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CONVERSION, CORE REDESIGN AND UPGRADE OF THE RHODE ISLAND ATOMIC ENERGY COMMISSION REACTOR*

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ABSTRACT

The 2 MW Rhode Island Atomic Energy Commission reactor is required to convert from the use of High Enriched Uranium (HEU) fuel to the use of Low Enriched Uranium (LEU) f using a standard LEU fuel plate which is thinner and contains more Uranium-235 than the current HEU plate. These differences, coupled with the fact that the conversion should be accomplished without serious degradation of reactor characteristics and capability, has resulted in core design studies and thermal hydraulic studies not only at the current 2 MW but also at the maximum power level of the reactor, 5 MW. In addition, during the course of its 23 years of operation, it has become clear that the main uses of the reactor are neutron scattering and neutron activation analysis. The requirement to convert to LEU presents an opportunity during the conversion to optimize the core for the utilization and to restudy the thermal hydraulics using modern techniques. This paper will present the preliminary conclusions of both aspects.

The Rhode Island Nuclear Science Center (RINSC) reactor is an open swimming pool reactor which has operated at 2 MW since 1968 using fully enriched MTR fuel. The reactor was designed by the General Electric Company for operation at 1, 2.5 and 5 MW and all permanent structures such as shielding, in-concrete piping, and pool depth were sized and installed for 5 MW operation. In addition, using the calculational techniques available in the late 1950's, operating parameters for all three operating power levels were established.

This reactor, as most reactors which became operational in the early 60's, was designed for wide ranging utilization and therefore incorporates a thermal column, bulk shielding facility, radial and through tubes, pneumatic irradiation systems, and in-core radiation baskets. Historically, however, the facility has been utilized for activation analysis as part of research programs conducted at the facility, and in neutron scattering. The size of our effort is demonstrated by the fact that each year we perform irradiations on about 5,000 samples, analysis of which lead to about 100,000 element identifications. We provide facilities for the entire operation, from clean rooms for sample preparation to counting equipment. In neutron scattering, two spectrometers are in operation with a third under construction. We operate the only polarized neutron, small angle scattering instrument in the United States. The neutron scattering effort at our facility is currently expanding through the addition of staff.

In both experimental areas, there is a need for more neutron flux. The NAA groups are interested in doing smaller samples and the neutron scatterers always want more flux.

In early 1986, as you know, the Nuclear Regulatory Commission (NRC) issued a regulation requiring all licensed reactors in the United States to convert to the use of low enriched uranium when technically possible unless the reactor could claim a unique purpose. The rule further stated that the costs of conversion would be borne by the Department of Energy (DOE) and that the conversion should be accomplished in such a way as to not seriously degrade the characteristics of the reactor. At the same time the DOE which supplies fuel for most university reactors decided to produce a standard fuel plate for use in all university reactors including the Rhode Island reactor. This standard plate is different from the fuel plate currently in use. These differences are shown in Figure 1. Note that our standard 18 plate element currently contains 124 grams of U^{235} while the proposed LEU plate will contain 225 grams of U^{235}. In addition, the proposed plate will lead to a fuel element with greater flow area. The net result will be a smaller core with increased flow through the core and less pressure drop across the core.

At first glance these are desirable changes: the increased flow will allow the reactor to operate cooler; the smaller core will increase the neutron flux. However, the design of the reactor does not readily accommodate these changes.

The pressure drop in the primary system is used to force coolant water through the thermal column cooling system. A decrease in pressure drop across the core will therefore decrease the coolant flow to the thermal column. It may be necessary to install a pump to provide adequate cooling to the thermal column.

The smaller core presents a problem because of the design of the existing grid plate and grid box.

Figure 2 shows the grid box of the reactor and shows the grid plate and the support for shrouds which contain control blades.

Figure 3 shows one control blade with its shroud. Four of these shrouds are permanently fixed in the grid box and cannot be moved. While these large control blades are desirable from a safety standpoint, they are obviously only effective when surrounded by fuel.

Figure 4 shows the current core used: a 30 element graphite reflected core with 5 irradiation baskets. This figure shows the HEU core which has become our standard operating core. Before arriving at this core however, critical experiments were performed for 19 cores for which excess reactivity and control rod worths were experimentally determined. These 19 cores were utilized in early 3 dimensional calculations to determine that the analytical techniques could predict the experimental results. These calculations, as well as all the calculations for the remainder of my presentation, have been performed by the Reduced Enrichment for Research and Test Reactors (RERTR) group at Argonne National Laboratory.

Note the arrangement of the facilities for experiments around this core. The spectrometers are at the two large radial tubes, and a new spectrometer is being constructed in the thermal column port. Rabbit irradiations are performed in the rabbit system and in a fast automated system installed in a beam tube. While not shown in the figure, the power peaking factor for this core is about 2.5.

