JAERI RERTR Program

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In 1979, Japan Atomic Energy Research Institute (JAERI) has started a five year program for the utilization of reduced enrichment uranium fuel, in place of currently used highly enriched uranium fuel for the JAERI research and test reactors, such as the JRR-2 (10 MWt), the JRR-4 (3.5 MWt), the JMTR (50 MWt) and the JMTRC (100 Wt, nuclear mockup of the JMTR), for contributing to the reduction of proliferation concerns.

In order to assess the feasibility of converting the JAERI reactors to use of fuel with reduced enrichment uranium, ANL and JAERI have embarked on a joint study program since January 1980.

This document provides outlines of the JAERI RERTR Program and of the ANL - JAERI Joint Study, and main results of JAERI's Phase A report which was made under the joint study.

1. Outline of JAERI RERTR Program

Figure 1 shows a schedule of the JAERI RERTR Program. The major goals of this program are to perform Full-Core Demonstration Tests of the JRR-2 and the JMTR with MEU fuel and the JRR-4 with LEU fuel, and to complete the feasibility studies of using LEU fuel for the JRR-2 and the JMTR.

The following five subtasks are to be carried out under the program.

Subtask 1. Core Design and Safety Analysis

These studies include reactor physics, thermo-hydraulics and structural analysis. Reactor physics study involves reactivity lifetime and safety considerations, such as control rod worth, and negative temperature and void coefficients.

Subtask 2. Flow Tests

Flow tests are performed using dummy fuel elements for each reactor. The main objectives of the flow tests particularly for the JMTR are to confirm the adequate margin of fuel mechanical strength against abnormal coolant flow. Drop impact tests in water will be performed to check mechanical integrity of the JMTR control fuel elements using a dummy fuel element. Flow distribution and pressure drop measurements for those dummy fuels will be followed. The dummy elements with depleted uranium for the JRR-2 and the JMTR are under fabrication by CERCA in FRANCE and by NUKEM in the FRG, respectively.

Subtask 3. Critical Experiments

Purposes of critical experiments in the JMTRC are to validate nuclear calculation and to obtain reactor characteristics of the MEU core. Items of the experiments are shown in Table 1.

Safety review for the JMTR core conversion from HEU to MEU fuel is now underway. Items of the safety review required are shown in Table 2(a).

Subtask 4. Irradiation Tests

Several full-sized fuel elements will be irradiated in the JRR-2, the JRR-4 and the JMTR at their rated powers. The fuel specifications for the irradiation tests are equivalent to those of full-core demonstration tests, as shown in Table 3. The average burn-up obtained will be up to about 60% of initial U-235. Items of post irradiation experiments are shown in Table 4.

Safety review for the MEU fuel irradiation tests in the JRR-2, the JRR-4 and the JMTR are now underway. Items of the safety reviews required are shown in Table 2(b).

Subtask 5. Full-Core Demonstration Tests

The full-core demonstration test of alternative fuel elements in each reactor at both low power and rated power will be carried out in the middle of 1983. The successful results of the demonstration will be the final goal of the five year program.

2. Outline of ANL-JAERI Joint Study

Outline of ANL-JAERI Joint Study is presented in Table 5. Phase A of the joint study terminated in July 1980. The frame-work of Phase B of the joint study was recently confirmed. The detailed plans for irradiation tests and critical experiment of Phase B are being examined by ANL and JAERI.

3. Results of Phase A Studies by JAERI

Following conclusions were drawn from the Phase A studies (see Figs. 2 through 8 and Table 6).

JRR-2

MEU Case:

1) The present JR-2 fuel could be converted to the MEU fuel with U-235 content of 210 g, that is uranium loading density of 1.6 g/cm^3 to be available with currently qualified technique, and with same dimensions to the present fuel.

2) The calculated k_{eff} for the MEU core is 1.22, which is high enough to obtain the same core life as the present core.

LEU Case:

Preliminary calculation shows that k_{eff} of 1.19 is necessary, and it is attained with uranium density of 2.4 g/cm^3 and with meat thickness of 1.0 mm, pending burn-up calculation.

Table 1 Items of Critical Experiments in the JMTRC MEU Core

1 Minimum critical core
   - Critical mass

2 Full core
   - Excess reactivity
   - Control rod worth
   - Power calibration (Reactor noise technique)
   - Space dependent mass coefficient
   - $\ell p/\beta$ (Pulsed neutron technique)
   - Flux distribution and power calibration
   - Shut-down margin
   - Void coefficient
   - Temperature coefficient
      - If infeasible in the JMTRC either JRR-4 with the LEU fuel or JMTR is to be used for this item.

Table 2 Items of Safety Reviews

(a) JMTRC Core Conversion

- Nuclear characteristics of the MEU core.
- Kinetic analysis.
- Corrosion of the MEU fuel cladding.
- Evaluation of radioactive hazard in the surrounding area - Maximum Credible Accident.

