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THE CONVERSION OF THE 2 MW REACTOR AT THE RHODE ISLAND NUCLEAR SCIENCE CENTER*

A. Francis DiMeglio and E. F. Spring
Rhode Island Atomic Energy Commission
Narragansett, Rhode Island, USA

and

J. E. Matos and K. E. Freese
Argonne National Laboratory
Argonne, Illinois, USA

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A. Francis DiMeglio
Rhode Island Atomic Energy Commission
Narragansett, Rhode Island, USA

J. E. Matos
Argonne National Laboratory
Argonne, Illinois, USA

K. E. Freese
Argonne National Laboratory
Argonne, Illinois, USA

E. F. Spring
Rhode Island Atomic Energy Commission
Narragansett, Rhode Island, USA

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) fuel using a standard LEU fuel plate which is thinner and contains more U-235 than the current HEU plate. These differences, coupled with a desire to upgrade the characteristics and capability of the reactor, have 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 23 years of operation, it has become clear that the main uses of the reactor have been neutron scattering and neutron activation analysis. The requirement to convert to LEU presents an opportunity to optimize the core for the utilization and to restudy the thermal hydraulics using modern techniques. This paper presents the current conclusions of both aspects.

INTRODUCTION

The Rhode Island Atomic Energy Commission operates an open pool, MTR type research reactor in Narragansett, Rhode Island. While the reactor has a maximum design power level of 5 MW, current, licensed operation is at a power level of 2 MW.

The reactor was designed by General Electric in the late 1950's with construction beginning in late 1962. The reactor went critical in 1964, to a power level of 1 MW in 1965 and to a power level of 2 MW in 1968.

Before discussing the conversion of the reactor to LEU, it will be useful to describe those aspects of the utilization and the original design of the facility which have influenced the approach taken for conversion. A detailed description of the reactor was presented at the 1987 RERTR meeting in Buenos Aires and only a synopsis will be presented here/1/.

REACTOR DESCRIPTION AND UTILIZATION

The reactor is a typical swimming pool research reactor with capabilities for a wide range of research activities. However, because of limited resources and staff, during these past 20 years of 2 MW operation, we have concentrated in 2 specific areas. These areas are neutron scattering now utilizing four beam ports and research programs which require neutron activation analysis as an analytical tool-including small sample analysis-utilizing five irradiation facilities. The University of Rhode Island has installed at one beam port the only polarized neutron, small angle scattering spectrometer currently operating in the United States.

Although the reactor has operated with as few as 28 and as many as 35 fuel elements, the normal, equilibrium operating HEU core consists of 30 fuel elements each containing 18 plates and a U-235 content of 124 grams when new. These elements sit on a grid plate in a grid box with permanently installed shrouds in which the boral control rods or blades move. The reactor has been reflected by graphite and the grid contains sufficient spaces for a boral regulating rod and several irradiation baskets. This arrangement is shown in Figure 1.

Note that the four boral control blades move in permanently fixed shrouds and these shrouds cannot easily be relocated. The boral regulation rod is also fixed in the reflector region of the 30 element core but its relocation is possible. For clarity, some of the grid positions are shown vacant. During operation, however, each grid position must contain a fuel element, a reflector piece, an irradiation basket or a plug. Otherwise the coolant flow will by-pass the core through the vacant grid position.

Figure 2 is a schematic representation of the HEU core showing 30 fuel elements surrounded by graphite reflectors and a row of irradiation baskets. The control blades are labeled 1, 2, 3 and 4 and the regulating rod is in position D1. This figure also shows the location of seven beam tubes, one of which has been cut through the thermal column. Note that the large beam tubes and the pneumatic irradiation systems terminate outside the grid box at row 5, in the center of the grid box. The neutron flux in this position is representative of the flux available to the beam ports. In addition to the two pneumatic irradiation facilities terminating just above the large beam tubes, a third horizontal facility is installed in a beam tube. Also note that there is a radiation basket in position D9. This position will be used later for flux comparisons between HEU and LEU cores.

