KANSAS STATE UNIVERSITY | TRIGA Mk II Nuclear Reactor Laboratory

5 October 2016

Subject: Facility Response to Request for Additional Information (Acc. # ML16189A194)

To Whom It May Concern,

On August 11, 2016, the NRC sent a Request for Additional Information (RAI) to Kansas State University nuclear reactor facility (license R-88, docket 50-188) regarding a license amendment request originally submitted on April 9, 2012 (Acc. # ML12109A063).

The following constitutes the facility's response to the RAI, and is organized as a numbered list of questions in the order of appearance in the RAI, followed by a response.

1. *SAR Section 4.2.5, "Core Support Structures," states "The bottom grid plate, which supports the weight of the fuel elements, has holes for receiving the lower end fixtures. Space is provided for the passage of cooling water around the sides of the bottom grid plate and through 36 experiment penetrations. The 1.5 in. (3.8 cm) diameter holes in the upper grid plate serve to space the fuel elements and to allow withdrawal of the elements from the core. Triangular-shaped spacers on the upper end fixtures allow the cooling water to pass through the upper grid plate when the fuel elements are in position. The reflector assembly supports both grid plates. Provide the drawings of the core support and other structures. Also provide documentation describing the flow path geometry around the side of the bottom grid plate.*

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2. The description of the flow geometry in the license amendment request is primarily based on the mechanical maintenance manual, GA-3399, "250-kW TRIGA Mark II Pulsing Reactor Mechanical Maintenance and Operating Manual." The corresponding section from the manual is attached as Attachment 1. The flow path geometry between the bottom grid plate and the reflector is almost totally unobstructed by structural components. The bottom grid plate is held by small L-shaped brackets. These are shown in an un-numbered shop sketch, attached as Attachment 2. This sketch also specifies that the reflector aluminum is 3/8" thick. Figure 1 is a photo from GA-3399 which depicts the gap between the lower grid plate and reflector.

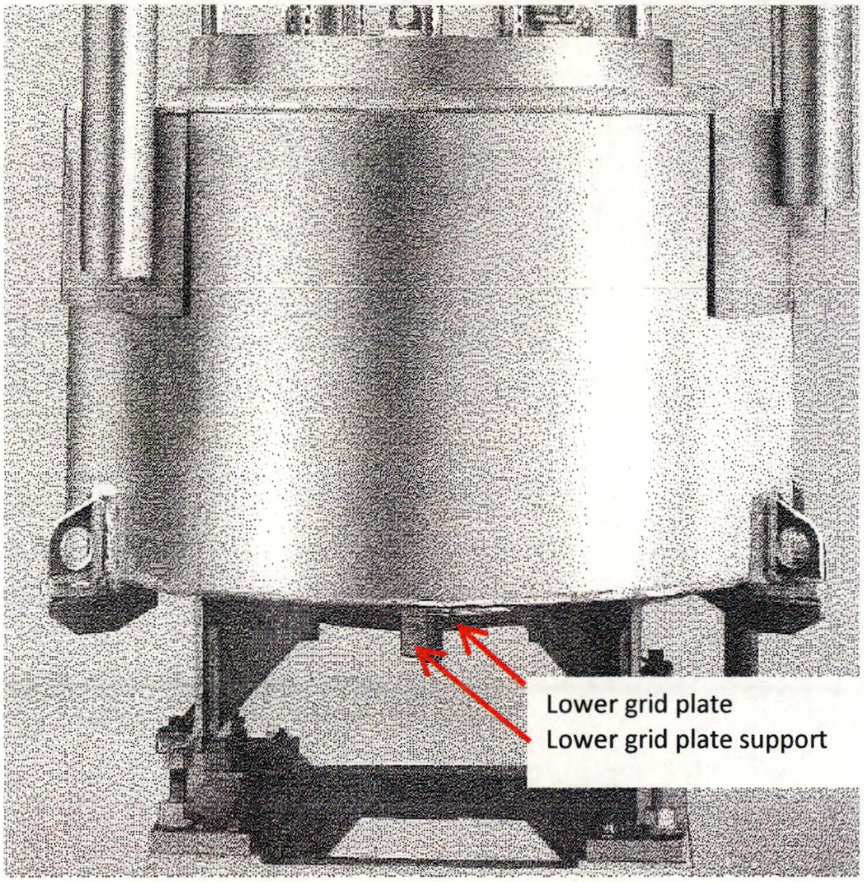

Figure 1 - Photo of reflector / grid plate assembly from GA-3399, showing space between grid plate and reflector.

3. *The loss coefficient for the core exit is calculated on page 4-26 of the SAR to be 0.171. It is described as a contraction loss. The actual flow will undergo a contraction followed by an expansion when flowing through the grid plate. Provide the basis for the formula used to calculate the core exit loss coefficient.*

The exit pressure loss, $\Delta P_e = \frac{K_e \rho v_e^2}{2}$, is based on the downstream flow velocity(v_e) . Since the velocity of the coolant exiting the core is very low, this expansion loss was ignored. Supporting calculations were performed using a TRIGA core model in ANSYS, for an operating power level of 1250 kW. These calculations show (see Fig. 2) that the pressure drop for coolant leaving the core of ~20 Pa, i.e., much less than one atmosphere.

