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「常陽」核特性の評価・検討

（キヤダラツシユ・セツトによる評価

および炉内燃料貯蔵ラック内での発熱量評価）

昭和45年5月

動力炉・核燃料開発事業団

「常陽」核特性の評価・検討

（キャダラッシ・セットによる評価および
炉内燃料貯蔵ラック内での発熱量評価）

要　　　旨

本報は，「常陽」の核特性のうち下記２つの事項について，検討・評価したものを取纒めた。

その一つは，「常陽」第３次概念設計の炉心体系について，フランス原子力庁がキャダラッシュ・セットを使用して，臨界特性・燃焼特性・制御棒特性などを計算した結果を中心にまとめたものである。

他の一つは，調整設計の結果，問題となつた炉内燃料貯蔵ラック内の炉心燃料集合体の発熱について，輸送近似によつて拡散近似の評価を行ない，両近似法の間に大きな差のないことを確認したものである。

以上の作業は，東京芝浦電気株式会社と日本原子力研究所の協力を得て，実施した。

（取　纒）

高速実験炉建設部

井　上　晃　次

吉　野　富士男

目　　次

Ⅰ 主要核特性の評価

Ⅰ－1. はじめに

本チェック計算は，フランス原子力庁がCadarache set Version2 を使用してＪＥＦＲ 第３次概念設計の体系で臨界主要特性，燃焼主要特性および制御棒中心反応度価値について行なつたものを中心にまとめたものである。

計算に対する日本側の質問およびフランス側の回答をⅠ－４に，また第３次概念設計で使用したＡＢＮ セットによる制御棒の中心反応度価値の計算（東芝が実施）をⅠ－５に示す。

I-2 The Core Composition

1. Sub-assembly dimension and composition

The core consists of the following sub-assemblies :

Name	Number of sub-assemblies
corc fuel sub-assembly	61
radial blankct fuel sub-assembly	192
control rod	
safety rod	4
shim rod	6
fine rod	2
radial reflcctor	126

The dimension of sub-assemblics is shown in Fig. 1.

The average atomic number densities in each sub-assembly is given in Table 1.

2. Core arrangement

The core arrangement is shown in Fig. 2.

3. Core configurations in physics calculations

The physics calculations are carried out for the following three configulations :

The configuration A : the 2-dimensional (R-Z) core with rod out.

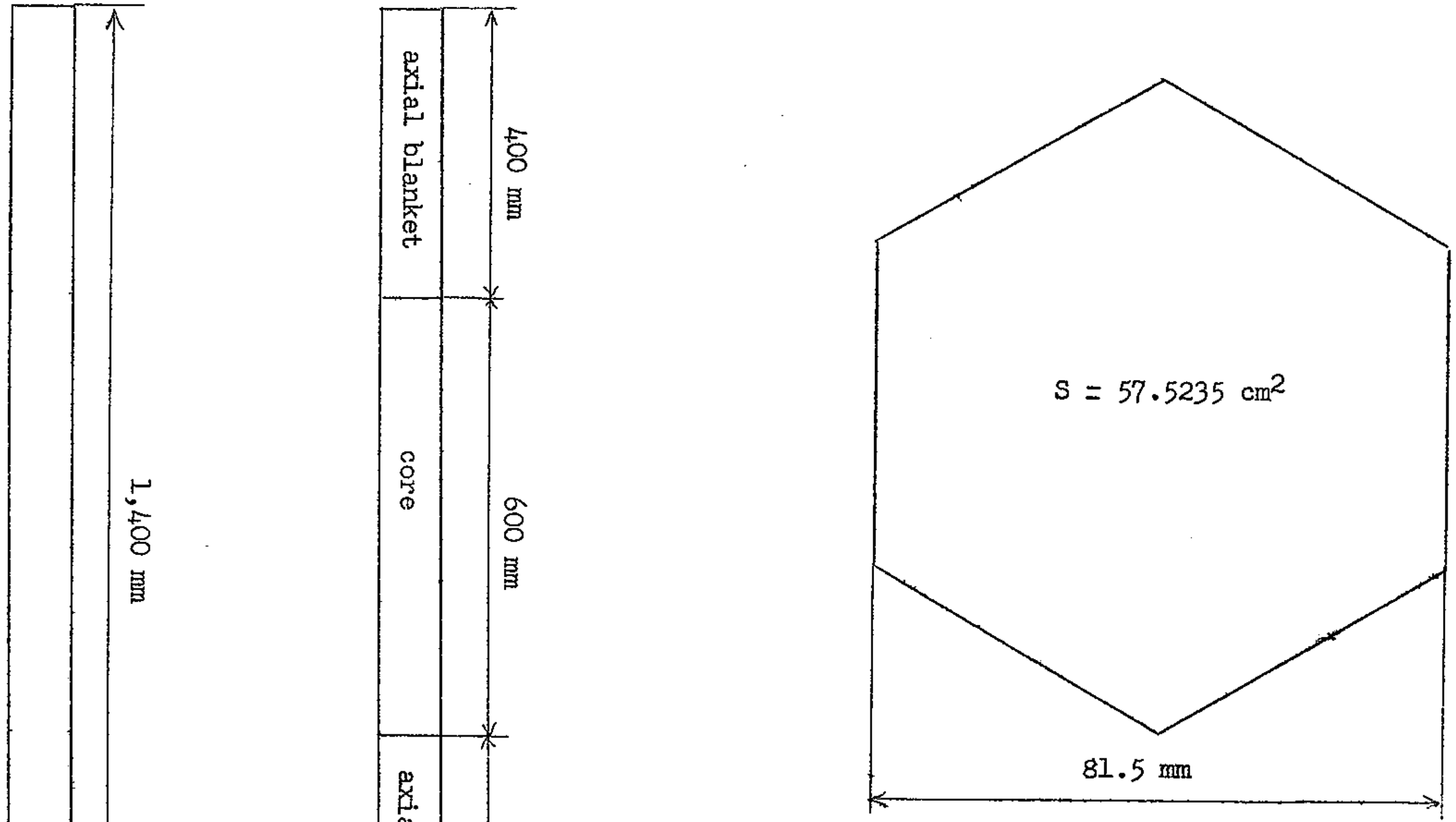
The configuration B : the 2-dimensional (R-Z) core with 6 shim rods in.

