Heavy Water Critical Experiments on Plutonium Utilization in Advanced Thermal Reactor "FUGEN"

Yoshio MIYAWAKI and Hidemasa KATO

Power Reactor and Nuclear Fuel Development Corporation

JAPAN

1 Introduction

The FUGEN project[1~3] has been under development to search for effective utilization of nuclear fuels including plutonium. FUGEN is a heavy water moderated, boiling light water cooled, pressure tube type reactor designed to generate 165 MWe. Main design data are shown in Table 1. Now, the reactor is under construction and scheduled to reach criticality in 1976.

Figure 1 shows the initial core configuration of FUGEN, in which , 96 mixed oxide(PuO_2-UO_2) fuel assemblies are to be loaded in the center region and 128 oxide(UO_2) fuels in the outer region. Plutonium is effective to decrease void reactivity in FUGEN type reactor[4~6] as shown in Fig. 2.

To reduce the local peaking factor, fissile plutonium concentration of fuel rods is selected 0.55 wt% for the outer ring and 0.8 wt% for middle and inner ring as shown in Fig. 3. Fig.4 shows the relative power distribution in the mixed oxide fuel assembly.

In this report experimental results and analyses are presented with emphasis on the void reactivity, neutron flux distribution and power distribution in the partial mixed oxide fuel core.

2. Heavy Water Critical Experiments[3)]

A series of reactor physics experiments are in progress using Deuterium Critical Assembly (DCA) to study characteristics of the heavy water moderated, light water cooled, pressure tube type reactor, and to evaluate the reliability of nuclear codes used in the design of an advanced thermal reactor FUGEN.

As mixed oxide fuel assemblies will be used in FUGEN, critical experiments on partial mixed oxide fuel core are now being carried out at DCA, which consists of 121 fuel assemblies arranged at 22.5 cm lattice pitch. The main core parameters of DCA are shown in the appendix.[7)]

Some typical results of the experiments and analyses are as follows.

2.1 Void Reactivity[8)]

Void reactivity was measured, using a pulsed neutron source under changing void fraction and with a progressive number of mixed oxide fuel assemblies in oxide core. This is shown in Fig. 5. Fig. 6 shows the result that the void reactivity becomes more negative as mixed oxide fuel assemblies are loaded. The calculations tend to evaluate the coolant void reactivity to the positive side.

2.2 Gross Neutron Flux Distribution[9)]

The copper wire activation method was adopted for measuring the gross radial flux distribution in the two region core having 37 (0.54 wt% PuO_2-UO_2) and 84 (1.2 wt% UO_2) fuel assemblies, and in checkerboard core having 25

(0.87 wt% PuO_2-UO_2), 32 (0.54 wt% PuO_2-UO_2) and 64 (1.2 wt% UO_2) fuel assemblies. This is shown in Fig. 7 and 8. The experimental results and calculated values are shown in Fig. 9 and 10. The accuracy of the calculated radial copper reaction rate distribution compared to the experimental values was within in 5 % for two region core, and about 10 % for the checkerboard core.

2.3 Intra-cell Neutron Density Distribution[10)]

The dysprosium foil activation method was used for measuring the intra-cell neutron density distribution in the mixed oxide fuel lattice as shown in Fig. 11. one of the experimental results is shown compared with calculation in Fig. 12. When compared with experiments, the accuracy of calculated neutron distribution was found accetable.

2.4 Local Peaking Factor[11)]

The rod scanning method was adopted for the measuring the local peaking factor of the mixed oxide fuel assembly. Fig. 13 shows the experimental results of power peaking factors, compared with calculations. These power peaking factors for mixed oxide fuel assemblies agree with experimental values within 1 % in the case of 100 % void condition, but over estimate by 3 % in the case of 0 % void condition.

Experiments on material buckling and microscopic lattice parameters in mixed oxide fuel core are now in progress.

For future studies, experiments of other lattice pitches, 20 cm and 25 cm. are being considered.

Conclusion

1) Experimental confirmation of the plutonium effect on coolant void reactivity was obtained from plutonium loaded experiment using DCA.

2) The calculated thermal flux and power distributions in partial mixed oxide core were found accetable.

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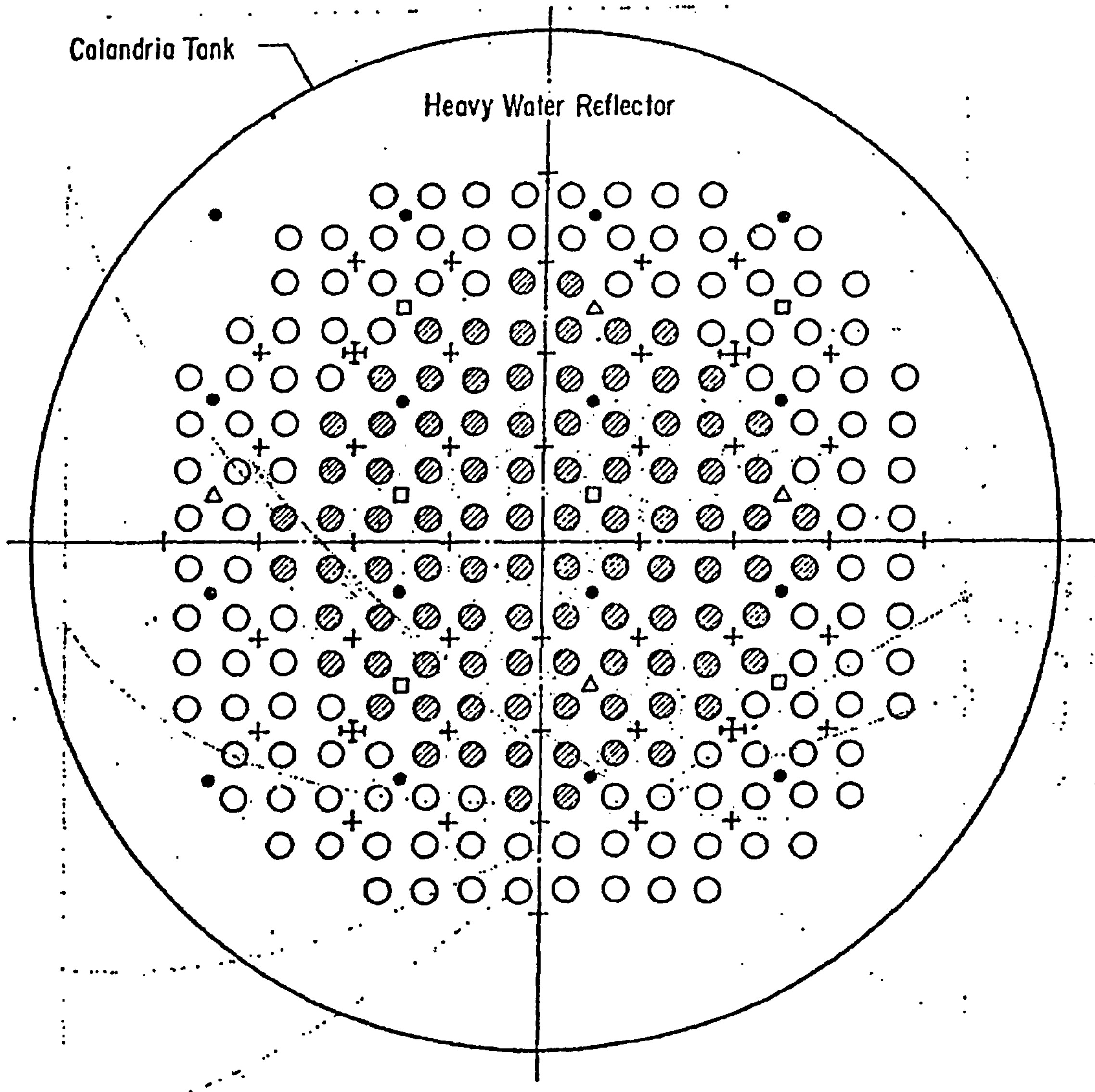
DCA-Memo 67 (1974).

