JAERI-M
89-194

CHARACTERISTIC TESTS OF MEDIUM-ENRICHED URANIUM FUEL CORE IN JRR-2

November 1989

Junsaku TSUNODA, Takashi KOGANEZAWA, Masao BANBA
Hajimu SHITOMI, Masahiro NAKANO, Mitsugu SATO
and Hiroyuki KIKUCHI

日　本　原　子　力　研　究　所
Japan Atomic Energy Research Institute

JAERI-Mレポートは，日本原子力研究所が不定期に公刊している研究報告書です。

入手の問合わせは，日本原子力研究所技術情報部情報資料課（〒319-11茨城県那珂郡東海村）あて，お申しこしください。なお，このほかに財団法人原子力弘済会資料センター（〒319-11茨城県那珂郡東海村日本原子力研究所内）で複写による実費頒布をおこなっております。

JAERI-M reports are issued irregularly.

Inquiries about availability of the reports should be addressed to Information Division Department of Technical Information, Japan Atomic Energy Research Institute, Tokai-mura, Naka-gun, Ibaraki-ken 319-11, Japan.

編集兼発行　日本原子力研究所
印　　刷　㈱高野高速印刷

Characteristic Tests of Medium-Enriched Uranium Fuel Core in JRR-2

Junsaku TSUNODA[+], Takashi KOGANEZAWA[++], Masao BANBA
Hajimu SHITOMI, Masahiro NAKANO, Mitsugu SATO
and Hiroyuki KIKUCHI

Department of Research Reactor Operation
Tokai Research Establishment
Japan Atomic Energy Research Institute
Tokai-mura, Naka-gun, Ibaraki-ken

(Received October 25, 1989)

The Japan Research Reactor No.2 (JRR-2) is a heavy water moderated and cooled research reactor using 93% enriched uranium fuel formed in cylindrical and MTR fuel elements.

Since attaining its initial criticality in October 1960, the JRR-2 has served with a maximum thermal neutron flux of 2×10^{14} n/cm^2•sec at the power level of 10 MW for various utilization, such as neutron physics and solid state physics.

Since the first ascending to the nominal power of 10 MW in October 1962, The JRR-2 has been operated in stability and utilized for more than 28 years, and achieved approximately 66,000 hours operation.

The reactor core has been converted from high-enriched uranium (HEU, 93% EU) fuel to medium-enriched uranium (MEU, 45% EU) fuel since November 1987, in order to increase proliferation resistance of nuclear materials in the JRR-2. In this paper the modification works and the characteristic tests on the JRR-2 are described.

Keywords: JRR-2, RERTR, HEU, MEU, Modification Works, Criticality Experiment, Characteristic Measurements, Nuclear Properties

+ Department of Administrative Services, Mutsu Establishment
++ Department of JMTR Project, Oarai Research Establishment

ＪＲＲ－２中濃縮燃料特性試験結果

日本原子力研究所東海研究所研究炉管理部
角田　準作[+]・小金沢　卓[++]・番場　正男・鄯　　肇
中野　正弘・佐藤　　貢・菊池　博之

（１９８９年１０月２５日受理）

ＪＲＲ－２は，重水減速・冷却の熱中性子炉であり，昭和６２年４月までに高濃縮燃料（Ｕ－２３５濃縮度９３％）を使用し利用運転を行ってきた。一方試験研究炉用燃料の核拡散防止の観点からＲＥＲＴＲプラグラムに基き，使用燃料の濃縮度低減化を計画した。この移行にあたっては，炉心形状・寸法を変更することなく，かつ原子炉の性能及び安全余裕を低下させないことを前提とし，使用する燃料の検討を行い，ウランアルミ合金分散型燃料（Ｕ－２３５濃縮度４５％）を採用することにした。このため，高濃縮燃料要素の炉心から，中濃縮燃料要素の炉心へと移行することになった。これにともない，昭和６２年１１月２５日に臨界試験を行い，続いて特性試験を昭和６３年１月末までに実施した。その結果，中濃縮炉心核特性は高濃縮炉心とほぼ同等であることが確認され，中濃縮化の目的は十分に達成することができたと思われる。

東海研究所：〒319－11　茨城県那珂郡東海村白方字白根２－４
＋　　むつ事業所管理部
＋＋　大洗研究所材料試験炉部

Contents

目　次

1. Introduction

The JRR-2 had been operated with high-enriched uranium (HEU, 93% U-235) fuel until April 1987.

From the view point of the Treaty on the Non-Proliferation of Nuclear Weapons, however, RERTR (Reduced Enrichment for Research and Test Reactors) program has been carried out over the world, and it was decided accordingly to use lower enriched uranium fuel for the JRR-2. The RERTR program on the JRR-2 was started by establishing "JAERI RERTR Program" in 1979.

At first candidates for new fuel were examined under the condition that core configuration and fuel element dimensions should not be changed and reactor performance should not be reduced. As a result, while low-enriched uranium (LEU, about 20% U-235) fuel was not met with the requirements on uranium loading density in the fuel core, medium-enriched uranium (MEU, 45% U-235) fuel was appropriate for a new fuel, which is uranium aluminum compound (UAl_x-Al) dispersed in aluminum matrix with 1.6 g/cm^3 of uranium density. The new fuel element is named JRR-2 cylindrical BM type fuel element, which is shown in Fig. 1. And specifications of JRR-2 cylindrical BM and B type fuel element are shown in Table 1.

To meet with the demands for in-core irradiation to the maximum extent possible, new JRR-2 reactor core composed by all of the cyrindrical fuel elements was designed so that 24 in-core irradiation holes could be provided in the JRR-2 reactor.

The safety review for the conversion of HEU fuel core into MEU fuel core was over in December 1986 and the works required for the fuel conversion program were completed in November 1987.

The following works, experiments and characteristic measurements had been carried out.

(1) Modification works for full MEU fuel core
   (i) reinforcement of emergency cooling system
   (ii) rearrangement of control system
   (iii) rearrangement of emergency electric power supply

(2) Characteristic measurements on reactor core loaded with MEU fuel elements
   (i) Criticality experiment
   (ii) Control rod calibration
   (iii) Measurements of individual fuel element reactivity worth and other reactivity effects
   (iv) Measurement of neutron flux distribution

(v) Xenon (Xe-135) poisoning effect

The details above are described as follows.

2. Modification works for full MEU fuel core

The JRR-2 operation using HEU fuel was terminated at the end of April 1987 (R2-62-01 cycle). After that, a reconstruction of the reactor safety system was done. New design criteria and technology were applied for the modificaton works in order to conform with the requirements by the safety review for the conversion.

The requirements include the followings.

(1) Reinforcement of emergency cooling system

Based on "Single Failure Criterion", the emergency heavy water pump DP-4 is required to run continuously during reactor operation, as a countermeasure for the main pumps DP-1 and DP-2 accident. In order to back up the accident of the sump pit recirculation pump named EP-1A is required to be installed additionally in the sump pit. An emergency core cooling system (ECCS) is also required to be provided with the reactor as main countermeasure for the loss of coolant accident (LOCA). The emergency core cooling system consists of an emergency heavy water storage tank ET-1, two emergency heavy water supply pumps EP-2, EP-2A and pipings (Refor to Fig. 2 and Fig. 7).

(2) Rearrangement of control system

Control system was reviewed from the view point of human engineering. Control system was modified and signal cables were renewed. Five control rods, neutron absorbers and drive mechanisms were changed to new ones (The JRR-2 has six control rods ... See Fig. 3). Residual control rod (C6) was changed in 1985.

(3) Rearrangement of emergency power supply

The emergency power supply system consists of a battery power supply and two diesel-engine generators.

Following the modification of the safety system, the emergency power supply system was rearranged.

These modification works were completed by the end of November 1987.

(v) Xenon (Xe-135) poisoning effect

The details above are described as follows.

2. Modification works for full MEU fuel core

The JRR-2 operation using HEU fuel was terminated at the end of April 1987 (R2-62-01 cycle). After that, a reconstruction of the reactor safety system was done. New design criteria and technology were applied for the modificaton works in order to conform with the requirements by the safety review for the conversion.