The existing core may be characterized as large with a very low power density resulting in a low thermal flux per unit power. It utilizes lightly loaded fuel elements to make the core large enough to encompass the control blades. Even with extraordinary techniques, the maximum burnup achievable is about 14% and this burnup is only possible because we are a one shift operation and do not have to contend with equilibrium xenon.

One other consideration is important to the LEU conversion. That is the decision by the Department of Energy to produce a standard fuel plate for use in all university reactors for which they provide fuel cycle assistance.

Figure 3 shows the characteristics of this standard fuel plate. Note that the standard plate is 1.3mm thick while our current plate is 1.5mm thick. In addition, the LEU standard plate contains 12.5 grams U-235 while our current HEU(93%) plate contains 6.9 grams U-235. A direct, LEU replacement plate, if available, would contain only about 8 grams U-235.

CONVERSION OBJECTIVES

There are six basic objectives of the LEU conversion program. These are:

1. Convert the reactor to the use of LEU.

2. Design a LEU core and an operating scheme to achieve burnups greater than the current 14%. This is especially important for anticipated higher power operation.

3. Design a LEU core to optimize the neutron flux in the beam tubes including an improved thermal to fast neutron ratio.

4. Design a reactor core with a flux trap for small sample neutron activation analysis.

5. Design a reactor core which can be operated at power levels up to 5 MW with the appropriate primary coolant flow.

6. Design a LEU core whose initial cost will be about the same as the cost of 30 HEU fuel elements since that is the amount allocated for the core by the Department of Energy.

During extensive scoping studies many core configurations were examined/1/. Incorporating all of the information gathered during these scoping studies and remembering our six objectives, a primary core design has emerged with a secondary design receiving some consideration.

LEU CORE DESIGN

Figure 4 presents this primary design which consists of 4 cores each containing 14 fuel elements. The elements now contain 22 standard plates for a total of 275 grams of U-235 per element. A central beryllium piece with a 38mm hole is incorporated as a flux trap. The regulating rod has been changed to stainless steel and moved one grid position so as to be adjacent to this smaller core.

Core C-1 is graphite reflected, with an excess reactivity of 2.3% $\Delta k/k$, a regulating rod worth of .44%, a shutdown margin with blade 3 stuck out of 7.1% and a total power peaking factor of 2.64. Remembering that the reactor operates on a one shift basis, the excess reactivity is marginal.

Core C-2 has the core partially reflected with beryllium. The parameters have changed in an expected way with this core having a greater excess reactivity and slightly less, but acceptable, shutdown margin.

Core C-3 is also partially reflected by beryllium with expected changes in excess reactivity and shutdown margin.

Core C-4 is fully reflected by beryllium. The excess reactivity is 7% and the shutdown margin with blade 3 stuck is 2.9%. Note that in all 4 cores the worth of the regulating rod and the total power peaking factors remain about the same.

The goal of the LEU program is a beryllium reflected compact core with a flux trap. These 4 cores present a progression to that goal starting with new LEU elements and using for the most part existing graphite reflectors. As reactivity is lost due to burnup, beryllium reflectors replace graphite reflectors which effectively increases reactivity. This is continued until the core is fully beryllium reflected with an outside row of graphite reflectors. At this point, an equilibrium operating condition is reached and fuel is replaced as required to maintain excess reactivity.

The details of the reflector replacement schedule will be worked out using computer simulated burnup of fuel. The fuel replacements in the equilibrium core will also be worked out using computer simulation.

Recall that the neutron scattering scientists still cling to the idea of a split core. Figure 5 presents a split core with a flux trap which may be thought of as the beginning core of a sequence as just described. Although the computer calculations of neutrons fluxes do not show any advantage to this type of core, we may perform critical experiments and flux plotting to verify the calculations.