Table 1 Design Data of FUGEN

Output	
Reactor thermal output	557 MW
Gross electrical output	165 MW
Core	
Core height	3,700 mm
Core diameter	4,060 mm
Lattice pitch	240 mm
Number of fuel channels	224
Fuel inventory	36 t
Heavy water inventory	86 t
Fuel	
Fuel material	UO_2 and PuO_2-UO_2
Pellet diameter	14.5 mm
Cladding material	Zircaloy-2
Cladding thickness	0.84 mm
Number of elements in cluster	28
Nominal element spacing	2.1 mm
Total length of fuel assembly	4.4 m
Pressure tube	
Material	Zr-2.5% Nb
Inside diameter	117.8 mm
Thickness	4.3 mm
Calandria tube	
Material	Zircaloy-2
Thickness	1.5 mm
Primary cooling system	
Coolant pressure at steam drum	68 kg/cm^2
Coolant temperature at steam drum	284°C
Coolant flow rate	7,600 t/h
Steam exit quality (mean)	14 %
Number of cooling loops	2
Number of recirculating pumps/loop	2
Turbine system	
Steam pressure at TSV	63.5 kg/cm^2
Steam temperature at TSV	279 °C
Steam flow rate to turbine	910 t/h



○	Fuel Assembly UO_2	128	●	IPM	16 x 4
⊘	〃 〃 PuO_2-UO_2	96	□	IM	6
+	Control Rod	45	△	SM	4
✠	Regulating Rod	4			