The requirements include the followings.

(1) Reinforcement of emergency cooling system

Based on "Single Failure Criterion", the emergency heavy water pump DP-4 is required to run continuously during reactor operation, as a countermeasure for the main pumps DP-1 and DP-2 accident. In order to back up the accident of the sump pit recirculation pump named EP-1A is required to be installed additionally in the sump pit. An emergency core cooling system (ECCS) is also required to be provided with the reactor as main countermeasure for the loss of coolant accident (LOCA). The emergency core cooling system consists of an emergency heavy water storage tank ET-1, two emergency heavy water supply pumps EP-2, EP-2A and pipings (Refor to Fig. 2 and Fig. 7).

(2) Rearrangement of control system

Control system was reviewed from the view point of human engineering. Control system was modified and signal cables were renewed. Five control rods, neutron absorbers and drive mechanisms were changed to new ones (The JRR-2 has six control rods ... See Fig. 3). Residual control rod (C6) was changed in 1985.

(3) Rearrangement of emergency power supply

The emergency power supply system consists of a battery power supply and two diesel-engine generators.

Following the modification of the safety system, the emergency power supply system was rearranged.

These modification works were completed by the end of November 1987.

3. Characteristic measurements on reactor core loaded with MEU fuel elements

The following characteristic measurements on the reactor core loaded with the MEU fuel elements were carried out from the end of November 1987 to the end of January 1988.

The results of the measurements are compared with the calculated values.

3.1 Criticality experiment

Loading of MEU fuel elements into the reactor core was started from the fuel position 1A at 11:24 on November 25, 1987. After loading of fuel element at the fuel position 5B, the first criticality was reached at 19:23 with eleven MEU fuel elements (Refer to Fig. 3). All shim rods from C1 to C5 were fully withdrawn and regulating rod C6 was withdrawn by 59.80%. The reactor power was 1W and heavy water temperature in the reactor core was 20.5°C. The critical mass was foreseen by a calculation as 2,222 g (10.1 fuel elements). It was a good agreement with the calculated value of about 2.2 kg by the Standard Reactor Analysis Code, SRAC.[1)]

The criticality approach curves are shown in Fig. 4.

3.2 Control rod calibration

Reactivity worth of each control rod was measured with the positive period method (P.P.M.) and the total reactivity worth was 32.9%$\Delta k/k$.

It agreed with the calculated value (31%$\Delta k/k$) by the SRAC. Measured values of excess reactivity, maximum control rod worth and shut down margin also agreed with the calculated values.

These results are shown in Table 2. Calibration curves of shim rod C1 on MEU and HEU fuel reactor cores are compared in Fig. 5. It is shown that both reactivity worth values are almost the same.

3.3 Measurements of fuel element reactivity worth and several reactivity effects

Results of reactivity measurements on JRR-2 reactor core loaded with the cylindrical BM type fuel elements are shown in Table 2. The measured reactivity worths agreed with calculated ones. The details are as follows:

(1) Fuel element reactivity depending upon location in reactor core

As the reactor core was under cold clean state, fuel element reactivity was measured for each location in the reactor core. A fuel element reactivity was determined by the difference between the excess reactivity of full fuel elements (24 fuel elements) loaded reactor core and that of 23 fuel elements loaded reactor core. (except the fuel element to be measured the reactivity)

Results are as follows:

UNIT : %Δk/k

location	A-ring	B-ring	C-ring	D-ring
1	2.05	1.33	0.86	1.14
2	2.19	1.19	0.90	1.40
3	2.11	1.26	1.36	1.03
4	1.98	1.39	1.26	0.82
5	1.88	1.71	0.85	0.85
6	1.98	1.44	0.89	0.97
average	2.03	1.39	1.02	1.04

Core average ----- 1.48%Δk/k

(2) Moderator temperature coefficient of reactivity

Experimental conditions are as follows:

Reactor power	50 W
Main heavy water pump (DP-1, DP-2)	in operation
Emergency heavy water pump (DP-4)	in operation
Shim rods (C1 ~ C5) position	flat pattern

The reactivity caused by temperature difference of the moderator was measured by the regulating rod, C6 position. Coolant temperature was changed using Joule's heat of the main pumps. The results are shown in Fig. 6 and Table 2.

(3) Reflector (heavy water) dump effect

Reflector material is heavy water. The reflector dump effect is expected to give negative reactivity enough to shut down the reactor when the control system accident is happened. Heavy water was drained about 620 mm from the normal level to the dump level through the dump valve (DV-14) (See Fig. 7 and Fig. 8).

As shown in Fig. 8, about 0.7%Δk/k of negative reactivity is obtained as maximum value for this effect.

3.4 Measurement of Neutron flux distribution

Neutron fluxes are measured by the foil activation method using gold foils for thermal neutron flux and nickel foils for fast neutron flux. Cadmium covered gold foils are also used to determine the cadmium ratio.

(1) Measurement of neutron flux distribution in JRR-2 cylindrical BM type fuel elements

Distribution of thermal neutron flux and fast neutron flux in the MEU fuel plate are shown in Fig. 9 and Fig. 10, respectively.

It is obviously estimated that the maximum thermal neutron flux on the fuel plates of fuel element was about 7.0×10^{13} n/cm^2·sec at 10 MW (thermal) and the maximum fast neutron flux was about 7.3×10^{13} n/cm^2·sec.

(2) Measurement of neutron flux distribution in irradiation holes

There are seven in-core irradiation holes (3A, 6B, 2C, 6C, 2D, 5D, 6D) in the fuel region, nine vertical irradiation holes (VT-1, 4, 5, 7, 8, 9, 10, 11, 12) and two pneumatic tubes in the reflector region.

Thermal neutron fluxes in some of the irradiation holes are decreased in the fuel region (in-core irradiation holes) in comparison with the HEU core. On the other hand, the thermal neutron fluxes in the reflector region are nearly equal to those of the HEU core. Fast neutron flux is increased in the fuel region comparing with that of the HEU core. It seems that the effect is caused by increased U-238 in comparison with HEU fuel element (Refer to Table 1).

The neutron flux measured is shown in Table 3. From these results, it is apparently understood that neutron flux of each irradiation hole in the MEU core is nearly equal to or about 10% lower than that in the HEU core.

3.5 Xenon (Xe-135) poisoning effect

Xe-135 is a fission product and its neutron absorption cross section is 2.7×10^6 barn (10^{-24} cm^2). As reactor operates, Xe-135 concentration in the core is increased. And its concentration is saturated. The Xe-135 poisoning effect is very important for reactor operations, especially for restart up after high power continuous reactor operation. A characteristic test for Xe-135 saturation was carried out to operate the reactor continuously for about 40 hours at the power level of 5 MW (thermal). And Xe-135 poisoning effect after reactor shut down was measured at the power level of 10 kW by means of the control rods position.

Poisoning effects for Xe-135 saturation and after shut down were as follows:

Xe-135 poisoning saturated value (5 MW)	3.9%Δk/k
Xe-135 over-ride	7.0%Δk/k

These values showed a good conformity with the calculated values. Results of Xenon poisoning effect comparing with the data on the HEU core are shown in Fig. 11.

4. Conclusion

According to the results of those characteristic tests on the fully loaded MEU fuel reactor core, it is concluded that the fuel conversion from HEU to MEU has been successfully completed. The obtained data can be utilized for the operation and management of the reactor with the MEU core.

Experimental results are as follows:

(1) Total reactivity worth is 32.9%Δk/k.

(2) Reflector (heavy water) dump effect is about 0.7%Δk/k of negative reactivity.

(3) The maximum thermal and fast neutron flux on the fuel plate were about 7.0×10^{13} n/cm^2·sec and 7.3×10^{13} n/cm^2·sec at 10 MW, respectively.

(4) Neutron flux of each irradiation hole in the MEU core is nearly equal or about 10% below in comparison with that in the HEU core.

(5) Xe-135 poisoning saturated value (5 MW) 3.9%Δk/k
Xe-135 over-ride 7.0%Δk/k

The JRR-2 has been operated for capsule irradiations, beam experiment and so on by using MEU fuel elements at the full power of 10 MW since Feburuary 8, 1988. No trouble in fuel elements and other parts have been observed and the JRR-2 has been operated safely on schedule.

continuously for about 40 hours at the power level of 5 MW (thermal). And Xe-135 poisoning effect after reactor shut down was measured at the power level of 10 kW by means of the control rods position.