The configuration C : the 2-dimensional (X-Y) core with all rods in.

The configurations A, B and C are illustrated in Figs. 3, 4 and 5 respectively.

The regional atomic number densities in the configuration A, B and C are given in Tables 2, 3 and 4 respectively.

The reactor temperature is assumed to be 20°C except for sodium which is at 370°C.



radial blanket subassembly, core fuel subassembly
control rod and reflector

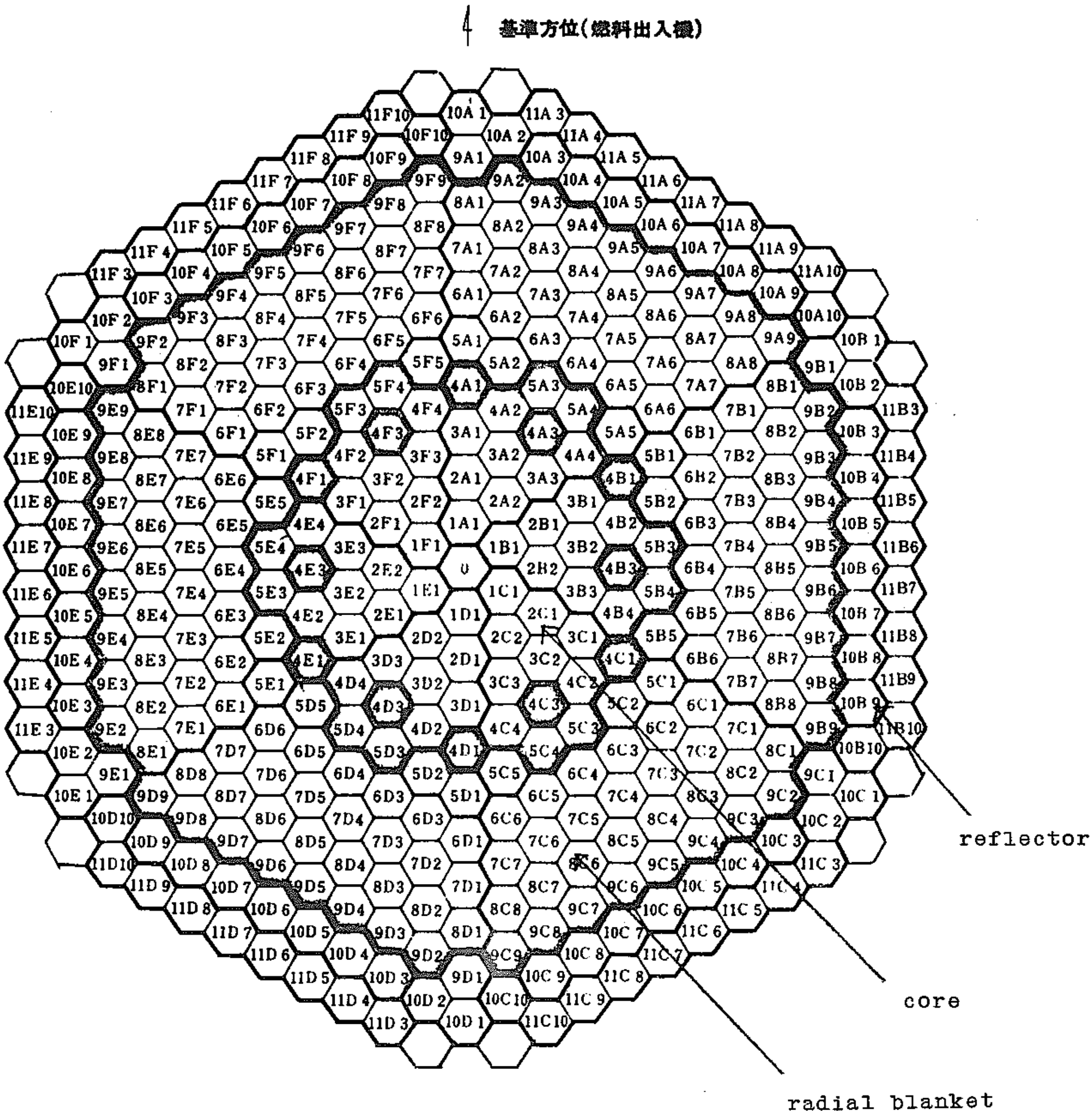
Axial Dimension

Radial Dimension

(common to all subassemblies)

(including the gap between subassemblies)

Fig.1 Sub-assembly dimension



Fine rod	4A1 , 4D1
Shim rod	4B1 , 4B3 , 4C1 , 4F1 , 4E3 , 4E1
Safety rod	4A3 , 4C3 , 4F3 , 4D3

