2.

8.1.6.2 Test Procedure

The test is conducted with each of the heat source in a controlled ambient environment to simulate normal conditions of transport. The temperature data are recorded every 30 minutes with a data acquisition system, permitting easy analysis and plotting of the results. Data are recorded until temperature remains significantly unchanged for a one-hour period.

8.1.6.3 Acceptance Criteria

The results of the thermal test are evaluated against the predicted thermal performances. If the evaluation shows a discrepancy, the analytical thermal model is corrected based on the test results, and a new thermal analysis will be conducted. If the new analysis results indicate deficiency in the thermal characteristics of the packaging, thermal barrier coating could be applied to the inner surface of the overpack structure as a corrective measure.

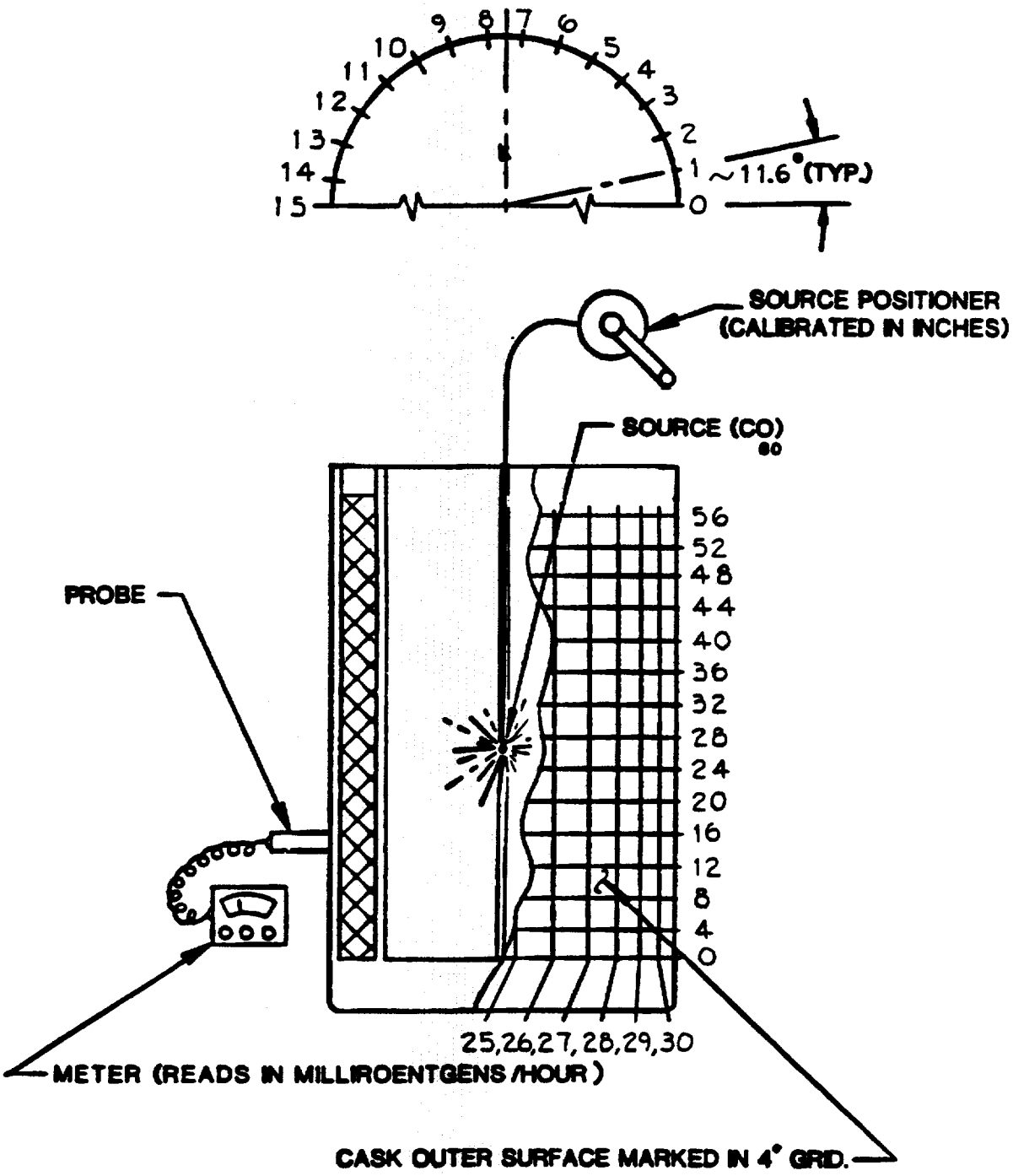
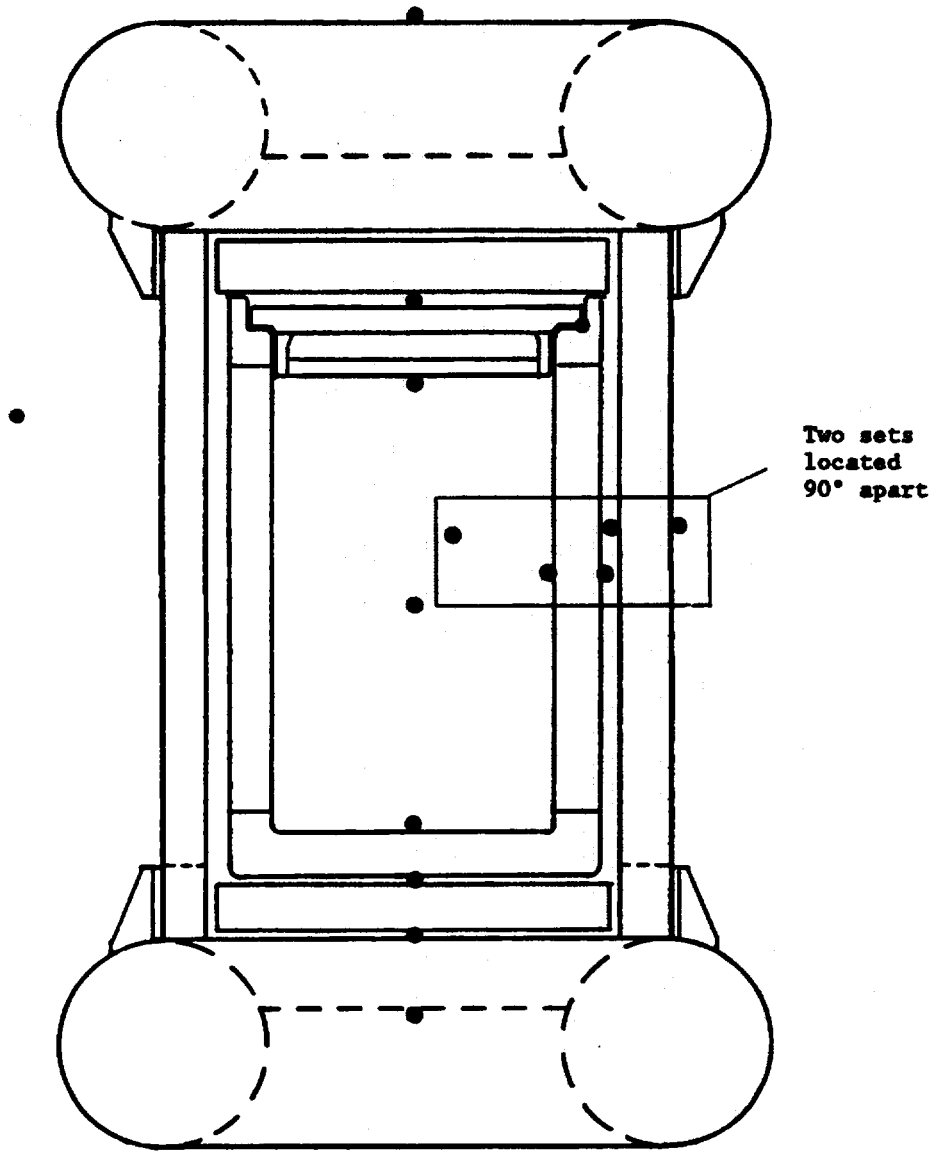


Figure 8.1 Cask Shielding Inspection Points



Black dots denote TC locations.