In the early core design work for an acceptable LEU core, the use of a flux trap was investigated. This was done to create facilities with higher flux for use in activation analysis programs and to make the core large enough to incorporate the fixed control blades. Figure 5 presents the end result of many calculations and shows an LEU core containing 21 elements and two flux traps. The core would also provide enhanced fluxes at the beam tubes and rabbit position. Note, however, that this core has a maximum power peaking factor of 4.16 which from a thermal hydraulics standpoint is unacceptable at the existing coolant flow rate. Calculations on several variations of this core were also performed which included half loaded elements, a central graphite reflector element, and 1/8" stainless steel liners in the flux trap. With these variations it was possible to reduce the power peaking factor to about 3 but usually at the expense of excess reactivity. From these calculations, it became clear that the power peaking factors would remain a problem.

Figure 6 shows the next core which was investigated. This core contains a row of beryllium elements in the center with irradiation holes in the beryllium. Also note that the row of beryllium now lines up with the beam tube in the thermal column creating a very desirable situation for neutron scattering for one beam tube. If, however, the row of beryllium were rotated by 90 degrees then 2 instead of 1 beam tube would have the advantage of "seeing" only scattered neutrons. At this point in the conversion redesign studies, it became clear that we should proceed in such a way as to peak the core for neutron scattering and the increased flux for NAA would take care of itself.

Figure 7 shows the next core which was and is still being investigated. Note the acceptable peaking factor and that all tubes now "see" only scattered neutrons. Also note the use of beryllium reflectors.

Figure 8 presents the most recent core design under investigation. Note again the acceptable power peaking factor and shut down margin even though the control blades are now outside the core. This core also utilizes beryllium reflectors.

Figure 9 presents thermal flux data for the four cores considered, i.e. the current HEU core,, the 9 element core designated as Be-13, the 16 element clustered core designated as Be-5B and the flux trap core designated as LEU-1. All data are at the 2 MW power level. Clearly the beryllium cores offer distinct advantages not only in increased thermal flux but also in an improved signal to noise ratio. The locations calculated are indicative of the relative flux for beam tubes and for the NAA irradiation facilities.

Calculations already performed on these beryllium reflected cores show that the excess reactivity is strongly dependent on the gap between the outside of the core and the reflector. For this reason, all the results should be considered preliminary.

At the present time, calculations on Be-5B and Be-13 are continuing. Burnup calculations already performed indicate that the excess reactivity is not adequate or at best marginal even at our low duty cycle. Calculations are continuing to increase the core lifetime perhaps by using more than 18 plates in each fuel element or increasing the uranium in each plate. Calculations are also being performed to determine if this deviation from standardization is justified by savings in fuel element fabrication.

Calculations are underway to optimize the thickness of the beryllium reflector. At the same time, a cost balance is being performed on the use of beryllium versus the use of additional fuel elements in the larger core which would result if beryllium were not used.

Calculations are also underway to improve still further the beam port flux. Ideally, the beam ports should extend closer to this smaller core. Since the grid box makes it impossible, calculations are underway to determine the effects of holes in the beryllium reflectors which effectively extend the beam tubes.

Finally, detailed calculations of xenon behavior and temperature coefficient are being performed.

Thermal hydraulic calculations and design basis accident considerations are also being performed concurrent with the core design.

The existing HEU reactor with its lightly loaded fuel element is adequately cooled by air convection after a short shut down period. Any new core incorporating the more heavily loaded fuel plates will probably not be adequately cooled by air convection after a short shut down period. The new core then may require an emergency core cooling system. Calculations are underway to make this determination. It should be noted however that the grid box, instead of only a grid plate, makes emergency core cooling more simple since it may be only necessary to keep the grid box filled with water.

As already stated, this reactor was designed to operate to a maximum power level of 5 MW. The coolant flow rate at 1 MW was set at 340 M^3/HR with 227 M^3/HR passing through the fuel elements. This flow rate at higher powers has been set at 658 M^3/HR with 454 through the fuel. In order to assure that these thermal hydraulic parameters are not seriously effected by the conversion, calculations have been performed using present day techniques.

Figure 10 presents the plate surface temperature for 4 cores as a function of power level. Also shown is the saturation temperature for the conditions of operation. Note that while the flux trap core may be acceptable under some conditions, it is unacceptable at our present power level and at 5 MW. The HEU, and the 9 elements and 16 element LEU cores are acceptable.

Figure 11 presents data for the onset of nucleate boiling as a function of power level for the 4 cores. Again the flux trap reactor is unacceptable while the remaining three provide a sufficient margin before the onset of nucleate boiling.

Figure 12 presents the preliminary calculation for critical heat flux as a function of power level for the 4 cores. These calculations are incomplete but for the cores of interest, Be-5B and Be-13, the margins appear more than adequate for burnout due to the departure from nucleate boiling and flow instability.

In conclusion, the federally mandated conversion coupled with the use of a standardized fuel plate has lead to a reanalysis of the nuclear, safety and thermal hydraulic characteristics of the RIAEC reactor. To insure that there is no reduction in capability, the analysis is being performed not only at 2 MW but at the 3 and 5 MW power levels. In addition, the study is proceeding to match the reactor with its utilization.