(b) JRR-2, JRR-4, and JMTR Irradiation Tests

- Nuclear characteristics.
- Thermo-hydraulics.
- Kinetic analysis.
- Fast neutron irradiation effects on fuel cladding material (A6061).
- Blistering temperature of fuel.
- Swelling of fuel.
- Corrosion of fuel cladding.
- Evaluation of radioactive hazard in the surrounding area - Maximum Credible Accident and Hypothetical Accident.

JRR-4

The present core could be converted with the LEU fuel under the following conditions.

1) The number of plates in each element is increased from 15 to 19.

2) The fuel meat thickness is increased from 0.51 mm to 0.89 mm.

3) The uranium density in the fuel meat is increased from 0.7 g/cm^3 to 1.75 g/cm^3 by UAl_x-Al powder metallurgy method.

4) The uranium enrichment is reduced to LEU.

JMTR

MEU Case:

1) The present JMTR fuel could be converted to the MEU fuel element with ^{235}U content of 310 g, that is, uranium loading density of 1.6 g/cm^3 to be available with currently qualified technique, and with same dimensions to the present fuel.

2) The calculated k_{eff} for the MEU core is 1.1146, which is high enough to obtain the same core life as the present core.

3) Nuclear calculations show that fast fluxes are about the same, and thermal fluxes decrease about 10% at most in the MEU case.

LEU Case:

1) Uranium 235 quantity per standard fuel element needed for the same core life was estimated at 340 g, based on the relation between calculated ρ_{ex} and available core life, pending burn-up calculation.

2) A uranium loading density as high as 4.0 g/cm^3 is necessary, providing dimensions of fuel element are maintained unchanged.

3) According to the preliminary thermo-hydraulics evaluation, the limit of meat thickness will be 0.7 mm under the flow rate of 6300 m^3/hr, which is the practical maximum flow rate obtained by the present pump system. Uranium loading density of 2.9 g/cm^3 will be required for ^{235}U quantity of 340 g per element. Further studies are indispensable for determining final fuel specifications.

4) Nuclear calculation shows that fast fluxes are about the same, and thermal fluxes are about 14% at most lower in the LEU case than in the HEU case.

Table 3 Fuel Specifications for Burnup and Full Core Demonstration Tests

Reactor	JMTR		JRR-2		JRR-4***
	Standard	Follower			
Fuel type	ETR	ETR	Cylindrical	JRR-4*	MTR
Enrichment (wt.%)	45(93)**	45(93)	45(93)	19.75	19.75(93)
U-235/element (gr)	310(279)	205(195)	220(195)	174	225(166)
Plates/element	19	16	3 x 5	16	19(15)
Meat dimension (mm)	0.50x59.5 x752.5	0.50x47.6 x743.5	0.51x600	0.89x58.8 x600	0.89x68x600 (.50x68x600)
Cladding thickness(mm)	0.385	0.385	0.38	0.38	0.38
Plate thickness(mm)	1.27	1.27	1.27	1.65	1.65(1.26)
Water gap(mm)	12x2.67 2x2.92 4x3.02	2.59	3.00	2.95	2.55(4.1)
Uranium loading density in fuel meat (g/cm^3)	1.6	1.6	1.6	1.75	1.75
Dimension of element(mm)	76.2x76.2 x1200	63.6x63.6 x890	103ϕx950	76.2x76.2 x950	80x80 x1025
Number of fuel elements to be tested: Demonstration	22	5	24	0	20
Burnup	2	0	2	1	0

* Burnup Test only.

** The figure in parentheses is for the present 93% EU fuels.

*** For the full-core demonstration test in the JRR-4.

Table 4 Items of Post Irradiation Experiments for Full-Sized Fuel Elements

- Visual inspection
- Sipping tests (fission product leak check)
- Dimensional measurements on element and plate
- Gamma scanning (for relative burnup measurements)
- Absolute burnup measurements by chemical analysis
- Measurements of swelling vs. burnup
- Oxide layer thickness measurements
- Hardness measurements of cladding
- Tensile strength measurements of plate
- X-ray radiography on plate for inspecting cladding defects

Table 5 OUTLINE OF ANL-JAERI JOINT STUDY ON REDUCED ENRICHMENT FUEL FOR JAERI REACTORS

Phase A (October 1979 - July 1980)

- Normalization calculations of IAEA benchmark problem.
- Transmittal by JAERI of detailed information on JAERI reactors.
- Feasibility studies on the use of LEU (<20%) Fuels in JAERI reactors.
- Planning and preparations for burnup tests.
- Planning and preparations for critical experiments and full-core demonstration.

Phase B (July 1980 - December 1981)

- Burnup tests in the ORR (<20%, 45%).
- Burnup tests in the HFR Petten (<20%).
- Burnup tests in JAERI reactors (<20%, 45%).
- Critical experiments and full-core demonstration in the FNR (<20%).
- Critical experiments in the JMTRC (45%).
- Hydraulics tests at JAERI.
- Further feasibility and analytical studies.

Phase C (December 1981 -)

- Full core demonstration tests in JAERI reactors.
- Final studies and evaluations.