Fig. 1 Core Configuration of FUGEN

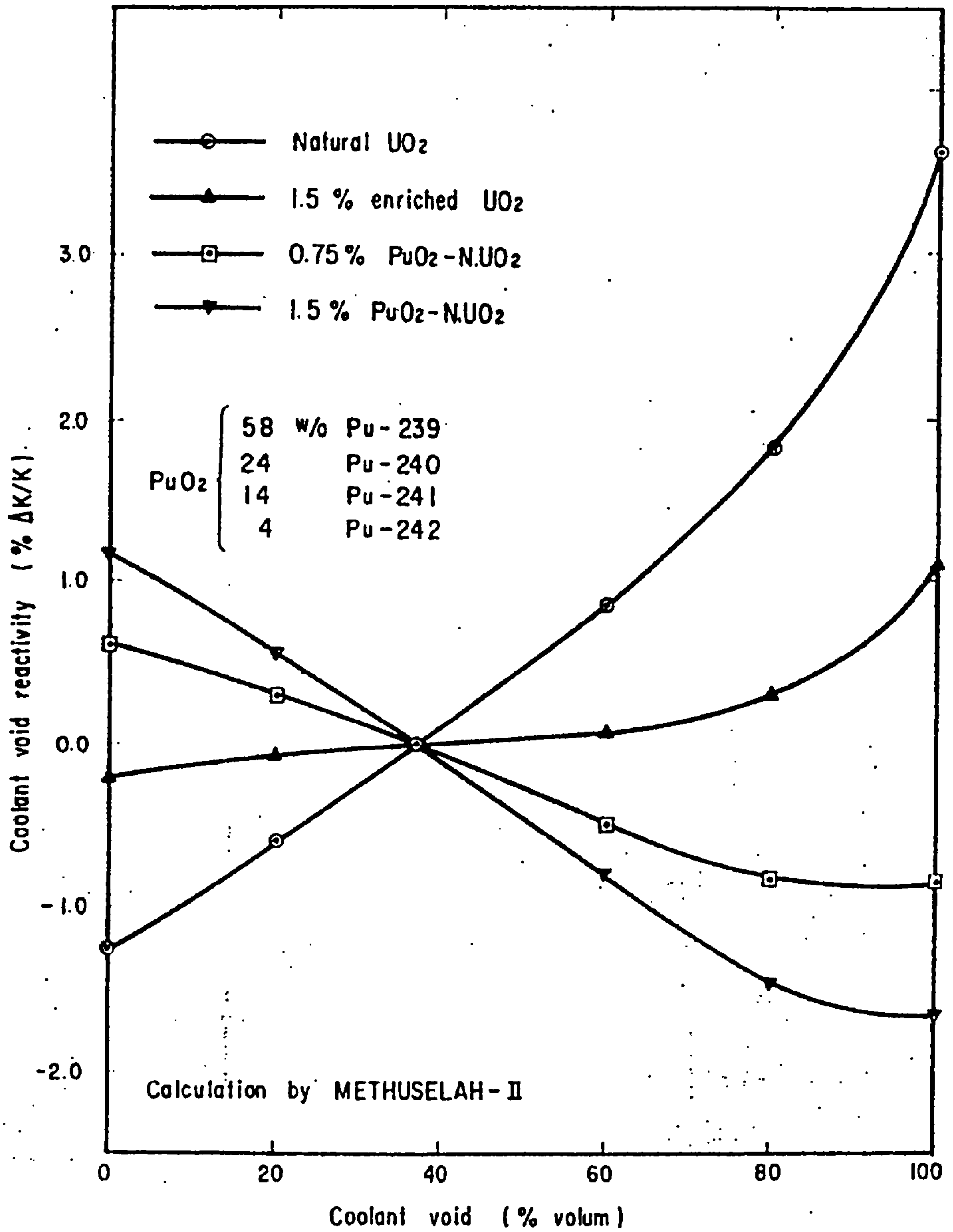


Fig. 2 Effect of Plutonium Enrichment on Coolant Void Reactivity

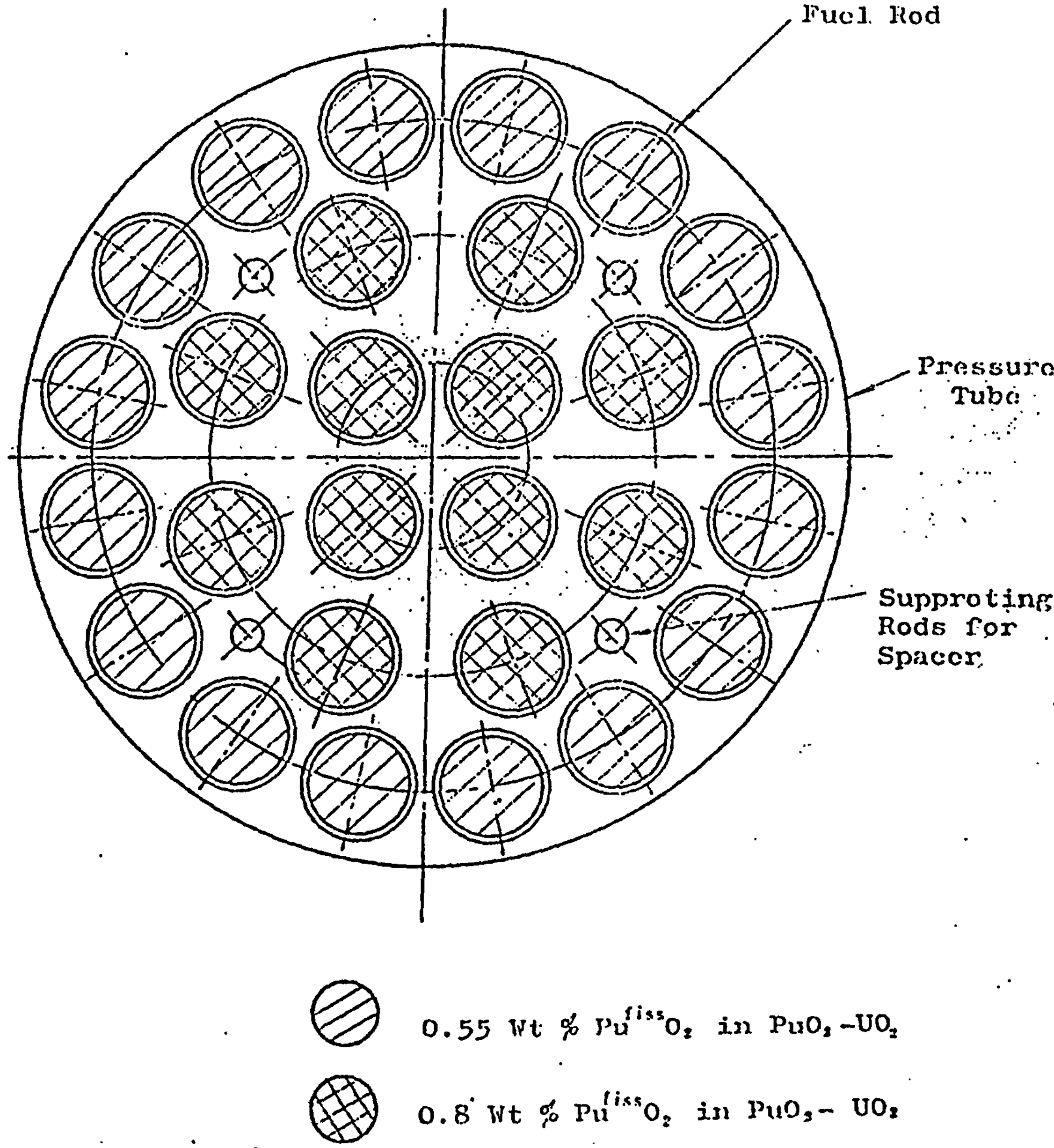


Fig.3 Cross Section of Mixed Oxide Fuel Assembly of FUGEN

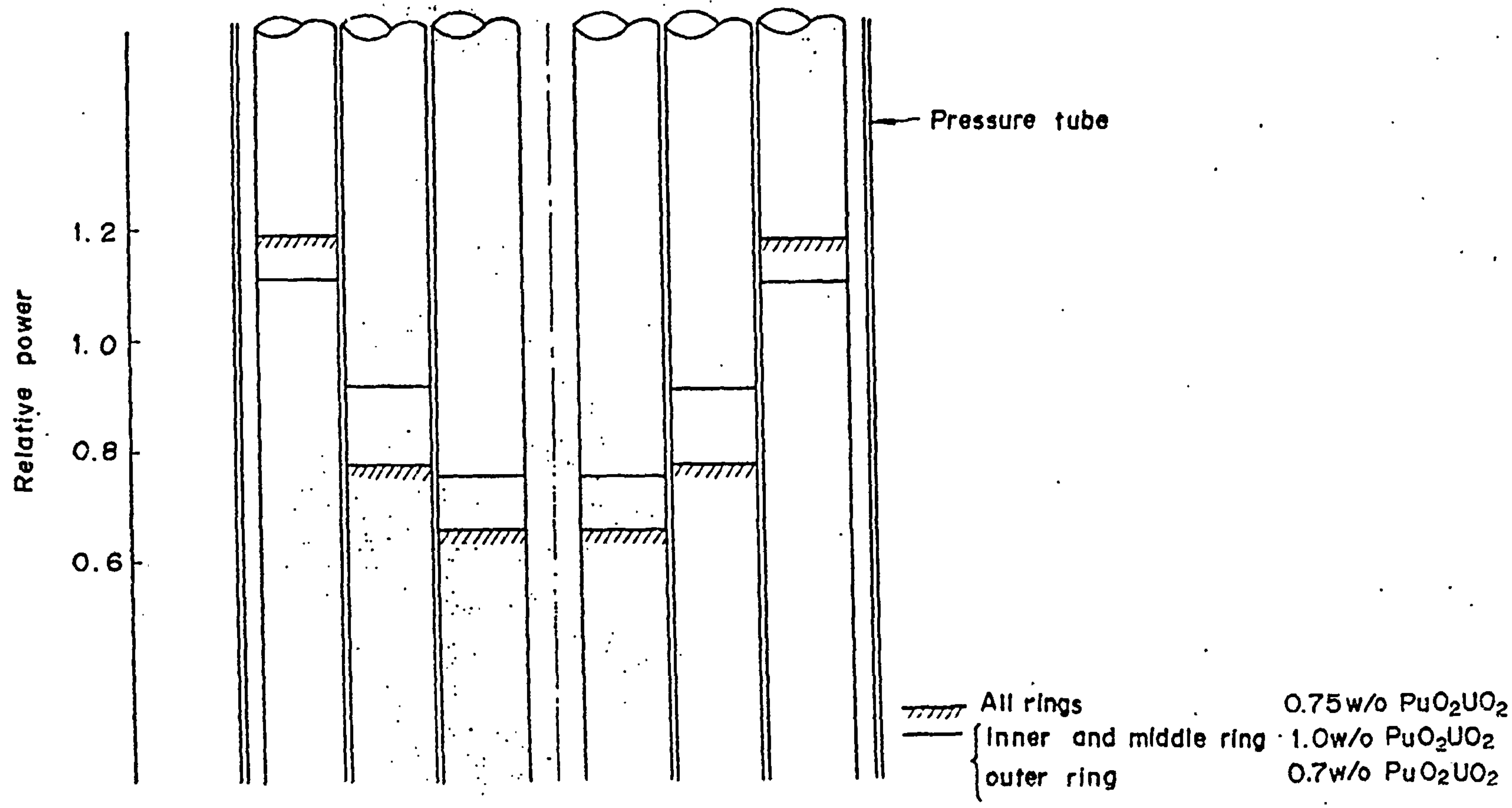


Fig. 4 Power Distribution in Mixed Oxide Fuel Assembly

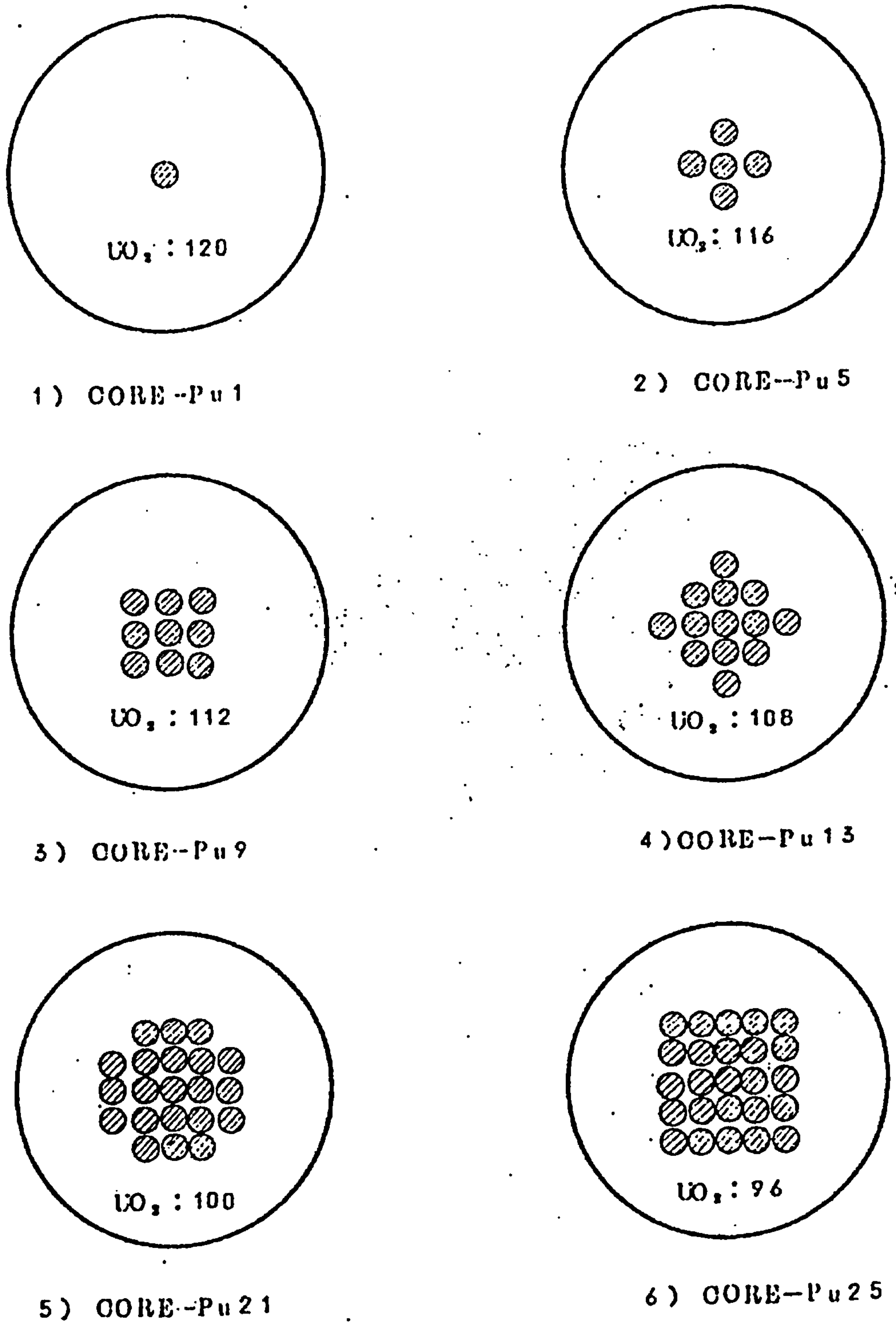


Fig. 5 Loading Patterns of PuO_2-UO_2 Fuel Assemblies