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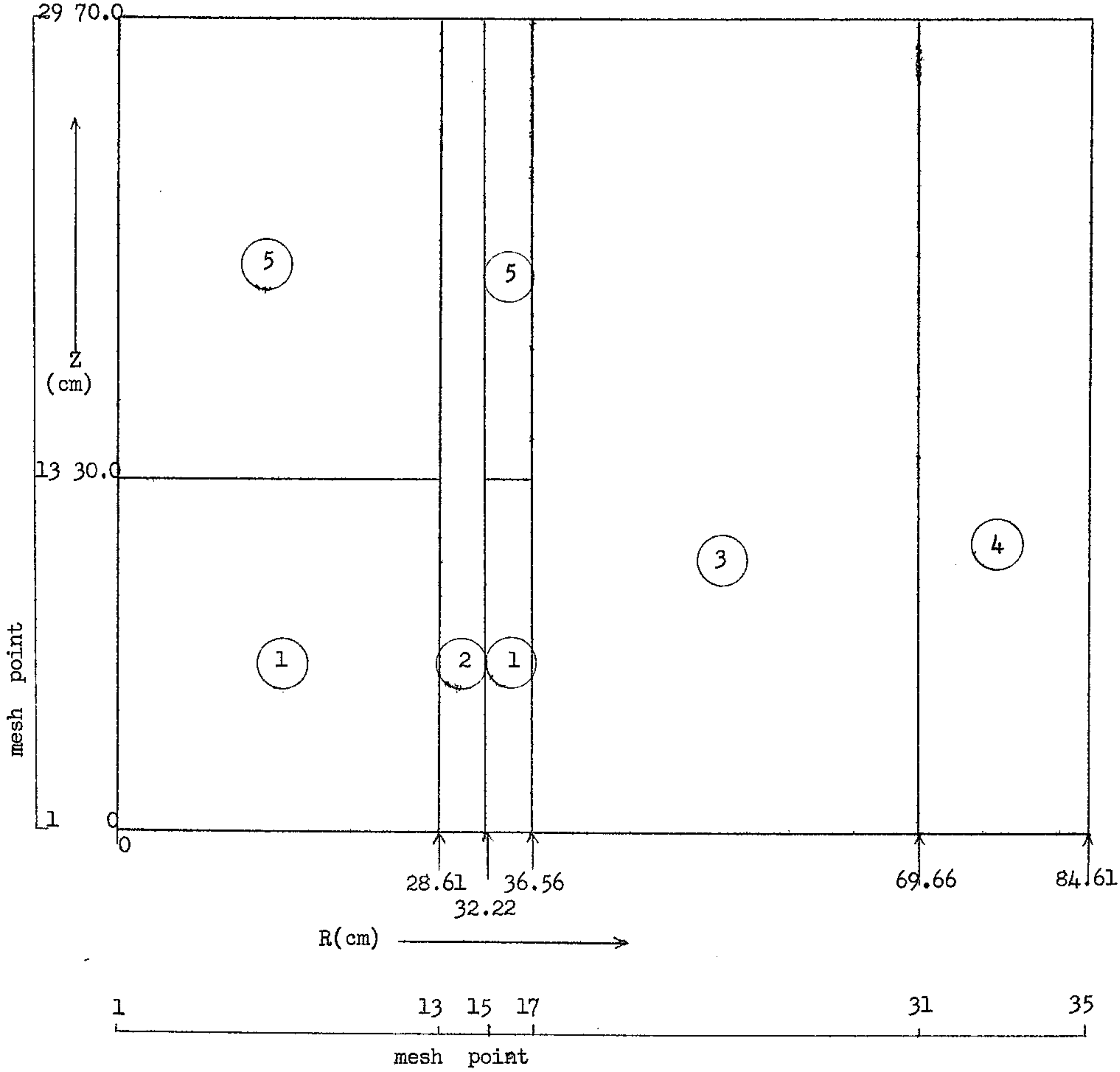
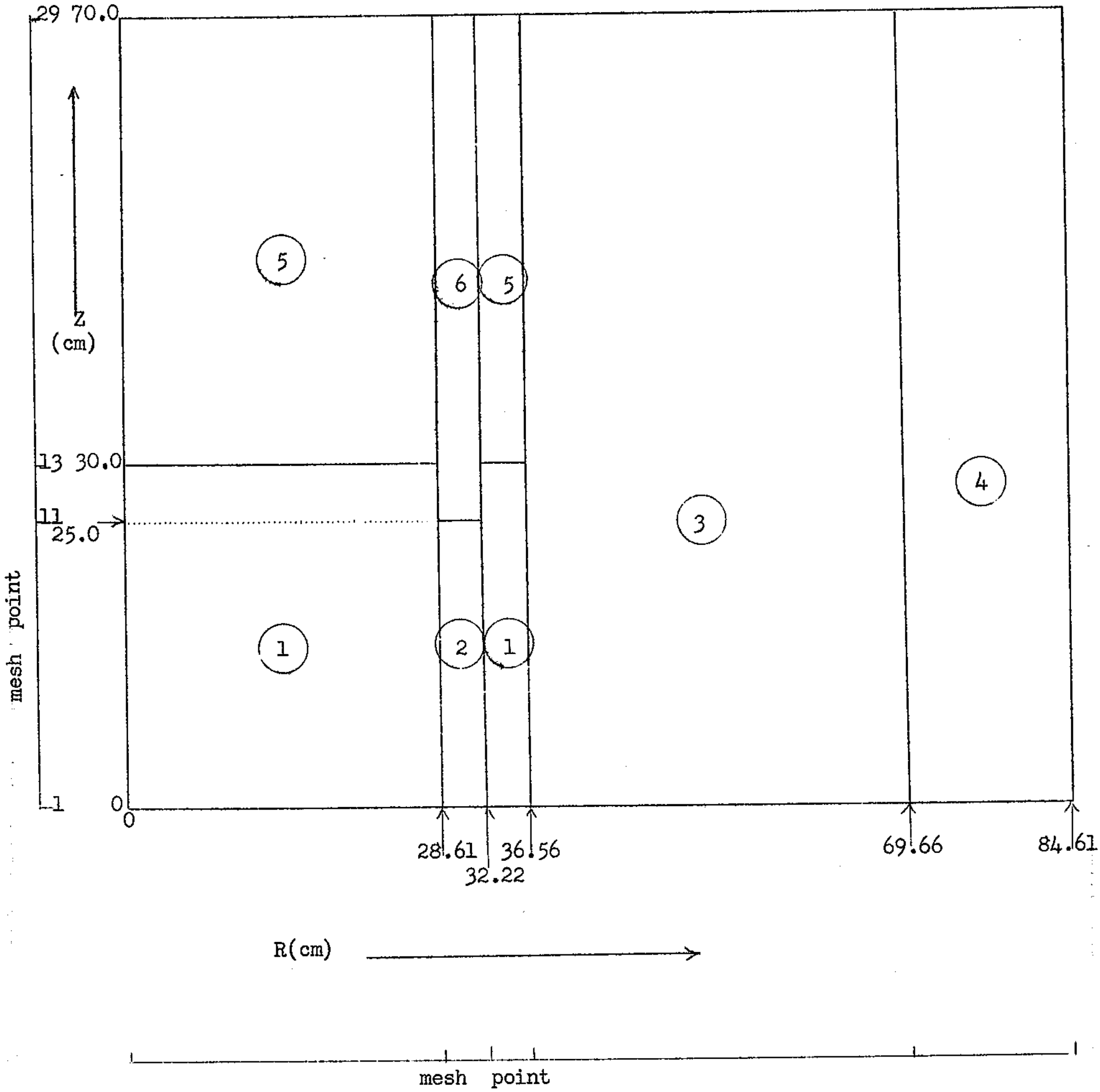
Fig.2 Core arrangement