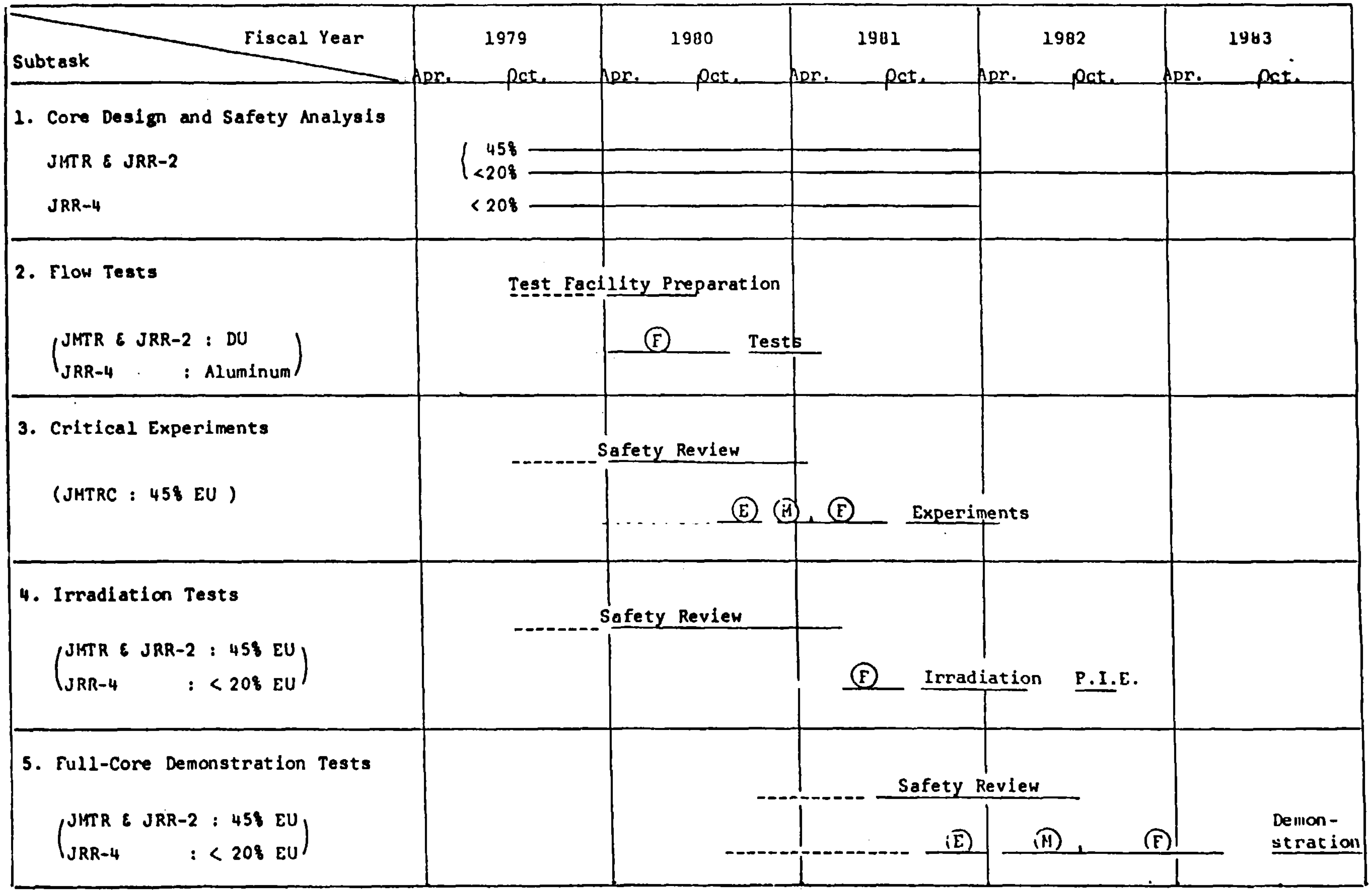
Table 6 Neutron Flux Performance in the JMTR

Unit : $n/cm^2 \cdot sec$

	93% EU Case	45% EU Case	20% EU Case
Fast Neutron Flux (> 1 MeV)			
Inner Fuel Region Irradiation Holes	1.77×10^{14}	1.73×10^{14}	1.75×10^{14}
Outer Fuel Region Irradiation Holes	1.32×10^{14}	1.31×10^{14}	1.32×10^{14}
First Layer Be Reflector	5.73×10^{13}	5.76×10^{13}	5.75×10^{13}
Second Layer Be Reflector	1.28×10^{13}	1.29×10^{13}	1.31×10^{13}
Thermal Neutron Flux (< 0.6826 eV)			
Inner Fuel Region Irradiation Holes	2.76×10^{14}	2.53×10^{14}	2.36×10^{14}
Outer Fuel Region Irradiation Holes	2.33×10^{14}	2.13×10^{14}	2.09×10^{14}
First Layer Be Reflector	2.24×10^{14}	2.11×10^{14}	2.02×10^{14}
Second Layer Be Reflector	1.12×10^{14}	1.09×10^{14}	1.06×10^{14}

Flux levels show the average.