Figure 6 presents the core mid plane fluxes for the LEU and the HEU core in the grid box at the center of row 5. Recall that this is an indication of the relative beam tube fluxes and also the flux in the two pneumatic tubes. While the total of the 7 group fluxes for the LEU cores are only somewhat increased over the 30 element HEU core, the sum of groups 5, 6, and 7, which represents the thermal flux, shows a decided 40% increase in the LEU compact cores and only a small increase in the split core. Also note that as the use of beryllium reflectors increases in the compact core, the thermal flux remains essentially the same.

Figure 7 presents the flux trap midplane fluxes for the LEU cores. There is no comparable flux trap in a HEU core. However, the highest available flux in a HEU core has been about $1x10^{13}$.

Figure 8 compares the fluxes in position D9 for the LEU core and the HEU core. In all cases this well thermalized flux is increases by about 50%.

From this data it is concluded that the use of a beryllium reflected compact core meets the objective of improved fluxes for neutron scattering and activation analysis. Still to be performed are the burndown calculations and other calculations- xenon, temperature coefficient, void coefficient ect.- for these LEU cores.

THERMAL HYDRAULIC STUDIES

The thermal-hydraulic characteristics of the compact core (C1- C-4 have been examined using the PLTEMP Code/2/. Figure 9 presents this data.

For 2 MW operation the existing flow is 386 M^3/hour. Of this, 250 M^3/HR goes through the core. The peak heat flux utilizing the total power peaking factor and hot channel factors is 0.35 MW/M^2. The critical heat flux or DNB and the critical heat flux for flow instability are seen to be well above this. The maximum temperature of a fuel plate is 102^{o}C, some 20^o below the saturation temperature of 122^{o}C.

Using this flow, operation at 3 MW was also examined. Note that the maximum surface temperature is now above boiling.

For operation above 2 MW, it was expected that the flow would increase to 681 M^3/HR. Note that PLTEMP predicts acceptable operation at 3 MW. For operation at 5 MW, the flow must be greater than the expected 681 M^3/HR.

CONCLUSION

In conclusion the redesign of the Rhode Island Atomic Energy Commission research reactor is nearing completion and the preparation of the safety analysis report for conversion to LEU is progressing. The redesign will not only accomplish conversion but will also improve the reactor characteristics for the utilization.

REFERENCES

/1/ DiMeglio, A.F., Matos, J.E., and Freese, K.E.: Conversion, Core Redesign and Upgrade of the Rhode Island Atomic Energy Commission Reactor, Proceedings of the 1987 International Meeting on Reduced Enrichment for Research and Test Reactors, Buenos Aires, Argentina, 28 Sept.-10 October, in press.

/2/ Mishima, K., Kanda, K., and Shibata, T.: Thermal-hydraulic Analysis for Core Conversion to the Use of Low-enriched Uranium Fuels in the KUR, KURRI-TR-258, Dec. 1984 and
Proceedings of the 1984 International Meeting on Reduced Enrichment for Research and Test Reactors, Argonne, Illinois, Oct. 15-18, 1984, ANL/RERTR/TM-6, CONF-8410173, July 1985, p. 375.