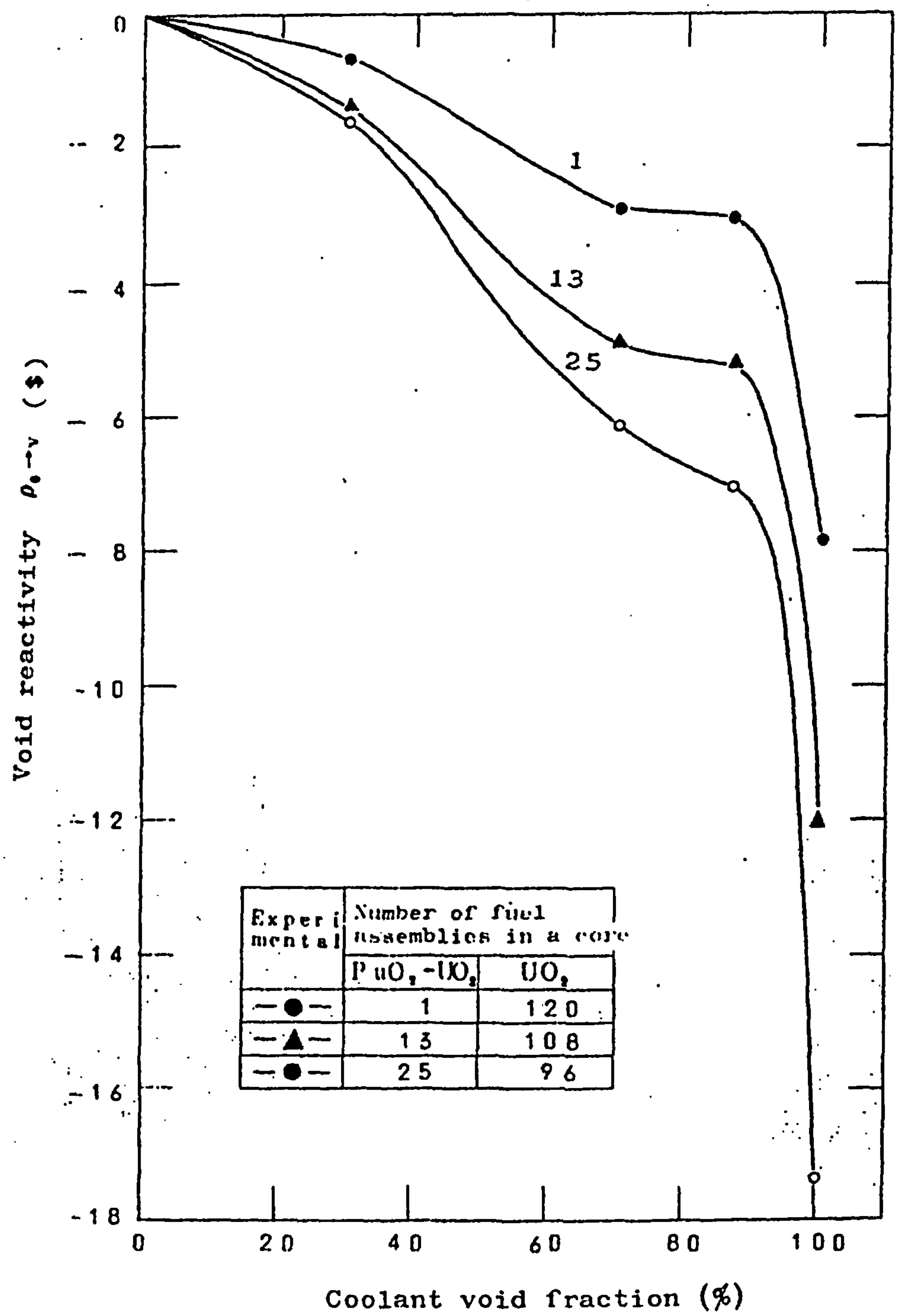
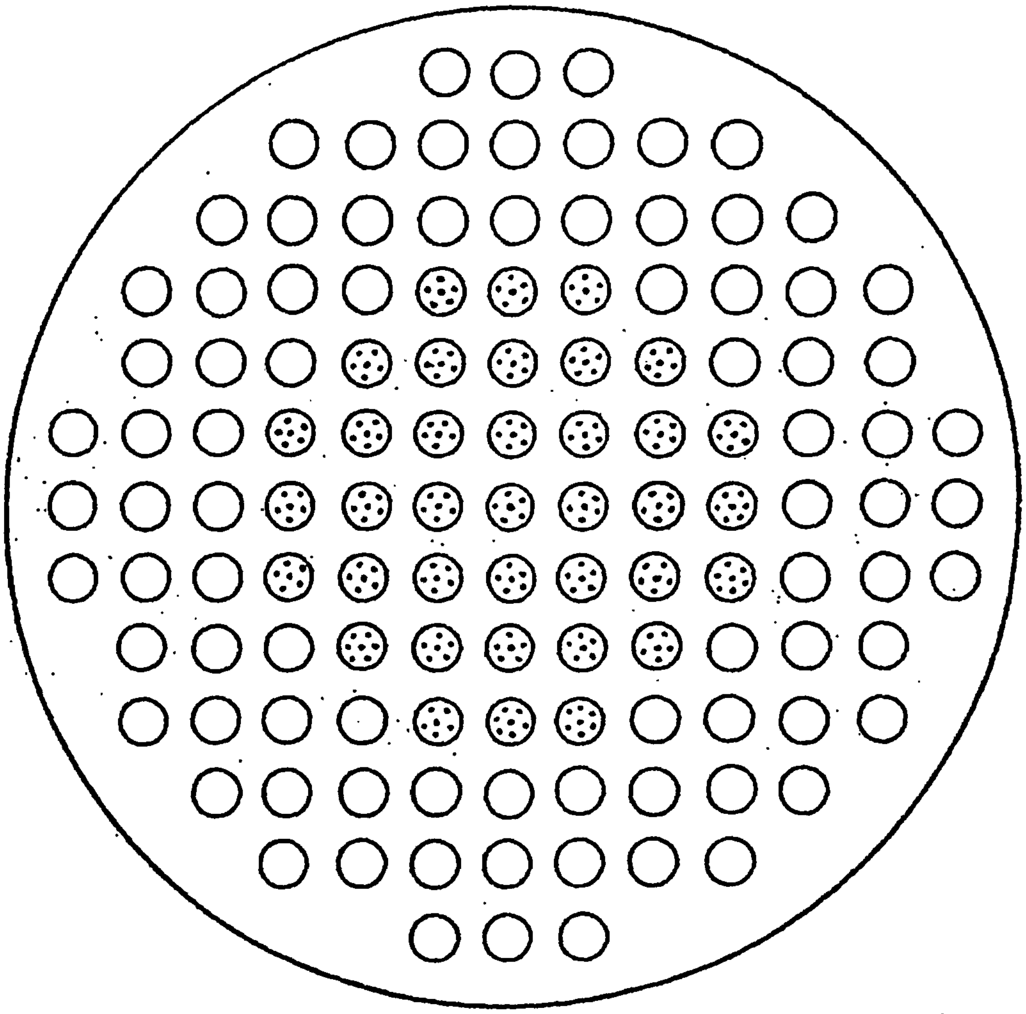
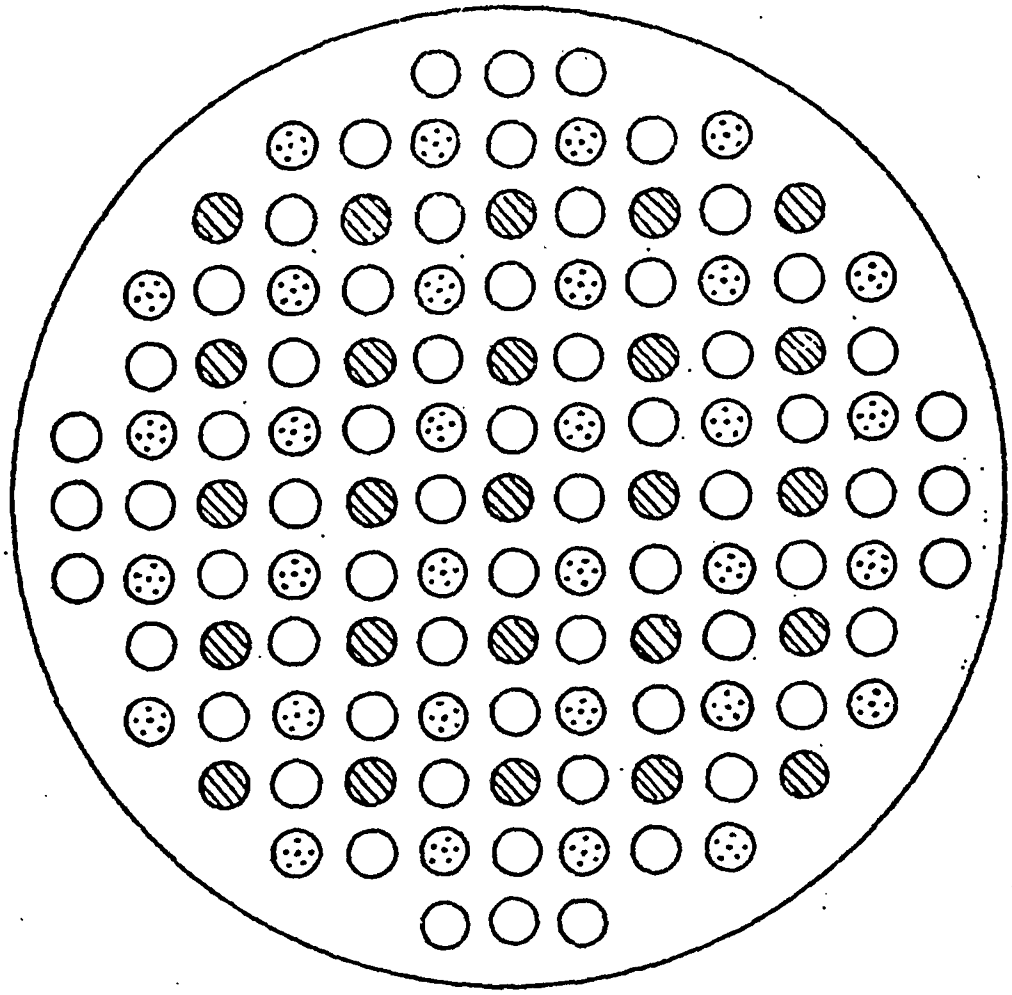


Fig. 6 Void Reactivity as a Function of Coolant Void Fraction



○	1.2w/o UO_2 Fuel Assembly	:84
⊙	0.54w/o PuO_2-UO_2 Fuel Assembly	:37

Fig. 7 Two Region Core Configulation



- 1.2w/o UO_2 Fuel Assembly :64
- 0.54w/o PuO_2-UO_2 Fuel Assembly :32
- 0.87w/o PuO_2-UO_2 Fuel Assembly :25