Fig.1 JAERI's Reduced Enrichment Fuel Development Program



Ⓔ : Enrichment Ⓜ : Metal Conversion Ⓕ : Fabrication

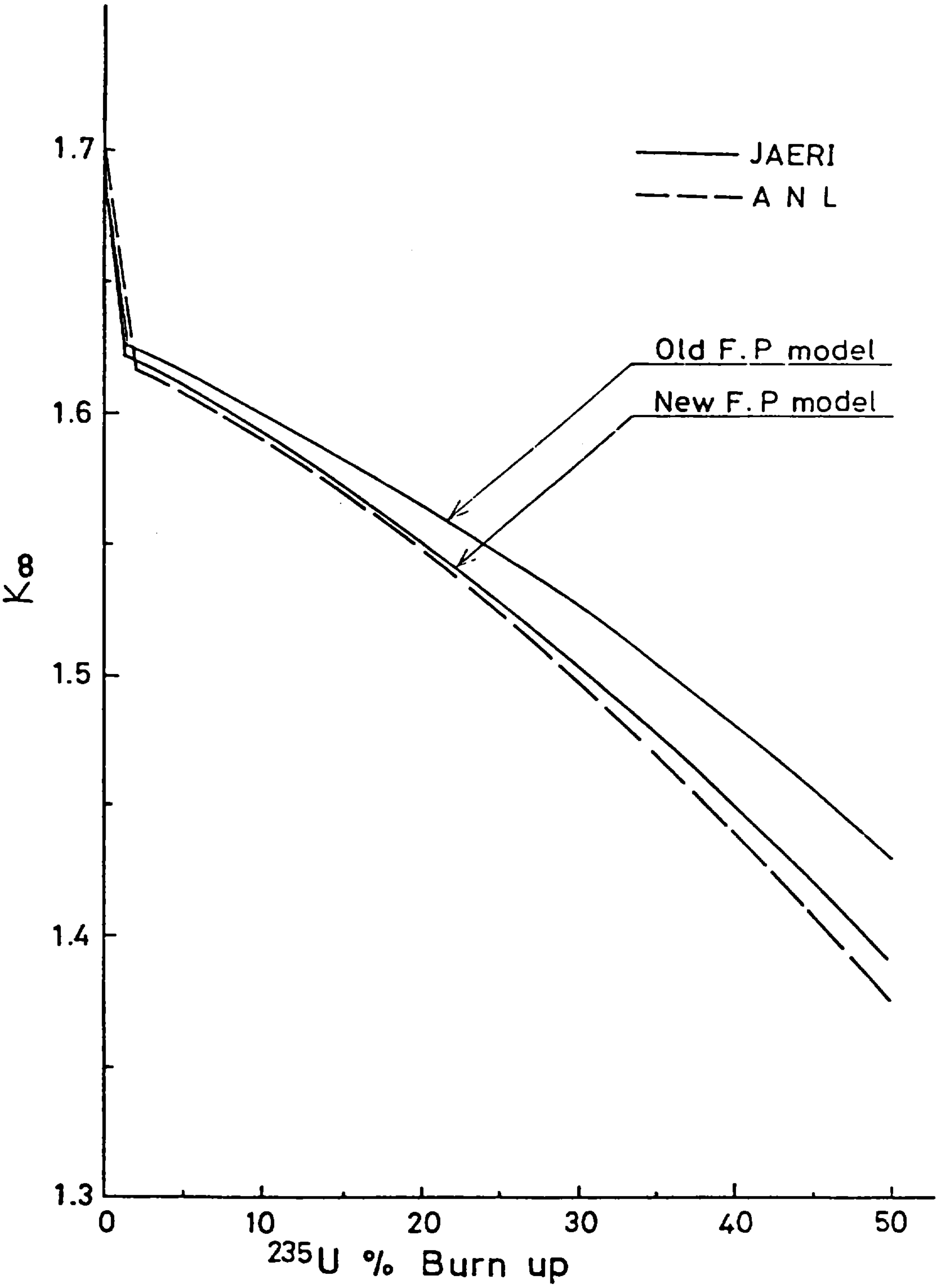


Fig. 2 Comparison of Burn-up Dependency of Infinite Multiplication Factors Computed by JAERI with Those by ANL at a Benchmark Problem of IAEA (40% Enriched Fuel Cell)