Figure 1: Grid Box

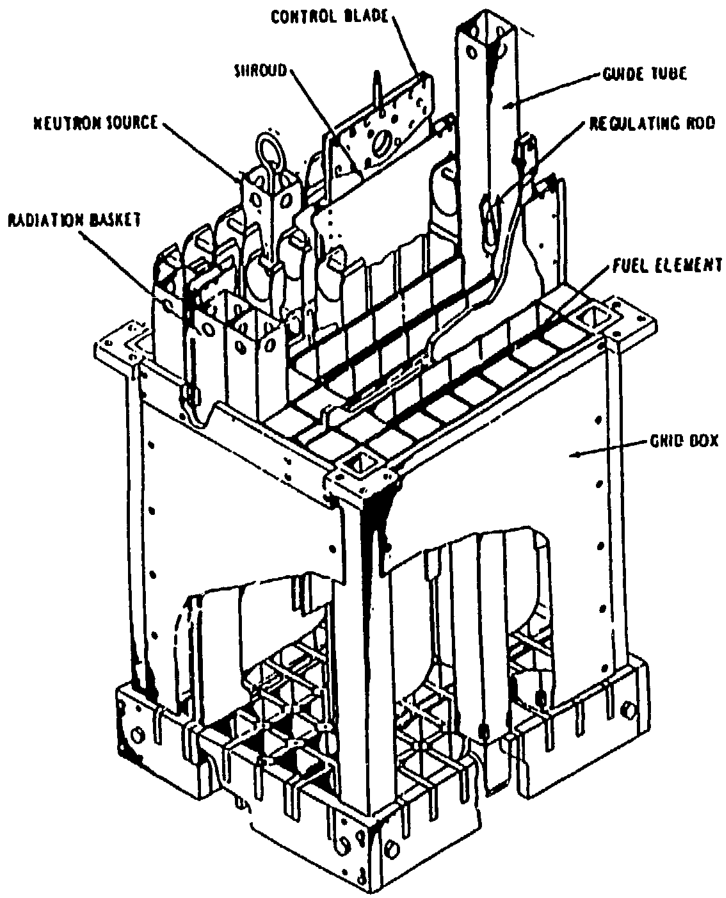
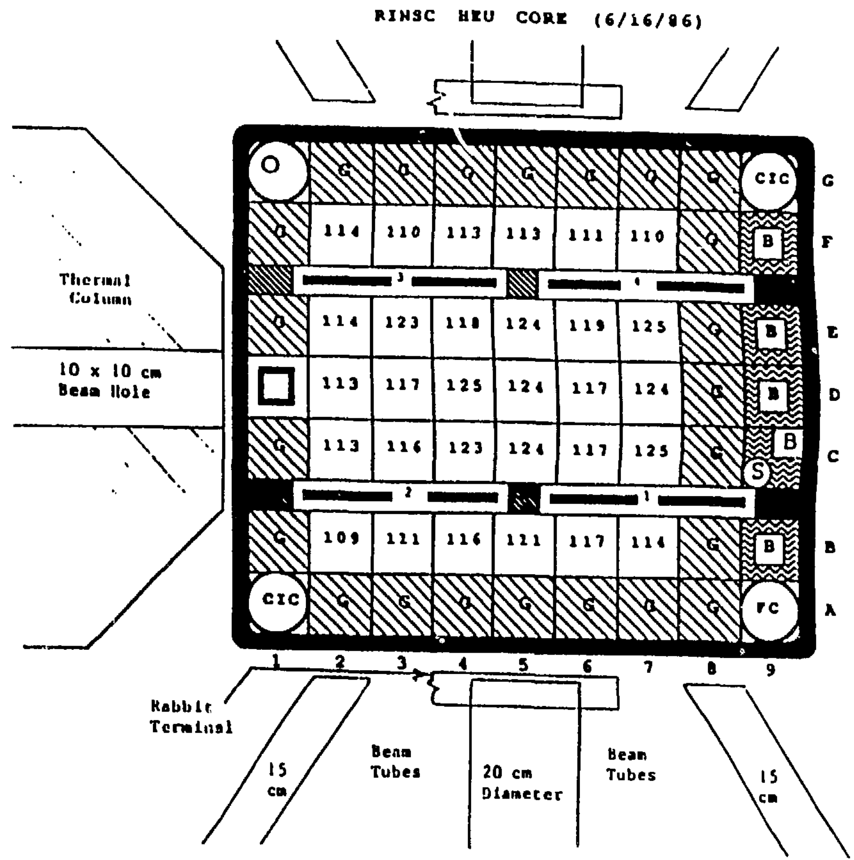


