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Excess Reactivities Associated with Certain Core Configurations of the PRNC Research Reactor and the Proposed Pool Critical Facility

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EXCESS REACTIVITIES ASSOCIATED WITH CERTAIN CORE CONFIGURATIONS OF THE PRNC RESEARCH REACTOR AND THE PROPOSED POOL CRITICAL FACILITY

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EXCESS REACTIVITIES ASSOCIATED WITH CERTAIN CORE CONFIGURATIONS OF THE PRNC RESEARCH REACTOR AND THE PROPOSED POOL CRITICAL FACILITY

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Scope

Excess reactivities associated with certain core configurations of the proposed PRNC-Pool Critical Facility are computed. The same computational method and the same input data, when used to compute the excess reactivity of a given core configuration of the PRNC 1 MW Research Reactor, yield results that agree very well (within .2%) with those measured in critical loading experiments on the same configuration - thus establishing confidence in the validity of the computations reported herewith. (See pp. 12 & 16) One of the objectives is to provide dependable reactor physics data to be used in the safety analysis of the proposed PRNC-Pool Critical Facility. However the usefulness of the data presented herewith is not limited to the solution of that problem, it is more general than that: The group constants may be used as input data to a variety of calculations concerning both the PRNC Research Reactor and the PRNC Pool Critical Facility, including calculations of flux distribution, depletion, perturbation etc. The fuel elements to be used in the proposed PRNC-Pool Critical Facility are identical with those used in the PRNC Research Reactor. They are MTR-type, 18 plate fuel elements containing 10.67 g of 20% enriched U_3O_8 powder per plate. For the exact description of the geometry and the materials' composition of these fuel elements reference is made to the Final Hazards' Summary Report PRNC-37. (see ref. 1)

The results are presented in the following order:

1. Computed values of few group constants.
2. Computed values of effective multiplication factors (k_{eff}) for a set of configurations of the PRNC Pool Critical Facility.
3. Comparison of measured and computed k_{eff} values for a given configuration of the PRNC Research Reactor.

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1. Computed Values of Few Group Constants

Two, three and four group constants were determined for the following regions:

a. Standard fuel element
b. Partial fuel element
c. Center well
d. Pure water reflector

The group constants were calculated at the Computing Center of Brookhaven National Laboratory, using the HAMMER-code which was developed at BNL. HAMMER contains THERMOS library for thermal and MUFT library for fast microscopic cross sections; the rest of the necessary input data describe the materials composition and the geometry of the region. HAMMER-computed few group constants by regions and by energy groups are given in Tables (1 - 4).

TABLE I

HAMMER-COMPUTED FEW GROUP CONSTANTS FOR PRNC STANDARD FUEL ELEMENT

Three fast groups Energy range	Σ_a	Σ_r	Σ_f	$\nu\Sigma_f$	D
10 Mev - .821 Mev	.000792	.079906	.000356	.001000	1.918509
.821 Mev - 5.53 Kev	.000505	.092361	.000240	.000594	1.105660
5.53 Kev - .625 ev	.010411	.085465	.003235	.007899	.809105
.625 ev - 0	.0730277			.119298	.251010
Two fast groups					
10 Mev - 5.53 Kev	.000643	.047917	.000296	.000790	1.496799
5.53 Kev - .625 ev	.010411	.085465	.003235	.007899	.809105
.625 ev - 0	.0730277			.119298	.251010
One fast group					
10 Mev - .625 ev	.003709	.026825	.001218	.003021	1.280954
.625 ev - 0	.0732077			.119298	.251010

TABLE 2

HAMMER-COMPUTED FEW GROUP CONSTANTS FOR PRNC PARTIAL FUEL ELEMENT

Three fast groups Energy range	Σ_a	Σ_r	Σ_f	$\nu\Sigma_f$	D
10 Mev - .821 Mev	.000602	.080021	.000178	.000501	1.896954
.821 Mev - 5.53 Kev	.000291	.092541	.000120	.000298	1.095532
5.53 Kev - .625 ev	.006550	.087288	.001640	.004006	.812558
.625 ev - 0	.0475492			.0646975	.240487
Two fast groups					
10 Mev - 5.53 Kev	.000440	.048045	.000148	.000395	1.480873
5.53 Kev - .625 ev	.006550	.087288	.001640	.004006	.812558
.625 ev - 0	.0475492			.0646975	.240487
One fast group					
10 Mev - .625 ev	.002387	.027811	.000624	.001545	1.267938
.625 ev - 0	.0475492			.0646975	.240487

TABLE 3

HAMMER-COMPUTED FEW GROUP CONSTANTS FOR PRNC CONTROL WELL REGION

Three fast groups Energy range	Σ_a	Σ_r	D
10 Mev - .821 Mev	.000413	.109229	1.938877
.821 Mev - 5.53 Kev	.000028	.147859	1.001139
5.53 Kev - .625 ev	.001081	.145800	.574438
.625 ev - 0	.0202578		.145759
Two fast groups			
10 Mev - 5.53 Kev	.000222	.073233	1.474426
5.53 Kev - .625 ev	.001081	.145800	.574438
.625 ev - 0	.0202578		.145759
One fast group			
10 Mev - .625 ev	.000508	.048515	1.174956
.625 ev - 0	.0202578		.145759

