# CHAPTER 4

# CALCULATIONS OF PREVIOUS CORE CONFIGURATIONS

## 4.1 The Initial Critical Core

### 4.1.1 Loading Sequence and Measured Excess Reactivity

The initial critical core (or startup core) was assembled by GA Technologies in November 1977 using fresh TRIGA LEU fuel containing 8.5 wt.% U. Measured and calculated data for this core are compared here in order to validate the methods and codes for reactivity calculations.

The approach to critical was performed with the core at the center of the small pool and the lazy susan in the up position. Criticality was achieved with 67 standard fuel rods and 4 fuel follower rods as shown in Fig. 4.1 Note that the loading is not symmetrical. The only control absorber in the core was the Transient Rod with its "air follower". The measured period of $\sim$ 11s implied an excess reactivity of $\sim$ \$ 0.24 (or 0.168 % $\delta k/k$ with $\beta = 0.007$).

The loading sequence for the approach to critical is described in the following table :

| Loading Step | No. of Fuel Rods | No. of Fuel Follower Rods | Fuel Rod Added | Excess Reactivity |
|---|---|---|---|---|
| 9* | 63** | 4 | - | Subcritical |
| 10 | 64 | 4 | F16 | Subcritical |
| 11 | 65 | 4 | F30 | Subcritical |
| 12 | 66 | 4 | F10 | Subcritical |
| 13 | 67 | 4 | F12 | \$0.24, 0.168 % δk/k |

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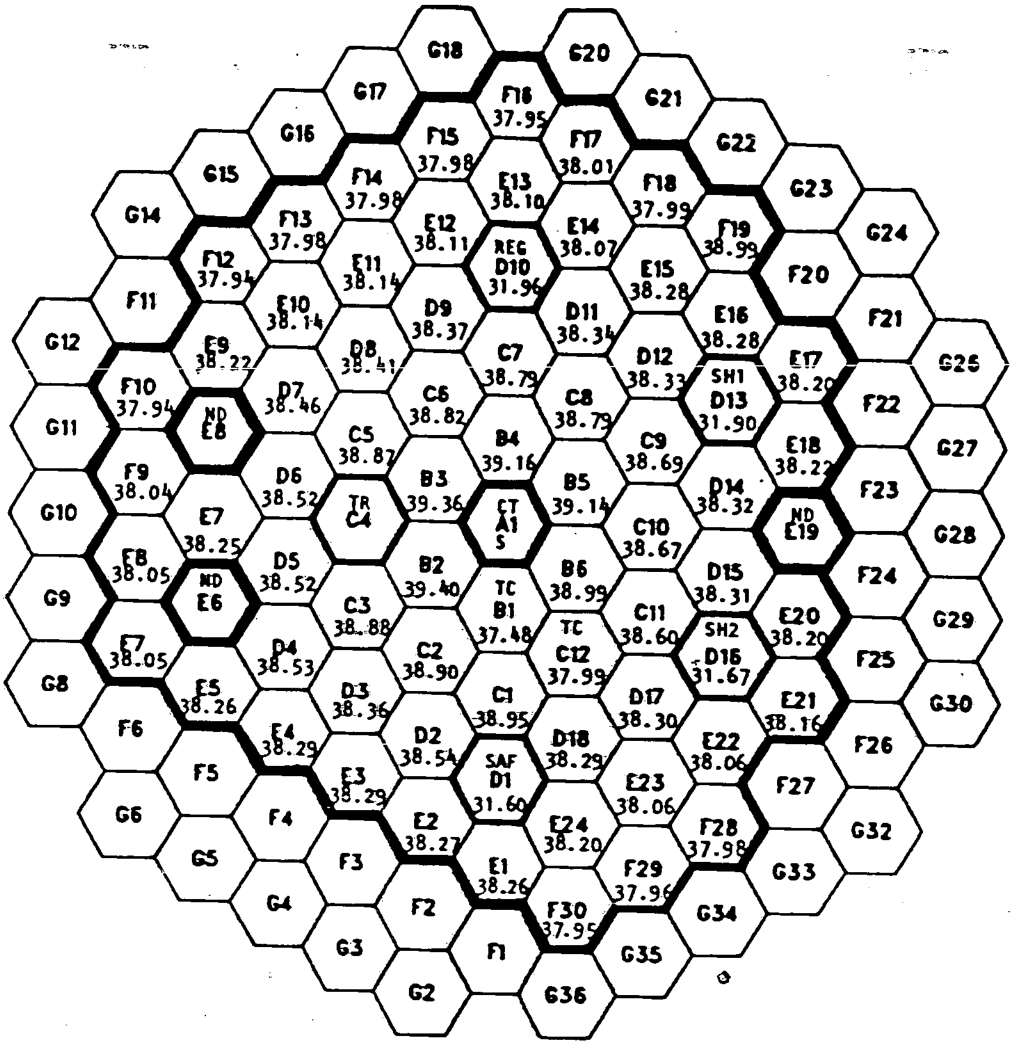
* All of the preceding steps are also subcritical (not shown in this table)