Figure 2: Typical 30 element HEU core



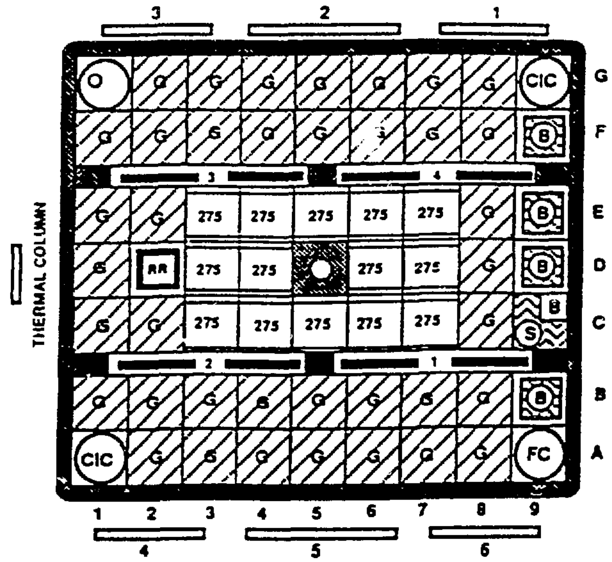
	^{235}U grams/plate	plates/element	^{235}U grams/element	Fuel Plate Thickness mm	Clad Thickness mm	Coolant Channel Width mm
HEU FUEL(EXISTING)	6.89	18	124	1.5	0.50	2.5
LEU EQUIVALENT	7.92	18	142.6	1.5	0.50	2.5
STANDARDIZED LEU FUEL	12.50	22	275	1.3	0.38	3.8

Figure 3: Comparison of HEU and LEU Fuel Plate

Figure 4: Compact Core Configurations and Selected Data

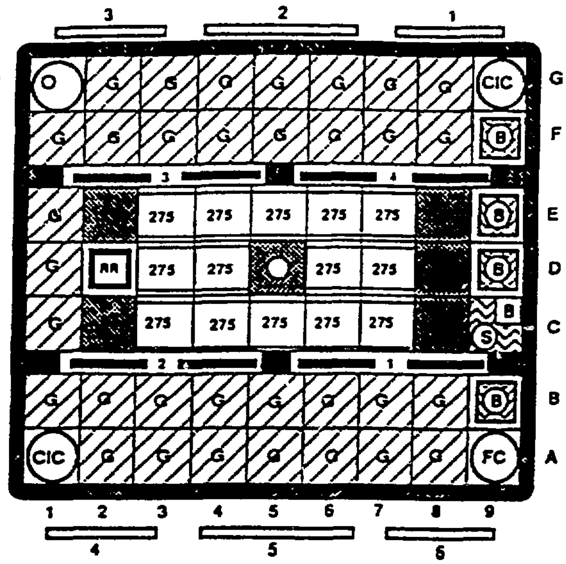
CORE C-1

Excess Reactivity = 2.30 % Δk/k
Worth of Regulating Rod = 0.44 % Δk/k
Shutdown Margin - Blade 3 Stuck = 7.1% Δk/k
Total Power Peaking Factor = 2.64 in D6