TABLE 4

HAMMER-COMPUTED FEW GROUP CONSTANTS FOR PURE WATER

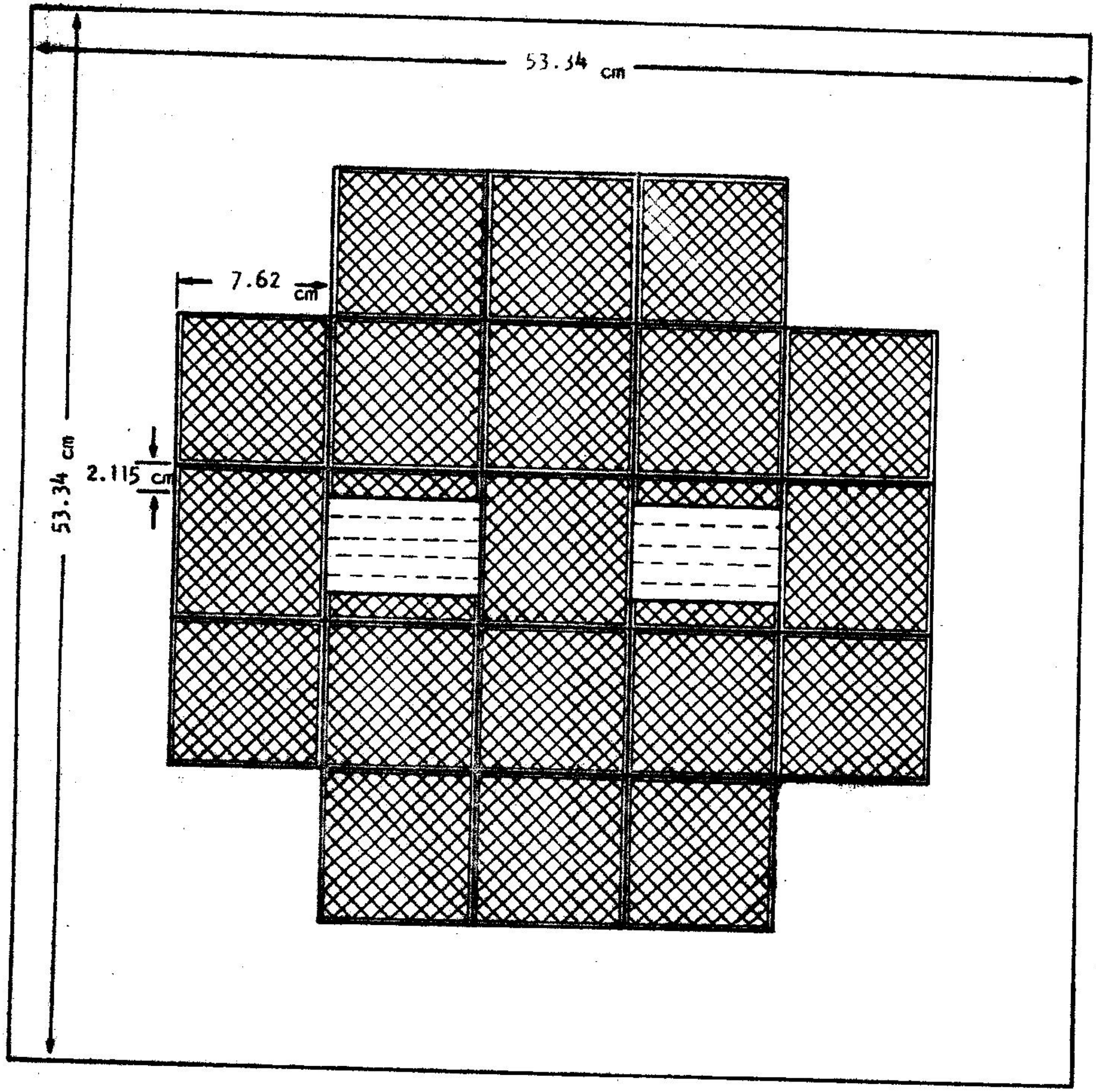
Three fast groups Energy range	$\sum_a$	$\sum_r$	D
10 Mev - .821 Mev	.000360	.106749	2.099140
.821 Mev - 5.53 Kev	.000013	.147631	1.076042
5.53 Kev - .625 ev	.001016	.145777	.585513
.625 ev - 0	.0190790		.146060
Two fast groups			
10 Mev - 5.53 Kev	.000190	.072330	1.597889
5.53 Kev - .625 ev	.001016	.145777	.585513
.625 ev - 0	.0190790		.146060
One fast group			
10 Mev - .625 ev	.000463	.048125	1.263674
.625 ev - 0	.0190790		.146060

2. Computed Values of Effective Multiplication Factors

Effective multiplication-factors were computed on the Control Data 1604-A computer of the ORNL Mathematics Division, using "TWENTY GRAND", a few group, few region diffusion code developed at ORNL.

Four groups were used. The core configurations chosen include the proposed basic configuration of the Pool Critical Facility as well as certain other configurations of the same facility obtained by adding one, two, three or four standard fuel elements to the basic configuration, into the corner positions. Some of these configurations were instrumental in determining the excess reactivity associated with the maximum credible accident, agreed upon in the case of the PRNC-Pool Critical Facility as inadvertently dropping a standard fuel element into a corner position,when the core is already critical in its basic configuration.

The configuration called "CONTROL CASE" refers to the actual configuration of the PRNC Research Reactor used in a critical loading experiment. TWENTY GRAND calculated effective multiplication constants, together with the configuration diagrams are given in figures 1 - 5.



LEGEND

▩ STANDARD FUEL

☐ WATER REFLECTOR

▤ CONTROL WELL

FIGURE 1.