Poisoning effects for Xe-135 saturation and after shut down were as follows:

Xe-135 poisoning saturated value (5 MW)	3.9%$\Delta k/k$
Xe-135 over-ride	7.0%$\Delta k/k$

These values showed a good conformity with the calculated values. Results of Xenon poisoning effect comparing with the data on the HEU core are shown in Fig. 11.

4. Conclusion

According to the results of those characteristic tests on the fully loaded MEU fuel reactor core, it is concluded that the fuel conversion from HEU to MEU has been successfully completed. The obtained data can be utilized for the operation and management of the reactor with the MEU core.

Experimental results are as follows:

(1) Total reactivity worth is 32.9%$\Delta k/k$.

(2) Reflector (heavy water) dump effect is about 0.7%$\Delta k/k$ of negative reactivity.

(3) The maximum thermal and fast neutron flux on the fuel plate were about 7.0×10^{13} n/cm^2•sec and 7.3×10^{13} n/cm^2•sec at 10 MW, respectively.

(4) Neutron flux of each irradiation hole in the MEU core is nearly equal or about 10% below in comparison with that in the HEU core.

(5) Xe-135 poisoning saturated value (5 MW) 3.9%$\Delta k/k$
Xe-135 over-ride 7.0%$\Delta k/k$

The JRR-2 has been operated for capsule irradiations, beam experiment and so on by using MEU fuel elements at the full power of 10 MW since Feburuary 8, 1988. No trouble in fuel elements and other parts have been observed and the JRR-2 has been operated safely on schedule.

Acknowledgement

The authors would like to express their hearty gratitude to Mr. E. Shirai, Deputy director of Department of Research Reactor Operation and to all the members of JRR-2 Operation Division. Their thanks are also forwarded to Mr. M. Isshiki, general manager of JRR-2 Operation Division and to Mr. K. Kaieda, general manager of JRR-4 Operation Division.

References

1) K. Tsuchihashi, et al., SRAC: JAERI THERMAL REACTOR STANDARD CODE SYSTEM FOR REACTOR DESIGN AND ANALYSIS JAERI-1285, 1983

2) CHARACTERISTIC MEASUREMENTS OF JRR-2 AFTER MODIFICATION JRR-2 OPERATION SECTION (In Japanese) JAERI-M 6943, 1977

3) ANNUAL REPORT ON OPERATION, UTILIZATION AND TECHNICAL DEVELOPMENT OF RESEARCH REACTORS AND HOT LABORATORY (In Japanese) JAERI-M 88-211, 1988

Acknowledgement

The authors would like to express their hearty gratitude to Mr. E. Shirai, Deputy director of Department of Research Reactor Operation and to all the members of JRR-2 Operation Division. Their thanks are also forwarded to Mr. M. Isshiki, general manager of JRR-2 Operation Division and to Mr. K. Kaieda, general manager of JRR-4 Operation Division.

References

1) K. Tsuchihashi, et al., SRAC: JAERI THERMAL REACTOR STANDARD CODE SYSTEM FOR REACTOR DESIGN AND ANALYSIS JAERI-1285, 1983
2) CHARACTERISTIC MEASUREMENTS OF JRR-2 AFTER MODIFICATION JRR-2 OPERATION SECTION (In Japanese) JAERI-M 6943, 1977
3) ANNUAL REPORT ON OPERATION, UTILIZATION AND TECHNICAL DEVELOPMENT OF RESEARCH REACTORS AND HOT LABORATORY (In Japanese) JAERI-M 88-211, 1988

Table 1 Spefification of JRR-2 cylindrical BM and B type fuel element

Items \ Fuel element		JRR-2cylindrical BM type fuel	JRR-2cylindrical B type fuel
Dimension(mm)		ϕ 105×950	ϕ 105×950
U-235 enrichment(wt%)		45	93
U-235 content(g/element)		220	195
U-density(g/cm^3)		1.6	0.69
Meat	thickness(mm)	0.51	0.51
	width(mm)	49 58 67 76 85	49 58 67 76 85
	length(mm)	600	600
Clad	thickness(mm)	0.38	0.38
Fuel plate	thickness(mm)	1.27	1.27
	width(mm)	58 67 76 85 94	58 67 76 85 94
	length(mm)	625	625
Cooling water pipe		6	6
Cooling water gap(mm)		2.59× 1 3.00× 5	2.59× 1 3.00× 5
Fuel meat material		dispersion (UAlx-Al)	alloy (U-Al)
Cover material		Al alloy AG 3 NE or corresponding article	Al JIS A 1200 or corresponding article
Structure material		Al alloy AG 3 NE or corresponding article	Al JIS A 6061-T6 or corresponding article
Maximum burnup		Element average 40%	

Table 2 Measurement values of demonstration test comparing with the calculated ones

Items	UNIT	MEU core		HEU core
		Measured	Calculated	(Measured)
Critical mass	g	2222	2200	2184
Excess reactivity	$\% \Delta k/k$	17.3	18	15
Total control rod worth	$\% \Delta k/k$	32.9	31	35
Highest control rod worth	$\% \Delta k/k$	6.4	10	6.3
Shut down margin	$\% \Delta k/k$	15.6	14	20
One rod stuck margin	$\% \Delta k/k$	9.2	4	14
Moderator dump effect	$\% \Delta k/k/℃$	0.7	0.8	0.7
Temperature coefficient	$\% \Delta k/k/℃$	-1.9×10^{-2} (at 17℃)	-2.3×10^{-2} (at 17℃)	-2.0×10^{-2} (at 17℃)
Thermal neutron flux				
in-core average	$n/cm^2 \cdot sec$	5×10^{13}	7×10^{13}	8×10^{13}
in-core maximum	$n/cm^2 \cdot sec$	1.3×10^{14}	1.5×10^{14}	2.0×10^{14}

※ Calculated by SRAC code

Table 3 Maximum neutron flux and cadmium ratio of the MEU and HEU Fuel Core

Irradiation holes		Thermal Neutron Flux ($n/cm^2 \cdot sec$)		Fast Neutron Flux ($n/cm^2 \cdot sec$)		Cadmium ratio		REMARK
		HEU core	MEU core	HEU core	MEU core	HEU core	MEU core	
In-core irradiation holes	3A	———	((5.6×10^{13}))	((5.5×10^{13}))*	((4.5×10^{13}))	———	((1.5))	Caution ( ): ϕ40 value of Al capsule (( )): ϕ19 value of Al pipe * : measured in 1983
	6A	(9.0×10^{13})	———	(7.6×10^{13})	———	(1.5)	———	
	3B	———	———	((4.3×10^{13}))*	———	———	———	
	6B	(7.0×10^{13})	((5.8×10^{13}))	(5.5×10^{13})	((5.2×10^{13}))	(1.5)	((1.6))	
	2C	———	((4.6×10^{13}))	———	((3.8×10^{13}))	———	((1.6))	
	6C	(5.4×10^{13})	((4.7×10^{13}))	(4.0×10^{13})	((3.6×10^{13}))	(2.0)	((1.7))	
	2D	———	((5.8×10^{13}))	((3.9×10^{13}))*	((4.7×10^{13}))	———	((1.8))	
	5D	———	((5.6×10^{13}))	((3.3×10^{13}))*	((3.8×10^{13}))	———	((1.9))	
	6D	((6.2×10^{13}))	((4.2×10^{13}))	((3.5×10^{13}))	((4.0×10^{13}))	(2.0)	((1.6))	
Vertical experimental thimbles	VT- 1	2.0×10^{14}	((1.3×10^{14}))	2.5×10^{13}	((2.8×10^{13}))	2.3	((1.9))	
	VT-10	1.0×10^{14}	((8.7×10^{13}))	7.3×10^{12}	((1.3×10^{13}))	3.1	((2.4))	
	VT-11	1.3×10^{14}	((7.0×10^{13}))	———	((1.2×10^{13}))	3.5	((2.4))	
	VT-12	1.2×10^{14}	((8.0×10^{13}))	———	((1.5×10^{13}))	3.2	((2.2))	
Pneumatic tube	Pn- 2	8.0×10^{13}	8.1×10^{13}	2.5×10^{12}	3.0×10^{12}	6.2	6.3	