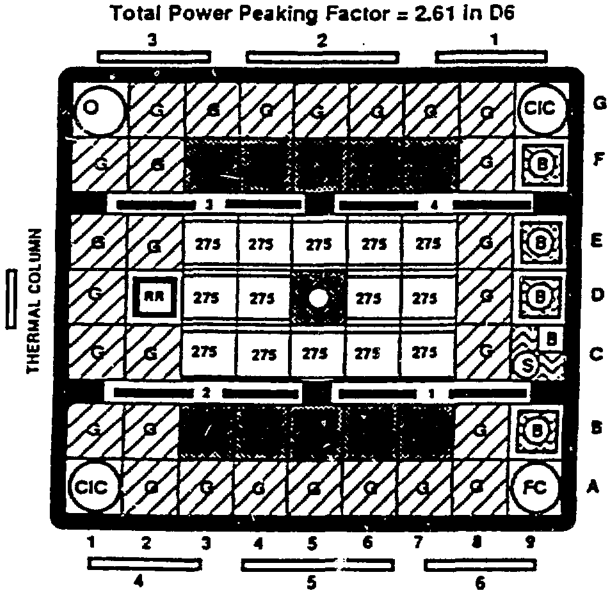
CORE C-2

Excess Reactivity = 4.24 % Δk/k
Worth of Regulating Rod = 0.45 % Δk/k
Est. Shutdown Margin - Blade 3 Stuck = -5.3 % Δk/k
Total Power Peaking Factor = 2.58 in D6



CORE C-3

Excess Reactivity = 5.19 % Δk/k
Worth of Regulating Rod = 0.40 % Δk/k
Est. Shutdown Margin - Blade 3 Stuck = -4.5% Δk/k
Total Power Peaking Factor = 2.61 in D6



CORE C-4

Excess Reactivity = 7.01 % Δk/k
Worth of Regulating Rod = 0.41 % Δk/k
Shutdown Margin - Blade 3 Stuck = 2.9 % Δk/k
Total Power Peaking Factor = 2.55 in D6

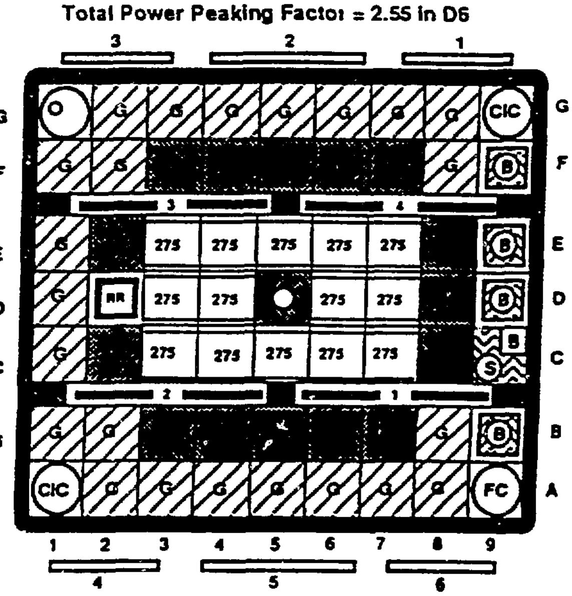


Figure 5: Split core S-1

Excess Reactivity = 3.92 % Δk/k
Worth of Regulating Rod = 0.44 % Δk/k
Total Power Peaking Factor = 2.81 in D4

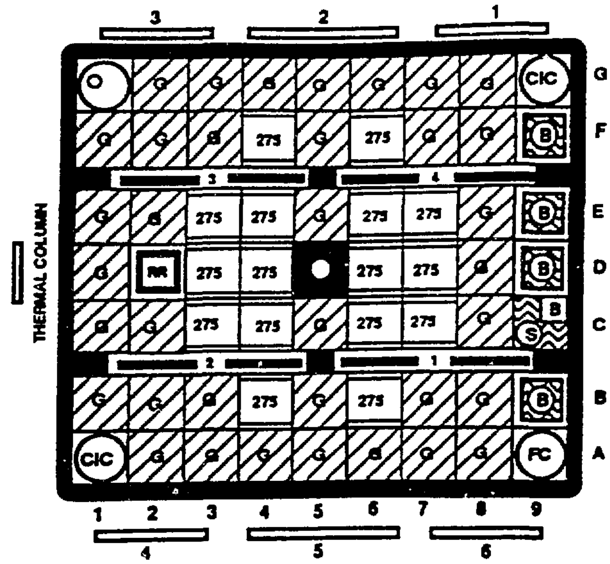


Figure 6: Core midplane fluxes in grid box at center of row 5

FLUXES X 10 exp12, n/sq.cm.-sec.

