INITIAL LOADING AND TESTING

OF

LOW ENRICHED URANIUM FUEL

AT THE

UNIVERSITY OF MISSOURI-ROLLA

REACTOR FACILITY

(January, 1993)

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1.0 Introduction

On July 18, 1992 the University of Missouri-Rolla (UMR) Reactor received low enriched uranium (LEU) fuel. The fuel was inspected and subsequently loaded into the reactor core. At 15:13, July 23, 1992, the first LEU core achieved criticality.

Calculations had shown that the expected core geometry, rod worths and kinetics response would be very similar to the high enriched uranium (HEU) fueled cores. Operationally, little change was expected other than increased U-235 loading to compensate for the higher resonance absorption and greater undermoderation associated with the LEU fueled core. This was; however, expected to have a deleterious effect on the thermal flux in our experimental facilities.

The UMR Reactor is a pool-type reactor licensed at 200 kW. The fuel is standard MTR plate-type fuel. The UMR Reactor had been operating with its initial batch of HEU fuel since 1961. Table 1 below summarizes the major differences between the old HEU fuel and the new LEU fuel.

Table 1. Comparison of LEU and HEU Fuel Parameters

PARAMETER	LEU	HEU
1. Element Dimensions	3"x3"x36"	3"x3"x36"
2. Plates/Element	18	10
3. Enrichment	19.75%	90%
4. U-235/Element	225 gram	170 gram
5. Fuel	U_3Si_2-Al	U_3O_8-Al

LEU core parameters have been characterized and compared to predicted and measured HEU core parameters. This information is provided in the sections that follow.

2.0 Receipt and Inspection of the LEU Fuel

Twenty LEU fuel elements were received at UMRR on Saturday, July 18, 1992. Eight more LEU elements were received on Thursday, August 27, 1992. The combined shipments totaled 28 elements containing 5,248 grams of U-235. The 28 elements consists of 18 standard elements, 5 control elements, 4 half elements, and 1 irradiation fuel element.

Elements were unloaded from Type 6M shipping containers, inspected, and placed in dry storage racks. No problems or difficulties were encountered. Standard eighteen plate elements are designated as "MTR-F-". Control elements (ten fueled plates per element) are designated "MTR-C-". Half elements (nine fueled plates per element) are designated as "MTR-HF-" or "MTR-HR-". The irradiation fuel element (nine fueled plates) is designated "MTR-IF-". Table 2 presents the element identifications and inspection results. (It should be noted that all incoming elements were judged to be satisfactory. Comments in Table 2 are observations, not statements of unacceptability.)

Table 2. LEU Fuel Receipt and Inspection Results

ELEMENT	INSPECTION RESULTS
MTR-C-001	Small lengthwise scratch noted on first fuel plate next to rear guide plate.
MTR-C-002	Satisfactory.
MTR-C-003	Satisfactory.
MTR-C-004	Satisfactory.
MTR-C-005	Satisfactory.
MTR-F-001	Satisfactory.
MTR-F-002	Satisfactory.
MTR-F-003	Satisfactory.
MTR-F-004	Satisfactory.
MTR-F-005	Satisfactory.
MTR-F-006	Small dent noted on the front fuel plate about 6 inches from the top of the plate and 1/2 inch from the side plate with the ID.
MTR-F-007	Small dent noted on the front fuel plate about 6 inches from the top of the plate and 1/2 inch from the side plate with the ID.
MTR-F-008	Satisfactory.
MTR-F-009	Satisfactory.
MTR-F-010	Satisfactory.
MTR-F-011	Small divot (hole) noted in front fuel plate (Plate #84-047-17) 1 1/8 inch from the left hand side and 7/8 inches down from the bail. The area appears to have been "buffed".
MTR-F-012	Satisfactory.
MTR-F-013	Satisfactory.
MTR-F-014	Satisfactory.
MTR-F-015	Satisfactory.
MTR-F-016	Satisfactory.
MTR-F-017	Satisfactory.
MTR-F-018	Satisfactory.
MTR-HR-001	Small dent noted on the front fuel plate about 6 inches from the top of the plate and 1/2 inch from the side plate with the ID.
MTR-HR-002	Satisfactory.
MTR-HF-001	Small depression noted on the rear fuel plate about 15 1/8 inch from the top, 7/8 inch from the right side.
MTR-HF-002	Satisfactory.
MTR-IF-001	Satisfactory.

3.0 LEU Core Loading

3.1 Initial Loading to Criticality

The initial LEU core was loaded in accordance with SOP 207, "Fuel Handling" and SOP 106, "Critical Experiment Procedures". Subcritical multiplication data was collected after the addition of each fuel element. A spare fission chamber was placed near the core region. This chamber provided the increased sensitivity needed to see multiplication at very low core loadings. Count data was collected on both the reactor Start-Up Channel and the spare fission chamber system. Control fuel elements were assumed to constitute one-half of an "effective" fuel element for the purpose of 1/M plots.

The 1/M data and predicted critical loadings from the auxiliary fission chamber system and from the Reactor Start-Up Channel are presented in Table 3 and Table 4, respectively. Data collected from both systems correctly predicted criticality with the addition of the fifteenth "effective" element. Figure 1 and Figure 2 present plots showing the expected critical loading for both systems.

Initial criticality was achieved at 15:13 on July 23, 1992 with the addition of LEU element F-14. The critical rod positions are shown below in Table 5.

Table 5. Critical Rod Positions - Initial Criticality

ID	POSITION (INCH)
Rod 1	24.00
Rod 2	24.00
Rod 3	24.00
Reg Rod	18.78

The U-235 loading was 3420.63 grams. Figure 3 shows the loading for initial criticality of the LEU core. Because of the low excess reactivity (estimated at 0.045% $\Delta k/k$), no loading number was designated.

Table 3. Initial LEU Core Loading: Auxiliary Fission Chamber System 1/M Data

Number of Elements	Shim Rods at 12.5 inch			Shim Rods at 24.0 inch		
	Counts	1/M	Predicted Critical Loading	Counts	1/M	Predicted Critical Loading
2[1]	5,774	1.00	--	6,182	1.00	--
3	6,332	0.912	13	7,888	0.784	7
4	9,401	0.614	6	10,675	0.579	7
5	12,177	0.474	9	15,324	0.377	7
6	18,782	0.307	9	23,789	0.260	8
7	20,415[2]	1.00	--	26,571[2]	1.00	--
8	21,879	0.933	--	29,157	0.911	--
9	29,352	0.696	12	42,415	0.626	12
10	38,961	0.524	13	62,547	0.425	13
11	95,270	0.214	12	175,862	0.151	12
12	107,838	0.189	17	233,754	0.114	15
13	206,037	0.099	15	580,243	0.046	14
14	270,745	0.075	17	1,968,843	0.013	15
15	490,989	0.042	16	critical		

[1] Four Control Rod Elements C-1, C-2, C-3, C-4 and Source Inserted.
[2] New C_o Values.