10	Comb
9	Capsule guide
8	Support pin
7	Upper capsule guide
6	Inner plate
5	Fuel plate
4	Fuel plate support
3	Outer tube
2	Upper adapter
1	Lower adapter

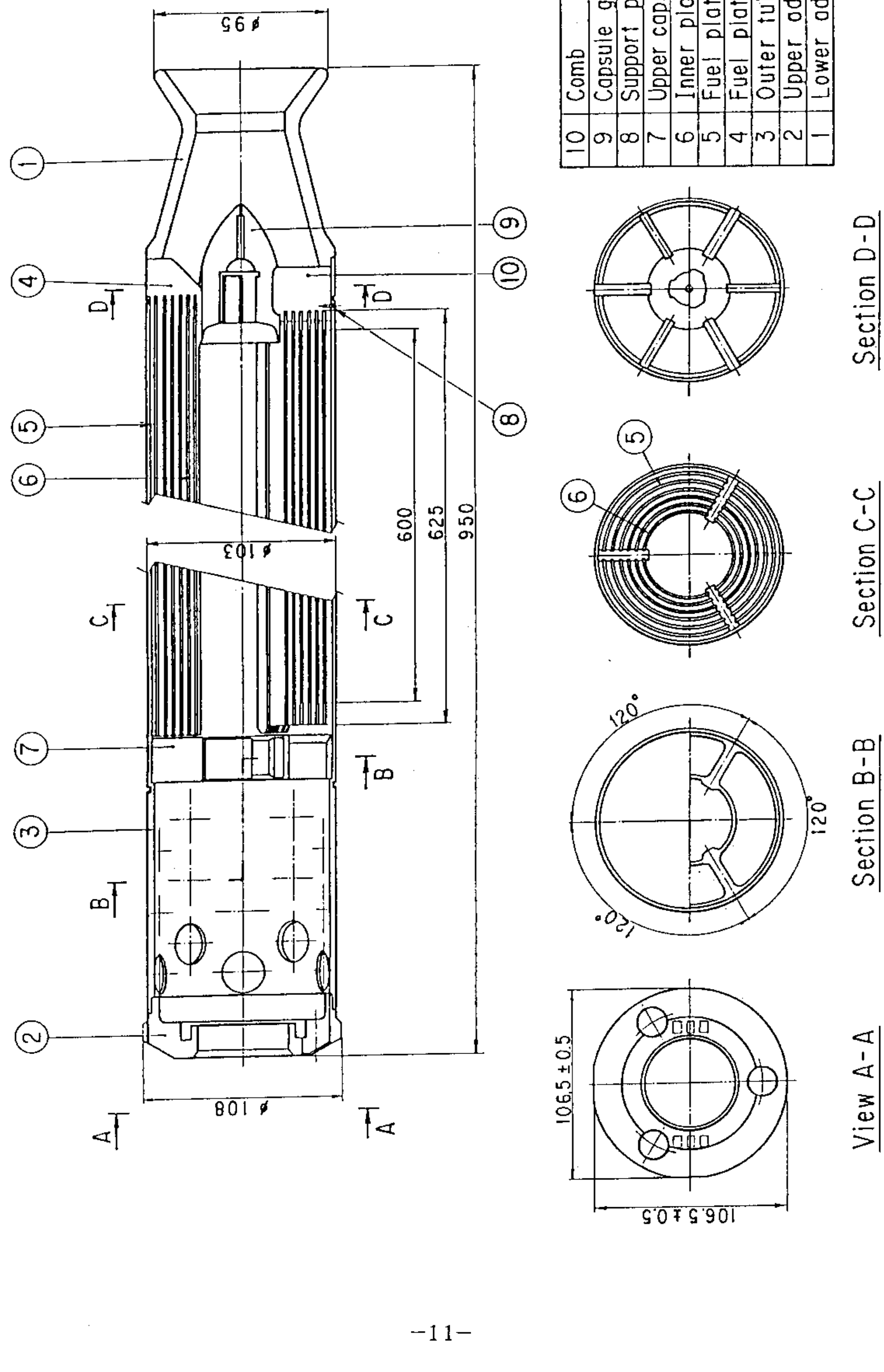


Fig. 1 JRR-2 cylindrical BM type fuel element

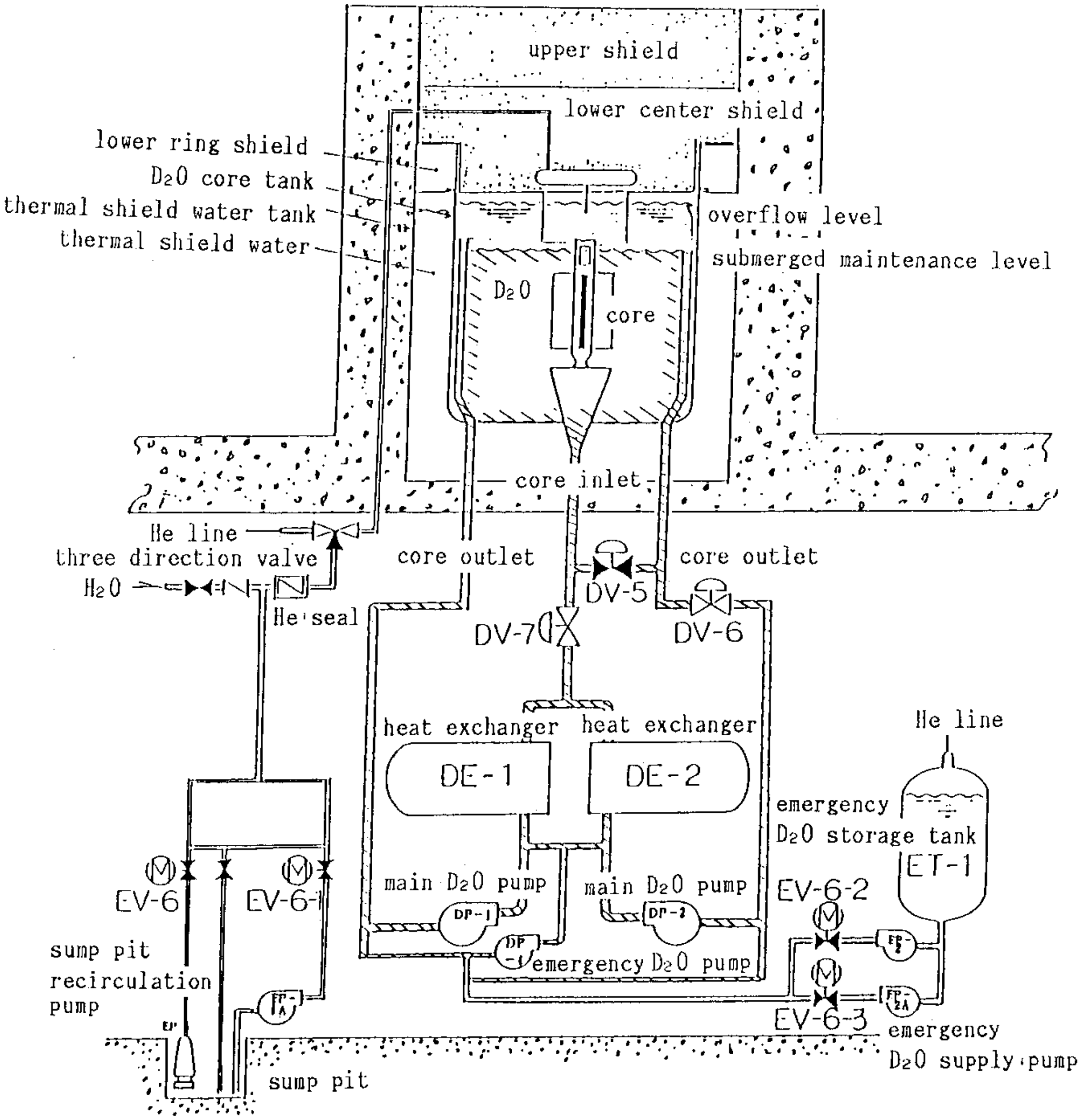