	^{235}U grams/ plate	plates/ element	^{235}U grams/ element	Fuel Plate Thickness mm	Clad Thickness mm	Coolant Channel Width mm
HEU FUEL(EXISTING)	6.89	18	124	1.5	0.50	2.5
LEU EQUIVALENT	7.92	18	142.6	1.5	0.50	2.5
STANDARDIZED LEU FUEL	12.50	18	225	1.3	0.38	3.8

Figure 1: Comparison of HEU and LEU Fuel Plate

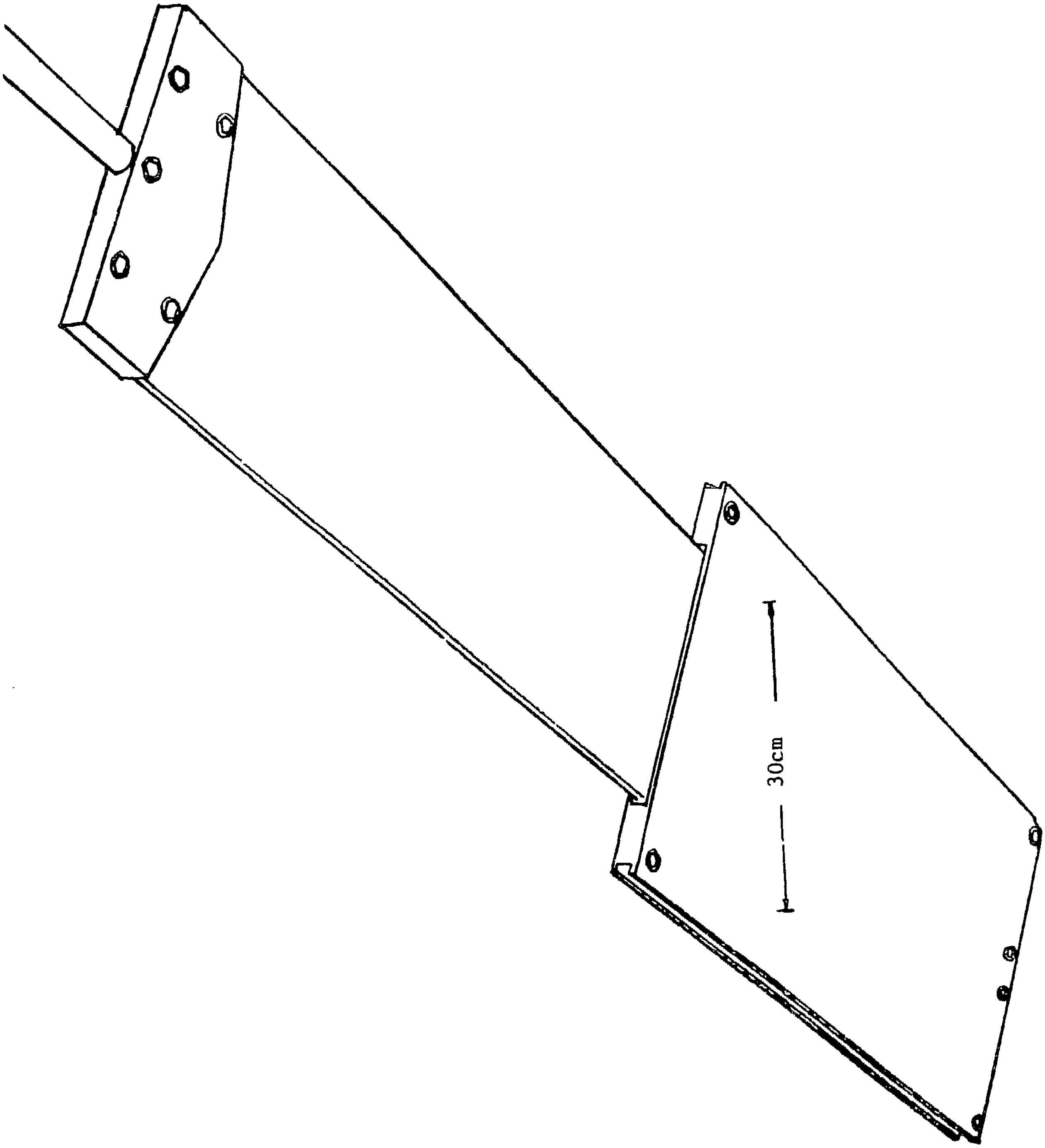

Figure 3: Control Blade and Shroud

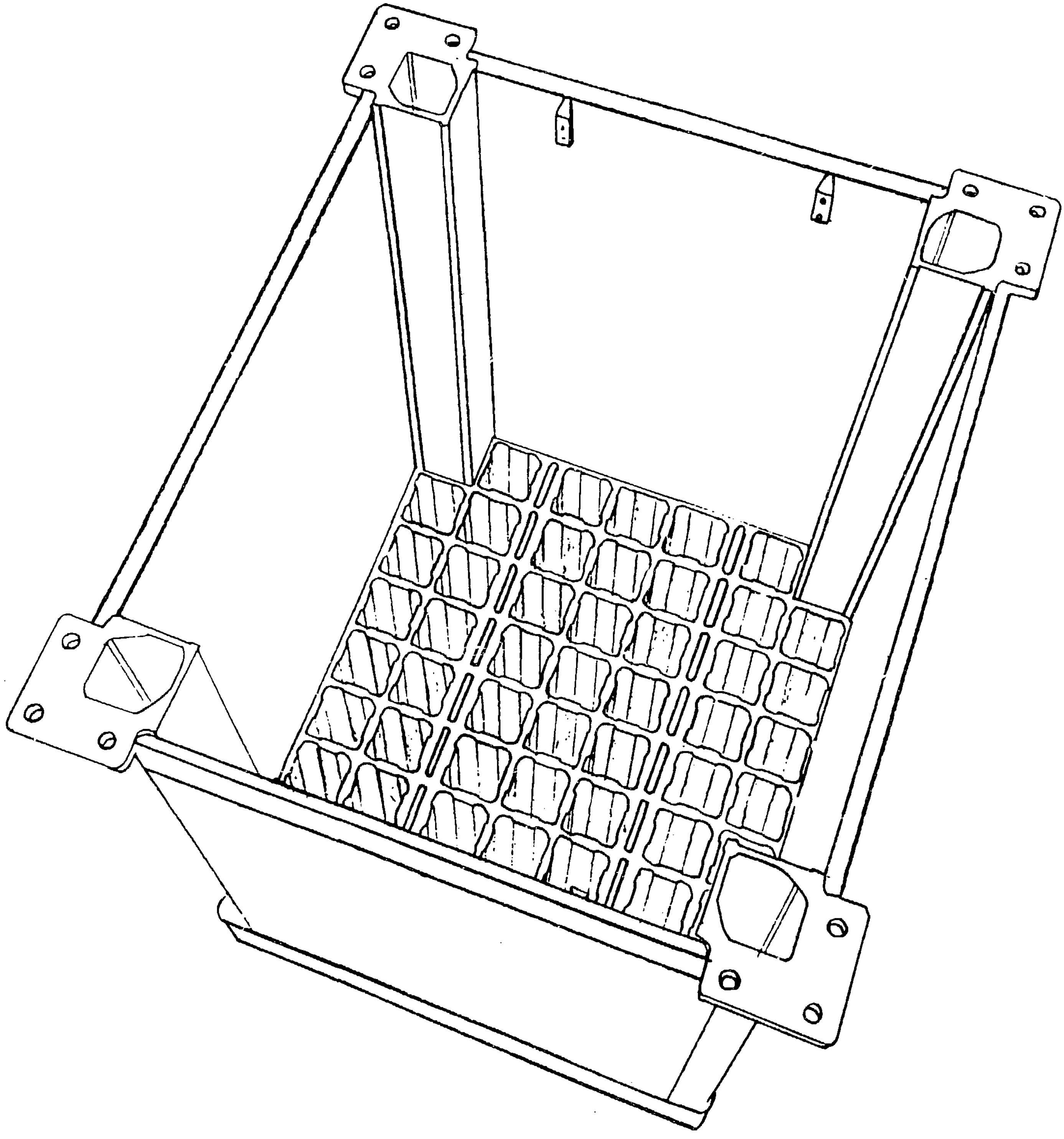

Figure 2: Reactor Core Grid Box

RINSC HEU CORE (6/16/86)