CORE CONFIGURATION A, COMPUTED $K_{eff} = 1.0143652$

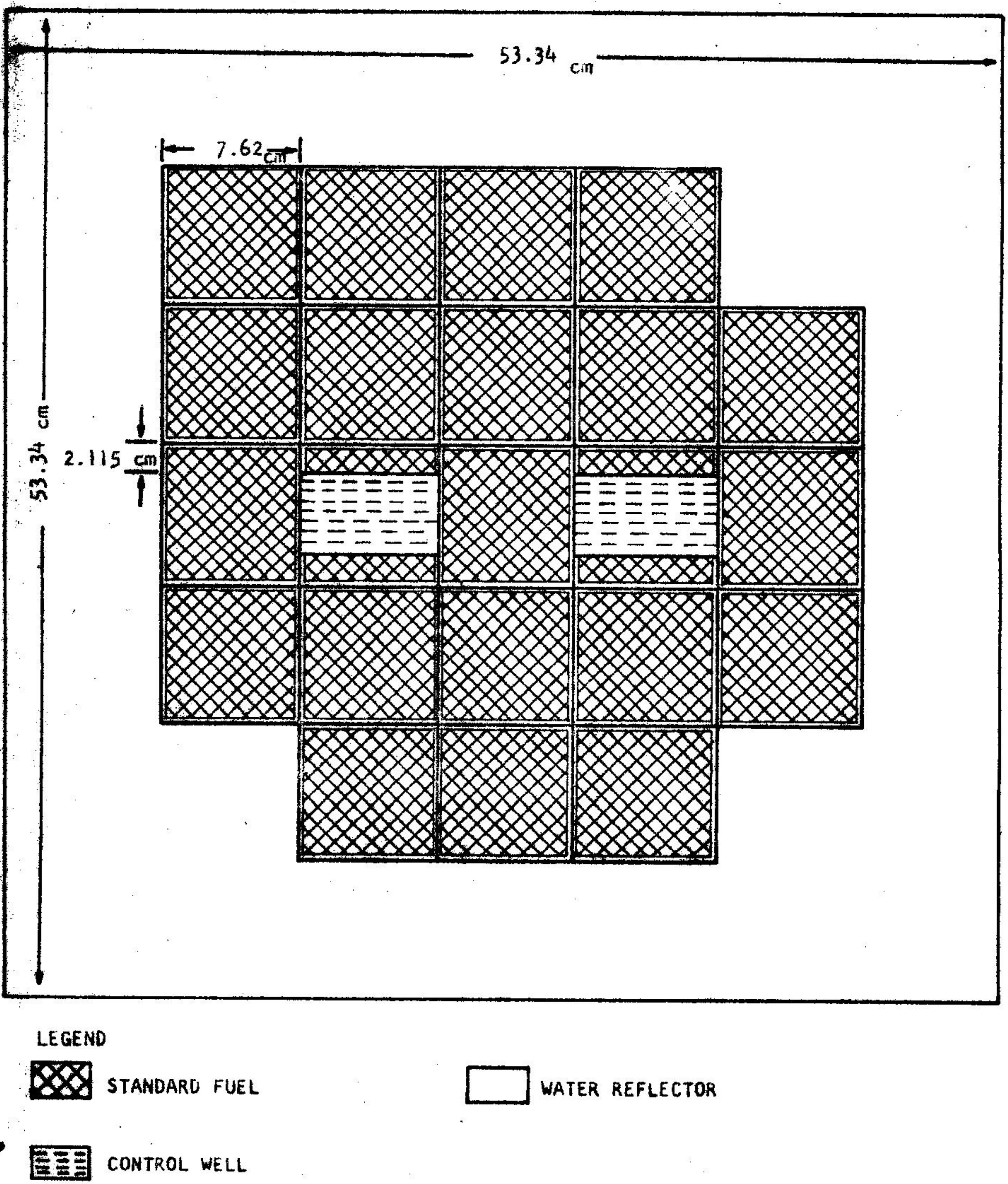
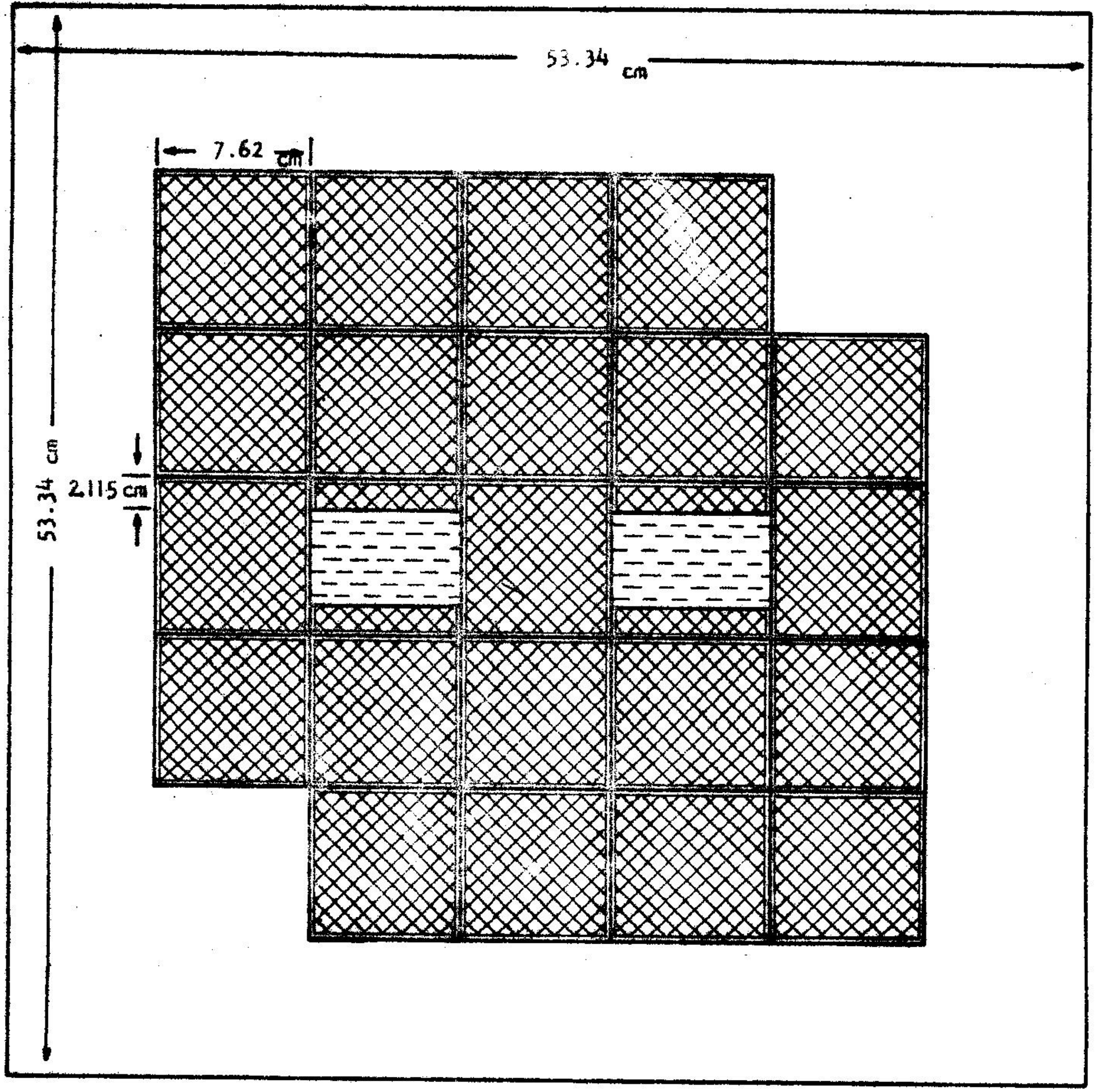