Table 4. Initial LEU Core Loading: Reactor Start-Up Channel 1/M Data

Number of Elements	Shim Rods at 12.5 inch			Shim Rods at 24.0 inch		
	Counts	1/M	Predicted Critical Loading	Counts	1/M	Predicted Critical Loading
2[(1)]	488	--	--	316	--	--
3	277	--	--	463	--	--
4	474	--	--	365	--	--
5	412	--	--	423	--	--
6	2,710	--	--	366	--	--
7	460	--	--	382	--	--
8	408	--	--	374	--	--
9	409	--	--	409	1.00	--
10	388	--	--	421[(2)]	0.972	24
11	380	1.00	--	472	0.866	19
12	507[(2)]	0.750	15	1,088	0.376	13
13	606	0.627	18	1,827	0.224	15
14	1,067	0.356	16	8,479	0.048	15
15	1,163	0.327	--	critical		

[(1)] Four Control Rods C-1, C-2, C-3, C-4 and Source Inserted.
[(2)] Recorder, for first time, is not bouncing on 2 cps relay.

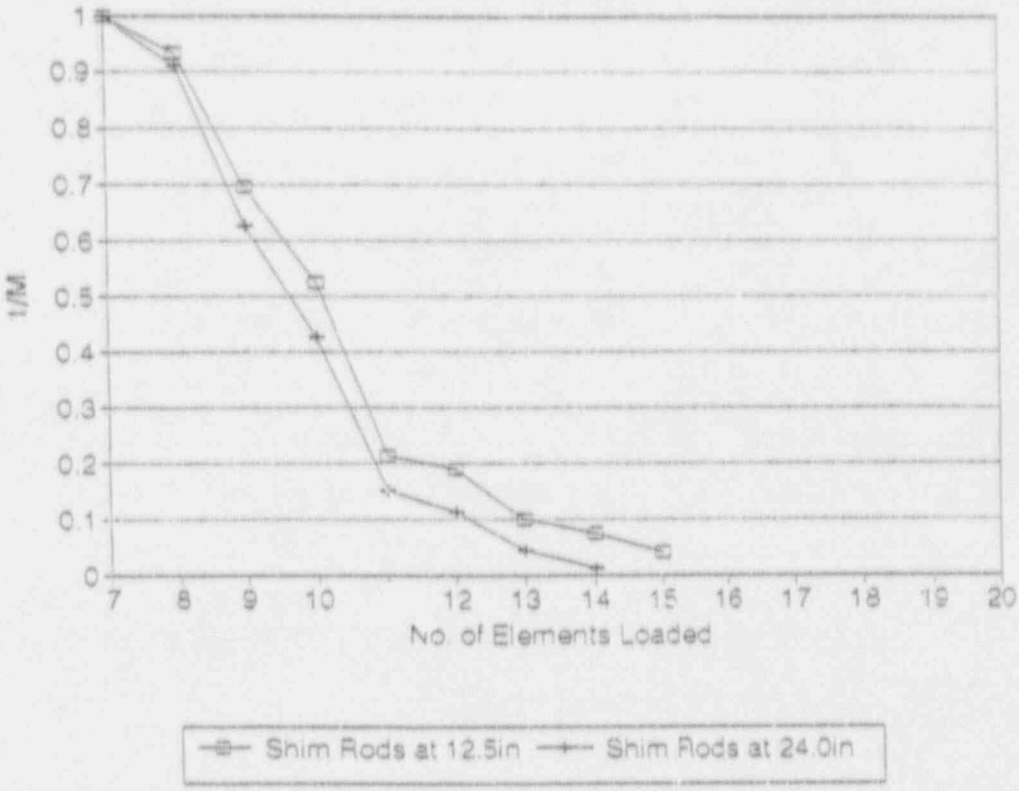

Figure 1. 1/M Plot - Approach to Criticality Based on Spare Fission Chamber System.

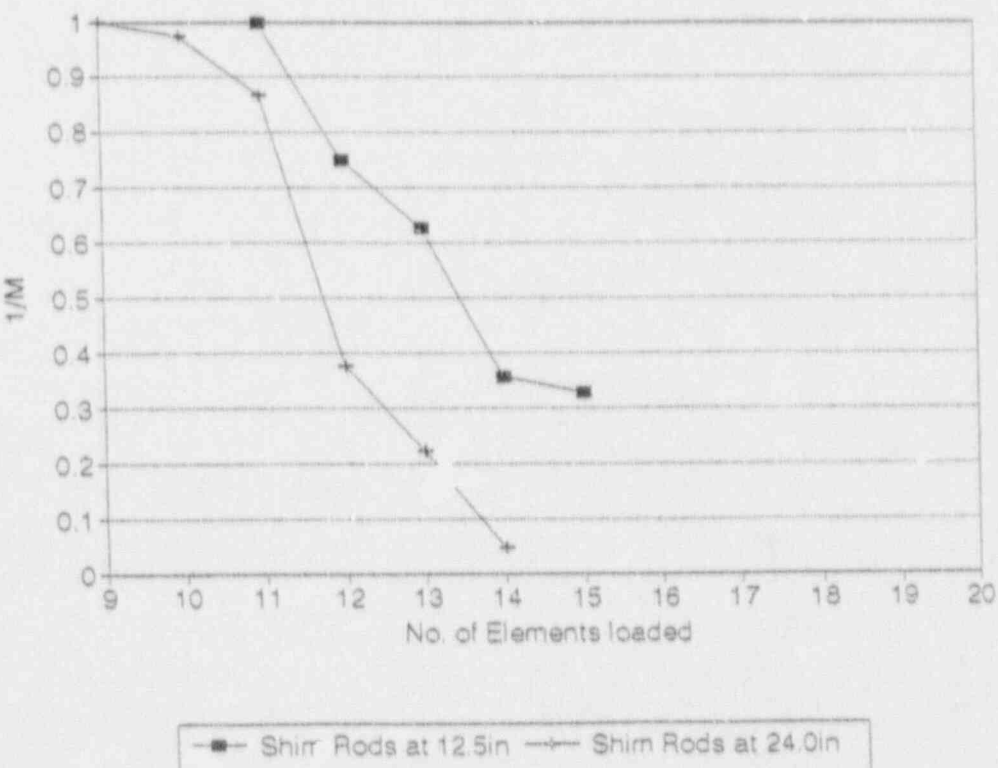

Figure 2. 1/M Plot - Approach to Criticality Based on Reactor Start-Up Channel.