Fig. 8 Checkerboard Core Configuration

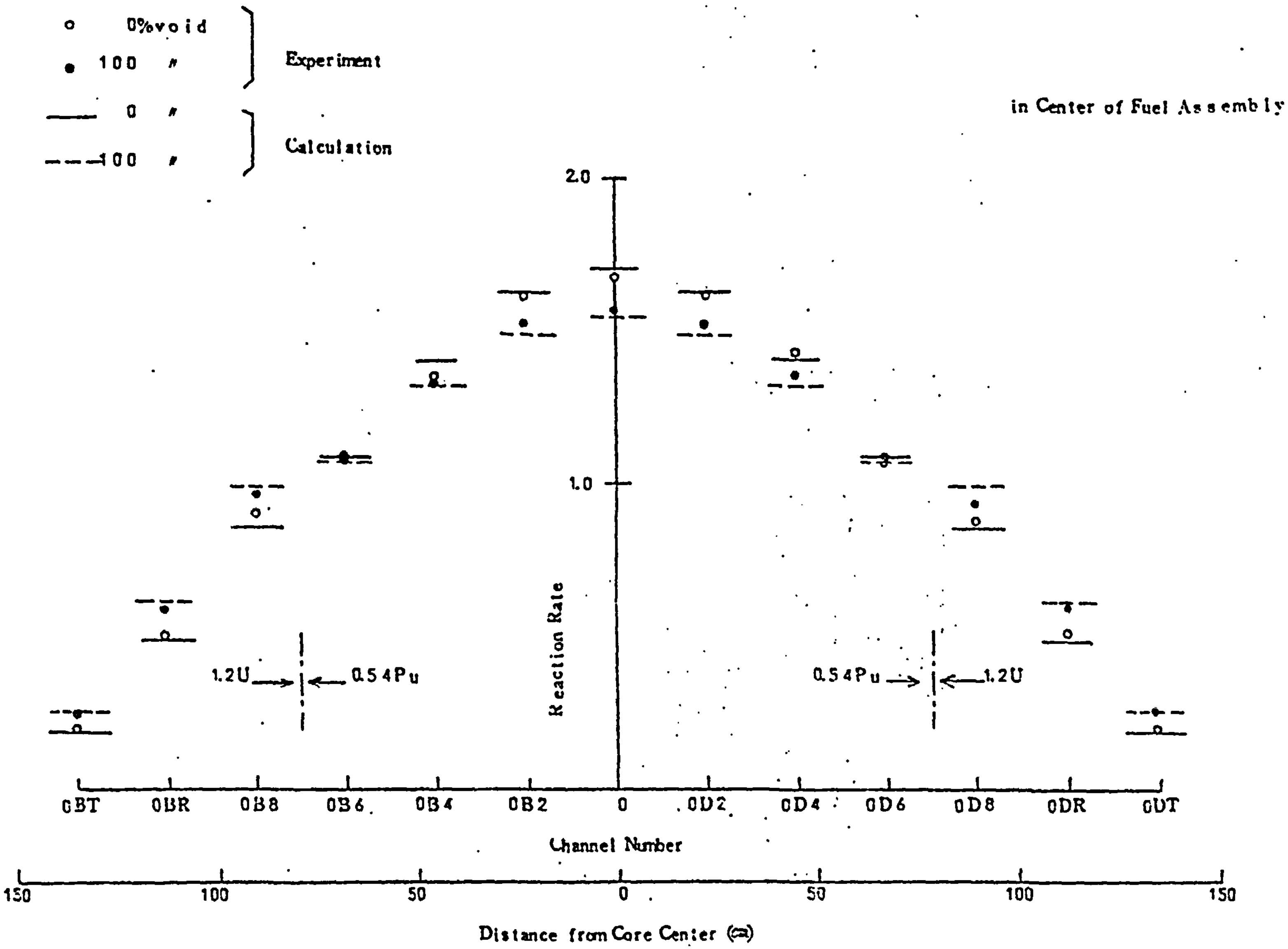


Fig. 9 Radial Copper Activation Distribution in Two Region Core

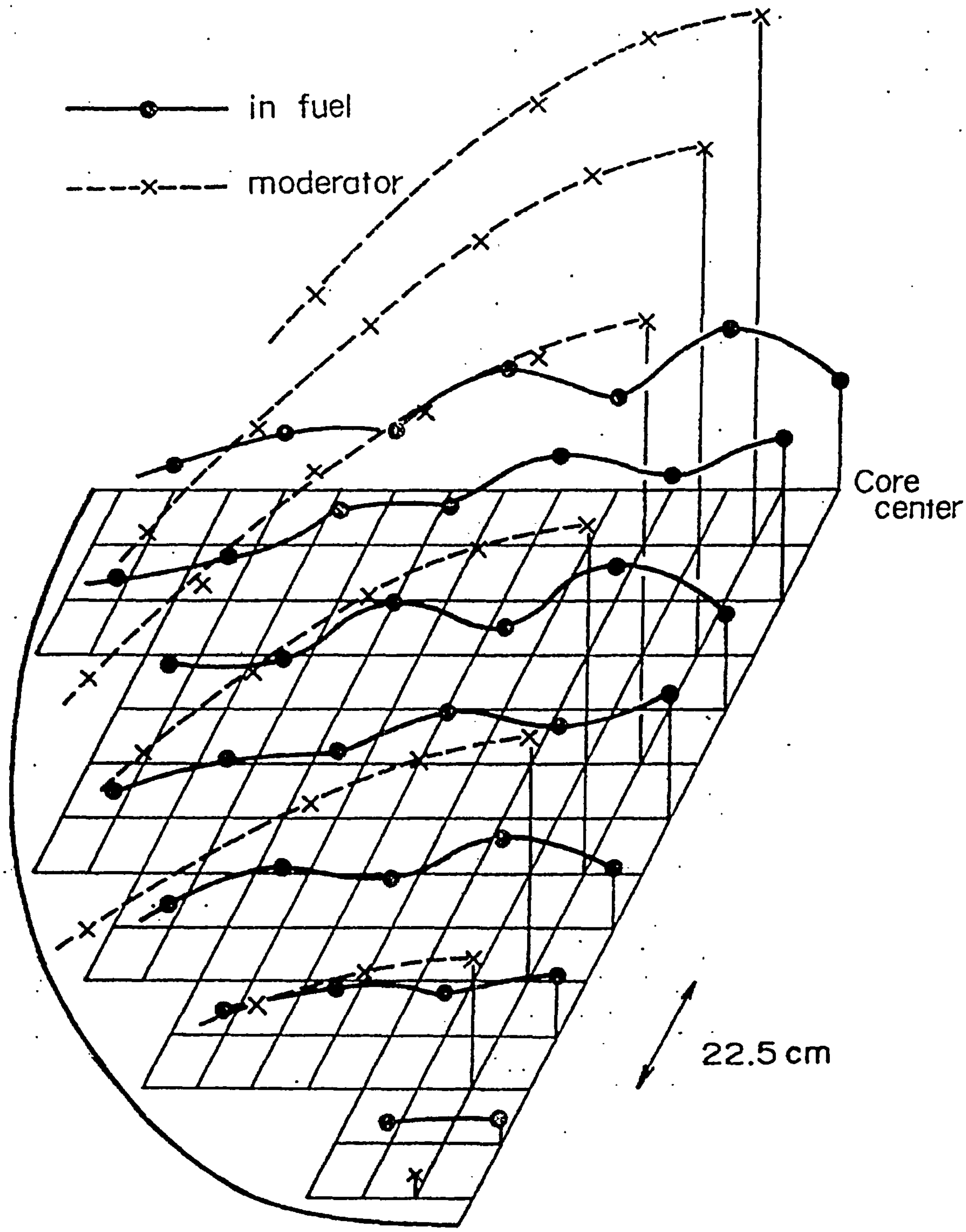


Fig. 10 Radial Copper Activation Distribution in Checkerboard Core (0% Void)