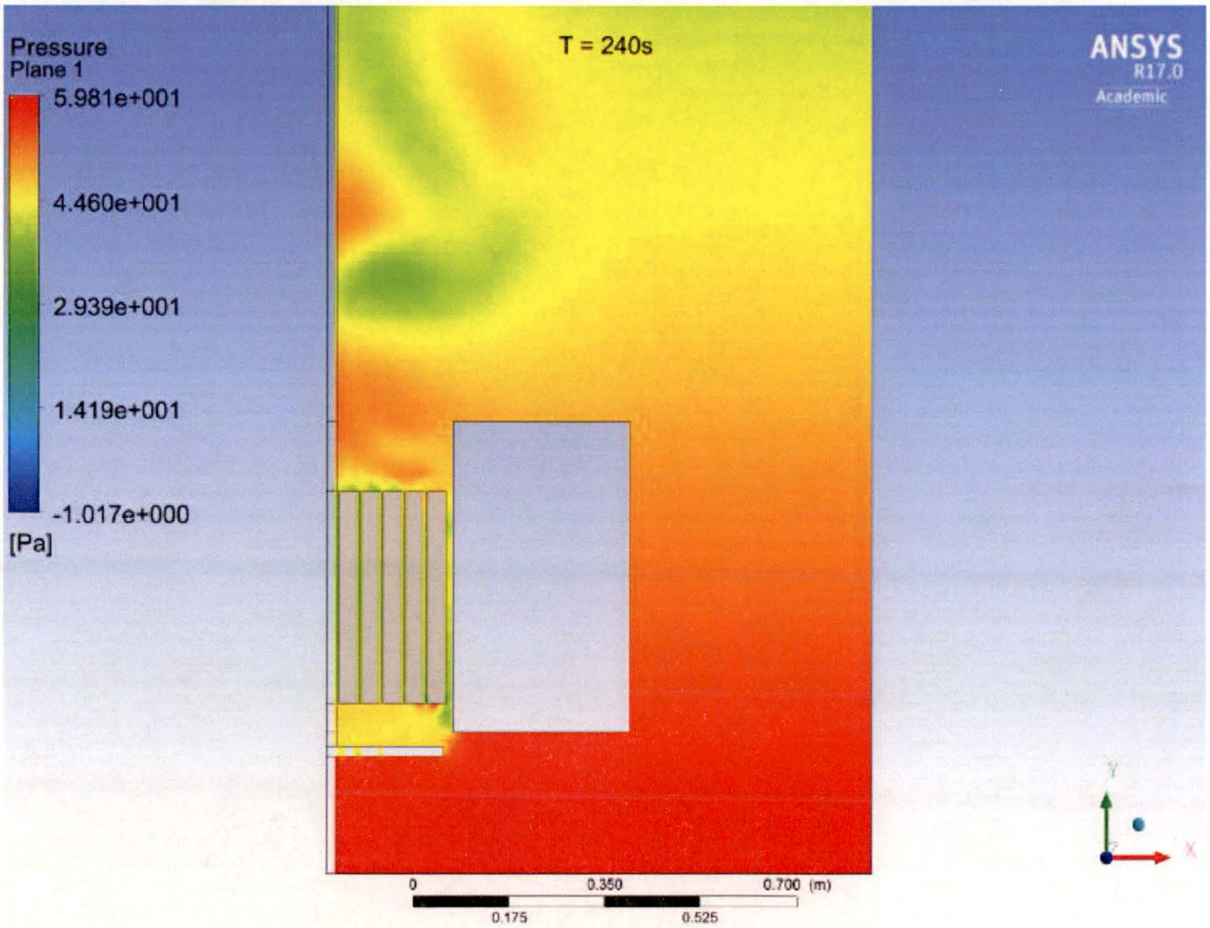

Figure 2 - ANSYS model of coolant pressure drop for TRIGA reactor operating at 1250 kW.

4. *Coolant flow rate and temperature rise for natural convection cooling are tabulated in Table 4.11 (of the SAR). Are the hydraulic diameter and flow area values used in the calculation core average values or hot channel values?*

These values are core average values.

5. *According to SAR Section 4.6, the calculation for core flow rate vs. power uses a core inlet temperature of 27 degrees Celsius and uses an equation that is applicable only to single phase flow. Are the pool temperature limits designed to ensure that single phase flow exists across the core?*

The coolant temperature limits are designed to prevent damage to the ion exchange resin used to maintain low primary water conductivity, not to ensure single phase flow. GA TRD 070.01006.04, "TRIGA Reactor Thermal-Hydraulic Design Study" (2008) contained a RELAP and STAT and concluded that the three 1 MW TRIGA cores analyzed in the study would not experience nucleate boiling at their design temperatures, and the void fraction at a 2 MW TRIGA considered in the study would be 1.5% for an 86°F inlet temperature. This inlet temperature is slightly higher than the 27°C temperature used in the KSU SAR, but is below the 130°F KSU Tech Spec limit on water temperature (130°F = 54.4°C). Calculations performed at KSU in support of this RAI response indicate that the reactor would reach nucleate boiling at 1250 kW for the power peaking assumed in the SAR (2.0), but would have several degrees of margin to nucleate boiling at more realistic power peaking factors calculated with MCNP. MCNP calculations were used to obtain volumetric heat generation rate in the maximum power B-ring fuel rod. A validated RELAP model was modified with this input heat generation rate and KSU tech spec limit as inlet temperature. The calculations were used to evaluate axial profile of coolant temperature (shown in Fig. 3). The outlet temperature of coolant was computed to be 101°C. This is above the boiling point of water at standard temperature and pressure, but slightly below the boiling point of water at the core depth of ~5 meters below the surface of the water.

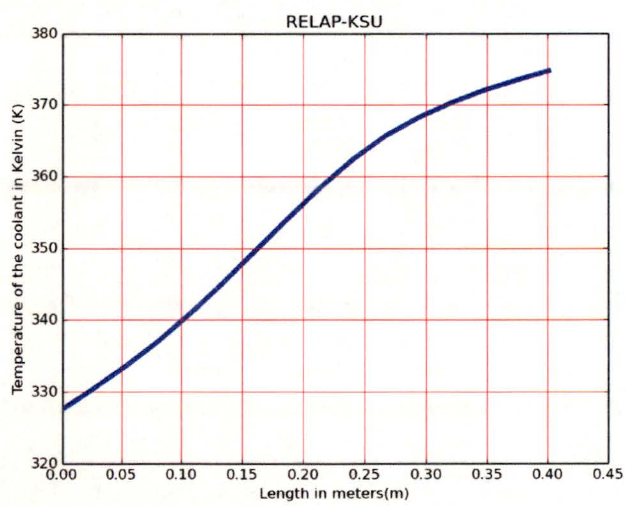

Figure 3- Axial temperature profile of reactor coolant in B-ring using RELAP calculations

6. SAR Section 4.6 states that the entrance of coolant into the core is from the side, above the lower grid plate (see Section 4.2.5) and the entrance pressure loss would be expected to be negligible. There is no basis for this statement. Provide the basis.

As indicated by the ANSYS model shown in Figure 4, the pressure drop above the grid plate is on the order of 20 Pa. These calculations also indicate that the majority of the coolant flow into the core will be from the side, which is the path of least resistance for the coolant. (See Fig. 4). These results are consistent with the pressure loss model in SAR report which models the overall flow resistance to be harmonic mean of flow resistance across the grid plate and flow resistance across the side gap between grid plate and reflector. Due to larger opening size, flow resistance through the side gap is negligible and thus most of the coolant is expected to flow through the side.