	1	2	3	4	5	6	7	8	9
A									
B					S				
C				F-8	F-4	C-4			
D			F-13	C-1	F-3	F-2	F-12		
E			F-10	C-2	F-1	C-3	F-9	F-14	
F				F-5	F-6	F-7			

UMRR CORE DIAGRAM

<u>KEY TO PREFIXES</u>
F - Standard Elements
C - Control Elements
HF - Half Front Element
HR - Half Rear Element
S - Source Holder

Elem.	Pos	U-235 Mass	Elem.	Pos	U-235 Mass	Elem.	Pos	U-235 Mass
C-1	D4	124.86	F-5	F4	224.59	F-14	E8	224.76
C-2	E4	124.88	F-6	F5	224.63			
C-3	E6	124.88	F-7	F6	224.66			
C-4	C6	124.87	F-8	C4	224.66			
F-1	E5	224.79	F-9	E7	224.67			
F-2	D6	224.83	F-10	E3	224.68			
F-3	D5	224.79	F-12	D7	224.69			
F-4	C5	224.65	F-13	D3	224.74			

Total U-235 Mass (Grams) <u>3420.63</u>

Figure 3. Core Loading Diagram for Initial Criticality of LEU Core

3.2 Core 100W and 100T

Half element HR-1 was added to Grid Position D-8 to increase core excess reactivity. The core was designated 100W. Excess reactivity, rod worths, and SDM were measured. The results are shown below in Table 6. The U-235 loading was 3533.04 grams. Figure 4 shows the core loading.

Table 6. Core 100W Parameters	
Parameter	Worth
Excess Reactivity	0.450% Δk/k
SDM_{min}	4.59% Δk/k
Rod 1	2.52% Δk/k
Rod 2	2.52% Δk/k
Rod 3	3.25% Δk/k
Reg Rod	0.338% Δk/k

Similarly, measurement of the excess reactivity and reg rod worth were made in the T mode. Table 7 lists the results for core 100T.

Table 7. Core 100T Parameters	
Parameter	Worth
Excess Reactivity	0.845% Δk/k
Reg Rod	0.330% Δk/k
T Column	0.395% Δk/k

	1	2	3	4	5	6	7	8	9
A									
B					S				
C				F-8	F-4	C-4			
D			F-13	C-1	F-3	F-2	F-12	HR-1	
E			F-10	C-2	F-1	C-3	F-9	F-14	
F				F-5	F-6	F-7			

UMRR CORE DIAGRAM

<u>KEY TO PREFIXES</u>

F - Standard Elements
C - Control Elements
HF - Half Front Element
HR - Half Rear Element
S - Source Holder

Elem.	Pos	U-235 Mass	Elem.	Pos	U-235 Mass	Elem.	Pos	U-235 Mass
C-1	D4	124.86	F-5	F4	224.59	F-14	E8	224.76
C-2	E4	124.88	F-6	F5	224.63	HR-1	D8	112.41
C-3	E6	124.88	F-7	F6	224.66			
C-4	C6	124.87	F-8	C4	224.66			
F-1	E5	224.79	F-9	E7	224.67			
F-2	D6	224.83	F-10	E3	224.68			
F-3	D5	224.79	F-12	D7	224.69			
F-4	C5	224.65	F-13	D3	224.74			

Total U-235 Mass (Grams) 3533.04

Figure 4. Core Loading Diagram for Core 100W

3.3 Core 101W and 101T (Without Rabbits)

On July 28, 1992 element HR-1 was replaced with F-15 to increase core excess reactivity. The U-235 loading was 3645.4 grams. Figure 5 shows the core loading. Both cores 101W and 101T were characterized; results are summarized below in Tables 8 and Table 9.

Table 8. Core 101W Parameters, Without Rabbits	
Parameter	**Worth**
Excess Reactivity	C.874% Δk/k
SDM_{min}	4.34% Δk/k
Rod 1	2.63% Δk/k
Rod 2	2.58% Δk/k
Rod 3	3.30% Δk/k
Rog Rod	0.350% Δk/k

Table 9. Core 101T Parameters, Without Rabbits	
Parameter	**Worth**
Excess Reactivity	1.28% Δk/k
Reg Rod	0.356% Δk/k
T Column	0.406% Δk/k

A									
B					S				
C				F-8	F-4	C-4			
D			F-13	C-1	F-3	F-2	F-12	F-15	
E			F-10	C-2	F-1	C-3	F-9	F-14	
F				F-5	F-6	F-7			
	1	2	3	4	5	6	7	8	9

UMRR CORE DIAGRAM

KEY TO PREFIXES
F - Standard Elements
C - Control Elements
HF - Half Front Element
HR - Half Rear Element
S - Source Holder
BR - Bare Rabbit
CR - Cadmium Rabbit

Elem.	Pos	U-235 Mass	Elem.	Pos	U-235 Mass	Elem.	Pos	U-235 Mass
C-1	D4	124.86	F-5	F4	224.59	F-14	E8	224.76
C-2	E4	124.88	F-6	F5	224.63	F-15	D8	224.77
C-3	E6	124.88	F-7	F6	224.66			
C-4	C6	124.87	F-8	C4	224.66			
F-1	E5	224.79	F-9	E7	224.67			
F-2	D6	224.83	F-10	E3	224.68			
F-3	D5	224.79	F-12	D7	224.69			
F-4	C5	224.65	F-13	D3	224.74			

Total U-235 Mass (Grams) 3645.40

Figure 5. Core Loading Diagram for Core 101W (Without Rabbits)

3.4 Core 101W and 101T (With Rabbits Inserted)

The Bare and Cadmium Rabbit Facilities were installed in the gridplate on July 28, 1992 as shown in Figure 6. Table 10 presents the measured parameters.

Table 10. Core 101W and 101T Parameters, With Rabbits Inserted

PARAMETER	CORE 101W	CORE 101T
Excess Reactivity	0.429% Δk/k	0.812% Δk/k
SDM_{min}	4.95% Δk/k	4.11% Δk/k
Rod 1	2.71% Δk/k	2.46% Δk/k
Rod 2	2.67% Δk/k	2.46% Δk/k
Rod 3	3.20% Δk/k	3.23% Δk/k
Reg Rod	0.355% Δk/k	0.355% Δk/k

The worth of the thermal column was 0.383% Δk/k.

Core 101W was determined to be tentatively acceptable.