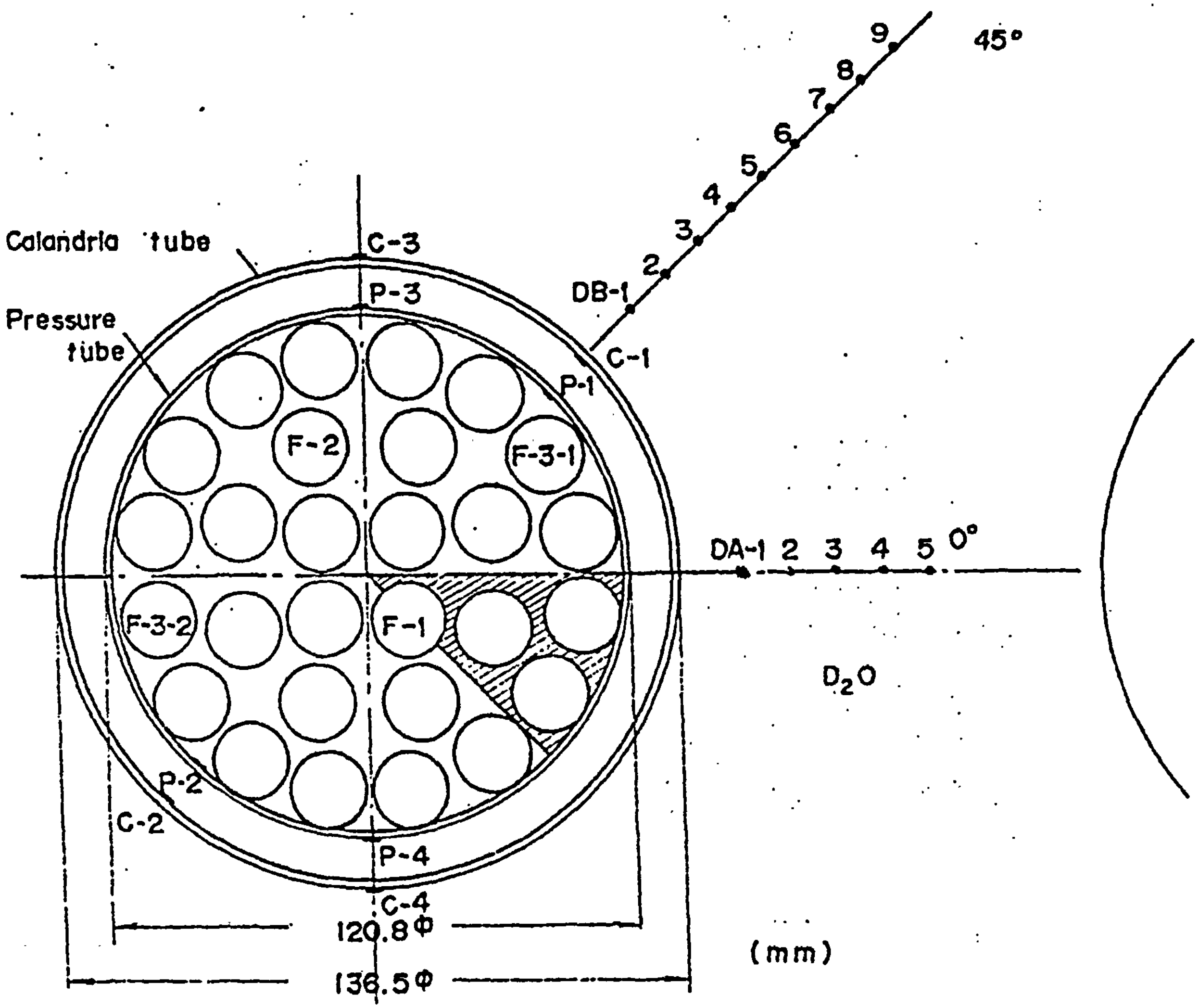


Fig. 11 Foil Arrangement in Unit Cell

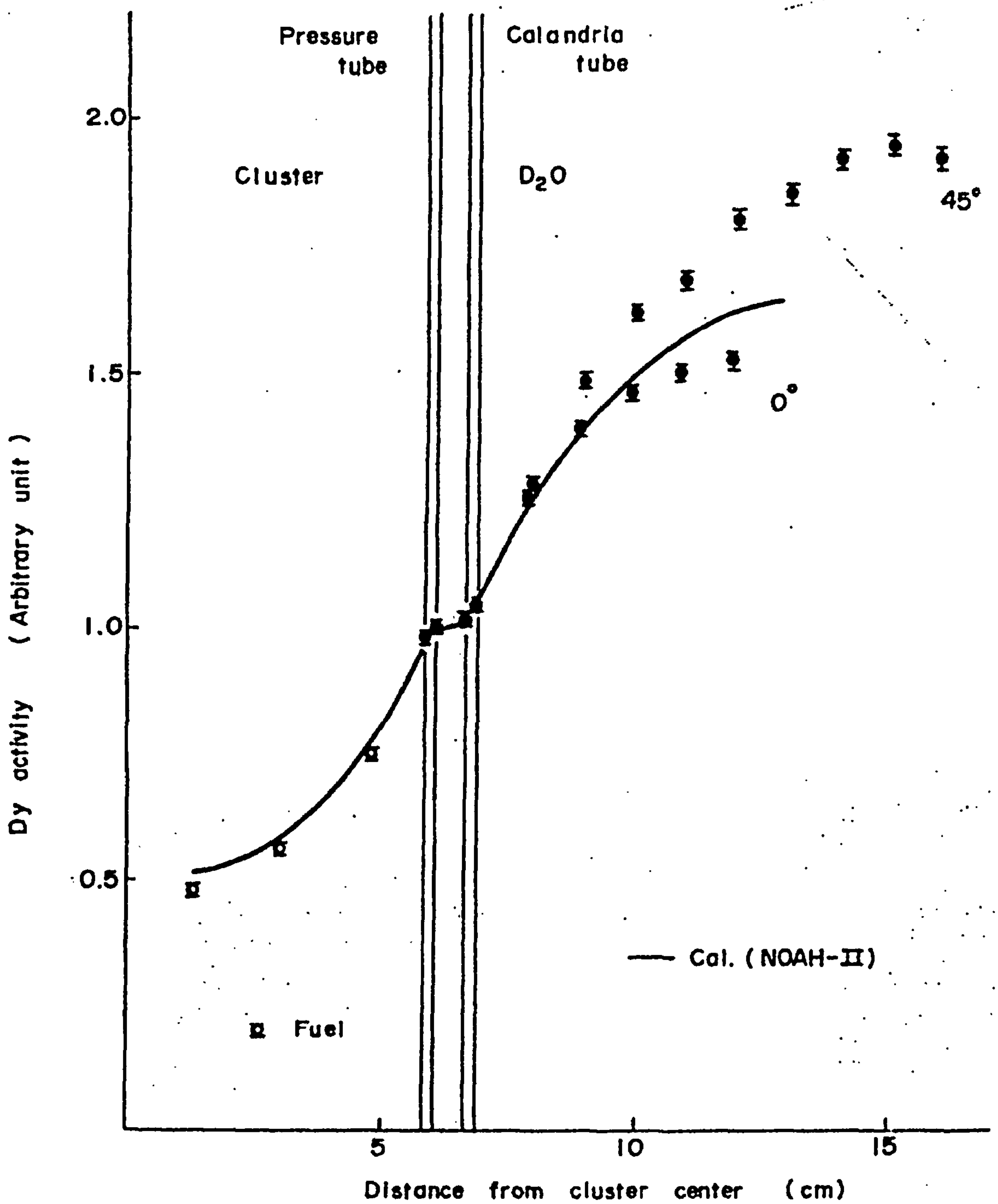


Fig. 12 Intra-cell Thermal Neutron Density Distribution
(0.54w/o PuO_2-UO_2, 100% Void)