Fig. 2 JRR-2 emergency core cooling system

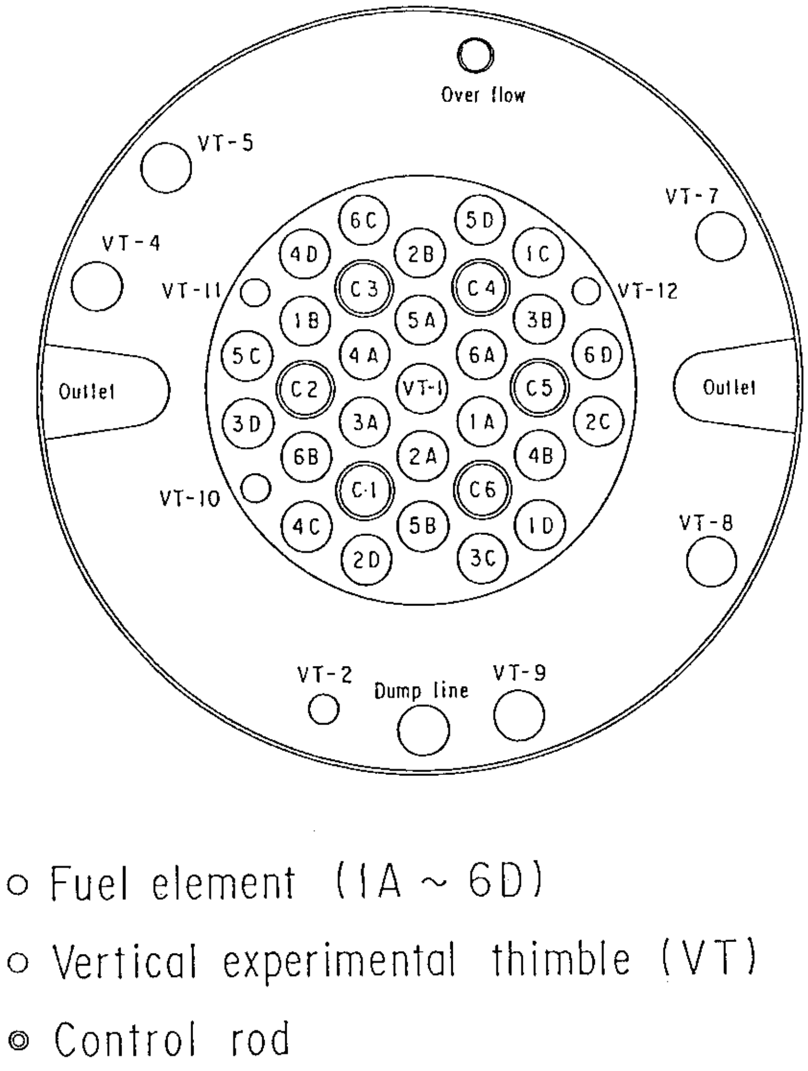


Fig. 3 JRR-2 core configuration

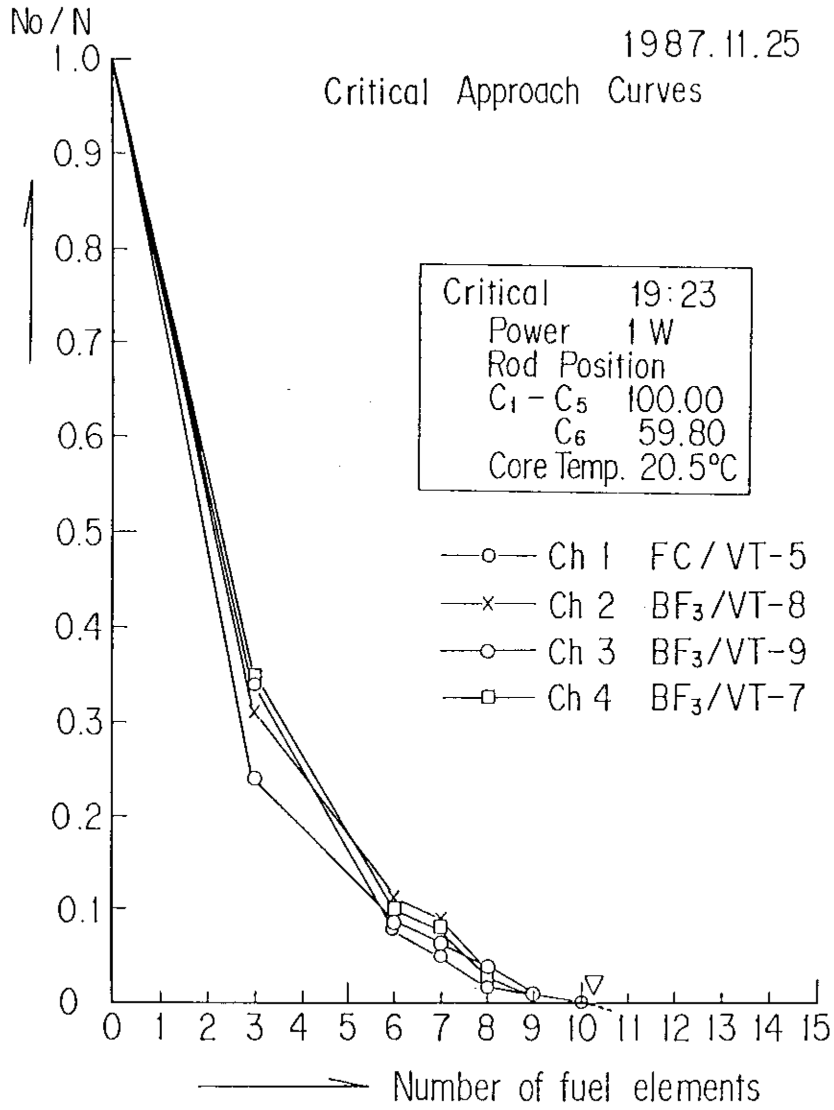


Fig. 4 Criticality approach curve

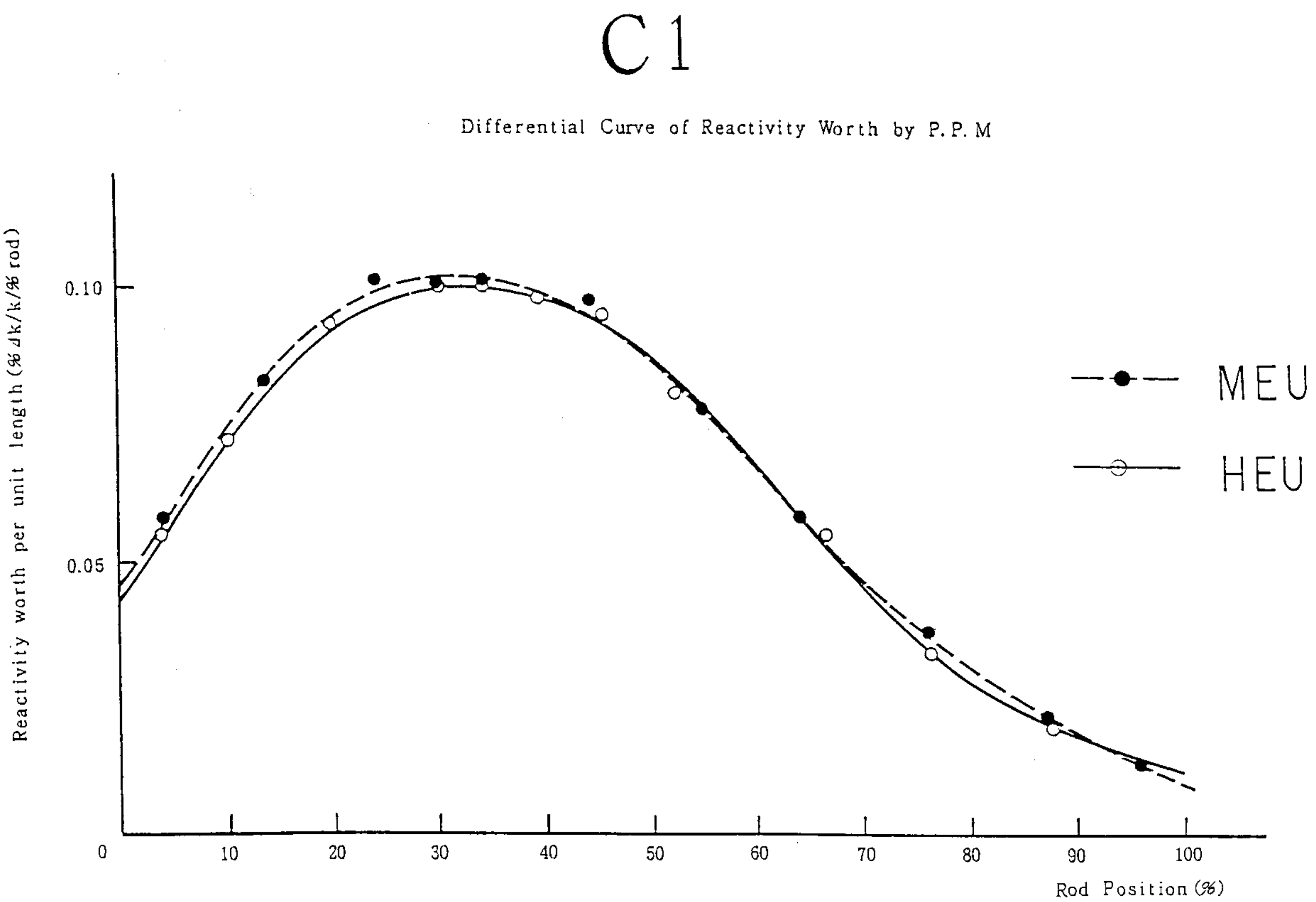


Fig. 5 Calibration of control rod worth (C1)