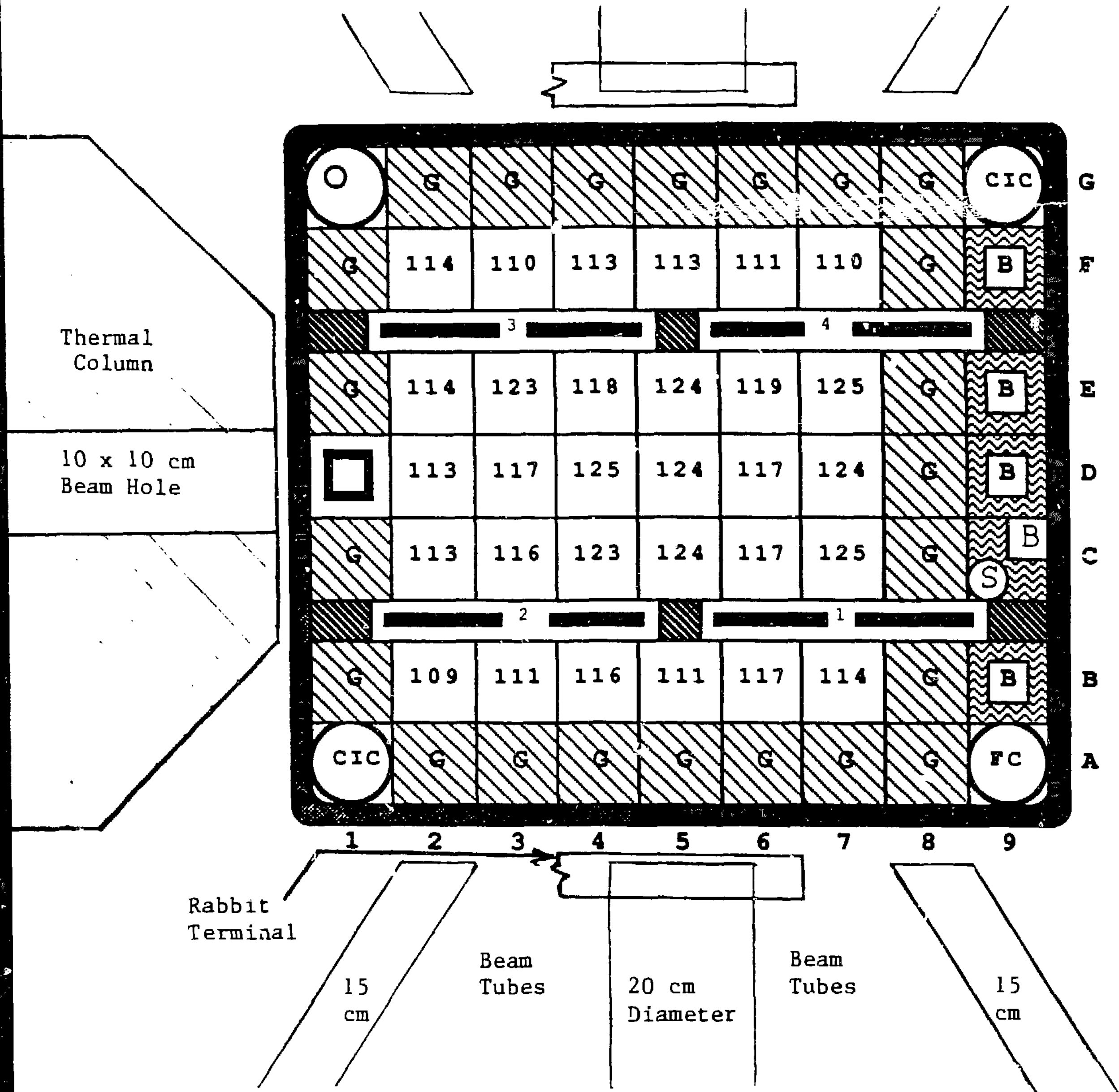

Figure 4: Typical 30 element HEU core

LEU STARTUP CORE: 21 Fresh Elements

POWER PEAKING FACTORS

Blades at 12.7" (Absorber Tip at Fuel Meat Centerline)