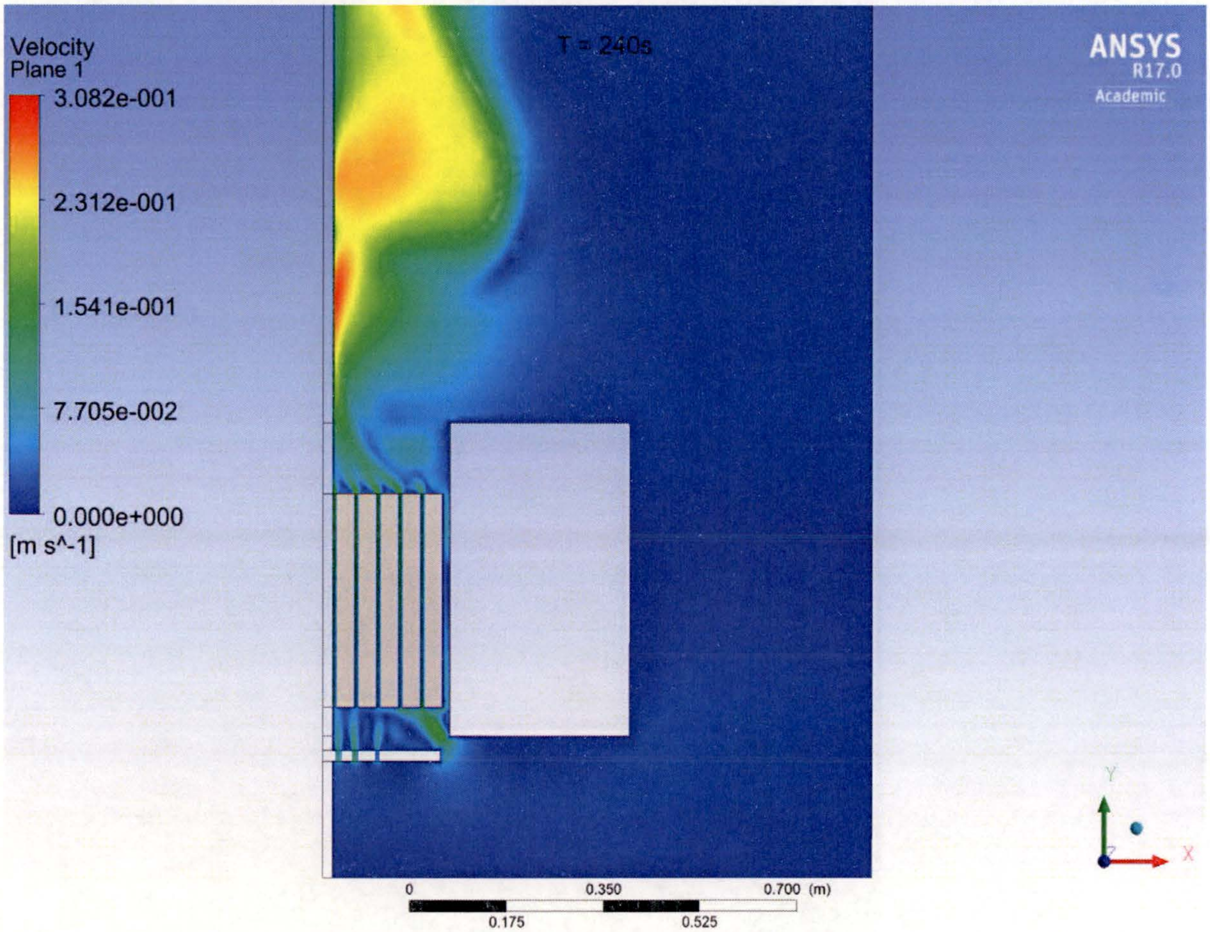

Figure 4 - ANSYS calculation of coolant flow velocity through the KSU TRIGA reactor core when operating at 1250 kW.

6. *The NRC staff wants to reconcile the fuel pin cylindrical radii given in surfaces 200 through 202 with what they were able to calculate from the SAR and some of the cited reference that describe Mark III fuel. The NRC staff arrived that the following values for pin radii: middle zirconium rod (0.3175 cm); fuel-moderator material (1.8161 cm); gap (1.8415 cm); and clad (1.8669 cm). Supply the basis for the dimensions given in Surfaces 200 through 202.*

No gap was modelled between the fuel meat and cladding; the void inside the fuel element was only modelled above the axial graphite reflector. The radii used in the model seem to be slightly off from the values in the SAR and other references. In order to verify that this did not significantly impact the safety basis for the addition of new fuel, one of the modeled cases was repeated with the fuel meat and cladding radii adjusted to exactly match the values in SAR Table 13.1, fuel radius = 1.8161 cm and clad outside radius = 1.8669 cm. The case that was re-modeled featured two adjacent 12%-loaded elements in the E-ring. As a result of this adjustment, the element to average power peaking changed minimally, with the greatest increase in calculated power peaking being an increase of +1.9% for element E-7 (one of the 12%-loaded elements). As can be seen from the results, the change in calculated power peaking that results from correcting the fuel feature radii is minimal and does affect the determination that 12%-loaded elements in the E- and F-ring will have a much lower power peaking and fission product density than 8.5%-loaded elements in the B-ring. The adjustments that were made to the fuel radii in the model were also incorporated into further revisions to the model that were made to address later questions in the RAI.

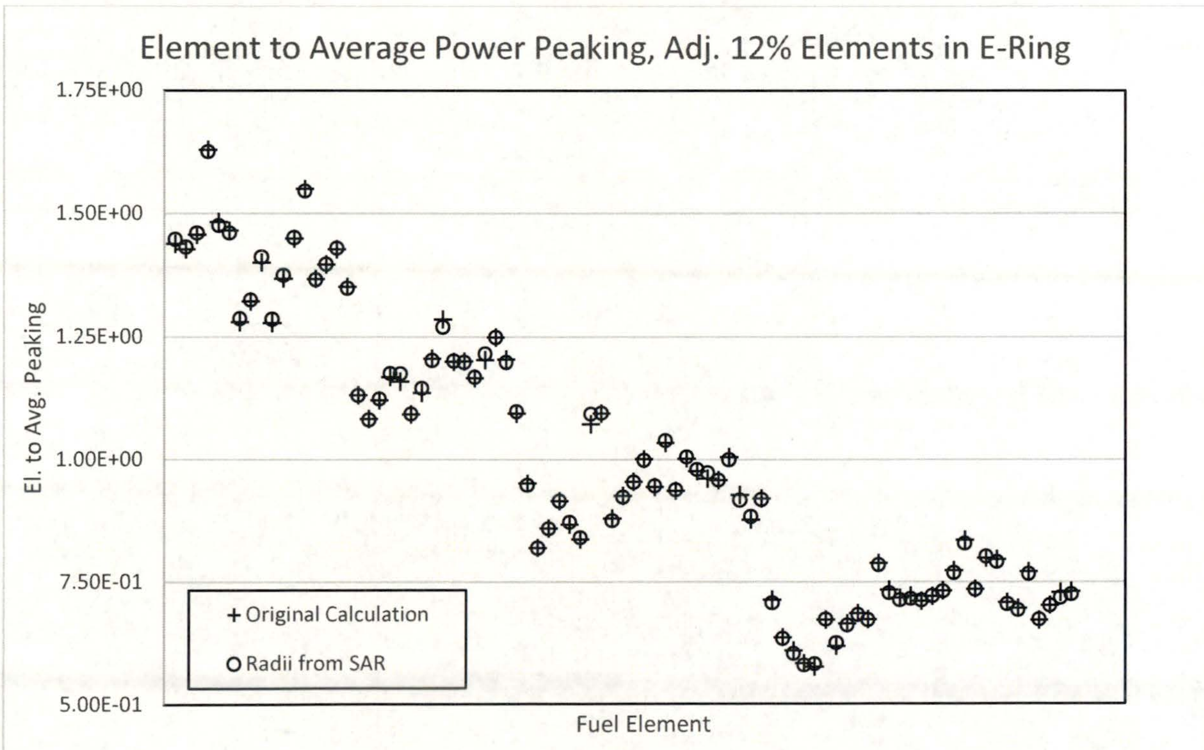

Figure 5 - Effect of fuel radius adjustment on power peaking.