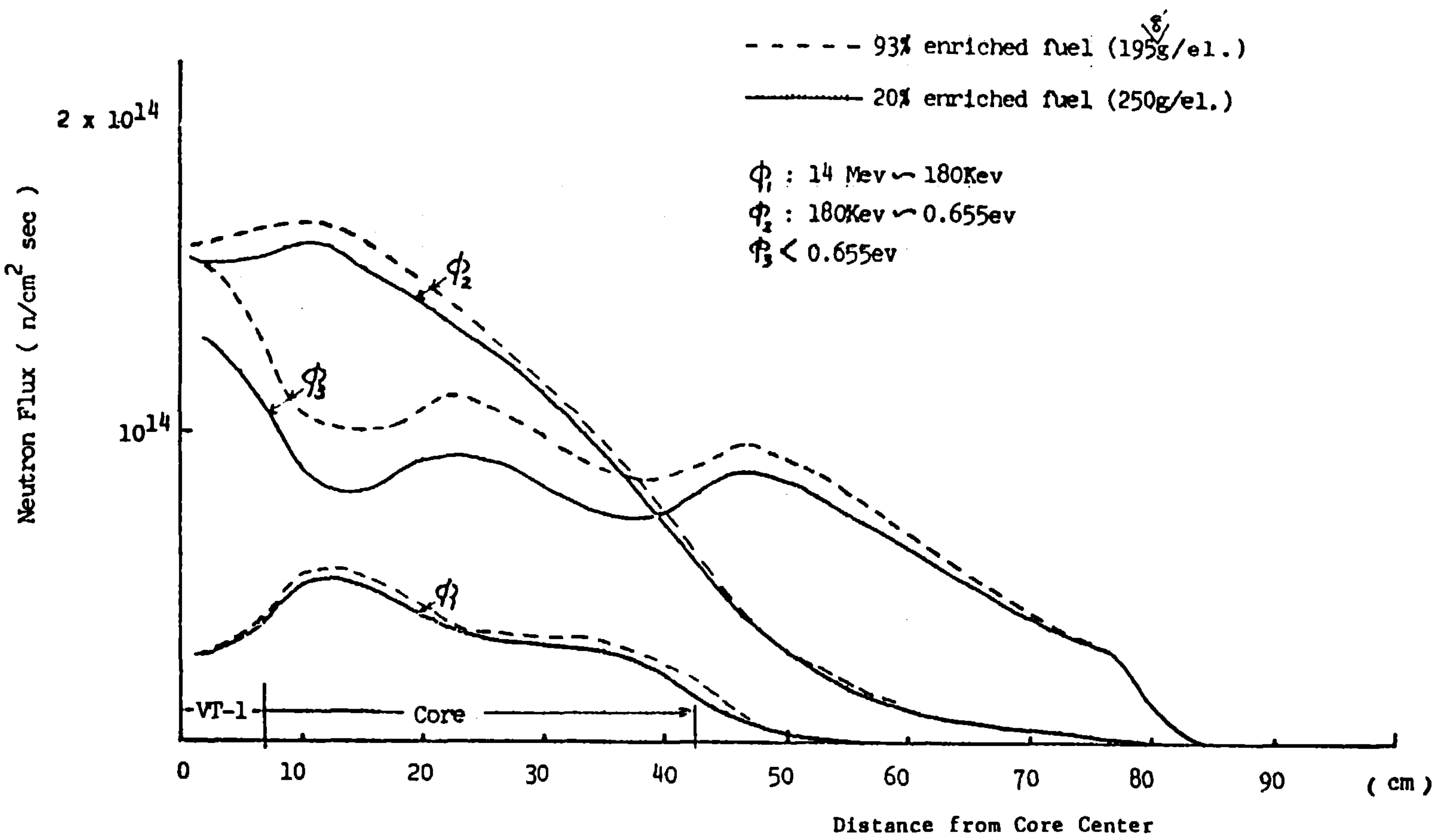


Fig.3 Radial Distribution of Neutron Flux in the JRR-2

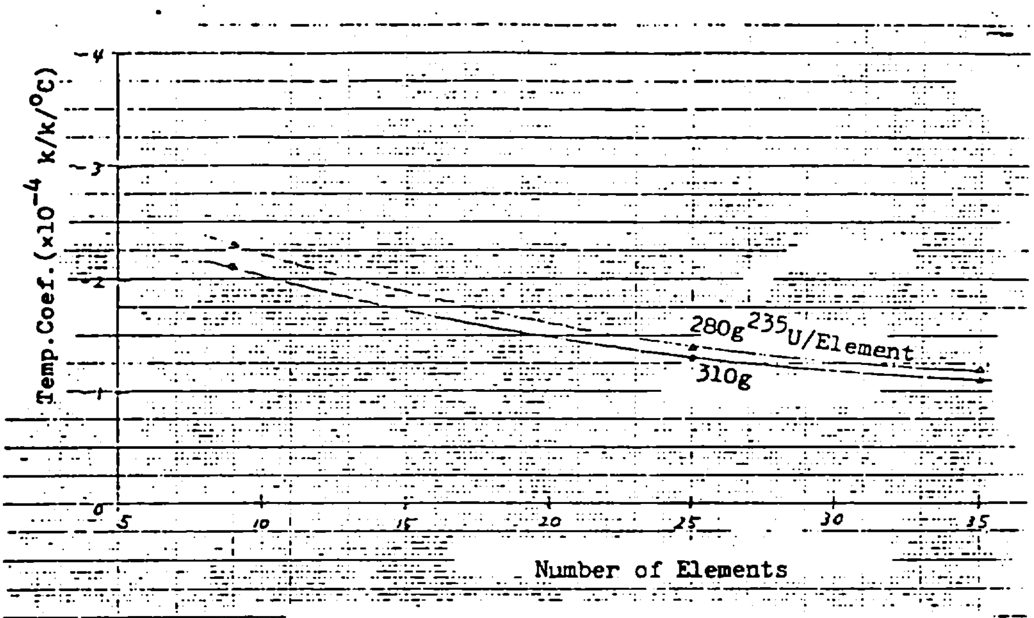


Fig. 4 Temperature Coefficient