Calculated Excess Reactivity = -1.38 % Δk/k

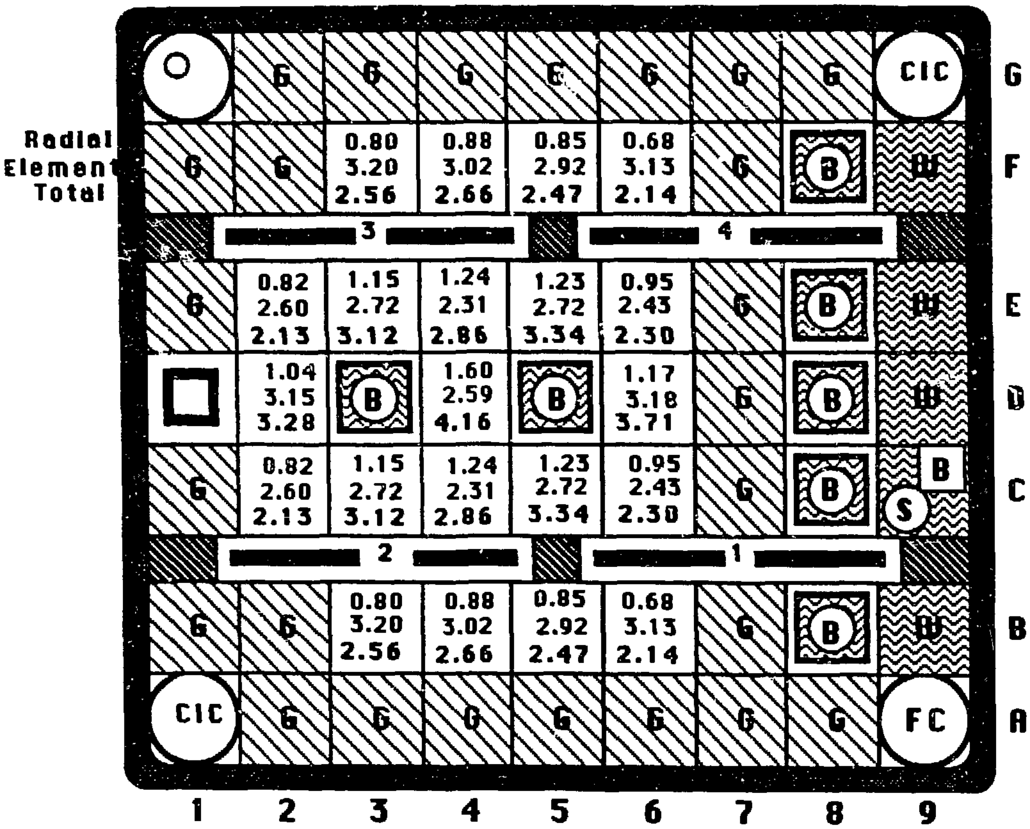

Figure 5: Flux Trap, 21 Element Core

LEU CORE BE-1

18 Fresh Elements

Calculated Excess Reactivity = 5.13 % Δk/k

Total Power Peaking Factor = 2.47 in C4 and E4

Shutdown Margin = 5.42 % Δk/k with Blade 3 Stuck

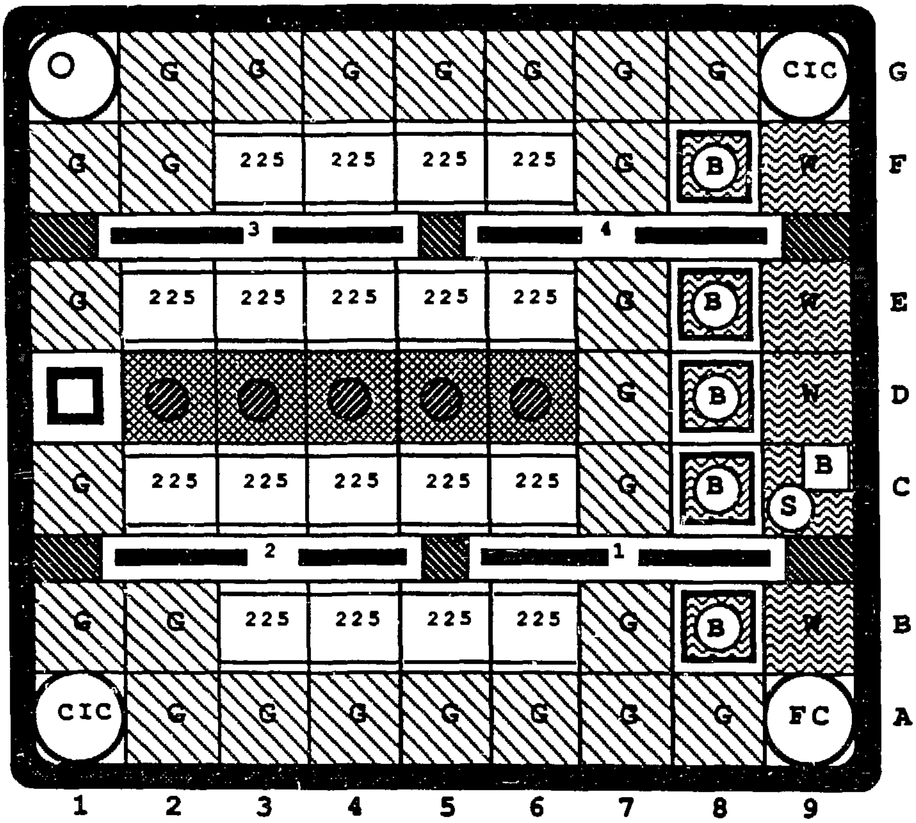

Figure 6: Be split, 18 element core

LEU CORE BE-5B

16 Fresh Fuel Elements

Calculated Excess Reactivity = 5.37 % k/k

Total Power Peaking Factor = 2.76 in C4 and E4

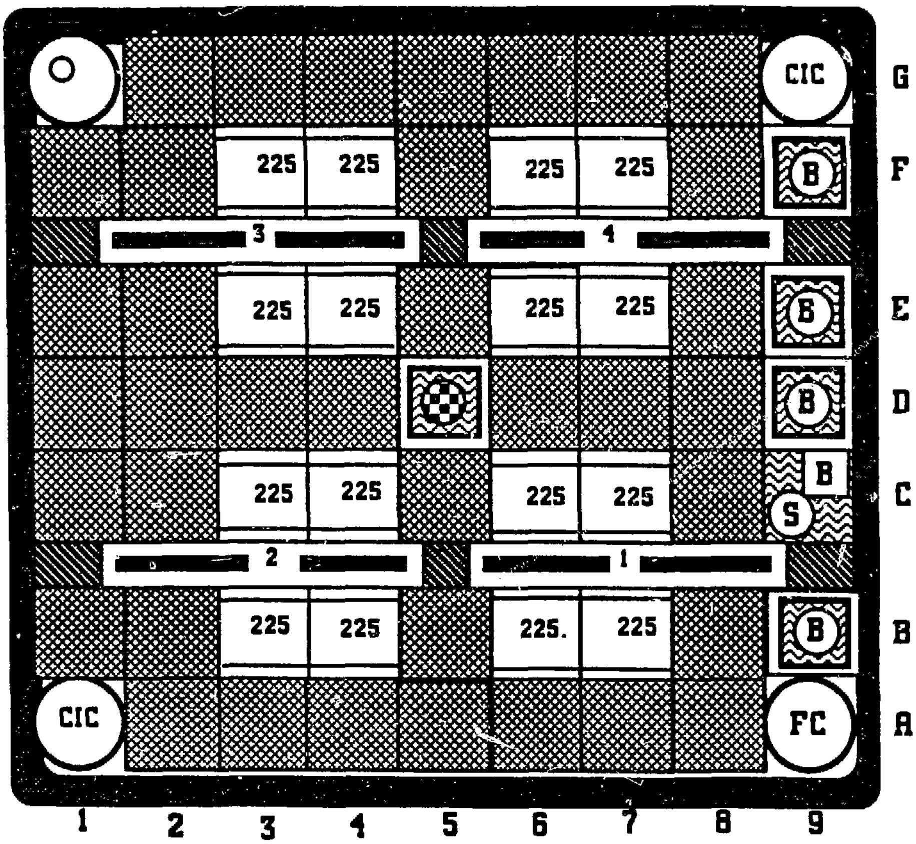