7. *For the surfaces that define the fuel elements (surfaces 1201 through 1630), the respective fuel element radii are all defined as 1.8985 cm, but NRC staff were expecting this value to be consistent with that defined for the universal fuel element radius in surface 202. Give the basis for this number.*

The radii defining the fuel elements in surfaces 1201 to 1630 are for the outside of the fuel meat; surface 202 gives the radius corresponding to the outside of the cladding. These radii seem to be incorrect, as described in RAI question 6.

8. *For the thickness of the aluminum casing surrounding the graphite reflector, NRC staff found different values in the MCNP code depending on what side of the graphite reflector was being considered. State what the value of the thickness should be.*

The reflector walls should be uniform in thickness, with a thickness of 3/8", i.e. 0.9525 cm.

9. *There are three fuel elements in the B ring of the core that are instrumented for temperature. In RAI No. 2 or the KSU RAI response (ADAMS Accession No. ML16200A317), KSU gives the results of a heat balance to infer the steady state temperatures from each ring in the core. Has the facility recorded any steady state temperatures from these elements to confirm the calculations and heat balance methodology? Have power readings ever been recorded during pulsing operation? If so, please describe the results of any applicable confirmatory measurements.*

Confirmatory measurements using thermocouple-instrumented fuel elements in rings other than the B-ring have not been performed. The maximum observed temperatures during steady state and pulsing operations in the B-ring are approximately 309°C (observed on 6/27/16 at 735 kW SS power) and 436°C (observed on 9/27/16 during a ρ = \$2.77, $\hat{n}$ = 1.56 GW pulse).

10. *In RAI No. 1 of the KSU RAI response, KSU gives a methodology for determining the change in Uranium-235 mass with burnup (initial fuel composition minus the burnup per element). Provide the composition of the maximum burnup element that is calculated through this methodology.*

This question led to the uncovering of an error in the calculated fuel masses for the depleted elements in the MCNP model. The magnitude of the error increased as a function of burnup. The model was re-run with updated fuel mass calculations, and the results varied little from the original model used to write the LAR. (The updated model also included the fuel radius modification described in the answer to question 6). Based on the updated calculation, the density and composition of the most highly-depleted element used in the model is as follows:

Fuel Element SN 4742 (E-9), ρ = 5.818 g / cm^3

Element / Isotope	Mass (g)	Mass fraction
H	35.530	0.01596
Zr	2009.764	0.90258
^{235}U	29.517	0.01326
^{238}U	151.866	0.06820

The corrected fuel radii and depleted fuel compositions led to slight difference in the model results. The updated model also included a revision to the RSR inner and outer radii, which were previously set to 26" (inner) and 30" (outer), but should have been 24" (inner) and 28" (outer). The difference in reactivity for the base model and model with four 12% elements changed as follows:

Case	Original Model	Corrected Model	Change
k_{eff}, Base Case	1.03526 +/- 0.00021	1.03636 +/- 0.00022	+0.00110 +/- 0.00030
k_{eff}, Four 12% Elements in E-ring	1.03987 +/- 0.00024	1.04461 +/- 0.00021	+0.00474 +/- 0.00032
Reactivity Effect of 12% Fuel	$0.64 +/- $0.05	$1.18 +/- $0.04	+$0.54 +/- $0.06

The maximum element-to-average power peaking due to the addition of four 12% elements in the E-ring was found to change as follows. Note that the four elements were placed in the same E-ring locations as in the original LAR-supporting calculations. These results are compared to the 12.3%-load case from the original work, since the 12% elements in the revised model were given a loading corresponding to the maximum load of 12% fuel on hand at KSU, which is approximately 12.3% uranium by weight. The reactivity effect of adding the 12% fuel is calculated to be higher based on the revised model; however, the calculation does not show that the minimum safety shutdown margin, which at present is approximately $2.60, will be challenged.

Location	Original Model	Corrected Model	Change
B-ring (8.5% fuel)	1.64	1.65	+0.01
E-ring (12% fuel)	1.19	1.13	-0.06

Figure 6 shows the power peaking for the updated MCNP model, with all 8.5%-loaded fuel (i.e., current license) versus a core with four 12.3% elements in the E-ring.