vs. Number of Fuel Elements in the JMTRC Core

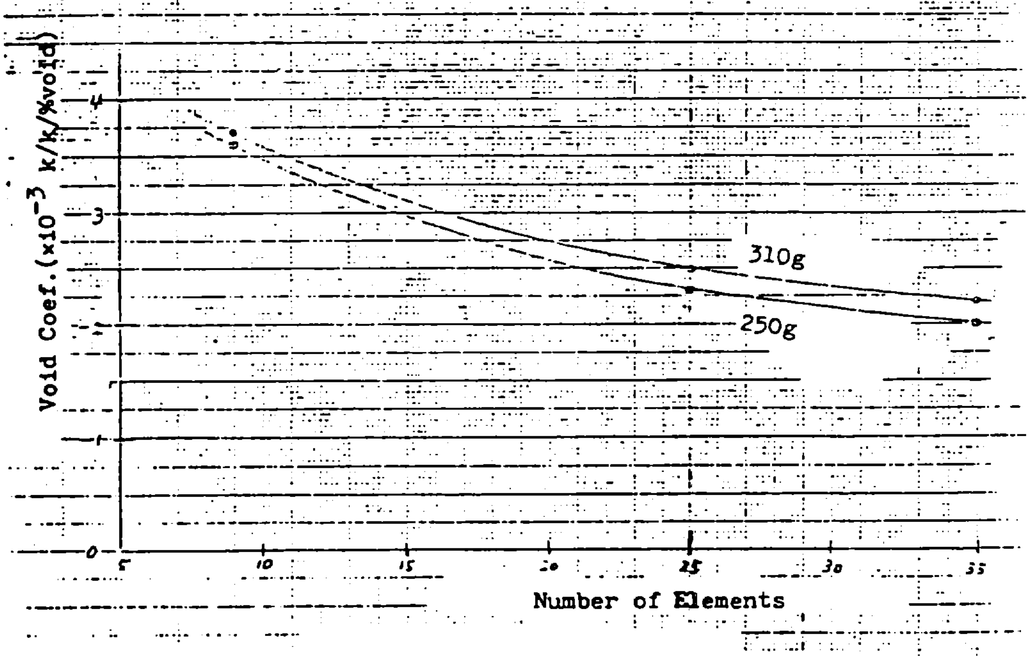


Fig. 5 Void coefficient vs. Number of Fuel Elements in the JMTRC Core