	1	2	3	4	5	6	7	8	9
A									
B					S				
C				F-8	F-4	C-4			
D			F-13	C-1	F-3	F-2	F-12	F-15	
E			F-10	C-2	F-1	C-3	F-9	F-14	
F			CR	F-5	F-6	F-7	BR		

UMRR CORE DIAGRAM

KEY TO PREFIXES
F - Standard Elements
C - Control Elements
HF - Half Front Element
HR - Half Rear Element
S - Source Holder

Elem.	Pos	U-235 Mass	Elem.	Pos	U-235 Mass	Elem.	Pos	U-235 Mass
C-1	D4	124.86	F-5	F4	224.59	F-14	E8	224.76
C-2	E4	124.88	F-6	F5	224.63	F-15	D8	224.77
C-3	E6	124.88	F-7	F6	224.66			
C-4	C6	124.87	F-8	C4	224.66			
F-1	E5	224.79	F-9	E7	224.67			
F-2	D6	224.83	F-10	E3	224.68			
F-3	D5	224.79	F-12	D7	224.69			
F-4	C5	224.65	F-13	D3	224.74			

Total U-235 Mass (Grams) 3645.40

Figure 6. Core Loading Diagram for Core 101W (With Rabbits)

3.5 Adjusted Parameters for Core 101W and Core 101T

It should be noted that all reactivity measurements made using the positive period method in Sections 3.1 through 3.4 were based on $\overline{\beta}_{eff}$=0.00755. Neutronics studies have yielded a calculated $\overline{\beta}_{eff}$=0.0079 for the LEU fuel. This value is presented in Table VIII of the SAR. To be consistent, measured reactivity values using the positive period method need to be adjusted accordingly.

Additionally, the spare fission chamber used for core loading was repositioned from the core side to a new position above and behind the core. The repositioning was measured to have a small positive reactivity effect of 0.045% Δk/k.

Table 11 presents the adjusted core parameters for Cores 101W and 101T which account for the new value of $\overline{\beta}_{eff}$ and the movement of the detector.

Table 11. Adjusted Core Parameters for Core 101 ($\overline{\beta}_{eff}$=0.0079)

PARAMETER	CORE 101W	CORE 101T
Excess Reactivity	0.496% Δk/k	0.897% Δk/k
SDM_{min}	4.92% Δk/k	4.10% Δk/k
Rod 1	2.73% Δk/k	2.50% Δk/k
Rod 2	2.69% Δk/k	2.50% Δk/k
Rod 3	3.22% Δk/k	3.27% Δk/k
Reg Rod	0.371% Δk/k	0.371% Δk/k

The thermal column worth was 0.401% Δk/k.

4.0 Excess Reactivity, Control Rod Worths and Shutdown Margin

HEU Core 67W presented in Figure 7 was similar in geometry to LEU Core 101W. The geometry differences are as follows:

1. The positions of the cadmium and bare rabbit facilities are reversed; and

2. Core 67W had an extra half-element in position C-3.

Although the geometries are not identical, the cores are very similar and merit comparison. Table 12 below compares excess reactivities, rod worths, and shutdown margins (SDM) for the two cores.

Table 12. HEU vs LEU Core Parameters

PARAMETER	LEU (101W)	HEU (67W)
1. U-235 Loading	3645 grams	2870 grams
2. # of "Effective" Elements[1]	16.0	16.5
3. Excess Reactivity	0.496% Δk/k	0.43% Δk/k
4. Rod Worths		
Rod 1	2.73% Δk/k	2.64% Δk/k
Rod 2	2.69% Δk/k	2.65% Δk/k
Rod 3	3.22% Δk/k	3.36% Δk/k
Reg Rod	0.37% Δk/k	0.35% Δk/k
5. SDM	4.92% Δk/k	4.86% Δk/k

As can be seen in the comparison in Table 11, the only parameter significantly affected by the conversion is the U-235 gram loading. The LEU core contains about 27% more U-235 than the HEU core. This additional loading is required to overcome the deleterious effects of increased resonance absorption and stronger under moderation.

The LEU core has an excess reactivity of 0.496% Δk/k achieved with 16 "effective[1]" elements while the HEU core had an excess reactivity of 0.43% Δk/k using 16.5 "effective" elements.

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[1]control elements are treated as one-half of an "effective" element.

	1	2	3	4	5	6	7	8	9
A									
B					S				
C			HR-1	F-14	F-1	C-4			
D			F-8	C-1	F-16	F-9	F-4	F-10	
E			F-6	C-2	F-19	C-3	F-12	F-11	
F			BR	F-17	F-15	CR			

UMRR CORE DIAGRAM

KEY TO PREFIXES
F - Standard Elements
C - Control Elements
HF - Half Front Element
HR - Half Rear Element
S - Source Holder

Elem.	Pos	U-235 Mass	Elem.	Pos	U-235 Mass	Elem.	Pos	U-235 Mass
HR-1	C3	84.912	F-16	D5	170.270	F-12	E7	168.774
F-8	D3	170.229	F-19	E5	170.264	F-10	D8	170.193
F-6	E3	169.160	F-15	F5	168.889	F-11	E8	168.969
F-14	C4	170.210	C-4	C6	102.112			
C-1	D4	102.112	F-9	D6	170.178			
C-2	E4	102.125	C-3	E6	101.978			
F-17	F4	169.111	F-7	F6	170.154			
F-1	C5	170.223	F-4	D7	170.206			

Total U-235 Mass (Grams) 2870.069

Figure 7. Core Loading Diagram for Core 67W

This comparison demonstrates that the reactivity worth per "effective" element in the LEU core is only slightly higher than with the HEU core.

Rod worths in the LEU core are (but not appreciably) different from the HEU core. The slight shift in rod worths shown in Table 12 may be as much a result of the slight changes in core configuration geometry as with the change in fuel type.

Finally, because excess reactivities and rod worths were very similar for the two cores, then necessarily the shutdown margins are similar.

Overall, the measured core parameters presented in Table 12 did not change appreciably with the LEU conversion, with the exception of the U-235 gram loading.

Neutronics calculations were performed for both the HEU and LEU cores for various core configurations. This work is presented in Covington[2]. Core 101W is very similar to the target core with the following exceptions:

1. The target core had an extra half-element in Grid Position C-3.

2. The positions of the cadmium and bare rabbit facilities were reversed.

Covington predicted an excess reactivity of 0.87% $\Delta k/k$. Core 101W has an excess reactivity 0.496% $\Delta k/k$. As presented in Section 5, a half element is estimated to be worth approximately 0.424% $\Delta k/k$. If we assumed a half element was added to Core 101W making it consistent with the target core configuration, the resulting excess reactivity is estimated to be 0.469% $\Delta k/k$ + 0.424% $\Delta k/k$ = 0.92% $\Delta k/k$. This value is in close agreement with the calculated value of 0.87% $\Delta k/k$.

Integral rod worth curves for Core 101W are presented in Figures 8 through 11. As was seen in Table 12, rod worth values changed very little with the fuel conversion. This was as expected.

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[2]Covington, Lorne J., "Neutronics Study of the Conversion of the University of Missouri-Rolla Reactor to Low Enriched Uranium Fuel". M.S. Thesis (1989) University of Missouri-Rolla.