FIGURE 2.

CORE CONFIGURATION B, COMPUTED $k_{eff} = 1.0212336$



LEGEND

▨ STANDARD FUEL

☐ WATER REFLECTOR

☰ CONTROL WELL

FIGURE 3.

CORE CONFIGURATION C, COMPUTED K_{eff} = 1.0279303

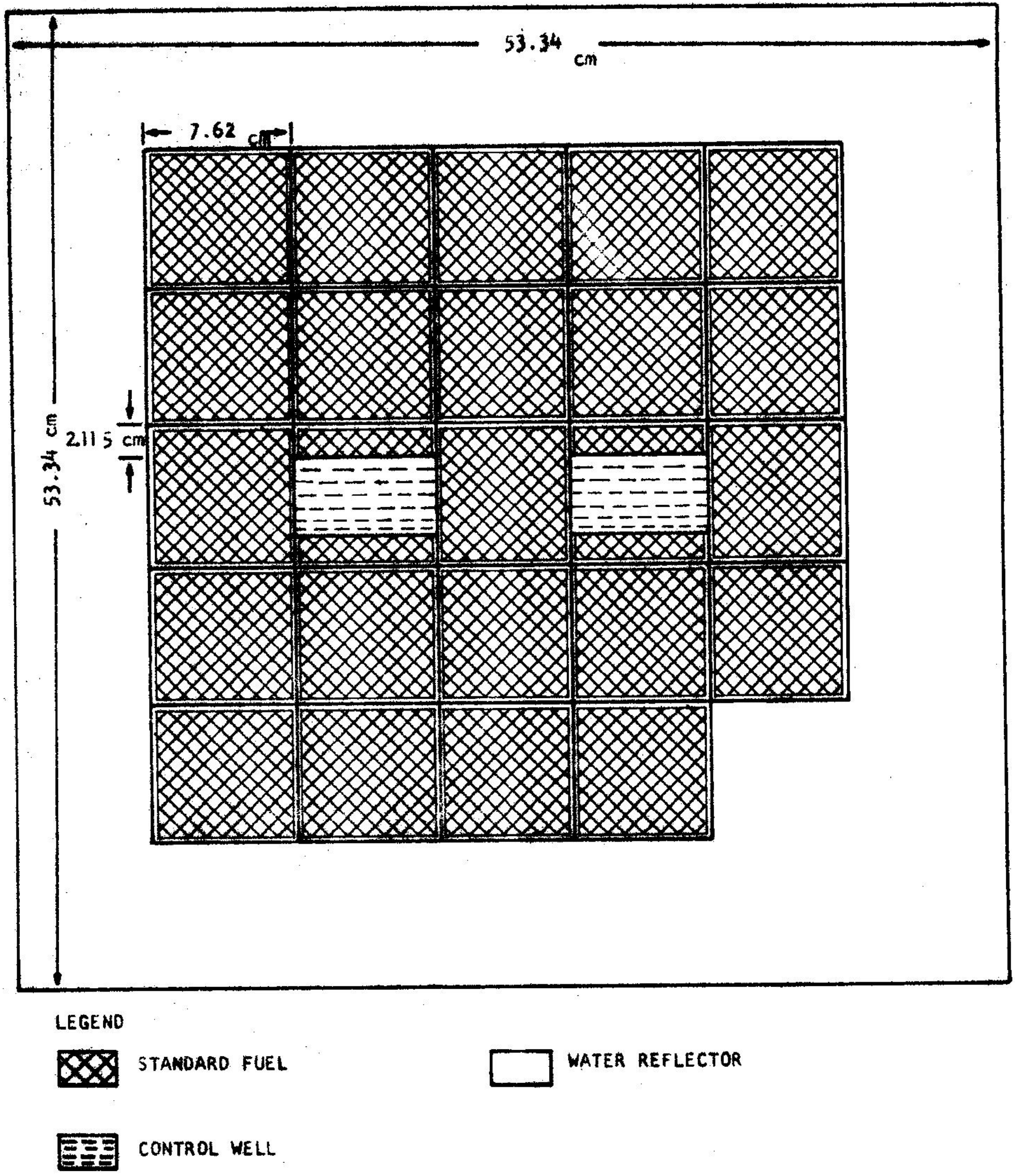


FIGURE 4. CORE CONFIGURATION D, COMPUTED K_{eff} = 1.0341291

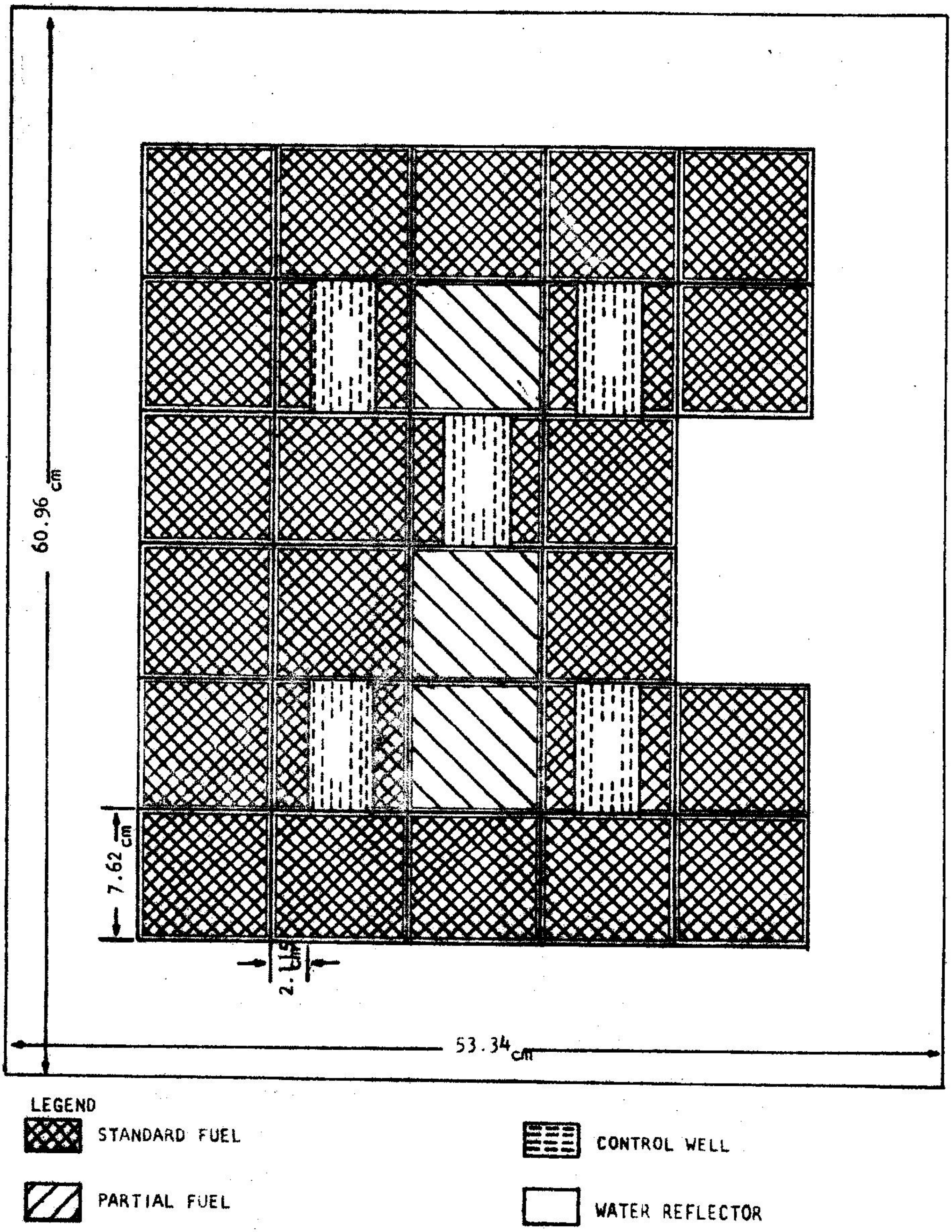


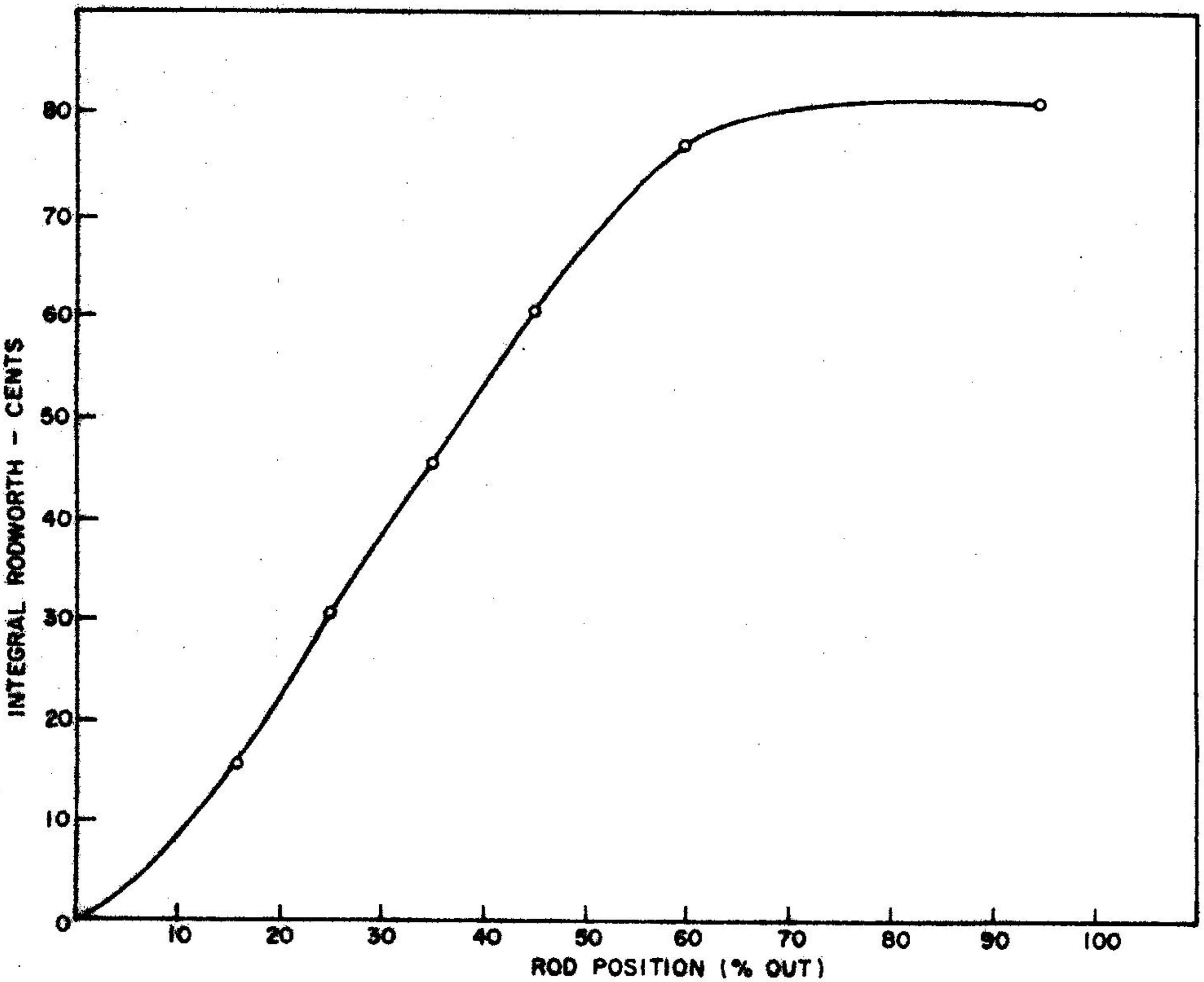
FIGURE 5. CONFIGURATION "CONTROL CASE"
COMPUTED K_{eff} = 1.0029783
MEASURED K_{eff} = 1.00

3. Comparison of Measured and Computed Data for the "CONTROL CASE"

In order to check the overall validity of these computations a comparison was made with experimentally determined results. A set of critical loading experiments were performed on the PRNC-Research Reactor Core in the open pool position and the excess reactivities were determined with the aid of a calibrated regulating rod and one calibrated shimrod. The regulating rod was calibrated by the stable period method and the shimrod by the trading method.