1. Core , 2. Control rod region (rod out) , 3. Radial blanket ,

4. Reflector , 5. Axial blanket .

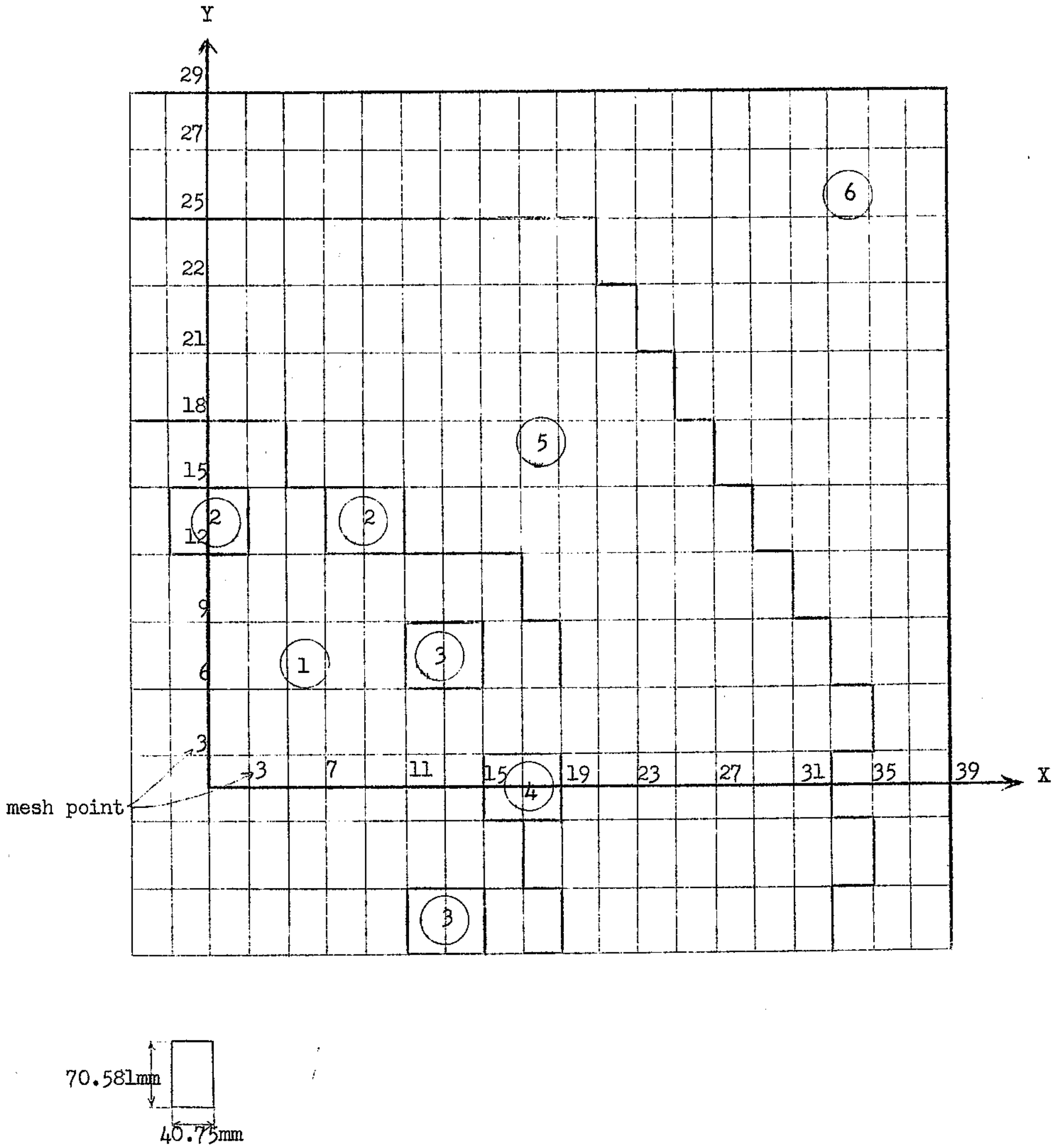
Fig. 3 The core configuration A : (R-Z) core with rod out



1. Core , 2. Control rod (absorber) , 3. Radial blanket ,

4. Reflector , 5. Axial blanket , 6. Control rod (structure) .

Fig. 4 The core configuration B : (R-Z) core with 6 shim rods in



1. Core , 2. Shim rod , 3. Safety rod , 4. Fine rod ,

5. Radial blanket , 6. Reflector .

Fig. 5 The core configuration C : (X-Y) core with rod in .