GRP	E, ev	LEU CORES C-1	C-2	C-3	C-4	S-1	HEU CORE 30 EL
1	1.00E+07	1.27	1.23	0.75	0.73	2.74	2.53
2	8.21E+05	2.33	2.26	1.82	1.76	4.33	3.72
3	5.53E+03	3.09	3.00	2.71	2.63	4.81	4.08
4	1.855	0.49	0.48	0.44	0.42	0.74	0.63
5	0.625	0.46	0.45	0.42	0.41	0.65	0.56
6	0.251	8.35	8.17	8.50	8.32	7.1	5.89
7	0.057	14.15	13.85	14.46	14.15	11.64	9.61
	TOTAL	30.14	29.44	29.10	28.42	32.01	27.02
SUM OF GRPS 5, 6, 7 (THERMAL FLUX)		22.96	22.47	23.38	22.88	19.4	16.1

Figure 7: Average midplane fluxes in flux trap in position D5

FLUXES X 10 exp12, n/sq.cm.-sec.

GRP	E, ev	LEU CORES C-1	C-2	C-3	C-4	S-1	HEU CORE 30 EL
1	1.00E+07	12.28	11.81	11.92	11.46	9	-
2	8.21E+05	16.60	15.99	16.18	15.59	12.84	-
3	5.53E+03	15.46	14.93	15.13	14.62	12.38	-
4	1.855	2.26	2.18	2.22	2.14	1.82	-
5	0.625	2.06	1.98	2.02	1.95	1.68	-
6	0.251	15.36	14.86	15.08	14.61	13.93	-
7	0.057	24.54	23.75	24.11	23.34	22.53	-
	TOTAL	88.55	85.52	86.65	83.70	74.18	-
SUM OF GRPS 5, 6, 7 (THERMAL FLUX)		41.96	40.59	41.21	39.90	38.14	

Figure 8: Average midplane fluxes in irradiation basket in grid position D9

FLUXES X 10 exp12, n/sq.cm.-sec.

GRP	E, ev	LEU CORES C-1	C-2	C-3	C-4	S-1	HEU CORE 30 EL
1	1.00E+07	1.03	0.66	0.98	0.63	0.94	0.62
2	8.21E+05	1.33	1.08	1.27	1.03	1.21	0.82
3	5.53E+03	1.49	1.30	1.43	1.25	1.36	0.93
4	1.855	0.23	0.20	0.22	0.19	0.21	0.15
5	0.625	0.23	0.21	0.22	0.20	0.21	0.15
6	0.251	3.97	3.78	3.82	3.65	3.65	2.58
7	0.057	6.80	6.50	6.55	6.25	6.27	4.53
	TOTAL	15.06	13.73	14.50	13.20	13.85	9.68
SUM OF GRPS 5, 6, 7 (THERMAL FLUX)		**11.00**	**10.49**	**10.59**	**10.10**	**10.13**	**7.26**

Figure 9: Thermal hydraulic parameters vs. power level for the C-1 core

POWER LEVEL MW	TOTAL FLOW M^3/HR (gpm)	CORE FLOW M^3/HR (gpm)	PEAK HEAT FLUX MW/M^2	CRITICAL HEAT FLUX MW/M^2	FLOW INSTABILITY MW/M^2	MAXIMUM SURFACE TEMPERATURE ^oC
2	386 (1700)	250 (1100)	0.35	2.36	1.38	102
3	386	250	0.52	2.36	1.38	125(boiling)
3	681 (3000)	454 (2000)	0.52	2.97	2.46	100
5	681	454	0.87	2.93	2.47	128(boiling)

Saturation Temperature = 122 ^oC
Hot Channel Factors
For Bulk Water Temp - 1.61
For Heat Flux - 1.41
For Heat Transfer Coef.- 1.4
Total Power Peaking Factor = 2.64