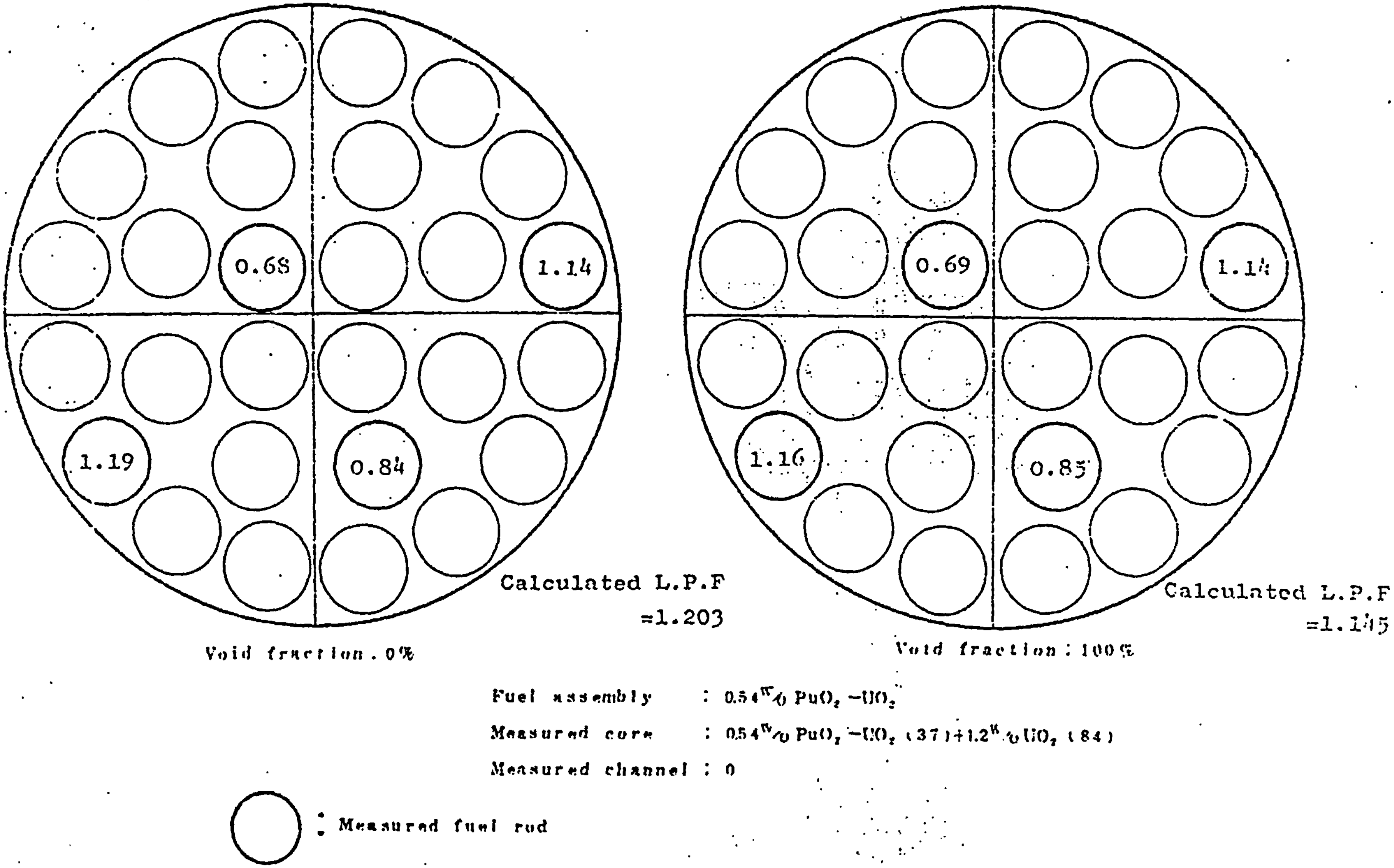


Fig. 13 Local Power Distribution in a Fuel Assembly

Appendix Core Parameter of DCA

1. Fuel Assembly

(i) 28 elements/assembly in 3 circular rings

Ring	No. of elements	Pitch circle dia of elements centers(cm)
1	4	2.625
2	8	6.000
3	16	9.515

(ii) Fuel Element

(1) 1.2 w/o Enriched UO_2 Fuel

	Inner dia (cm)	Outer dia (cm)	Material	Density (g/cm³)
Fuel pellet	—	1.480	1.203w/o enriched UO_2	10.36
Gap	1.480	1.503	Helium	—
Fuel sheath	1.503	1.673	Aluminum alloy	2.674

Composition		w/o in fuel pellet	w/o in sheath	Atomic No. density (10^{24}/cm³)
pellet	^{235}U	1.057		0.0002806
	^{238}U	86.793		0.02275
	O	12.150		0.04738
Sheath	Al		96.98	0.05788
	Mg		2.60	0.00172

(2) 0.54 w/o Enriched PuO_2-UO_2 Fuel (Standard Grade)

	Inner dia (cm)	Outer dia (cm)	Meterial	Density (g/cm³)
Fuel pellet	--	1.469	0.542w/o enriched PuO_2-UO_2	10.17
Gap	1.469	1.506	Helium	—
Fuel sheath	1.506	1.668	Zry-2	6.523

Composition		w/o in Pu	w/o in fuel pellet	w/o in sheath	Atomic density (10^{24}/cm³)
Pellet	^{235}U		0.6214		0.0001620
	^{238}U		86.782		0.02233
	^{238}Pu	0.021	0.000102		0.000000026
	^{239}Pu	90.360	0.4304		0.0001103
	^{240}Pu	8.640	0.04115		0.00001050
	^{241}Pu	0.915	0.004359		0.000001108
	^{242}Pu	0.064	0.000305		0.0000000767
	O		12.12		0.04640
Sheath	Zr			98.22	0.04218
	Sn			1.48	0.0004897
	Fe			0.14	0.0000985
	Cr			0.10	0.0000756
	Ni			0.06	0.0000401

Date of Analysis ; 23 August 1971

(iii) Hanger Wire

№ in assembly	Pitch circle dia of hanger wire center (cm)	Outer dia (cm)	Material	Density (g/cm³)
4	10.60	0.20	Aluminum alloy	2.674

Composition	w/o in wire	Atomic № density (10^{24} /cm³)
Al	96.98	0.05788
Mg	2.60	0.00172

(iv) Spacer

№ in assembly	Outer dia (cm)	Thickness (cm)	Material	Density (g/cm³)
2 *1	11.44	0.30	Aluminum alloy	2.674

Composition	w/o in Spacer	Atomic № density (10^{24} / cm³)
Al	96.98	0.05788
Mg	2.60	0.00172

*1 The positions are 70 cm and 140 cm from the lowest end of fuel.

2. Fuel Channel

	Inner Dia(cm)	Outer Dia(cm)	Material	Density(g/cm³)
Pressure tube	11.68	12.08	Alumimun alloy	2.674
Air gap	12.08	13.25	Air	0.001205
Calandria tube	13.25	13.65	Alumimun alloy	2.674

Composition		w/o in Al	w/o in Air	Atomic № density
Al		96.98		0.05788
Mg		2.60		0.00172
Air	O		23.5204	0.00001067
	N		76.4796	0.00003962

3. Moderator

(1) Density of D_2O (99.50 mol/o) 1.1078

Material	w/o in moderator	Density(g/cm³)
D_2O	99.55	1.10834
H_2O	0.45	0.99777

Composition	w/o. in D_2O	Atomic № density(/cm³ × 10^{24})
H	0.05036	0.00003333
D	20.0223	0.06632
O	79.9283	0.03333

4. Coolant

Simulated void fraction(%)	w/o in Coolant				Density(g/cm³)
	H_2O	D_2O	H_3BO_3	Air	
0	100	-	-		0.99777
30	63.17	36.82	0.00921	-	1.0359
70	18.07	81.91	0.0215		1.0866
86.7	0.45	99.55	-	-	1.1078
100				100	0.000001
Density g/cm³	0.99777	1.10834	1.435	0.001205	

Composition	w/o in Coolant				
	0% void	30% void	70% void	86.7% void	100% void
H	11.1901	7.0693	2.0231	0.05036	
D		7.4055	16.4744	20.0223	
O	88.8099	85.5231	81.5001	79.9283	23.5204
^{10}B		0.0003158	0.000737		
B(Natural)		0.001611	0.003760		
N					76.4796

Composition	Atomic No. density (10^{24}/cm³)				
	0% void	30% void	70% void	86.7% void	100% void
H	0.06671	0.04375	0.01313	0.0003333	
D		0.02294	0.05353	0.06632	
O	0.03335	0.03335	0.03334	0.03333	0.00001067
B (Natural)		0.0000009	0.0000023		
N					0.00003962

5. Others

(i) Temperature : 22℃≈295°k

(ii) Square lattice pitch : 22.5cm or 25.0cm

(iii) Diameter of core tank : 300.5cm

(iv) No. of fuel channel (Standard core) : 121 for 22.5cm lattice pitch

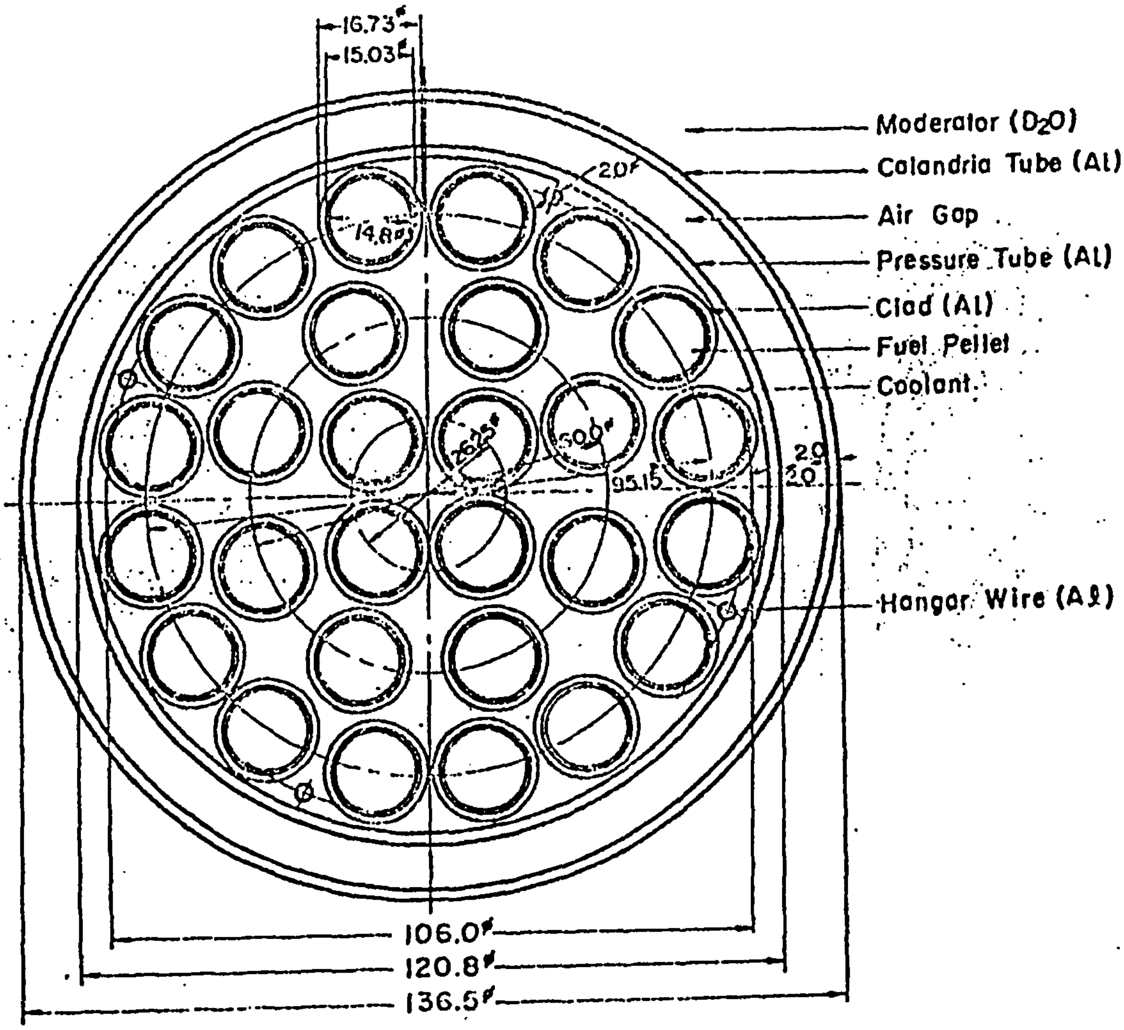


Fig. A-1 Fuel Assembly of DCA (1.2% UO_2)