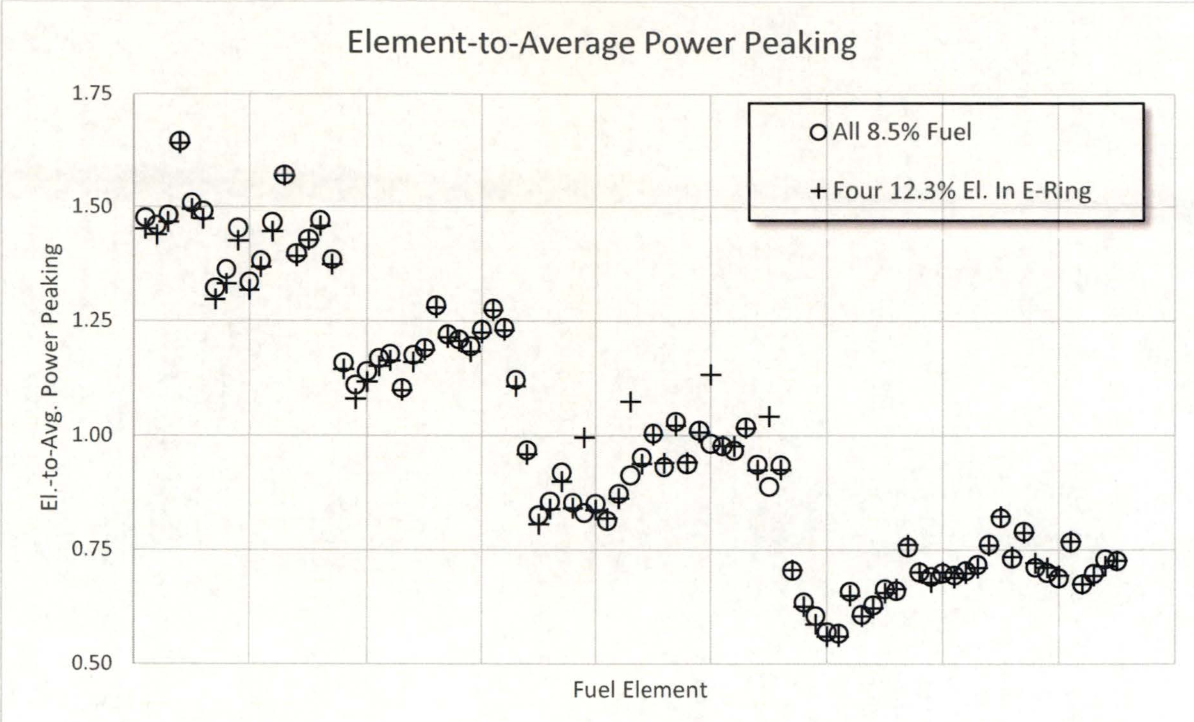

Figure 6 - Updated power peaking calculation from MCNP, based on F7 tally.

11. *For Cell 176, the stainless steel shell of the source is defined as 0.394473 grams per cubic centimeter (g / cc). This is almost an order of magnitude less than the source density given in the Stainless Steel material card (m9, 7.9 g/cc). Has this cell been volume homogenized?*

Yes, source shell cell is homogenized with the internal source volume, resulting in a low mass for the steel. The density of 0.394473 g / cc corresponds to the homogenization of a thin stainless steel shell and internal void. The external void between the source holder and source capsule is separately modeled with a density of 0.001239 g / cc.

12. *This RAI is generated from your current TS 3.4, "Safety Channel and Control Rod Operability," and it is beyond what is addressed in your LAR. 10CFR50.36(c)(2)(ii) requires a technical specification limiting condition for operation of a nuclear reactor must be established for a structure, system, or component (for example, control rods) that meet specific criteria. Specifically, 10CFR50.36(c)(2)(ii) Criterion 3 states "A structure, system, or component that is part of the primary success path and which functions or actuates to mitigate a design basis accident or transient that either assumes the failure of or presents a challenge to the integrity of a fission product barrier." In additional, American National Standard Institute / American Nuclear Society-15.1-2007, "The Development of Technical Specifications for Research Reactors," Section 2.2, "Limiting safety systems settings," states that limiting safety systems settings shall be established. The guidance in NUREG-1537, Part 1, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors: Format and Content," Chapter 14,*

"Technical Specifications," Appending 14.1, "Format and Content of Technical Specifications for Non-Power Reactors," Subsection 3.2, item (1), "Operable Control Rods," asks the number and type of operable control and safety rods be specified. However, under the current TS 3.4 there are no technical details regarding the operability and numbers of your reactor control rods. Provide a specific proposal to the current TS 3.4 that would demonstrate, as a limiting condition, control rods in reactor core provide a success path for the safe operation of your reactor.

The KSU reactor Technical Specifications do not give a required minimum number of control rods. However, the typical definition of "operable" is "capable of performing the intended safety function." The safety function of control rods is to insert and reduce the reactivity of the core, specifically, to a value of zero minus the shutdown margin. The KSU reactor Technical Specifications define the minimum safety shutdown margin as at least $0.50 from reference core conditions with the most reactive control rod fully withdrawn. Since the operability of the control rods is based on their ability to reduce reactivity, if the rods are not moveable but fully inserted, they are still performing their safety function. In other words, it is not important to specify the minimum number of operable control rods as the specification of a minimum safety shutdown margin guarantees (as long as it is met) that the control rods can perform their safety function of adequately reducing core reactivity. This consideration would seem to be why the NRC approved the Technical Specifications without a specified number of control rods or a definition of control rod operability. The Facility operates within the bounds of these approved Technical Specifications, and therefore is limited by the defined minimum safety shutdown margin to operate with adequate control rod functionality to ensure that the reactor can be safely shut down.

I swear under penalty of perjury that the foregoing is true and correct.

Regards,

JA Geuther

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Attachment 1 – Excerpt from GA-3399, "250-KW TRIGA MARK II PULSING REACTOR MECHANICAL MAINTENANCE AND OPERATING MANUAL"

2. BASIC REACTOR COMPONENTS

The reactor core and reflector assembly (see Figure 2.1) form a cylinder approximately 43 inches (1.09 meters) in diameter by 23 inches (0.58 meter) high. The core is surrounded by the graphite reflector and consists principally of a lattice of fuel-moderator elements, graphite dummy elements, and control rods. Submerged in water in the aluminum tank, the reflector assembly rests on a platform which positions the lower edge of the reflector about 2 feet (0.61 meter) above the tank floor. Shielding above the reflector is provided by approximately 16 feet (4.9 meters) of water. The core is cooled by natural circulation of water. Coolant water occupies about one-third of the core volume.

2.1. REFLECTOR PLATFORM

The reflector platform (see Figure 2.2) is a square, all-welded aluminum frame structure. It rests on four legs that are held down by aluminum anchor bolts welded to the bottom of the aluminum tank. Four pads with spherical indentations are mounted on top of the platform to serve as receptacles and supports for the reflector assembly. Oversized bolt holes in the pads and legs permit some horizontal adjustment during initial installation.