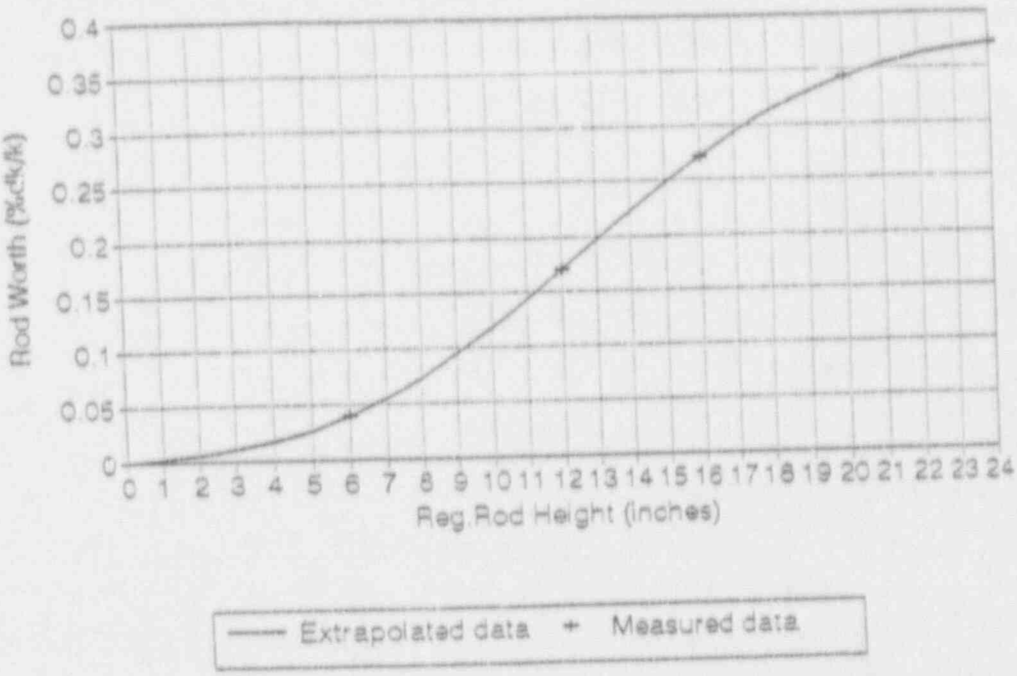

Figure 8. Regulating Rod Integral Rod Worth Curve, Core 101W (Total Worth: 0.371% Δk/k)

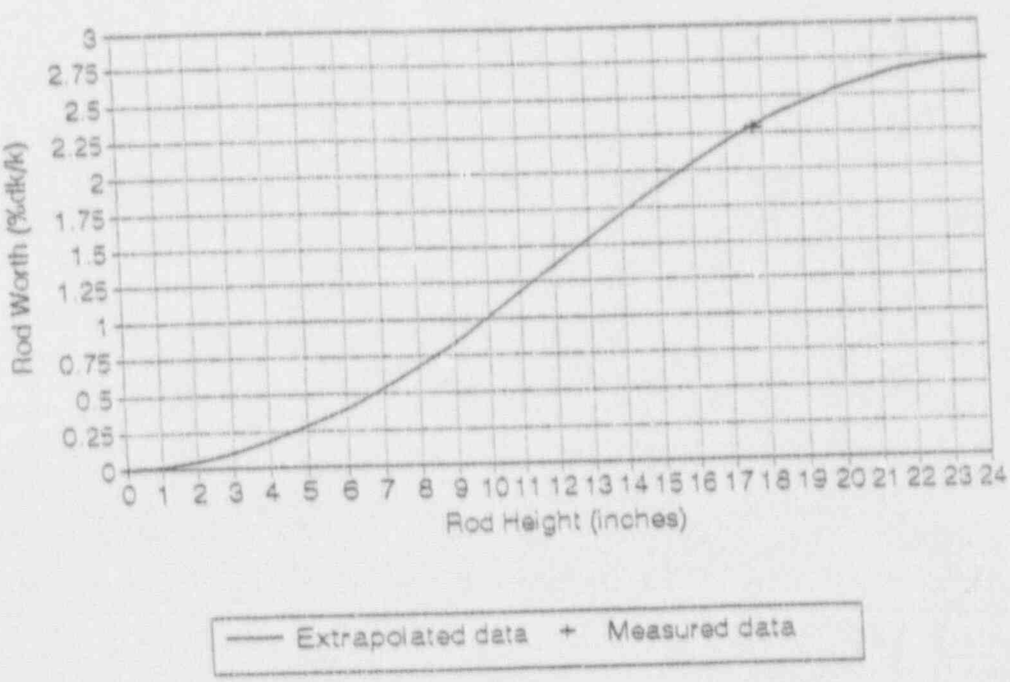

Figure 9. Rod 1 Integral Rod Worth Curve, Core 101W (Total Worth: 2.73% Δk/k)

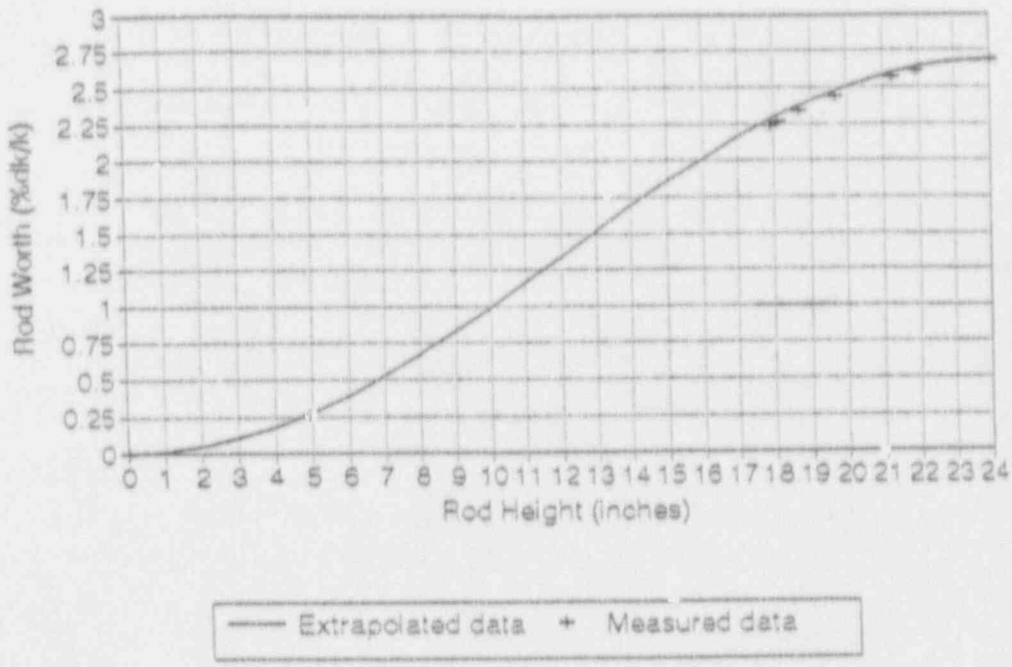

Figure 10. Rod 2 Integral Rod Worth Curve, Core 101W (Total Worth: 2.69% Δk/k)