** Fuel rods in each ring were B:6, C:11, D:14, E:21, plus 11 F-ring positions (7,8,9,13,14,15,17,18,19,28,29).

### 4.1.2 Calculated Excess Reactivities

The excess reactivity of the cold clean for the approach to criticality (loading step 11, 12 and 13) were calculated for "nominal" $^{235}$U loading per fuel and follower rod using microscopic cross sections computed with EPRI-CELL/RERTR(9) (The calculations of "nominal" $^{235}$U loading per fuel and follower rod are shown in Appendix A)

The "nominal" $^{235}$U loadings used in all of the calculations in this study were 38.69 g in the standard fuel rods and 32.27 g in the fuel follower rods with 8.5 wt % U. (These nominal loadings were used because a significant fraction of the calculations had already been completed when data for the as-built loadings became available ). The as-built loadings shown in Fig. 4.1 have average $^{235}$U contents of



CT: Central Thimble (A1)

ND: Neutron Detectors (E6, E8, E19)

TR: Transient Rod (C4)

REG: Regulating Rod (D10)

SH1: Shim Rod (D13)

SH2: Shim Rod (D16)

SAF: Safety Rod (D1)

Measured Excess Reactivity: \$0.24 or 0.168% δk/k

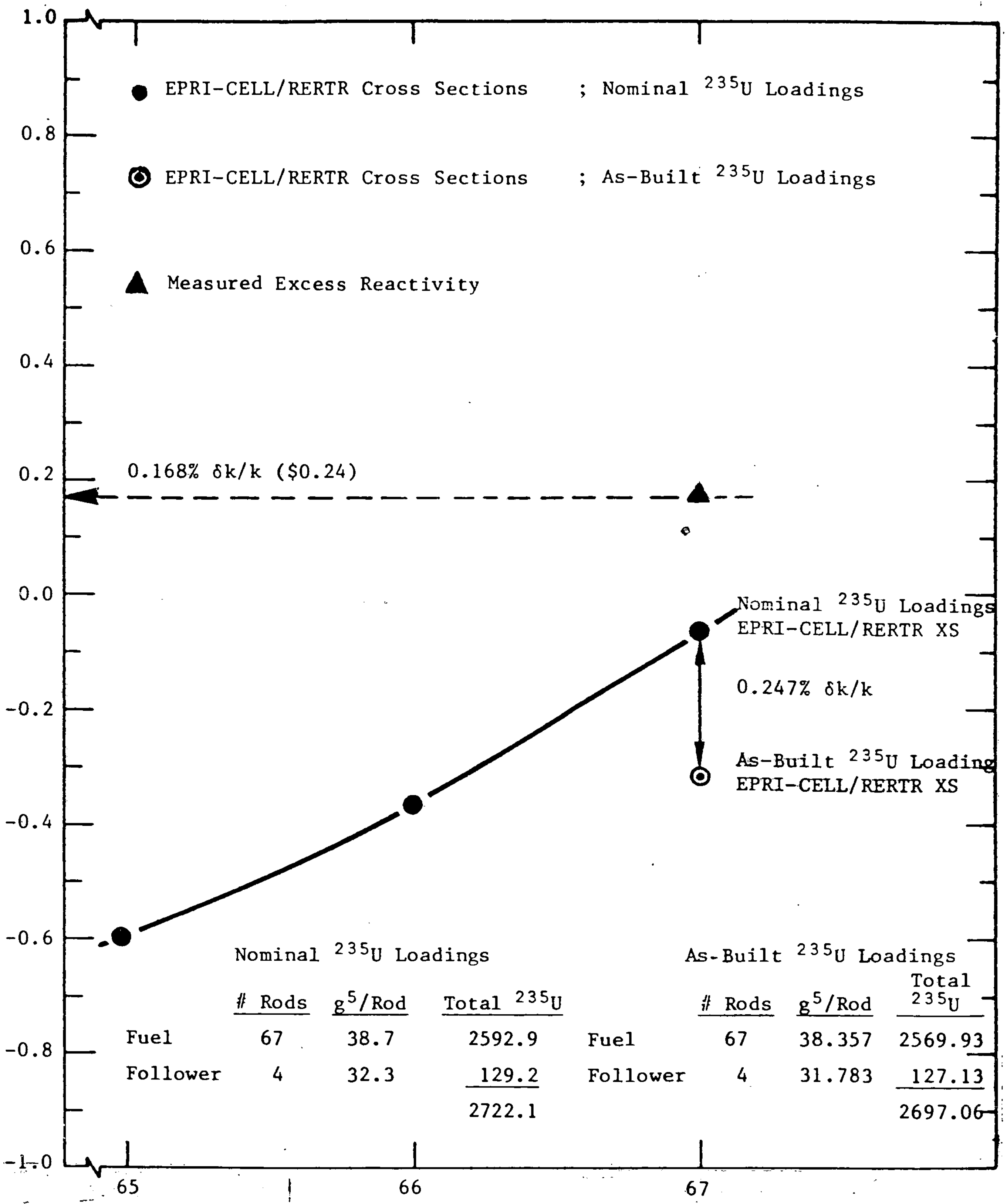
Fig.4.1 Configuration of the TRR-1/M1 Initial Critical Core With As-Built $^{235}U$ Loadings in the 67 LEU Fuel Elements and 4 LEU Fuel Follower Elements with 8.5 wt% U.