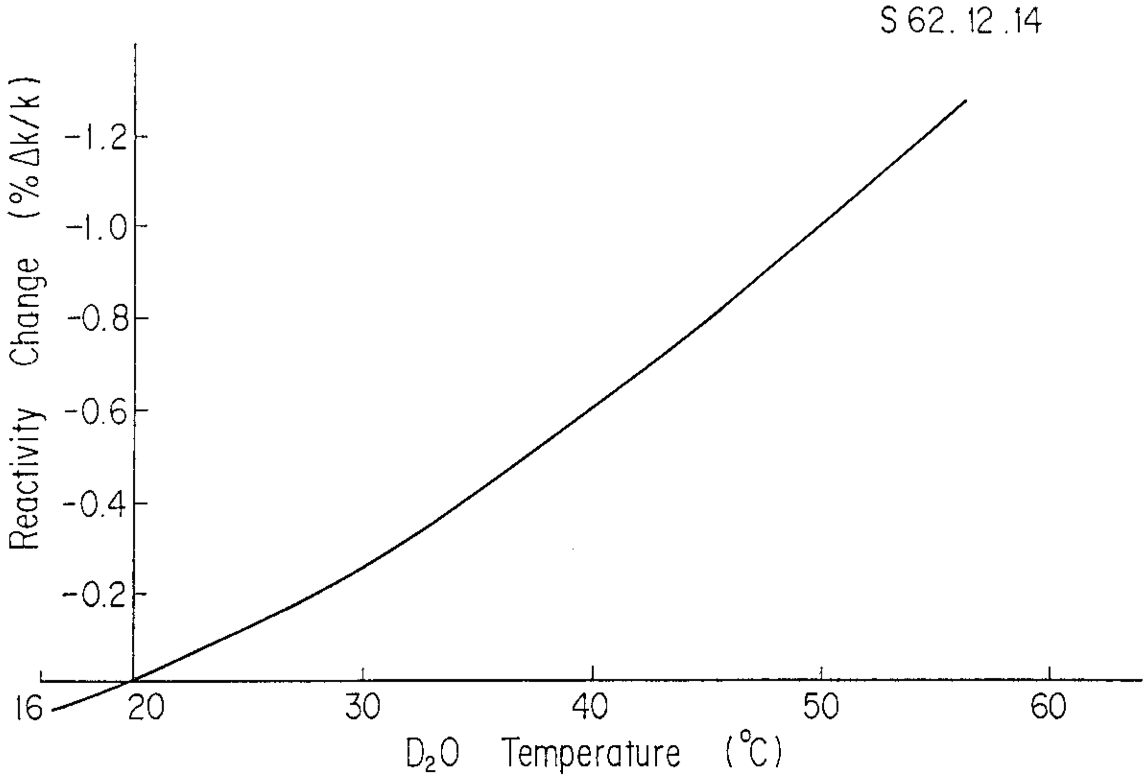


Fig. 6 Temperature reactivity coefficient of moderator

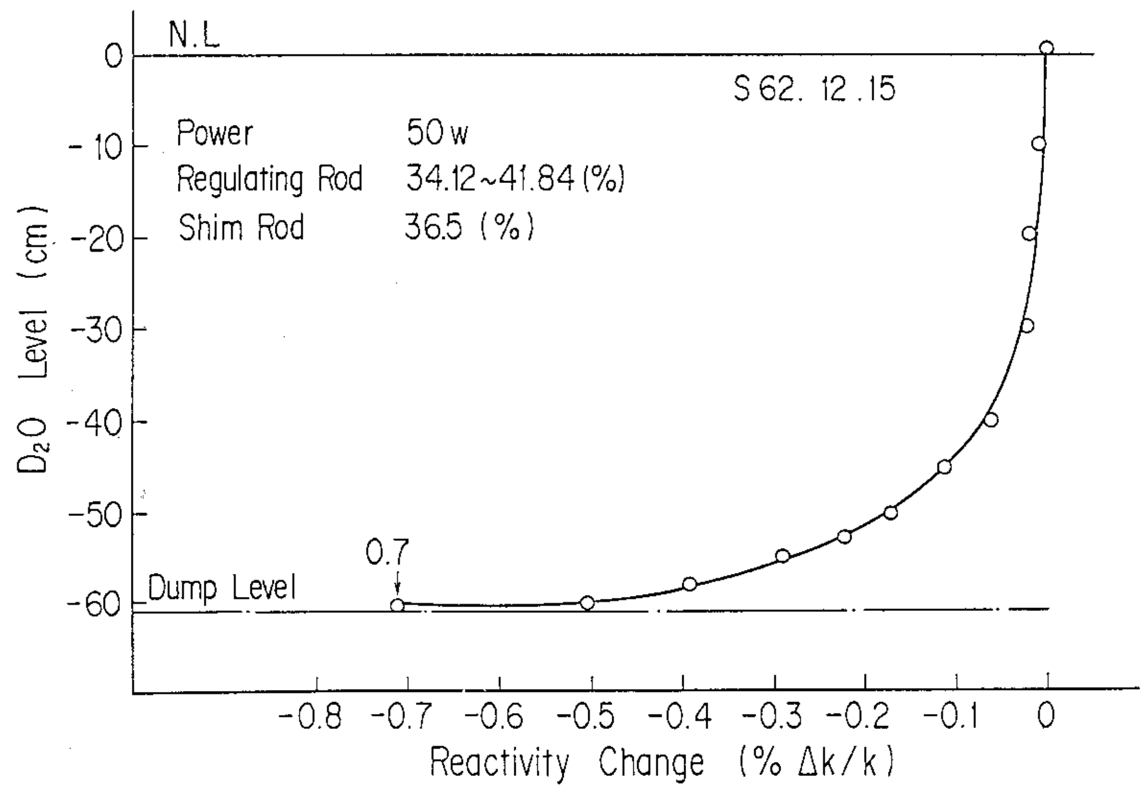
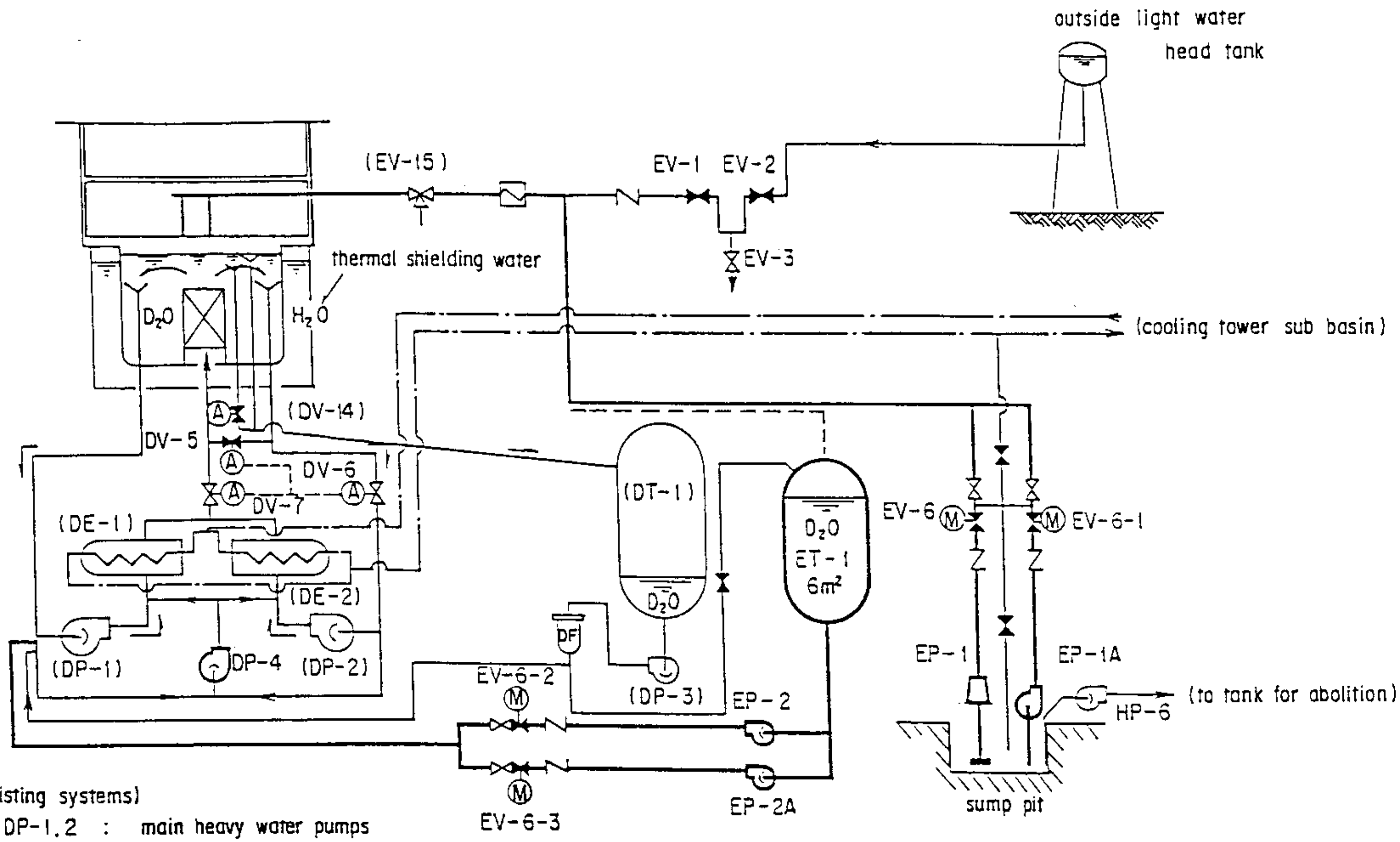


Fig. 8 Reflector (heavy water) dump effect



(existing systems)

DP-1,2	:	main heavy water pumps
DE-1,2	:	main heat exchanger
DP-4	:	emergency heavy water pump
DV-5,6,7	:	natural circulation valves
DV-14	:	emergency dump valve
HP-6	:	sump pit draining pump

(newly established system)

ET-1	:	emergency heavy water storage tank
EP-2,2A	:	emergency heavy water supply pumps

(extension system)