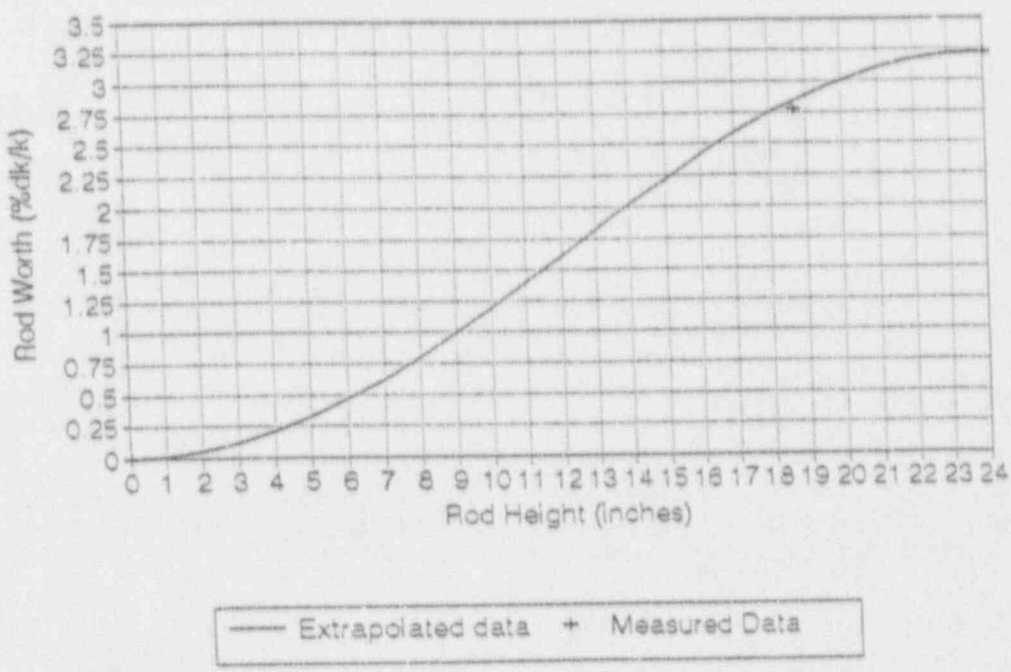

Figure 11. Rod 3 Integral Rod Worth Curve Core 101W (Total Worth: 3.22% Δk/k)

5.0 Partial Fuel Element Worth

The worth of a partial (or half) fuel element at the core periphery was determined by the change in core excess reactivity between core 100W and 101W. This core change involved replacing the half element (HR-1) located in Grid Position D-8 with a full fuel element (F-15).

The swing in excess reactivity was 0.424% Δk/k (W mode) and 0.435% Δk/k (T mode).

6.0 Critical Mass

The critical mass of U-235 for the LEU fuel was estimated to be 3409 grams based on actual core loading data. The critical mass of U-235 for the HEU core was estimated at 2,797 grams based on previous core loading information. Thus, the critical U-235 mass of the LEU core is about 22% larger than the HEU cores.

The estimated critical mass for the LEU core was determined by comparing the excess reactivities and U-235 loadings of cores 100W and 101W. Core 100W had a loading of 3533.0 grams U-235 and excess reactivity of 0.450% Δk/k. Core 101W had a loading of 3645.4 grams U-235 and excess reactivity of 0.874% Δk/k. The reactivity worth per gram of U-235 can be estimated as:

$$\frac{(0.874\%\Delta k/k - 0.450\%\Delta k/k)}{(3645.4 - 3533.0)\ grams} = 0.0038\ \frac{\%\Delta k/k}{gram}$$

The initially critical LEU core contained 3421 grams of U-235 and had an excess reactivity of 0.045% Δk/k. This implies an excess of about (0.045% Δk/k) ÷ (0.0038% Δk/k-g) = 12 grams. The estimated LEU mass is therefore 3421 grams - 12 grams = 3409 grams U-235.

The critical mass of the HEU core was estimated based on Core 67W. Core 67W contained 2870 grams of U-235 and had a measured excess reactivity of 0.43% Δk/k. Experiments at the UMRR with different core configurations[3] have shown that the worth of a fuel element (170 grams U-235) is between 0.5% and 1.5% Δk/k depending on its position at the core periphery. Taking an average of 1.0% Δk/k and using the same methodology as above, the reactivity worth per gram of U-235 can be estimated as:

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[3]Safety Analysis Report for the University of Missouri-Rolla Reactor. Docket Number 50-123, Page 9-13. (1984)

$$\frac{1.0\%\Delta k/k}{170\ grams} = 0.00588\frac{\%\Delta k/k}{gram}$$

The HEU core 67W thus had a surplus of about 73 grams of U-235 above the critical mass. Therefore, the minimum critical mass of U-235 for the HEU fuel is approximately 2,797 grams.

7.0 Power Calibration

After low power core characterization, the reactor operated at an indicated power of 1 kW on the Linear Channel for one hour. The core was checked and the operation appeared normal.

A power calibration was performed on August 4, 1992. The procedure involves operating the reactor at an intermediate indicated power of 40 kW for one hour. The resulting "heat balance" is obtained by measuring thermal expansion of the pool. The power calibration procedure (SOP 816) is provided as Attachment A. Detectors had to be positioned slightly closer to the core as a result of the calibration. It was expected that nuclear instruments would read a bit high due to the higher core leakage associated with the harder flux spectrum. A second power calibration, performed on Aug[illegible] 1992 verified that the detectors were correctly positioned.

8.0 Void Coefficient of Reactivity

An aluminum void tube fabricated to fit into the grid plate was used to measure the void coefficient of reactivity. The tube is hollow and sealed. Core reactivity is measured with the tube both filled with air and with water. These measurements are used to calculate the void coefficient. The void coefficient (α_v) is calculated by taking the ratio of the change in reactivity to the effective volume of the void:

$$\alpha_v = \frac{\Delta\rho_{air\ filled} - \Delta\rho_{water\ filled}}{Vol}$$

The volume of the tube is 1300 cm^3.