38.36 g and 31.78 g in the fuel and fuel follower rods, respectively.

The results of these calculations are summarized in Table 4.1 and plotted in Fig.4.2

Table 4.1 Reactivity Calculations for the TRR-1/M1 Initial Critical Core Using the EPRI-CELL/RERTR Cross sections (The Measured Excess Reactivity for Loading Step 13 was 0.168 %δk/k)

| loading atep | $k_{eff}$ | Reactivity | |
|---|---|---|---|
| | | % δk/k | $ |
| 11 | 0.99406 | -0.598 | -0.854 |
| 12 | 0.99637 | -0.364 | -0.520 |
| 13 | 0.99931 | -0.069 | -0.099 |



Nominal $^{235}U$ Loadings

| | # Rods | $g^5$/Rod | Total $^{235}U$ |
|---|---|---|---|
| Fuel | 67 | 38.7 | 2592.9 |
| Follower | 4 | 32.3 | 129.2 |
| | | | 2722.1 |

As-Built $^{235}U$ Loadings

| | # Rods | $g^5$/Rod | Total $^{235}U$ |
|---|---|---|---|
| Fuel | 67 | 38.357 | 2569.93 |
| Follower | 4 | 31.783 | 127.13 |
| | | | 2697.06 |

Fig. 4.2 Comparison of Measured and Calculated Excess Reactivities for TRR-1/M1 Initial Critical Core (November 1977).

Overall, the measured and calculated excess reactivity values are in good agreement. For the as-built $^{235}$U loadings, the excess reactivity computed using EPRI-CELL/RERTR (9) cross sections is about 0.48 % δk/k smaller than the measured value.

As shown in Fig.4.2 there is a consistent reactivity difference of about 0.25 % δk/k between the calculated values for the "nominal" and as-built $^{235}$U loadings.

All of the calculations in the remainder of this study were performed using EPRI-CELL/RERTR cross sections and "nominal" $^{235}$U loadings in the standard and follower fuel rods with 8.5 wt % U. The reactivity bias with experiment is about 0.24 % δk/k. However, since all of the calculations were performed in a consistent manner, this reactivity bias will have little or no effect on the conclusions.

## 4.2 Burnup History (Core No.'s 1-4)

### 4.2.1 Introduction

The objective of this study is to determine a reasonable fuel management strategy for future refueling of the TRR-1/M1. The current core is Core No.5, which began operation on March 7, 1985. However, in order to provide a consistent and systematic analysis, the burnup histories of Core No.'s 1-4 were first computed using the actual MWd's that each of the cores has been operated.