Table 1 The average atomic number densities in a sub-assembly

Tamperature : 20℃ except for sodium at 370 ℃

unit 10^{22} cm^{-3}

	CORE	AXIAL BLANKET	RADIAL BLANKET	ANY CONTROL ROD (ROD OUT)	SAFETY ROD (ROD IN)	SHIM ROD (ROD IN)	FINE ROD (ROD IN)	RADIAL REFLECTOR
Pu 239	0.10928	0	0	0	0	0	0	0
Pu 240	0.03905	0	0	0	0	0	0	0
Pu 241	0.00782	0	0	0	0	0	0	0
U 235	0.17369	0.00605	0.00761	0	0	0	0	0
U 238	0.54307	0.85840	1.07997	0	0	0	0	0
B 10	0	0	0	0	4.0580	2.4228	1.2450	0
B 11	0	0	0	0	0.4014	0.4276	1.5216	0
C	0	0	0	0	1.1148	0.7126	0.6916	0
O	1.72834	1.7116	2.1534	0	0	0	0	0
Na	0.9267	0.9267	0.7364	1.9449	0.6869	0.9333	0.9333	0.1135
Cr	0.3522	0.3522	0.3164	0.2491	0.5000	0.5572	0.5572	1.6563
Fe	1.1477	1.1477	1.0312	0.8119	1.6295	1.8158	1.8158	5.3975
Ni	0.1970	0.1970	0.1770	0.1394	0.2797	0.3117	0.3117	0.9265
Mo	0.0251	0.0251	0.0226	0.01776	0.03565	0.03973	0.03973	0.1181

Table 2 The regional atomic number densities in tne configuration A

unit $10^{22}\ cm^{-3}$

	CORE	CONTROL ROD (OUT)	RADIAL BLANKET	RADIAL REFLECTOR	AXIAL BLANKET	
	①	②	③	④	⑤	
Pu 239	0.10928	0	0	0	0	
Pu 240	0.03905	0	0	0	0	
Pu 241	0.00782	0	0	0	0	
U 235	0.17369	0	0.00761	0	0.00605	
U 238	0.54307	0	1.07997	0	0.85840	
B10	0	0	0	0	0	
B11	0	0	0	0	0	
C	0	0	0	0	0	
O	1.72834	0	2.1534	0	1.7116	
Na	0.9267	1.9449	0.7364	0.1135	0.9267	
Cr	0.3522	0.2491	0.3164	1.6563	0.3522	
Fe	1.1477	0.8119	1.0312	5.3975	1.1477	
Ni	0.1970	0.1394	0.1770	0.9265	0.1970	
Mo	0.0251	0.01776	0.0226	0.1181	0.0251	

Table 3 The regional atomic number densities in the configuration B

unit 10^{22} cm^{-3}

	CORE ①	SHIM ROD IN ②	RADIAL BLANKET ③	RADIAL REFLECTOR ④	AXIAL BLANKET ⑤	CONTROL ROD STEM ⑥	
Pu 239	0.10928	0	0	0	0	0	
Pu 240	0.03905	0	0	0	0	0	
Pu 241	0.00782	0	0	0	0	0	
U 235	0.17369	0	0.00761	0	0.00605	0	
U 238	0.54307	0	1.07997	0	0.85840	0	
B 10	0	1.2114	0	0	0	0	
B 11	0	0.2138	0	0	0	0	
C	0	0.3563	0	0	0	0	
O	1.72834	0	2.1534	0	1.7116	0	
Na	0.9267	1.4391	0.7364	0.1135	0.9267	1.9449	
Cr	0.3522	0.40315	0.3164	1.6563	0.3522	0.2491	
Fe	1.1477	1.31385	1.0312	5.3975	1.1477	0.8119	
Ni	0.1970	0.22555	0.1770	0.9265	0.1970	0.1394	
Mo	0.0251	0.028745	0.0226	0.1181	0.0251	0.01776	

Table 4 The regional atomic number densities in the configuration C

unit 10^{22} cm^{-3}

	CORE	SHIM ROD (ROD IN)	SAFETY ROD (ROD IN)	FINE ROD (ROD IN)	RADIAL BLANKET	RADIAL REFLECTOR	
	①	②	③	④	⑤	⑥	
Pu 239	0.10928	0	0	0	0	0	
Pu 240	0.03905	0	0	0	0	0	
Pu 241	0.00782	0	0	0	0	0	
U 235	0.17369	0	0	0	0.00761	0	
U 238	0.54307	0	0	0	1.07997	0	
B 10	0	2.4228	4.0580	1.2450	0	0	
B 11	0	0.4276	0.4014	1.5216	0	0	
C	0	0.7126	1.1148	0.6916	0	0	
O	1.72834	0	0	0	2.1534	0	
Na	0.9267	0.9333	0.6869	0.9333	0.7364	0.1135	
Cr	0.3522	0.5572	0.5000	0.5572	0.3164	1.6563	
Fe	1.1477	1.8158	1.6295	1.8158	1.0312	5.3975	
Ni	0.1970	0.3117	0.2797	0.3117	0.1770	0.9265	
Mo	0.0251	0.03973	0.03565	0.03973	0.0226	0.1181	

I-3 Nuclear Check Calculation by CEA

1. Cross sections

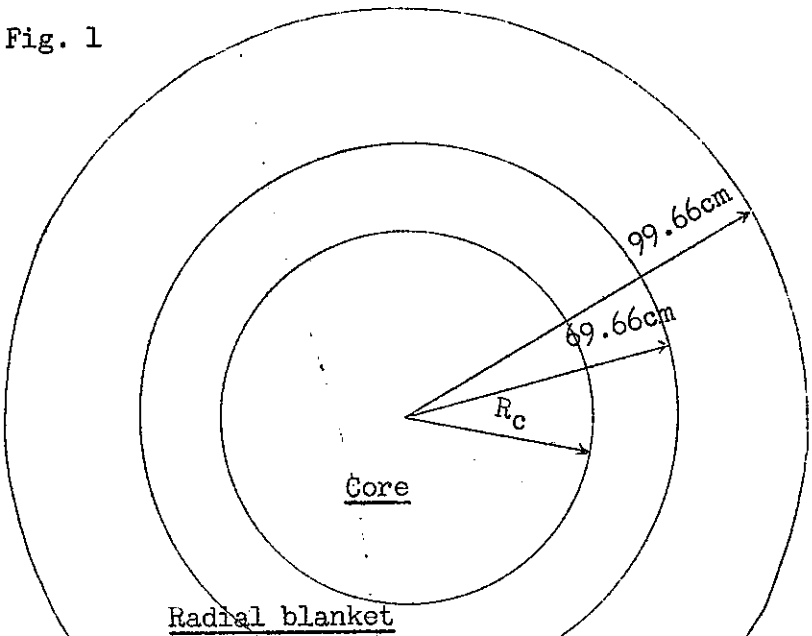
A 25 group set was prepared, from our Cadarache set Version 2. Version 1 was directly derived from the Winfrith Data File. Version 2 was obtained in the following manner : With the BARRACA method, and with Version 1 as a starting point, many critical experiments were analysed (cf. J.Y. BARRE and J. RAVIER, papers presented at the IAEA Meeting, Karlsruhe 1967, and BNES Meeting this June, London).