Figure 7: Be reflected, 16 element core

LEU CORE BE-13

9 Fresh Fuel Elements

Calculated Excess Reactivity = 4.43 % k/k

Total Power Peaking Factor = 1.97 in C4

Shutdown Margin = 5.6% D k/k with Blade 3 Stuck

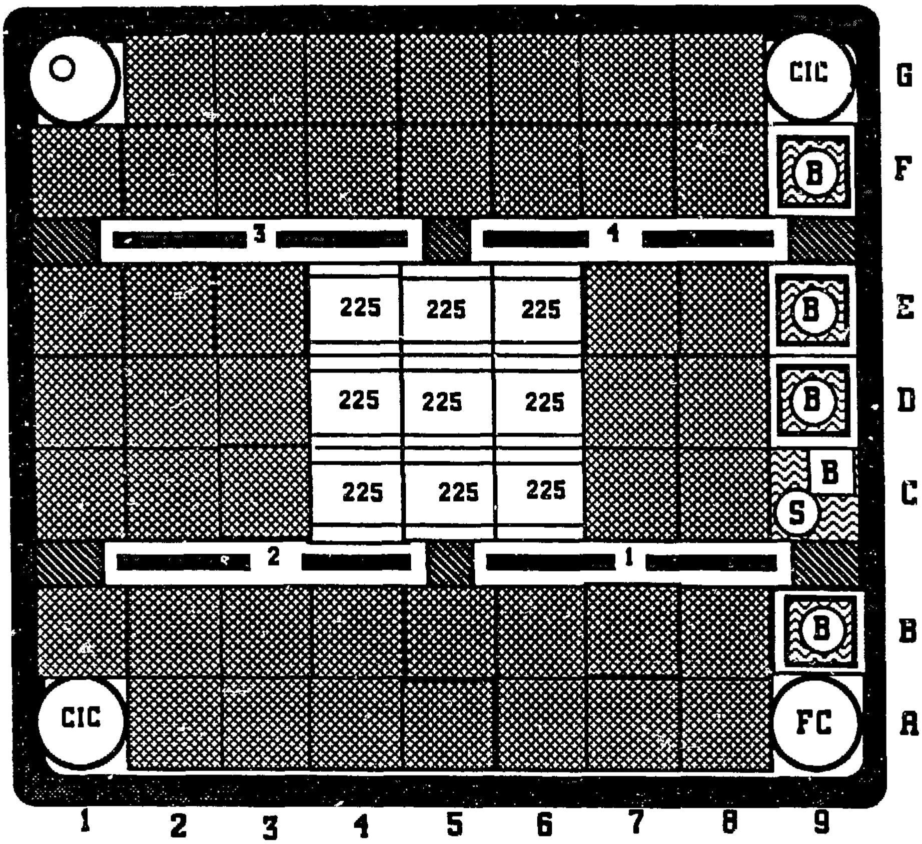

Figure 8: Be reflected, 9 element core

THERMAL NEUTRON FLUX
10^{12} n/cm^2-sec

	THERMAL COLUMN CENTERPOINT	GRID BOX CENTERLINE ROW 5	GRID BOX $\Phi_{THERMAL}/\Phi_{TOTAL}$ percent
HEU	3.7	16.1	59
Be-13(9 elements)	2.6	35.0	84
Be-5B(16 elements)	3.1	24.5	64
LEU-1(Flux trap)	3.9	15.6	55