The reactor is normally operated 7 hours per day, 5 days per week, at a power level of 1 MW. The calculations could have been run in a manner that it would follow actual reactor operation, but this would have been very expensive because a large number of k-calculations with short burn-times would be required.

Instead, the burnup calculations were run as if each core had been operated continuously for the specified number of MWd. In this way, only a few computational timesteps are needed to represent the excess reactivity as a function of the energy released in each core.

The burnup calculations were also run with all of the control absorbers fully-withdrawn and with cold cross sections in the fuel, clad, and moderator. Due to it is very little change in reactivity of lazy susan between up and down positions (typically about \$ 0.25 to \$ 0.30) and in order to reduce the computer inputs, the lazy susan was not modeled in the calculations.

### 4.2.2 Calculated Values of Excess Reactivity

Core No.1 was the initial fresh operational core that was assembled in November 1977 using LEU fuel rods containing 8.5 wt.% U. Nominal $^{235}$U loadings of 38.69 g in the 96 standard fuel rods and 32.27 g in the 4 fuel followers were used in the calculations. This core was operated for a total of 61.22 MWd between November 1977 and January 1980.

In early 1980, the core was refueled for the first time due to lack of excess reactivity. For Core No. 2, 5 partially-burned LEU standard elements with 8.5 wt.% U were moved from the C-ring to G-ring and 5 fresh LEU elements with 20 wt.% U were inserted into the C-ring positions. One of these elements was instrumented. This core was operated for 76.33 MWd beginning in March 1980 through May 1982. In the burnup calculation for Core No. 2, the xenon was set to zero at BOC in all of the partially-burned elements, but the initial samarium and lumped fission product poison concentrations were the same as those at EOC for Core No. 1. This same procedure was followed in all subsequent cores.

In June 1982, a fission product leak occurred due to a cladding rupture in the instrumented 8.5 wt.% U standard element in position B1. This element was transferred to a storage well in the biological shield. Core No.3 was established by moving the instrumented element in position C1 to position B1 and by moving the standard 8.5 wt % U element in position G2 to position C1. Position G2 was left empty. No fresh fuel was added. In-core irradiation tubes were installed in grid positions G5, G6, G32, and G33. This core was then operated for 86.99 MWd beginning in june 1982 through March 1984.

Core No. 4 was established by moving 4 partially-burned standard elements with 8.5 wt.% U from the C-ring into the G-ring and inserting 4 fresh LEU elements with 20 wt.% U into the vacated C-ring positions. This core was operated for 47.45 MWd beginning in March 1984 through February 1985.

A summary of operational and calculated data for Core No.'s 1-4 is shown in Table 4.2 . More detailed information showing the calculated fissile loadings, the excess reactivity vs energy release, and the peak and average power density distributions at BOC are shown for each core in Appendix C.

## 4.3 Xenon Poison

The xenon itself is not of interest, but its effects to the reactivity is more important to the study of burnup calculations. Due to the method of burnup calculations the reactor was assumed to have been operated continuously until the specified number of MWd's had been attained. In this way the xenon poison had also builtup and almost reached the equilibrium value, depends upon flux and time of operation, normally reached after about 60 hours of operation(8). Thus, the EOC reactivities from this calculation are much lower than the measured data. To compare the reactivity at EOC in each core with the measured data, the xenon effects must be taken into account. More details about Xenon for core No.s 1-4 are summarized in table 4.3

As mentioned previously, xenon buildup quickly and almost reached the equilibrium value at EOC of each core. To compare the calculated value with the measured value itis necessary to include the reactivity loss due to Xenon poison forexample, the calculated EOC excess reactivity in Core No.1 is $ 1.839 or 1.287 % δk/k (see burnup history data in Appendix C) and the reactivity loss due to xenon poison is $2.49 or 1.74 % δk/k (see table 4.3) Thus the actual EOC excess reactivity in Core No.1 should be $ 4.329(1.839 + 2.49) as shown in table