This procedure suggested some modifications in the cross sections. Based on this, and on the differential measurements available, a new evaluation was made, leading to Version 2.

2. Comparision between "MUDE" and DTF 4 (S_4 and S_8) by spherical models

On the spherical model, as shown on Fig. 1, we made a first calculation using diffusion theory (MUDE Code, 25 g).

Fig. 1



Atom numbers were taken from the JEFR paper of Feb. 21, 1969 : "the core composition of JFER". For an eigenvalue of 1.0, we found a critical radius of :

$$Rc = 33.15 \text{ cm.}$$

The core radius was divided into 40 mesh points, blanket thickness into 30 mesh points and reflector thickness into 30 mesh points.

The value of the critical radius found by MUDE calculation, as well as the atom numbers used, were taken as input data for transport 1D calculation (DTF_4). Results are :

- Calculation by S_4 , 25 g (see fig. 1) : k_{eff} = 1.01610
- Calculation by S_8 , 25 g (see fig. 1) : k_{eff} = 1.01477

The same number of mesh points as used in diffusion calculation was used for each zone. The result, found for ΔK :

$$(S_8) - (\text{diffusion}) = 1477 \; 10^{-5} \quad \Delta k/k$$

seems to be in agreement with our former calculations.

3. Nuclear characteristics research by "524 S"

This code "524 S", also named in Cadarache "code REVE", is a 2D diffusion theory code, with burn-up calculations. The geometrical configurations and the mesh point scheme are given in fig. 2. We used a 11 group cross section set from the 25 group set; see fig. 3 for the group condensation, where is also given the weighting spectrum, which is that calculated at the core center (DTF S_8 spherical model).

Total thermal power

was fixed at 92 MWth. Conversion factor : number of fissions /sec by watt was fixed at 2.98 10^{10} in order to take into account all the thermal release inside the reactor (γ etc...)

Burn-up calculations were done for three steps of 28 days. The results are the following :

- Initial value of k_{eff}	1.01318
- successive values of k_{eff} after each cycle of 28 days :	1.00835
	1.00375
	0.99915

A loss of 1403 10^{-5} $\Delta k/k$ for a period of 84 days (an average value of 16.7 10^{-5} $\Delta k/k$ per day) is then derived.

Breeding ratios are defined as follows :

$$\text{IBR} = \text{Internal breeding ratio} = \frac{\text{fissile atoms created in the core}}{\text{fissile atoms destroyed in the core}}$$

(captures + fissions)

$$\text{EBR} = \text{External breeding ratio} = \frac{\text{fissile atoms created in the blanket}}{\text{fissile atoms destroyed in the core}}$$

(captures + fissions)

Breeding ratio values were found to be :

Initial state of the core	after 84 days burn-up
IBR = 0.207	IBR = 0.212
EBR = 0.714	EBR = 0.735
total B.R. = 0.921	total B.R. = 0.947

Fig. 4 and Fig. 5 give the power distributions in the core (radial and axial distributions) for initial conditions and after 84 days of burn-up.

4. Control rod calculations by transport theory (DTF 4) -

1D - Transport calculations were done in order to calculate the worth of safety rod and shim rod at the center of JEFR [DTF 4 - S_4 cylindrical model of the core; axial height used in DTF 4 : 84.5 cm, i.e. extrapolated height - ($2 \times 0.71 \times \lambda_t$)]

Results obtained are :

- reference core, nominal enrichment	k_{eff} = 1.04150
- central zone (1 subassembly) with "rod out" medium	k_{eff} = 1.02527
- central zone with safety rod	k_{eff} = 0.96960
- central zone with shim rod	k_{eff} = 0.98360

The worth of the control rods at the core center is then the following

- safety rod	:	$5567\ 10^{-5}\ \Delta k/k$
- shim rod	:	$4167\ 10^{-5}\ \Delta k/k$

Remarks :

1° - Mesh points divisions are given here-under :

total number of mesh point (m.p.) : 100

8m.p.	41m.p.	8m.p.	7m.p.	28m.p.	8m.p.
Central Control rod	Core	Control rod region	Core	blanket	Reflector

0

2° - The relative difference between the 524 S calculation (11 g) and the DTF 4 reference calculation (25 g)

$$k = 1.04150 - 1.01318 = 2832\ 10^{-5}.$$

may be explained as follows :

- 25 g → 11 g condensation :		$550\ 10^{-5}$	$\Delta k/k$
- effects of the presence of the control absorbing zone in the upper axial blanket		$950\ 10^{-5}$	$\Delta k/k$
- transport → diffusion	~	$1500\ 10^{-5}$	$\Delta k/k$
- remaining reactivity (inaccuracies on the buckling or extrapolated height)	~	$-178\ 10^{-5}$	$\Delta k/k$
Total		$2832\ 10^{-5}$	$\Delta k/k$

5. Comments

Tests of the Cadarache set Version 2 have been performed on various assemblies, as described in the paper by J.Y. BARRE and J. RAVIER et al. to be presented at the BNES London Conference, June 1969)

Calculations made in transport theory (S_∞), with heterogeneity and geometrical corrections, provided the following results (given as Pu assemblies examples)