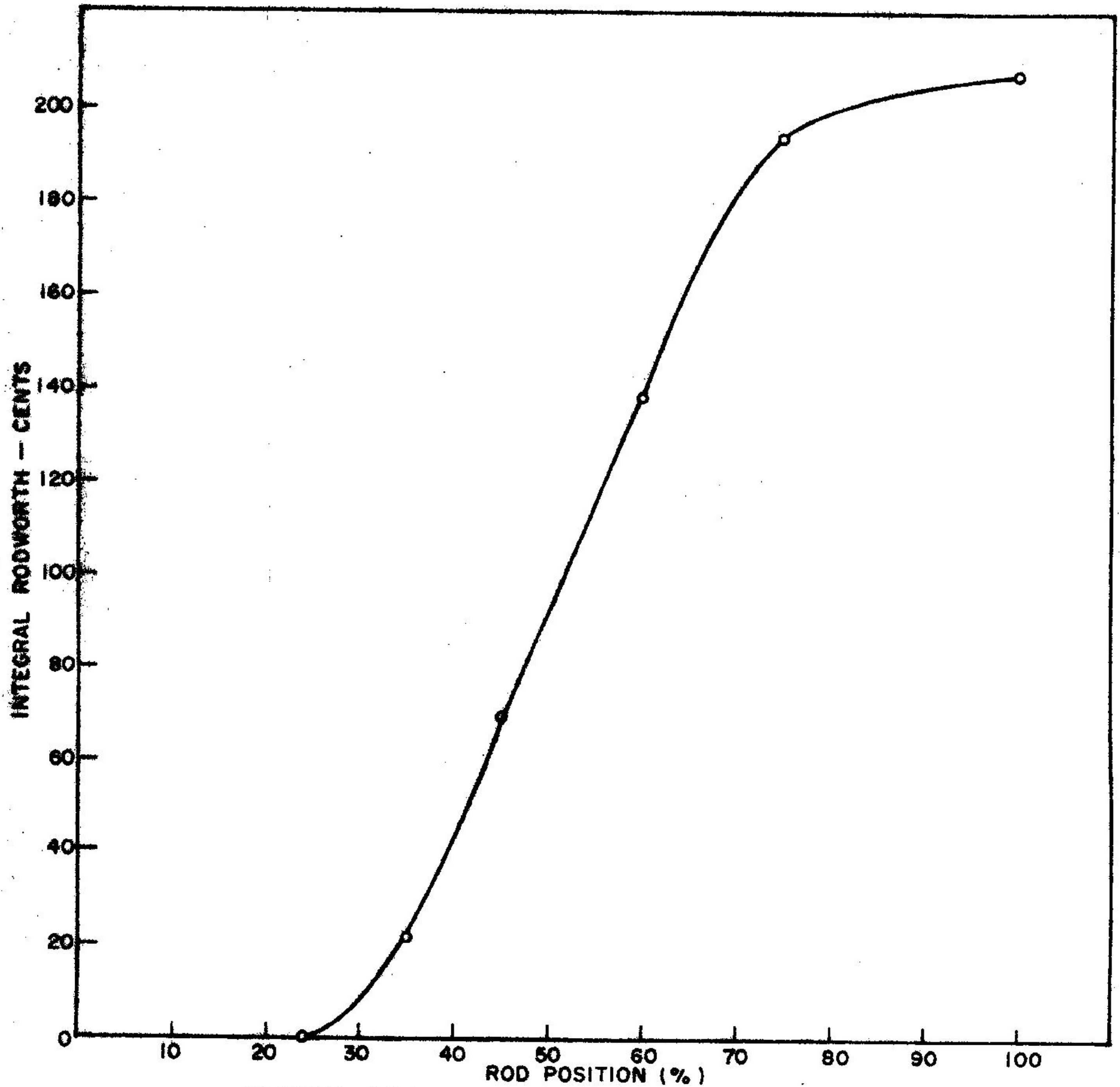
Integral calibration curves of the regulating and of the shimrod are shown in figures 6 and 7 respectively.

Figures 8 through 11 show the core-configurations for which a critical loading has been performed.



REGULATING ROD CALIBRATION CURVE
INTEGRAL RODWORTH VS ROD POSITION

Figure 6



PARTIAL ROD CALIBRATION CURVE OF SHIMROD # 3
INTEGRAL RODWORTH VS ROD POSITION

Figure 7

CONTROL CASE - MEASURED

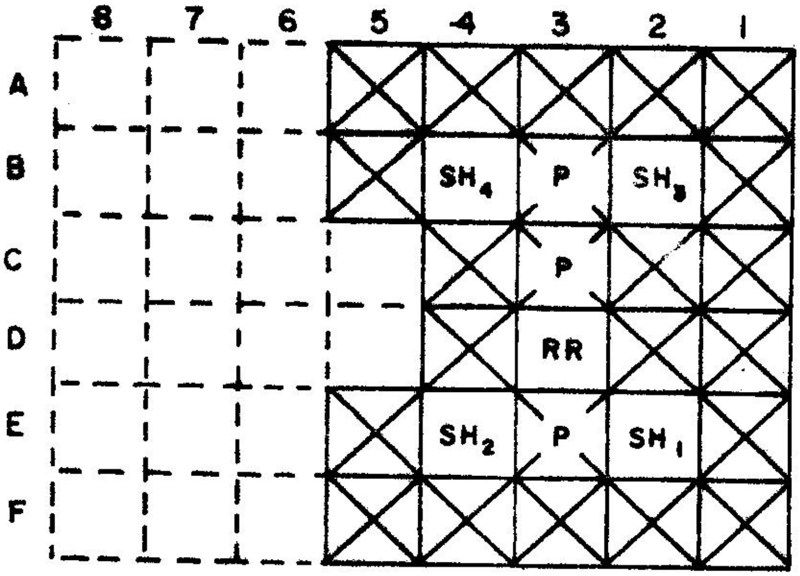


Figure 8: "CONTROL CASE" - Configuration
Rod positions at criticality: all rods 100% out
Measured k_{eff} = 1.00000
Computed k_{eff} = 1.0029783