The average void coefficient measured for the new LEU Core 101W was $-7.1\ X\ 10^{-5}\ (\frac{\%\Delta k/k}{cm^3})$. The previously measured value for HEU Core 67W was $-6.9\ X\ 10^{-5}\ (\frac{\%\Delta k/k}{cm^3})$. The void coefficient for the LEU core appears to be slightly more negative than the HEU core. This trend is as expected due to the harder flux spectrum. In fact, measurement showed that the void coefficient of the LEU core is approximately 20% more negative than the HEU core at similar peripheral positions. This is illustrated in Table 13, which presents void coefficients measured in various locations for both the LEU and HEU cores. It should be noted that the cores geometries are not identical, as mentioned in Section 4.

Neutronic calculations[4] for the void coefficient of reactivity were also performed for both proposed HEU and LEU cores. Table 14 presents measured and calculated values.

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[4]Covington, Lorne J., "Neutronics Study of the Conversion of the University of Missouri-Rolla Reactor to Low Enriched Uranium Fuel". M.S. Thesis (1989), University of Missouri-Rolla.

Table 13. **Measured Void Coefficients as a Function of Selected Position for LEU Core 101W and HEU Core 67W.**

POSITION	LEU CORE (% $\Delta k/k\text{-cm}^3$)	HEU CORE (% $\Delta k/k\text{-cm}^3$)
B-6	-8.62×10^{-5}	-7.25×10^{-5}
C-8	-5.75×10^{-5}	-4.90×10^{-5}
D-9	-5.44×10^{-5}	-4.80×10^{-5}
E-9	-5.69×10^{-5}	-4.45×10^{-5}

Table 14. **Measured and Calculated Values for Void Coefficient** $\left(\frac{\%\Delta k/k}{cm^3}\right)$

DESCRIPTION	HEU CORE	LEU CORE
Measured	-6.85×10^{-5}	-7.08×10^{-5}
Calculated	-7.0×10^{-5}	-9.0×10^{-5}

The calculated value for the LEU void coefficient is about 28% more negative than for the HEU fuel. Comparing measured values for selected locations presented in Table 13 showed that the LEU void coefficient ranged from about 13% to 28% more negative than the HEU values.

9.0 Temperature Coefficient of Reactivity

The temperature coefficient of reactivity will be measured in the Winter, 1993 semester as a Senior class Nuclear Engineering project. It was planned to perform the experiment during the Christmas break of '92/'93; however, required reactor maintenance lasted longer than planned, thus the experiment has been postponed.

10.0 Thermal Neutron Flux Distribution

These measurements are somewhat time consuming and have not yet been obtained for the new core. We plan to characterize the flux in the beamport facility, bare and cadmium rabbit facility, and at some various core positions during this next semester. As we have a very small staff and because these measurements make excellent student projects we plan to obtain these measurements via student labs and projects. We anticipate an M.S. Thesis project for the completion of the core flux profile measurements.

11.0 Delayed Neutron Fraction

The new value of β_{eff} is 0.0079 as presented in the SAR. This is about 4.6% larger than the previously assumed value of 0.0075 used with the HEU core.

No kinetics measurements have been made with the LEU core and to our knowledge, there is no documented measurement of kinetics parameters with any of the HEU cores. Operationally, the LEU core behaves very similarly to the HEU cores.

At present, we have assigned two Senior Nuclear Engineering students to explore ways of determining kinetics parameters with computer noise analysis. This will involve interfacing a computer data collection to the isolated outputs of our newly (and as yet not installed) nuclear instrument drawers. We feel this will be a suitable topic for an M.S. Thesis.

12.0 Conclusions

The receipt and inspection of the new elements went smoothly and all elements were determined to be satisfactory. Initial core loading to criticality went smoothly with 1/M data correctly predicting criticality.

The target core configuration based on neutronics calculations differed from the actual final core configuration by only one-half element. Excess reactivity, control rod worths and shutdown margin for the new core are very similar to those in the HEU cores. As expected, the critical mass in the LEU core was significantly higher than with the HEU fuel although the overall core geometry was negligibly affected.

Detector positions changed very little but did have to be positioned slightly closer to the core as a result of the core change. This was as expected due to the greater leakage anticipated with the harder flux spectrum.

The void coefficient was found to be slightly more negative than with the HEU fuel. This was consistent with calculations.

Still to be further characterized are the temperature coefficient, flux distribution, and kinetics parameters which are to be characterized in the near future.

No abnormalities or surprises have been uncovered with regard to the new fuel. We plan to ship out our remaining balance of HEU fuel as soon as possible. We hope this fuel will last us well into the 21st century.

ATTACHMENT A

SOP 816

"POWER CALIBRATION"

A. Purpose:

To ensure that the power indicated on the linear and log channels is the power generated in the reactor.

B. Precautions, Prerequisites, or Limitations:

1. In accordance with Technical Specification 4.2.2(3) all console instruments and safety system shall be calibrated twice each year, not to exceed ~~8~~ 7 1/2 months. REV. FJ 8-29-89 AEB

2. The power generation in the UMR Reactor is limited by Technical Specifications to 200 kW. It is, therefore, important that the reactor power is less or, in an ideal case, equal to the power indicated in the reactor control room. The calibration of the power instruments is performed by the calibration procedure described below. (For more details see the report UMRR/85-1.) Stable atmospheric condition are helpful for a successful calibration.

C. Procedure

1. Turn on both nitrogen diffusers and the pool lights.

2. Set up pool level measuring equipment. It is recommended that two gauges be used in order to have redundant measurements. (Minimum recommended scale division is 0.001 inches.)

3. After the diffusers have been on for at least 30 minutes start to take level readings every 15 minutes. Continue for at least one hour prior to the reactor startup to determine the average pool level drop. Be sure to note accurately the time of each reading. Record also the temperature of the pool water using all three reactor thermocouples.

4. Take the reactor to some intermediate power level, e.g. 20, 30, or 40 kW. Note the time the reactor reaches that power level. After running the reactor at this power for a time t_o such that the reactor thermal output is between 30 and 50 kW hr, shut down the reactor and note the shutdown time. For example, it is recom-