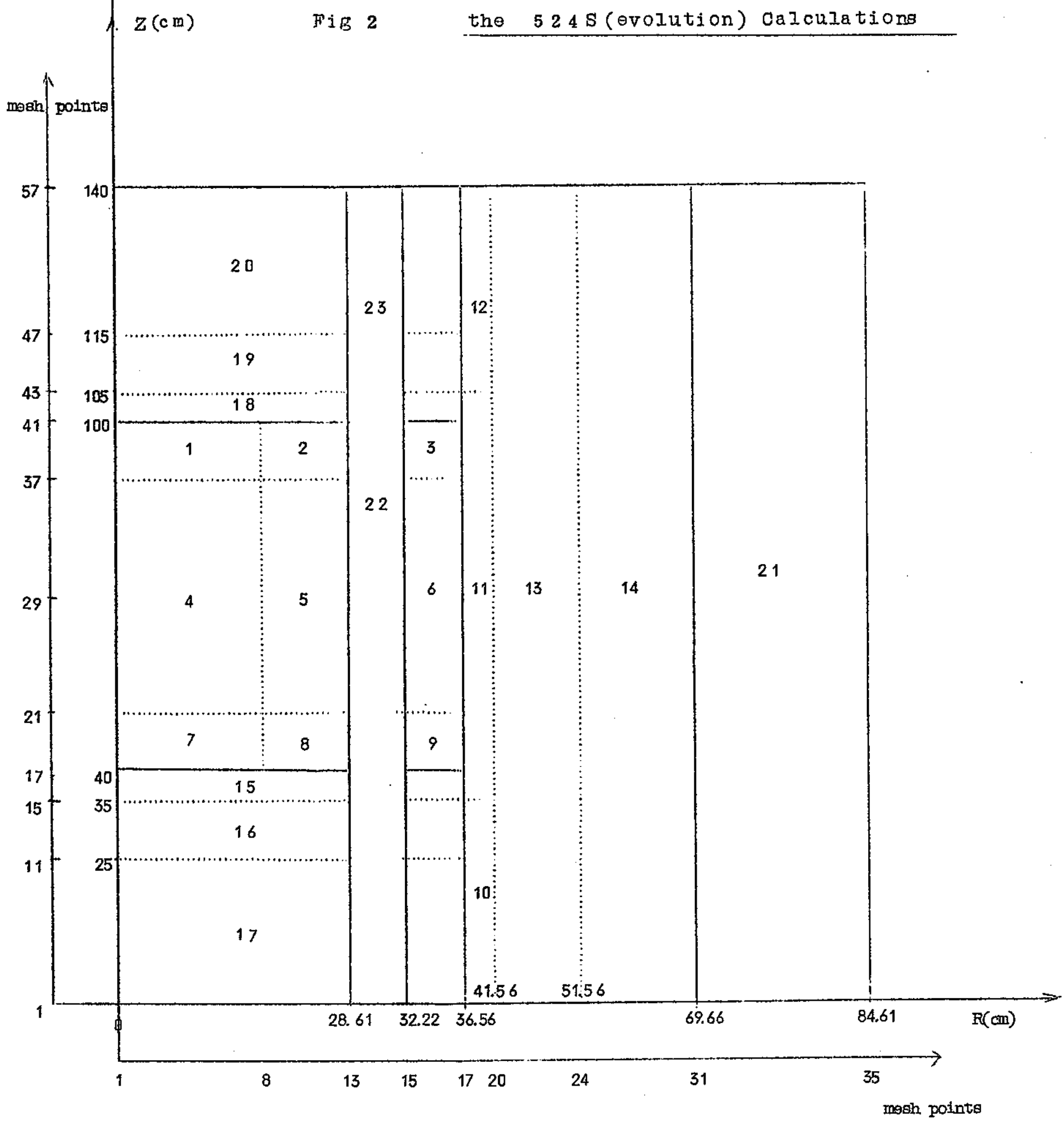
			experimental	calculated version 2
Rapsodie	k_{eff}	=	1.0	1.006
Masurca 1A	k_{eff}	=	1.0	0.993
ZPR N° 48	k_{eff}	=	1.0	1.008

Control rod calculations made for Rapsodie gave a discrepancy of 30% (diffusion theory), that is about 20 % (transport theory).

	experimental	calculation
safety rod worth (Rapsodie) at the edge of the core	$1640\ 10^{-5} \pm 60\ 10^{-5}\ \Delta k/k$	$2150\ 10^{-5}\ \Delta k/k$