Figure 9: Comparison of 2MW Thermal Flux for Four (4) Cores

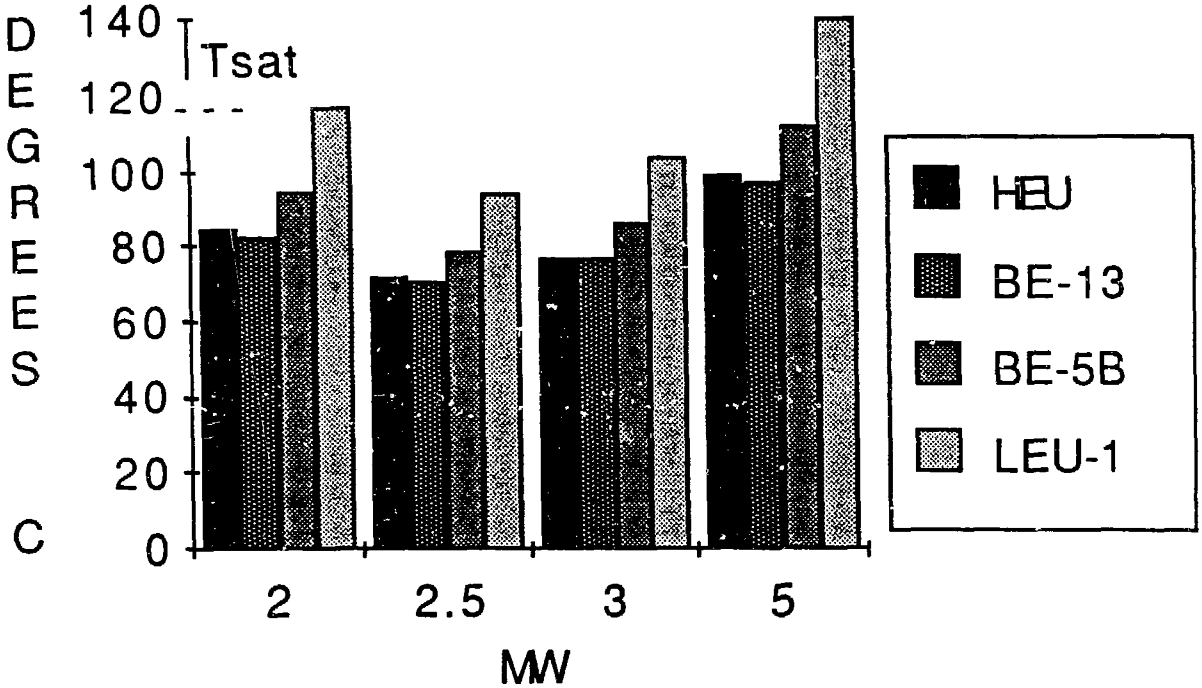

Figure 10: Power Level vs
Max Plate Surface Temp

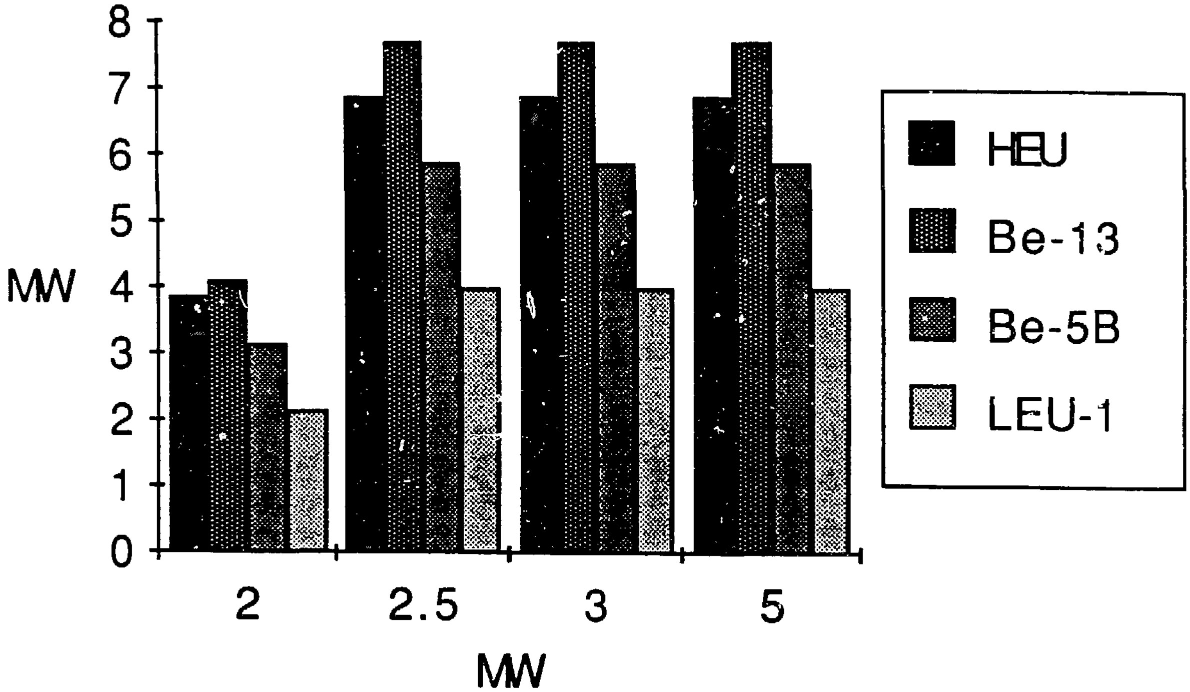

Figure 11: Power Level vs
Onset of Nucleate Boiling

	FLOW RATE M^3/HR	POWER LEVEL MW	PEAK HEAT FLUX W/cm^2	CRITICAL HEAT FLUX — DNB — MIRSHAK W/cm^2	LABUNTSOV W/cm^2	FLOW INSTABILITY* — WINKLER W/cm^2	FORGAN W/cm^2
HEU	227	2	14	324	486	28	
Be-13	227	2	33	374	706	104	
Be-5B	227	2	26	331	561	55	
LEU-1	227	2	30		REACTOR BOILING		
HEU	454	3	21	357	616	70	
Be-13	454	3	50	454	993	202	
Be-5B	454	3	40	381	757	117	
LEU-1	454	3	45	344	672	88	
HEU	454	5	35	339	595	70	
Be-13	454	5	84	434	993	202	
Be-5B	454	5	66	356	732	117	
LEU-1	454	5	76		REACTOR BOILING		

*preliminary data

Figure 12: Critical Heat Flux vs Power Level for Four Cores