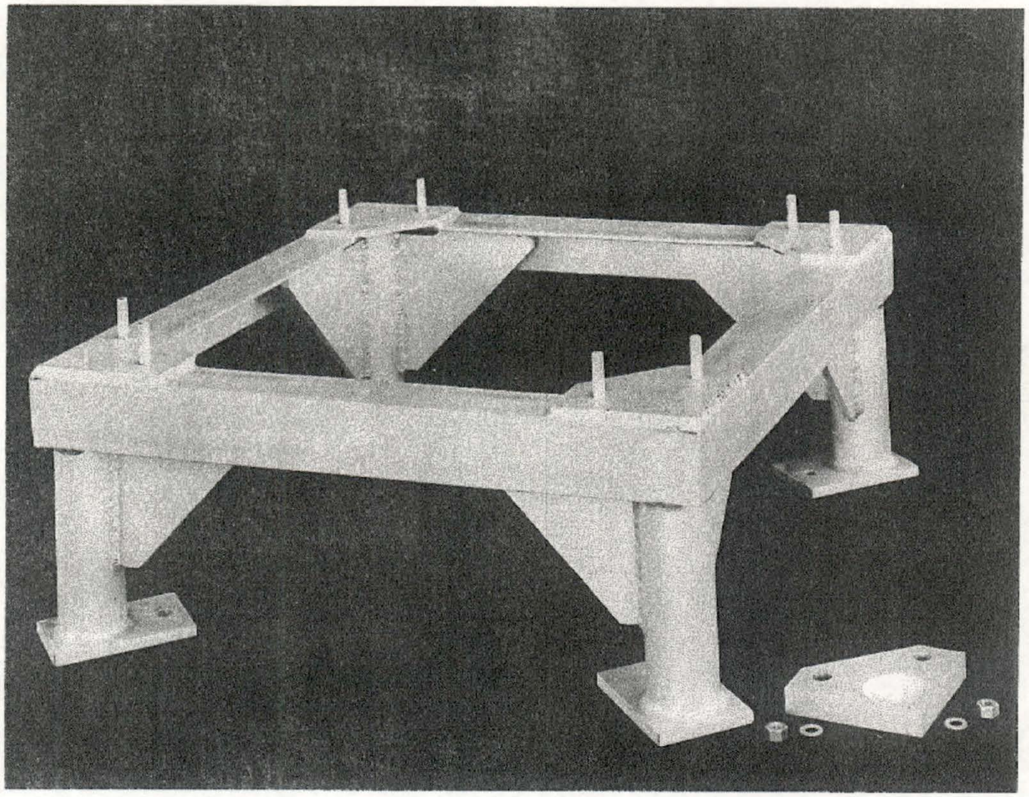


Fig. 2.2--Reflector platform

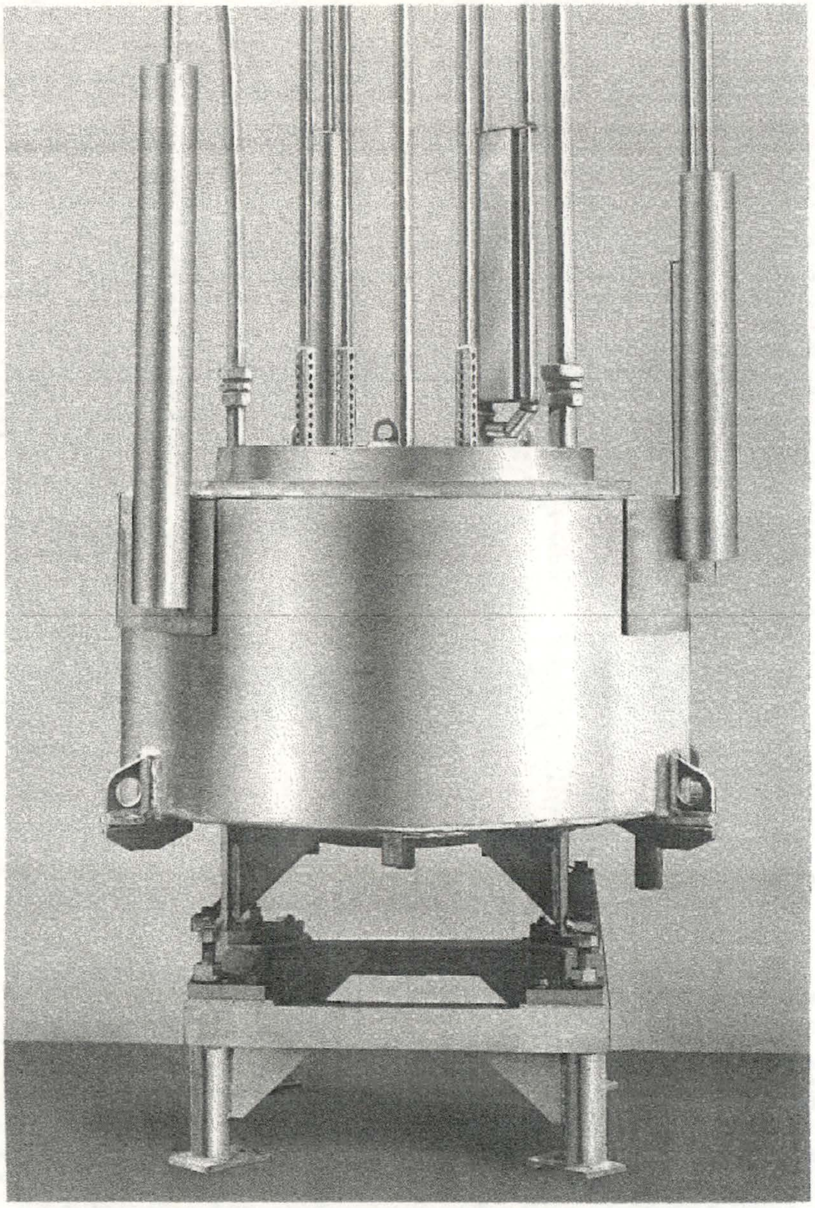


Fig. 2.1--Core and reflector assembly

2.2 REFLECTOR

The reflector surrounding the core (see Figure 2.3) consists primarily of a ring-shaped block of graphite having an approximate inside diameter of 18 inches (45.7 cm), a radial thickness of 12 inches (30.5 cm), and a height of 22 inches (55.9 cm). Water is kept from contact with the graphite by encasing the entire reflector in a welded aluminum can. Provision for the isotope-production facility (rotary specimen rack) is made in the form of a ring-shaped well in the graphite that is open toward the tank top. This well is also aluminum lined, the lining being an integral part of the aluminum reflector can. At no place does the rotary-specimen-rack mechanism penetrate the sealed reflector assembly.

The reflector assembly rests on the reflector platform. Support is provided by two aluminum channels welded to the bottom of the reflector container. Four tapped holes in the lower flanges of the channels accept the leveling screws, which transmit the weight of the reflector and core to the reflector platform. The reflector assembly also provides support for the two grid plates. The anodized aluminum leveling screws allow for a vertical adjustment of approximately 2-1/4 inches (57 mm). For easy turning, each screw has a hexagonal head. When adjustment has been completed, the position is secured by tightening an anodized aluminum jam nut located under the flange on each leveling screw.

Four lugs with 2-inch (51 mm) diameter holes are provided for lifting the reflector assembly. Its weight is approximately 1700 pounds (770 kg). When lifting the reflector, the use of a cable spreader is necessary to prevent damage to the aluminum container caused by the lifting slings.