Table 4.2 Summary of Operational and Calculated Values of Excess Reactivities No's 1-4

| Core No. | Start up Date | Shut down Date | MWd operated | Excess Reactivity, Dollars* | | | | BOC Peak Power density in Homoginized cell | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | BOC | | EOC | | $w/cm^3$ | Location | U-235 content (g) |
| | | | | cal. | Exp. | cal. | Exp. | | | |
| 1 | 11/1977 | 1/1980 | 61.72 | 6.417 | 7.43 | 4.329 | 4.30 | 40.36 | B6 | 38.71 |
| 2 | 3/1980 | 5/1982 | 76.33 | 6.720 | 7.16 | 5.458 | 5.28 | 52.91 | C8 | 99.67 |
| 3 | 6/1982 | 3/1984 | 86.99 | 5.400 | 6.06 | 4.050 | 4.45 | 53.56 | C8 | 97.62 |
| 4 | 3/1984 | 2/1985 | 47.45 | 5.789 | 6.32 | 5.139 | 5.58 | 51.33 | C9 | 99.67 |

* Excess Reactivity in this study is defined in Dollars ($) in order to compare more simply with the operational data. (base on $\beta_{eff}$ =0.007)

Table 4.3 Equilibrium Xenon in Core No's 1-4

| care No. | Equilibrium Xenon, $ |
|---|---|
| 1 | 2.49 |
| 2 | 2.47 |
| 3 | 2.48 |
| 4 | 2.44 |

4.2 . It should also be noted that the BOC excess reactivities were measured at the reactor power of 15 Watts.

The excess reactivity at EOC in Core No.'s 1-4 had a large variation, mostly due to varying reactivity loads for isotope production. Since the demand for radioisotopes has been increasing in recent years, it was decided to run all subsequent burnup calculations to an EOC excess reactivity of 1.9 % $\delta k/k$ or \$ 2.714 (very close to the value of 1.889 % $\delta k/k$ or \$ 2.698 without xenon effect, \$ 2.44,(See table 4.3 for core No.4) in predicting the number of MWd each core could be operated.

## 4.4 Temperature Defect

While the rise in fuel temperature in UZrH, TRIGA fuel-moderator elements, the thermal neutrons gain energy from the oscillating hydride and shift to the higher average energy (the spectrum is hardened) and increase the mean free path for neutrons in the element. For a standard TRIGA fuel, the average chord length is comparable to the mean free path and increases the escape probability from the element as the temperature is increased. This phenomena causes a loss of reactivity in the core is called "Temperature Defect" or "Temperature Coefficient" and because of the temperature of fuel reacts immediately to change in reactor power, the fuel temperature coefficient is also called "Prompt Negative Temperature Coefficient" (6)

The temperature defect was studied only in Core No. 1 by performing the calculations in both cold and hot cores. The cold to hot reactivity change was about \$ 2.41 (1.69 $\delta k/k$ as show in Fig 4.3 and table 4.4