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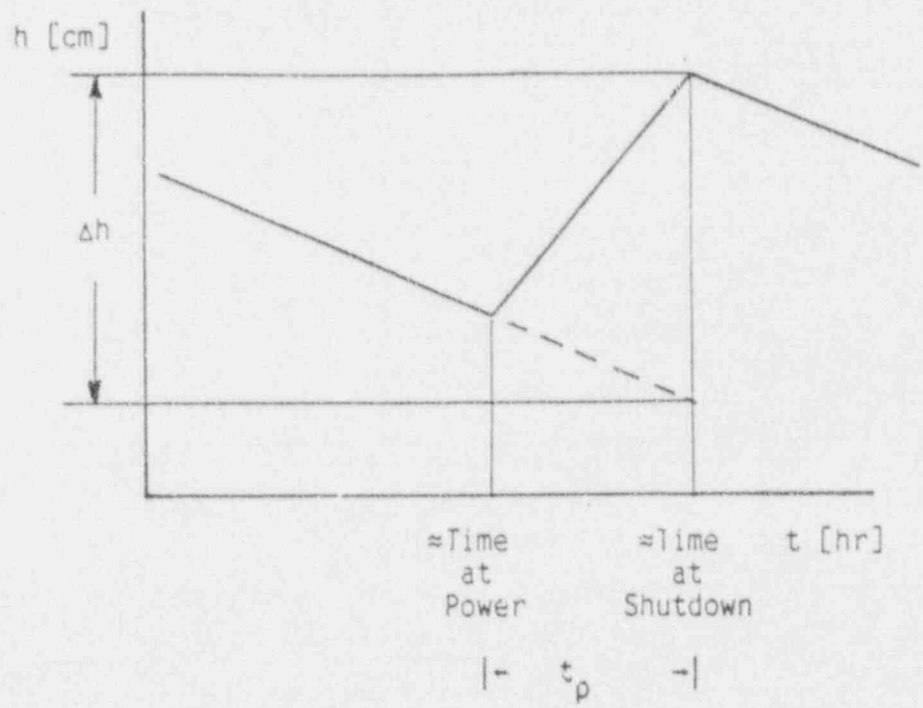
mended that the reactor power be chosen 40 kW and the operational time t_p 1 hr.

5. Once all control rods and magnets are fully inserted, note time and pool level every 15 minutes until level decreases equal the rate of decrease before the power run. During this time also continue to take temperature readings using all reactor thermocouples.

6. Plot the data measured with both relative height gauges such as to construct the time-dependent plot of h, i.e. the relative change in height of the pool water surface before, during, and after the power run. (Use units of cm for the plot of h.)

7. Determine Δh as shown in the sketch below



8. Calculate the average pool water temperature T_w using the data taken immediately before the beginning of the power run and after the reactor shutdown. (Use only the inlet temperature readings.)

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9. Using Figure 1 and data determined in step 7 and 8 determine the amount of heat Q generated in the reactor during the calibration run. (The fact that the coefficient of the thermal volumetric expansion is to be taken at the temperature which is 1 K higher than the average pool temperature has already been taken into account while constructing the plot in Figure 1.)

10. Calculate the reactor power using the relationship

$$P[kW] = \frac{Q\ [kWhr]}{t_p\ [hr]}$$

11. If the power indicated on the linear and/or Log N recorder is equal to or greater than the calculated power P by not more than 5% no further action is needed. In any other case the position of the pertinent neutron detector needs to be adjusted so as to satisfy the above condition.

12. After both power channels (linear and Log N) have been properly adjusted take the reactor to ~~100 kW~~ 200KW and adjust, if necessary, both safety channels so as to indicate the reactor power of ~~100 kW.~~ 200KW

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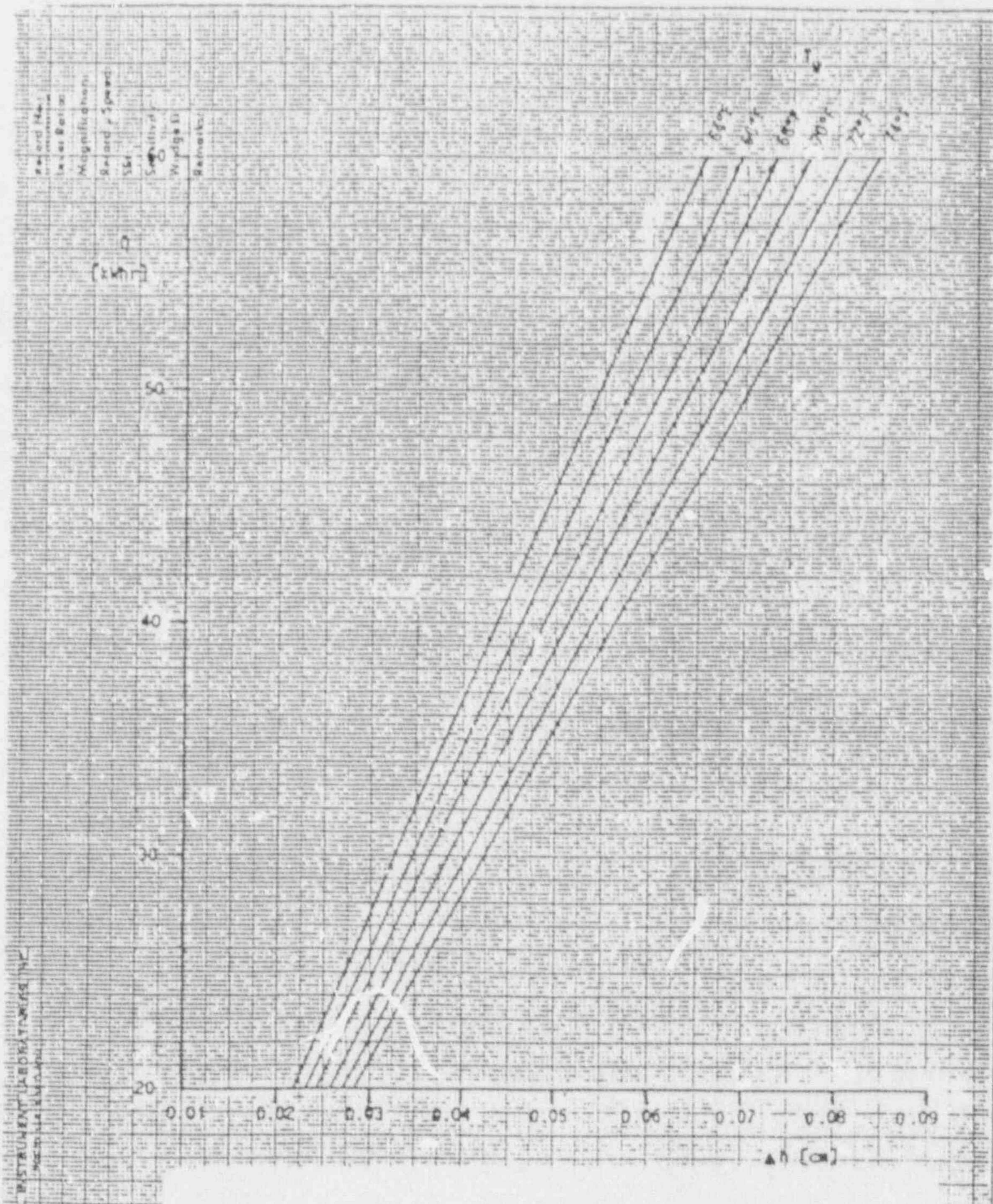

Figure 1. UMRR Thermal Output vs. Change in Height of the Pool Surface

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