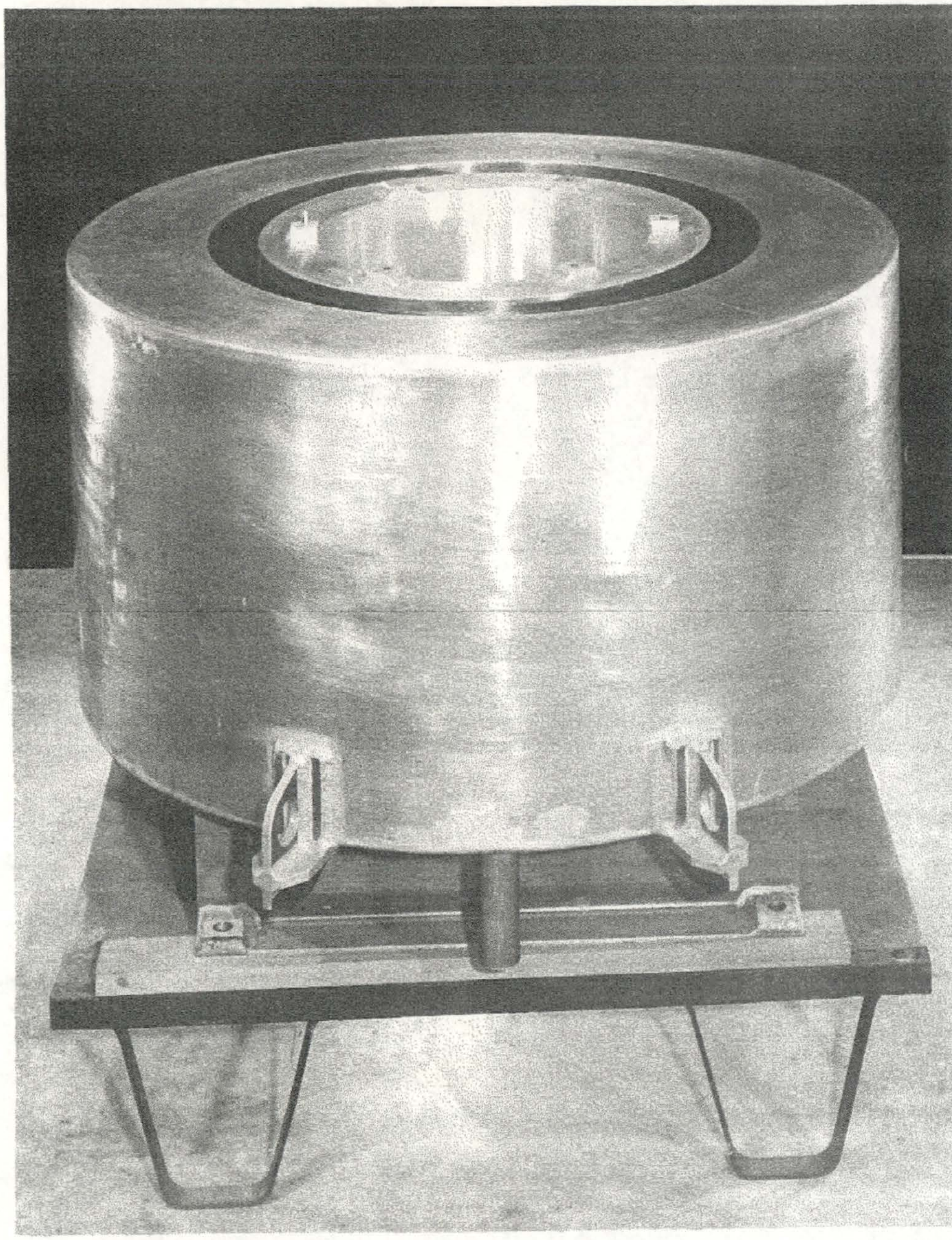


Fig. 2.3--Reflector assembly

2.3. GRID PLATES

The top grid plate (see Figure 2.4) is of aluminum and is 19.44 inches (49.5 cm) in diameter and 3/4 inch (19 mm) thick. It provides accurate lateral positioning of the core components. It rests on six anodized aluminum washers, which in turn rest on six pads welded to the top side of the reflector container. Two stainless steel dowel pins, which fit tightly in the pads and loosely in the grid plate, orient the grid. Four hexagonal-head captive screws, of anodized aluminum and 9/16 inch (14.3 mm) across flats, secure the top grid plate to the reflector. In addition, they also serve as hold-down screws for the clamps that secure the rotary specimen rack in its location. Ninety fuel locations are provided, distributed in five circular rings. Each element location is a hole 1.505 inches (38.23 mm) in diameter through the plate, which is anodized to retard wear and corrosion.

Cooling-water passes through the differential area between the triangular spacer block on the top of each fuel element and the round holes in the grid plate. The nominal diametral clearance between the tips of the spacer blocks and the grid plate is 0.029 inch to 0.040 inch (0.74 to 1.02 mm). The center hole in the top grid plate, which is 1.515 inches (38.4mm) in diameter, serves as a guide for the central thimble.

Sixteen foil insertion holes, 0.314 inch (8 mm) in diameter, are drilled at various positions through the top grid plate (see Figure 2.4). These holes make possible the insertion of foils into the core to obtain flux measurements.

The bottom grid plate (see Figure 2.4), in addition to providing accurate spacing between the fuel-moderator elements, also carries the entire weight of the core. It is of aluminum and is 16 inches (40.7 cm) in diameter by 3/4 inch (19 mm) thick. The bottom grid plate is supported by six anodized aluminum washers on six L-shaped lugs welded to the underside of the reflector container. Two stainless steel dowel pins, which