Figure 8.2 Thermocouple Locations

8.2 MAINTENANCE PROGRAM

The cask maintenance program is described in detail in GE Specification 22A9380, *Operations and Maintenance of the Model 2000 Transport Package.* The Specification was developed to implement the requirements established in this Chapter. Operators of the Model 2000 Package may develop procedures of their own within the requirements of the GE Specification to include site-specific procedures.

Routine inspections are performed prior to each assembly and prior to each shipment. These inspections include visual checks of the packaging and any support structure(s) or device(s) required to properly assembly the package. It also includes pressurization of the cask cavity. This pressurization is part of the leak check procedure. Additional, more detailed, inspections are also performed every 12 usages or once a year which ever comes first.

8.2.1 Structural and Pressure Tests

8.2.1.1 Routine Inspection

Prior to each loading and assembly operation, the packaging is inspected for physical damage, especially the bolt holes, vent ports and sealing surfaces. The lid bolts, port plugs and O-rings, and lid gasket are all inspected visually and for proper dimensions and identification. As part of the leak check, the cask cavity is pressurized to 15 psig with helium.

Any support structure(s) or device(s) (lead liner, fuel divider, rack, etc.) used with the packaging are also visually inspected for signs of damage, wear, cracked welds, deformation, etc.

8.2.1.2 Periodic Inspections

After every 12 usages or 12 months, whichever comes first, the following inspections are made. Any maintenance work required is identified on a maintenance checksheet.

a. Overpack

The overpack is inspected for:

1. Signs of excessive heat or fire.
2. Punctures, holes, or other surface defects.
3. Crushed sides or ends indicating a drop or severe impact.
4. Defects resulting from normal or abnormal wear.
5. Compression or damage to the honeycomb absorber material.
6. Cracks or other damage to welds
7. Proper identification and damage to the bolts.

b. Cask

The cask is inspected for:

1. Wear, corrosion or damage to the vent and drain port plugs, caps, and O-rings.
2. Damage to sealing surfaces on the cask and lid.
3. Damage or cracks to welds on the cask and lid.
4. Proper identification or damage to the lid and ear bolts.

c. MTR-Type Fuel Divider

The Fuel divider is inspected for:

1. Wear, corrosion or damage to the fuel cavities
2. Damaged or cracked welds
3. Wear or tear of elevating pads

8.2.2 Leak Tests

8.2.2.1 Routine

Leakage testing of the cask closure seal and vent and drain plugs is performed with a thermal conductivity sensing instrument. The test is performed by pressurizing the cask cavity to 15 psig with helium then "sniffing" with the instrument which senses differences in the thermal conductivity of the sampled gas if helium is present. The instrument will be calibrated to a sensitivity of 1×10^{-5} atm cm^3/sec (helium). If leakage greater than 1×10^{-3} atm cm^3/sec is detected, the suspect components will be repaired or replaced and then retested for leakage.

8.2.2.2 Periodic

After every 12 usages, the cask closure seal and vent and drain plugs will be leak checked with a helium Mass Spectrometer Leak Detector (MSLD). This instrument has a sensitivity of $< 1 \times 10^{-9}$ atm cm^3/sec (helium). This test is performed by pressurizing the cask cavity to 15 psig and then testing for leaks. If any leaks 1×10^{-7} atm cm^3/sec are detected, the suspect component will be repaired or replaced and then retested.

8.2.3 Subsystems Maintenance

There are no auxiliary cooling systems or other subsystems requiring maintenance.

8.2.4 Valves, Rupture Disks, and Gaskets on Containment Vessel

The cask closure seal will be used until either the routine or periodic test inspections identify the seal as needing replacement. The O-rings on the three penetration caps will be replaced when visual or leak test inspections identify them as defective, or during the periodic inspection, whichever comes first.

8.2.5 Shielding

The shielding material is lead. The initial tests for voids during fabrication and the required radiological surveys following each loading assure shielding integrity.

If the results of surveys exceed the regulatory requirements, the contents are reduced and/or the lead liner is installed.

8.2.6 Thermal

Thermal testing is only performed following fabrication of the first unit built, Serial Number 2001. Because the cask is constructed of lead and steel, no thermal degradation will occur during normal transport operations.