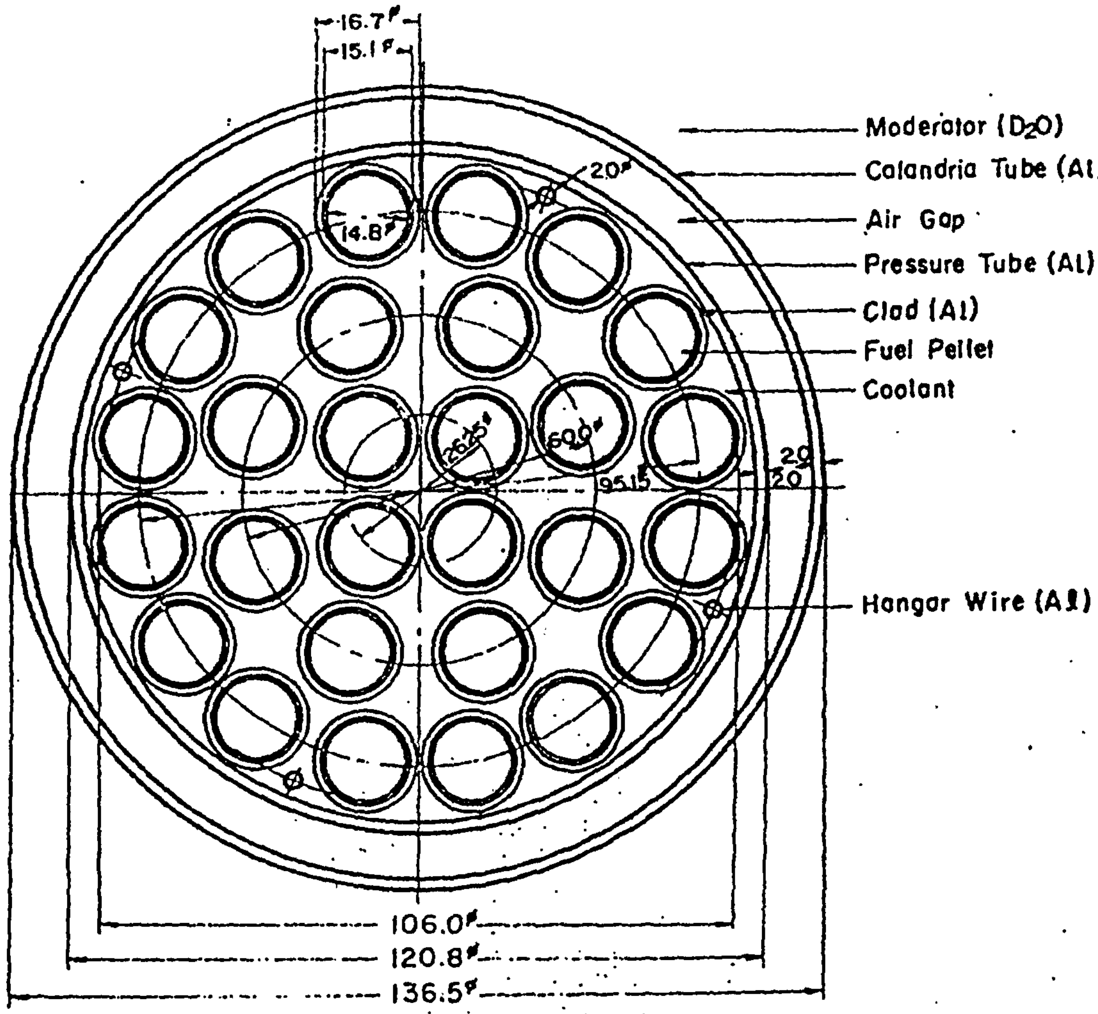
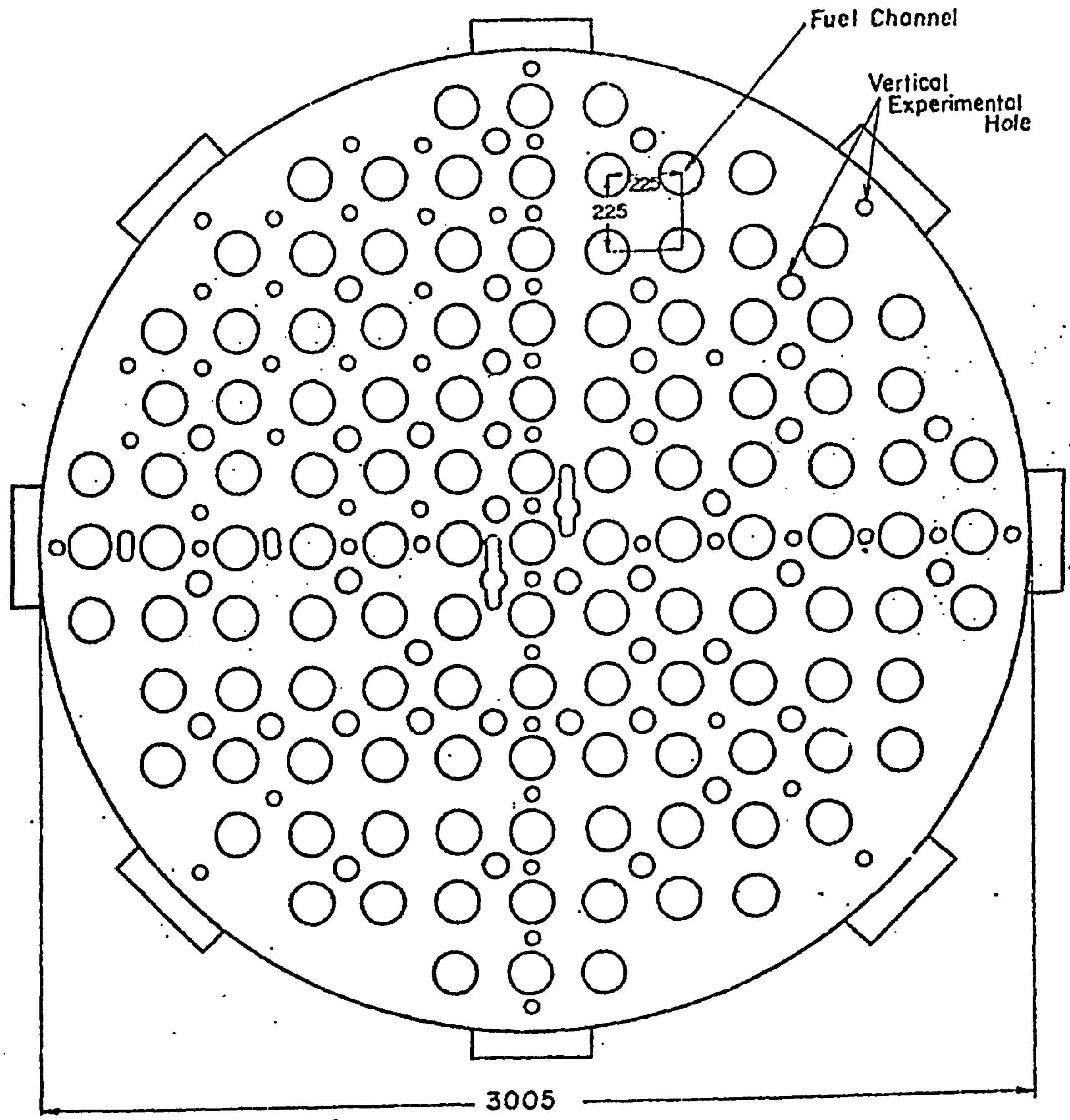


Fig. A-2 Fuel Assembly of DCA (0.54w/o PuO_2-UO_2)



Total Number of Fuel Assembly : 121

Fig. A-3 DCA Core Configuration
(Lattice Pitch :225 mm)