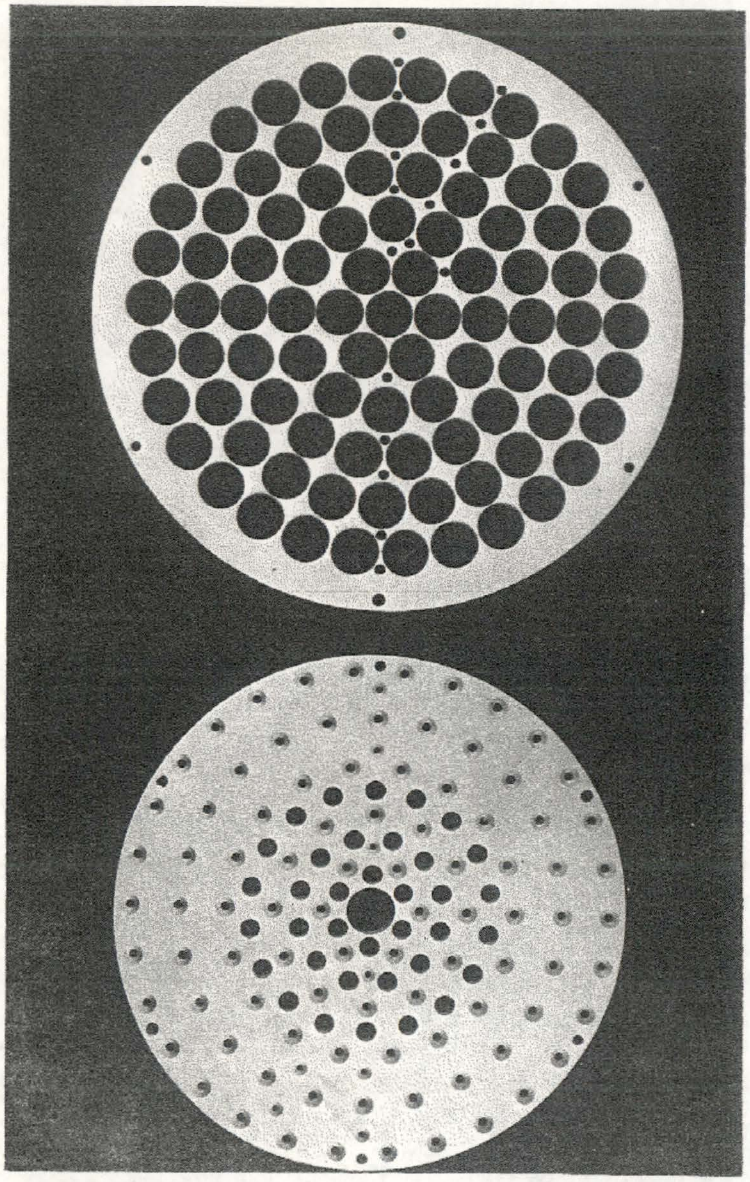
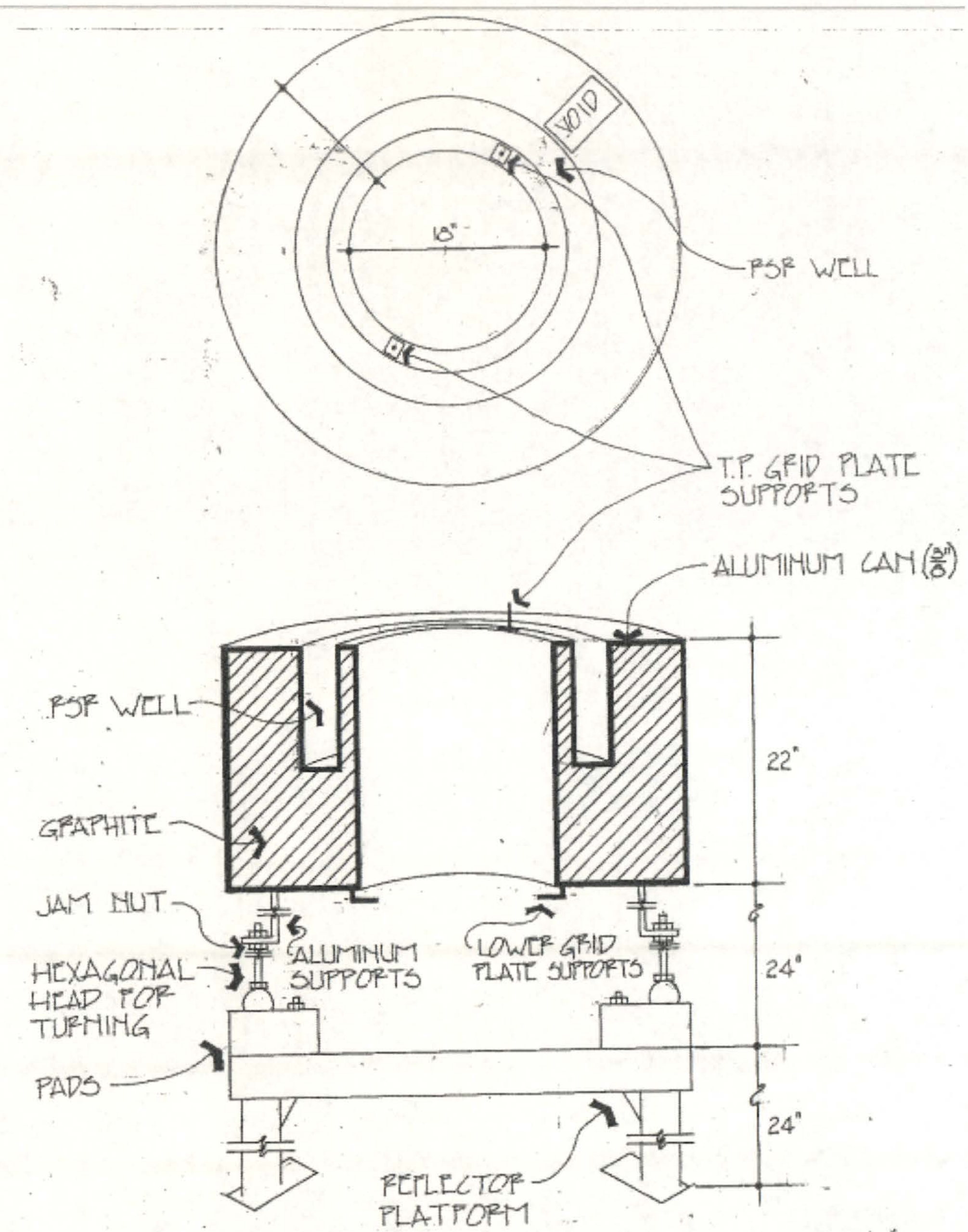


Fig. 2.4--Grid plates

fit tightly in the lugs and loosely in the plate, orient the grid. Four hexagonal-head captive screws of anodized aluminum that are 9/16 inch (14.3 mm) across flats secure the grid to the support lugs. The size of the bottom grid plate allows it to be inserted and removed through the core void when the top grid plate and other core components are removed. Ninety holes 0.281 inch (7.15 mm) in diameter countersunk 90 degrees by 0.625 inch (15.9 mm) in diameter are machined in alignment with the holes in the top grid plate. The countersink supports the lower end fixture of the fuel-moderator element. The holes in both grid plates also orient and support the three control-rod guide tubes. The central hole, which is 1.562 inches (39.7 mm) in diameter, serves as a clearance hole for the central thimble.

Thirty-six holes, 5/8 inch (15.9 mm) in diameter and oriented in three circular bands concentric with the central-thimble hole, provide a water-passage area through the lower grid plate. Most of the water used to cool the core, however, flows by natural convection into the lower core plenum through the annular space provided between the top of the bottom grid and the bottom of the reflector. The lower grid plate is also anodized after machining to retard wear and corrosion.

Attachment 2 – Shop Sketch of Reflector Assembly



VOID
18"
RSR WELL
T.R. GRID PLATE
SUPPORTS
ALUMINUM CAN (3/8")
RSR WELL
GRAPHITE
22"
JAM NUT
ALUMINUM
SUPPORTS
LOWER GRID
PLATE SUPPORTS
HEXAGONAL
HEAD FOR
TURNING
24"
PADS
24"
REFLECTOR
PLATFORM