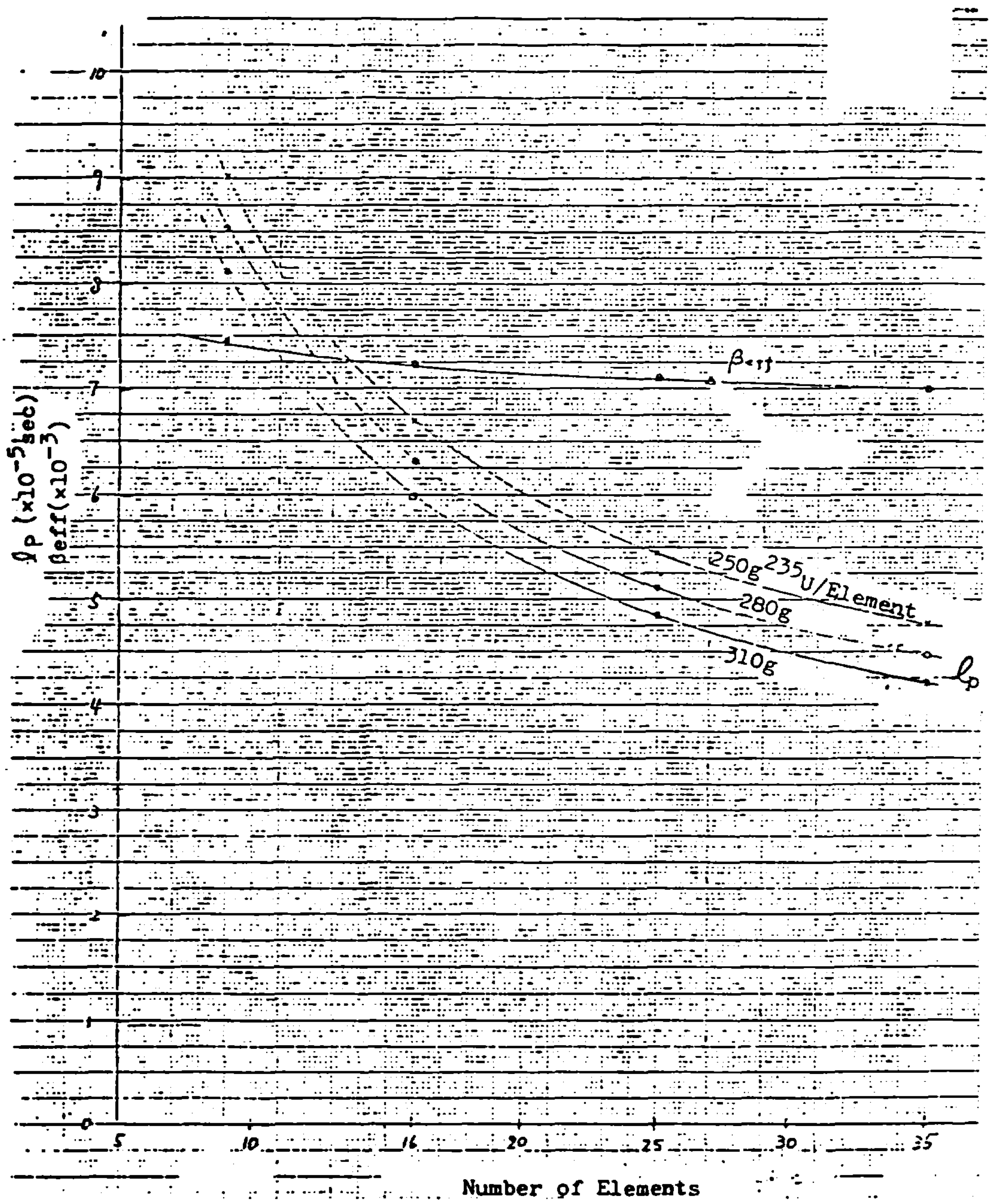


Fig. 6 ℓ_p and β_{eff} vs. Number of Fuel Elements in the JMTRC Core

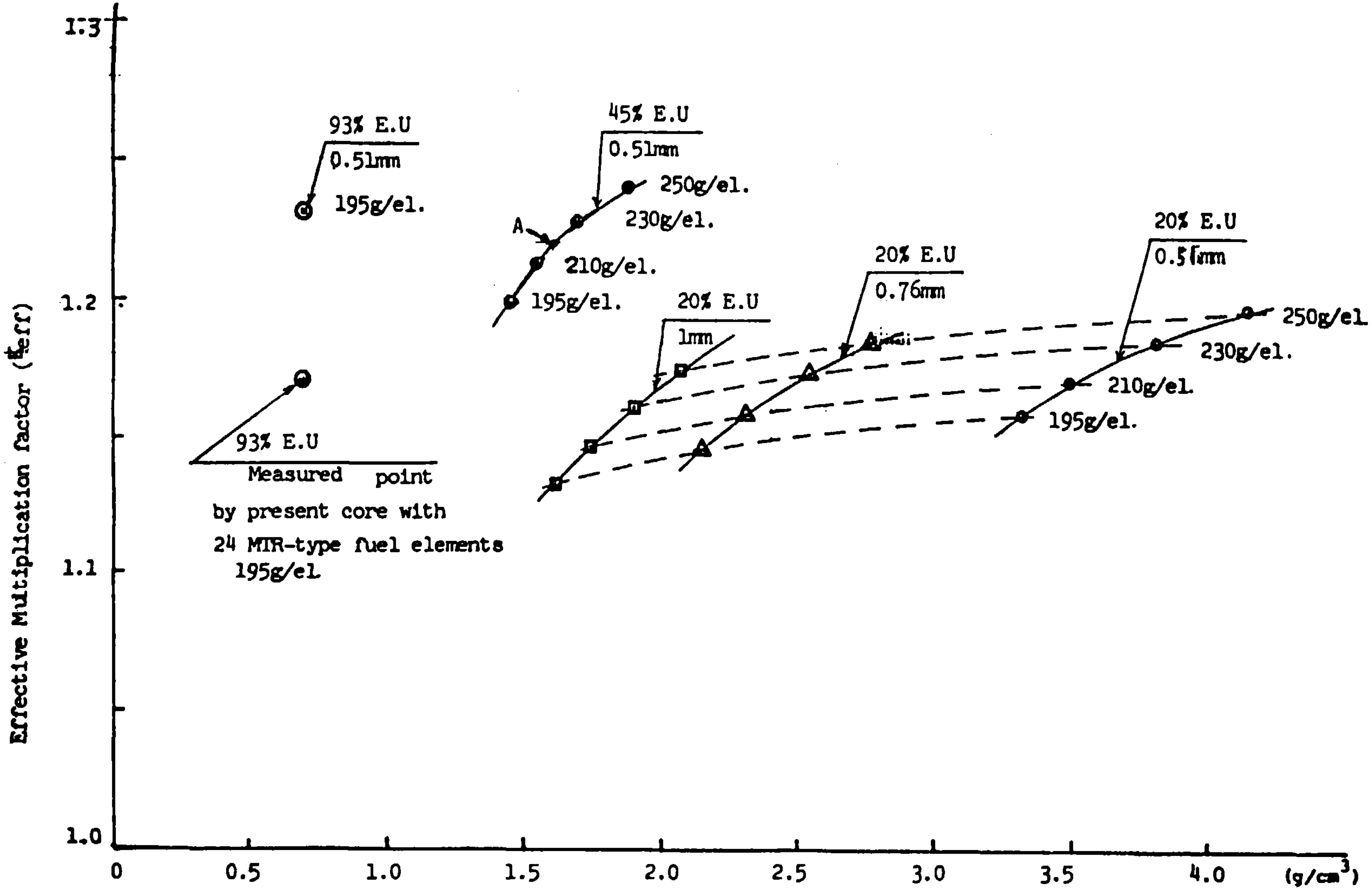


Fig. 7 Relation of k_{eff} and Uranium