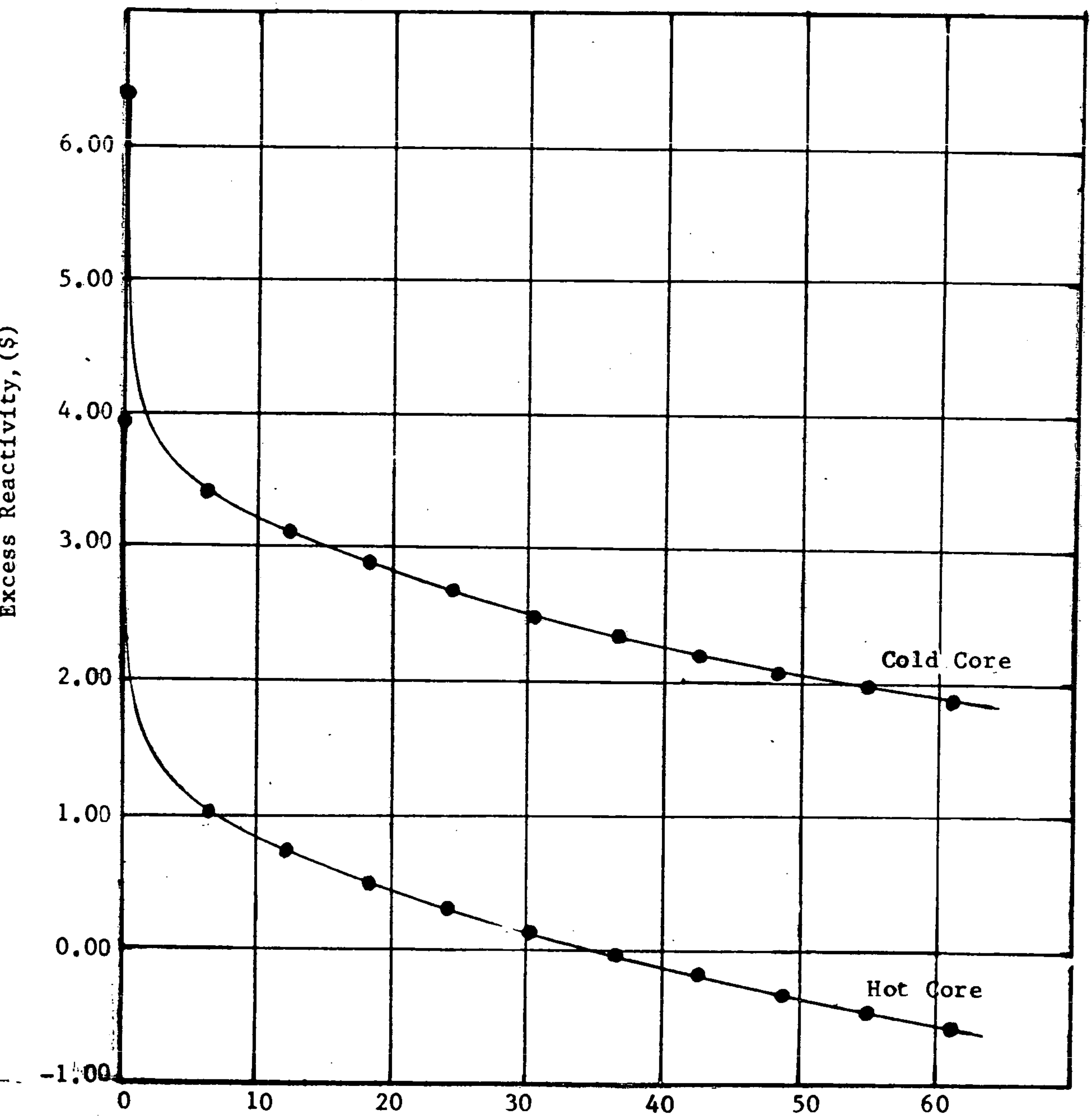


Fig. 4.3 Cold to hot reactivity rundown data

Table 4.4 Cold to hot reactivity changes in Core No.1

| MWd | K-effective | | Reactivity | | Change of |
|---|---|---|---|---|---|
| | Cold | Hot | Cold | Hot | Reactivity,$ |
| 0.000 | 1.04703 | 1.02864 | 6.417 | 3.977 | 2.440 |
| 6.122 | 1.02436 | 1.00697 | 3.397 | 0.988 | 2.408 |
| 12.244 | 1.02239 | 1.00511 | 3.128 | 0.726 | 2.403 |
| 18.366 | 1.02074 | 1.00351 | 2.901 | 0.500 | 2.403 |
| 24.488 | 1.01932 | 1.00216 | 2.707 | 0.308 | 2.398 |
| 30.610 | 1.01806 | 1.00095 | 2.534 | 0.136 | 2.398 |
| 36.732 | 1.01694 | 0.99986 | 2.380 | -0.020 | 2.400 |
| 42.854 | 1.01590 | 0.99885 | 2.236 | -0.164 | 2.400 |
| 48.976 | 1.01486 | 0.99772 | 2.091 | -0.327 | 2.418 |
| 55.098 | 1.01393 | 0.99683 | 1.963 | -0.454 | 2.417 |
| 61.220 | 1.01304 | 0.99595 | 1.838 | -0.581 | 2.420 |
| | | | | AVE. | 2.410 |

Note : The following temperatures were used in the cold and hot core calculations

| | Fuel meat | cladding | Water |
|---|---|---|---|
| cold core | 20°C | 20°C | 25°C |
| hot core | 235°C | 100°C | 25°C |

The bulk water temperature for cold and hot core calculations were used the same values (25°C) due to it was the optimum value in the EPRI-CELL/RERTR library that could be used . However, from the test, by varying the water temperature, from 20°C to 25°C it was very little affect to the results.