EP-1A	:	sump pit recirculating pump

Fig. 7 Construction of the JRR-2 emergency cooling system

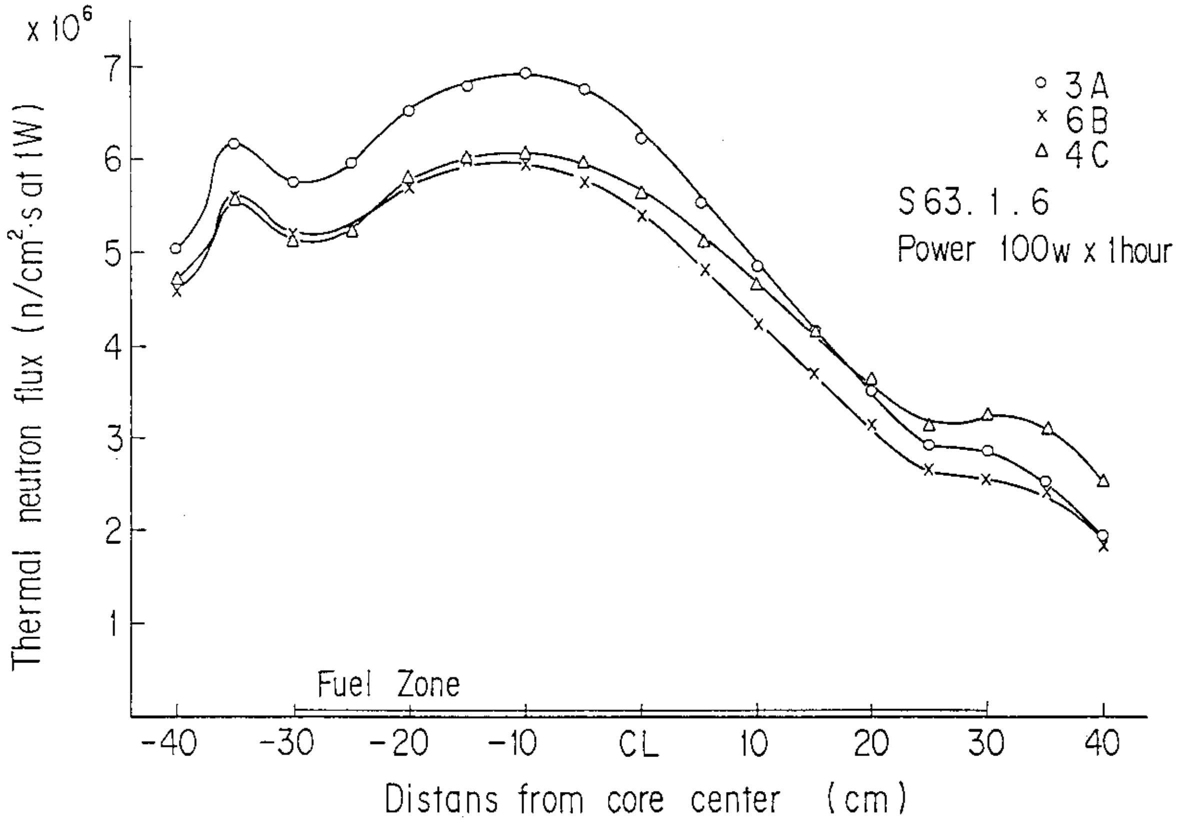


Fig. 9 Distribution of thermal neutron flux at fuel plate in MEU core

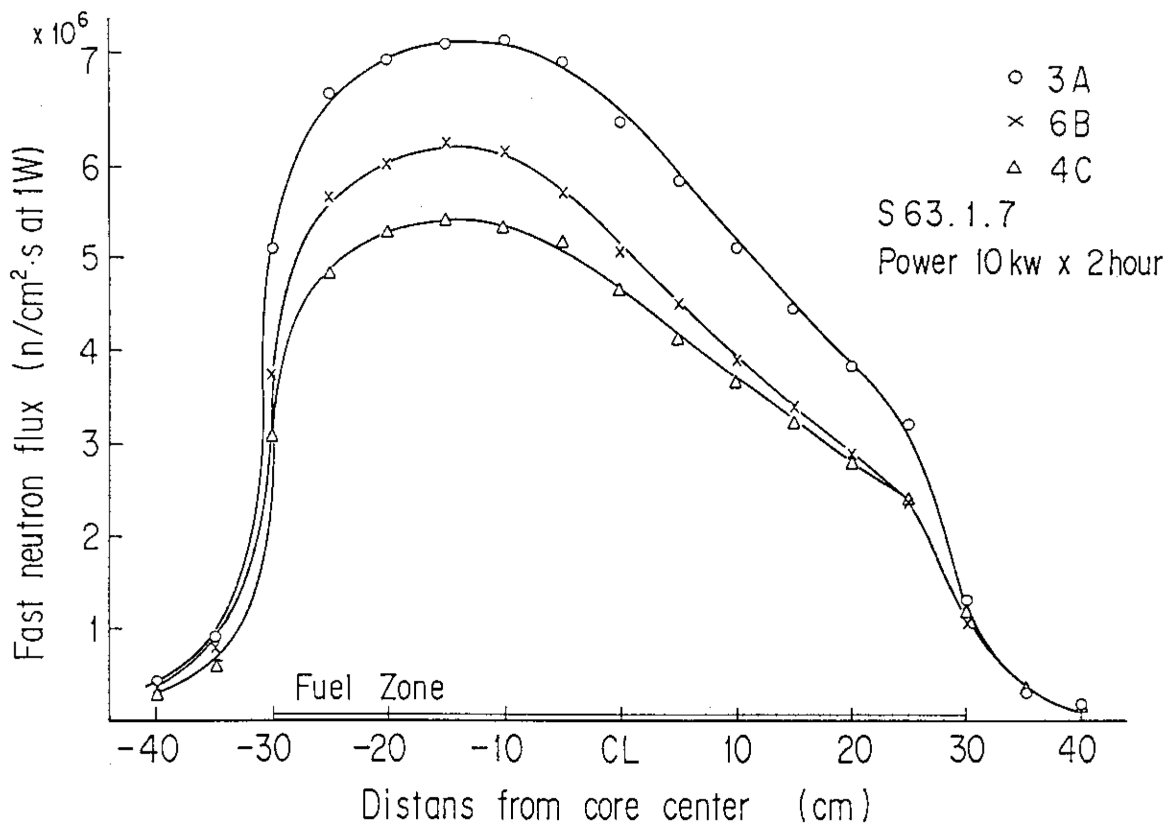


Fig. 10 Distribution of fast neutron flux at fuel plate in MEU core

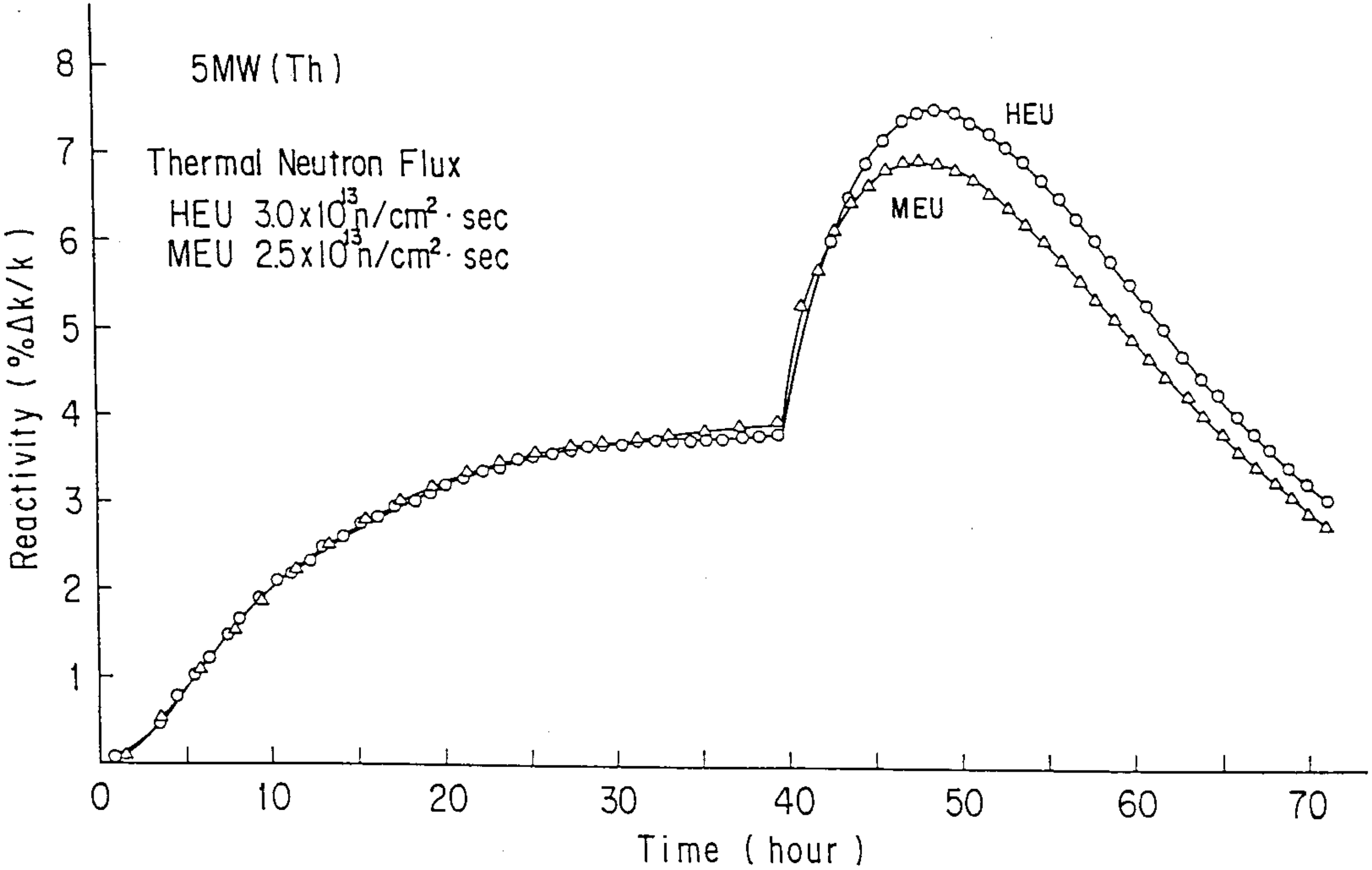


Fig. 11 Xenon poisoning in JRR-2 core (measured)

Appendix Main items of JRR-2 RERTR program

YEAR	ITEM
1977	The President of the United States published Non-Proliferation policy
1977	INFCE under the auspices of IAEA (International Nuclear Fuel Cycle Evaluation) Started discussion by the eighth department conference
1979	Established " JAERI RERTR program "
1980	INFCE conclusion To use HEU fuel is undesirable under the Non-proliferation policy
1980	Fabrication of dummy fuel elements using depleted uraninm
1981	Flow test using dummy fuel elements
1983	Application for permission of change of reactor establishment concerning fuel element for irradiation test March 31, 1983 Application July 22, 1983 Permission Application for sanction of the design and methods of construction August 8, 1983 Application August 22, 1983 Sanction
1984	Irradiation of test fuel element Oct. 1. 1984～Dec. 20. 1985 (Average Burnup 40%)
1985	Post-irradiation examination of test fuel element (Metal phase test and scanning type electron microscope inspection etc.)
1986	Reactor modification application on Full Core MEU conversion September 10. 1984 Start of prehearing May 30. 1986 application December 5. 1986 Permission
1987	Construction application on making MEU fuel element December 26. 1986 application March 26. 1987 Sanction

YEAR	ITEM
1987	Construction application on installed more several equipments and repair March 31, 1987 application May 2, 1987 Authorization Modification and repair work May 6, 1987～Nov. 22, 1987 Criticality test 19 : 23 November 25, 1987 Achieved first critical Characteristic test Nov. 26, 1987～
1988	Jan. 29, 1988 Routine operation by MEU fuel element at 10MW (thermal) February 8, 1988