Density in Fuel Meat at JRR-2 Cold Clean Core with 24 Cylindrical Fuel Elements

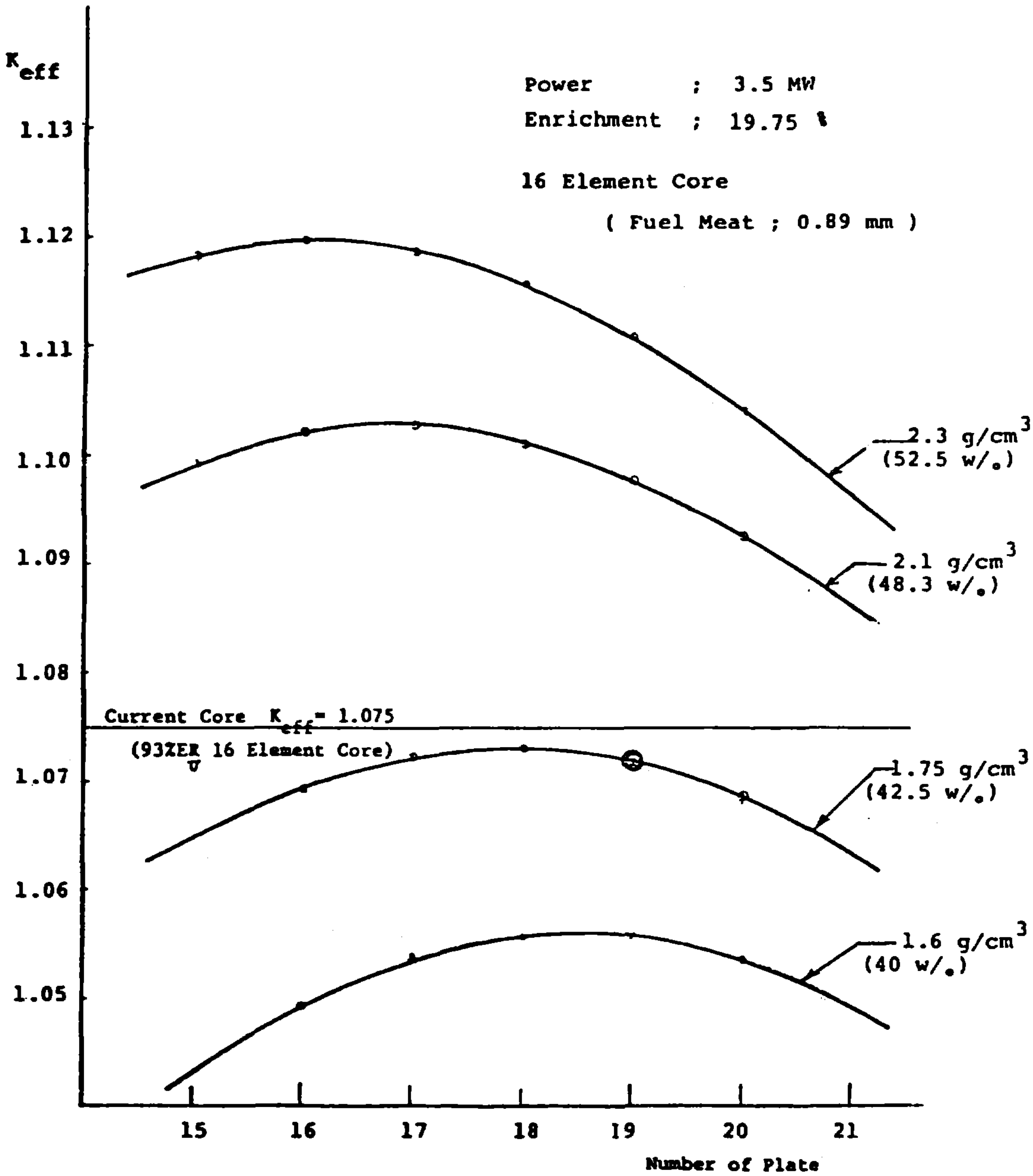


Fig. 8 JRR-4 20% Enrichment Fuel Core Design Calculation