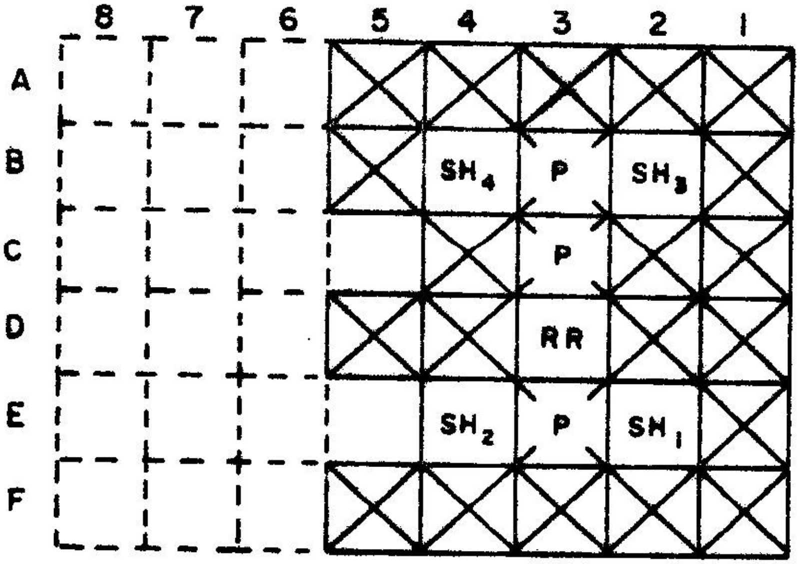
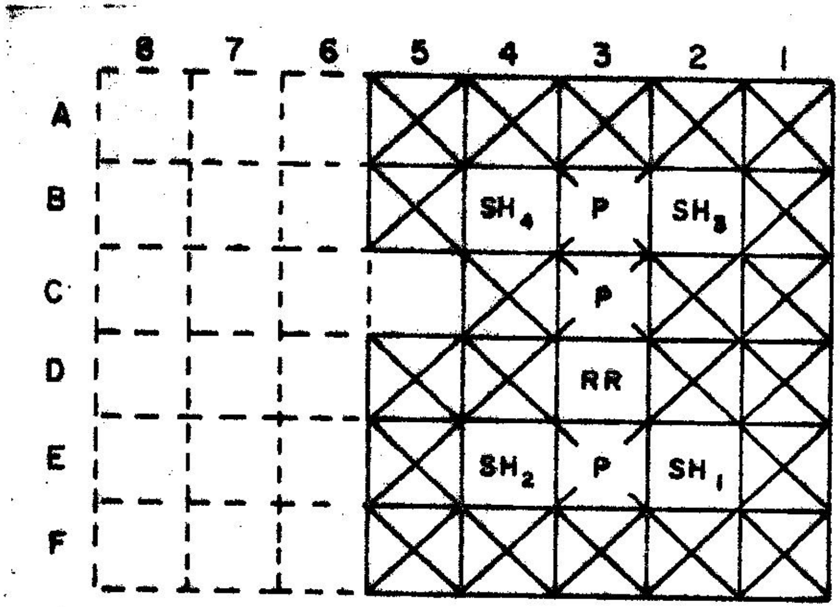


Figure 9: CONFIGURATION "G"
Rod positions at criticality: all rods 100% out
Measured k_{eff} = 1.00000

Figure 10: CONFIGURATION H

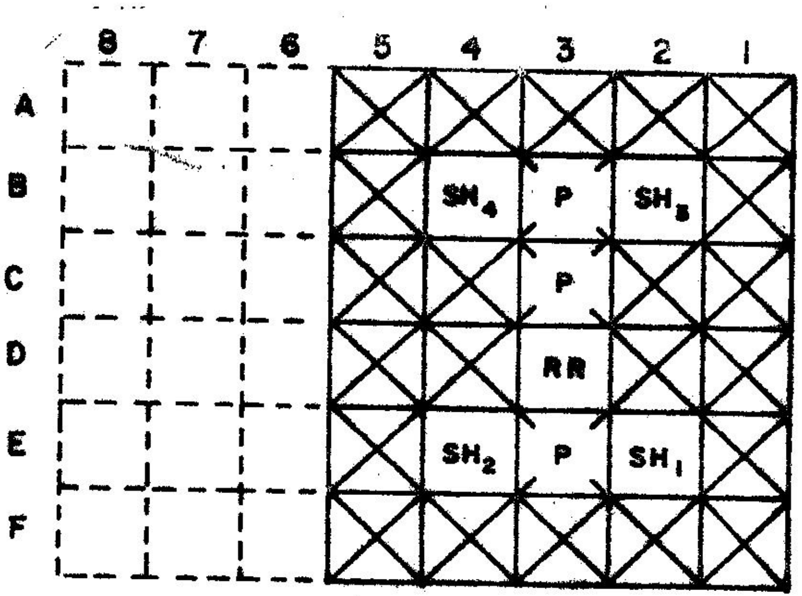


Rod positions at criticality

SH-1	SH-2	SH-3	SH-4	RR
100.	100.	100.	100.	36.49

Additions of one standard fuel element in lattice position 5D to the "CONTROL CASE" core results in 33.¢ excess reactivity - as it can be read off from the calibration curves.

Figure 10: CONFIGURATION K



Rod positions at criticality

SH-1	SH-2	SH-3	SH-4	RR
100.	100.	23.9	100.	100.

Addition of the last fuel element amounts to an addition of $1.75 of reactivity - as can be read off the calibration curves of the regulating rod and shimrod #3.

The discrepancy between measured and computed k_{eff} values in the "CONTROL CASE" is .0029, which is very satisfactory especially if one takes into account that the computations refer to a clean core and the measurements were performed on a core that has had an operating history of approximately 80 megawatt days.

Conclusions

1. From the close agreement obtained between measured and computed values we conclude that using the BNL-HAMMER code for generating few group constants and the ORNL-TWENTY GRAND code for determining the effective multiplication factor leads to valid computed results. In an attempt to corroborate this conclusion further calculations are being made on measured cores.
2. We have seen that for configuration A of the proposed PRNC Pool Critical Facility we obtain a computed $k_{eff} = 1.014$ corresponding to clean cold excess reactivity of approximately $2.00 which is a reasonable value for a facility of that type. One can decrease this value by substituting partial fuel elements for some of the standard elements - preferably in the center of the core.
3. The excess reactivity associated with the postulated maximum credible accident is computed as the difference between the k_{eff}'s of cases A and B i.e.

$$\Delta K = 0.0068684 \simeq 90¢$$

References

1. Hazards Summary Report for the Puerto Rico Nuclear Center Research Reactor, 1965, PRNC 37.
2. TWENTY-GRAND Program for the Numerical Solution of few Group Neutron Diffusion Equations in Two Dimensions - by M. L. Tobias & T. B. Fowler Feb. 1962, ORNL 3200