JEFR Neutronic model used for

Fig 2 the 524S (evolution) Calculations



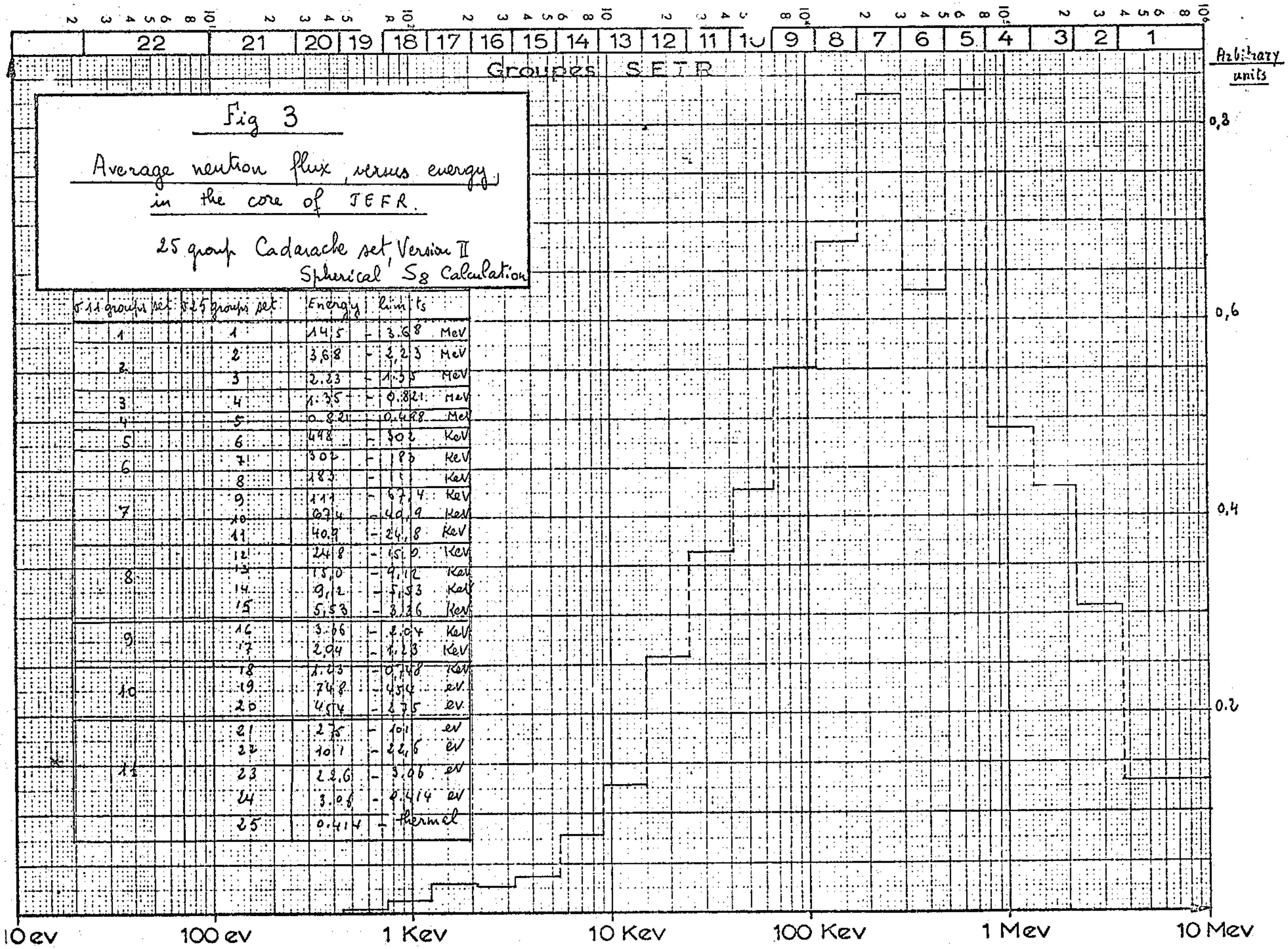
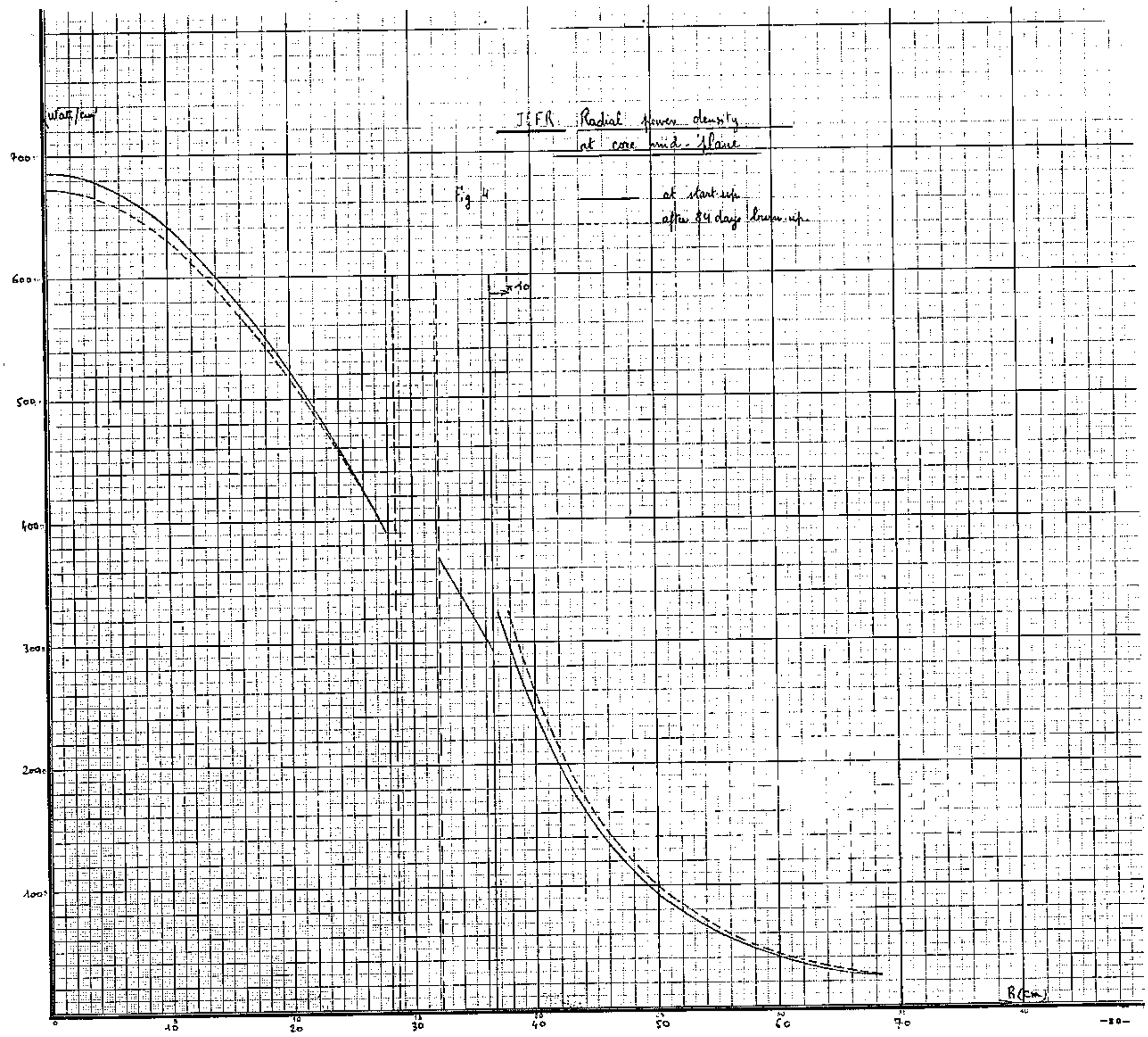


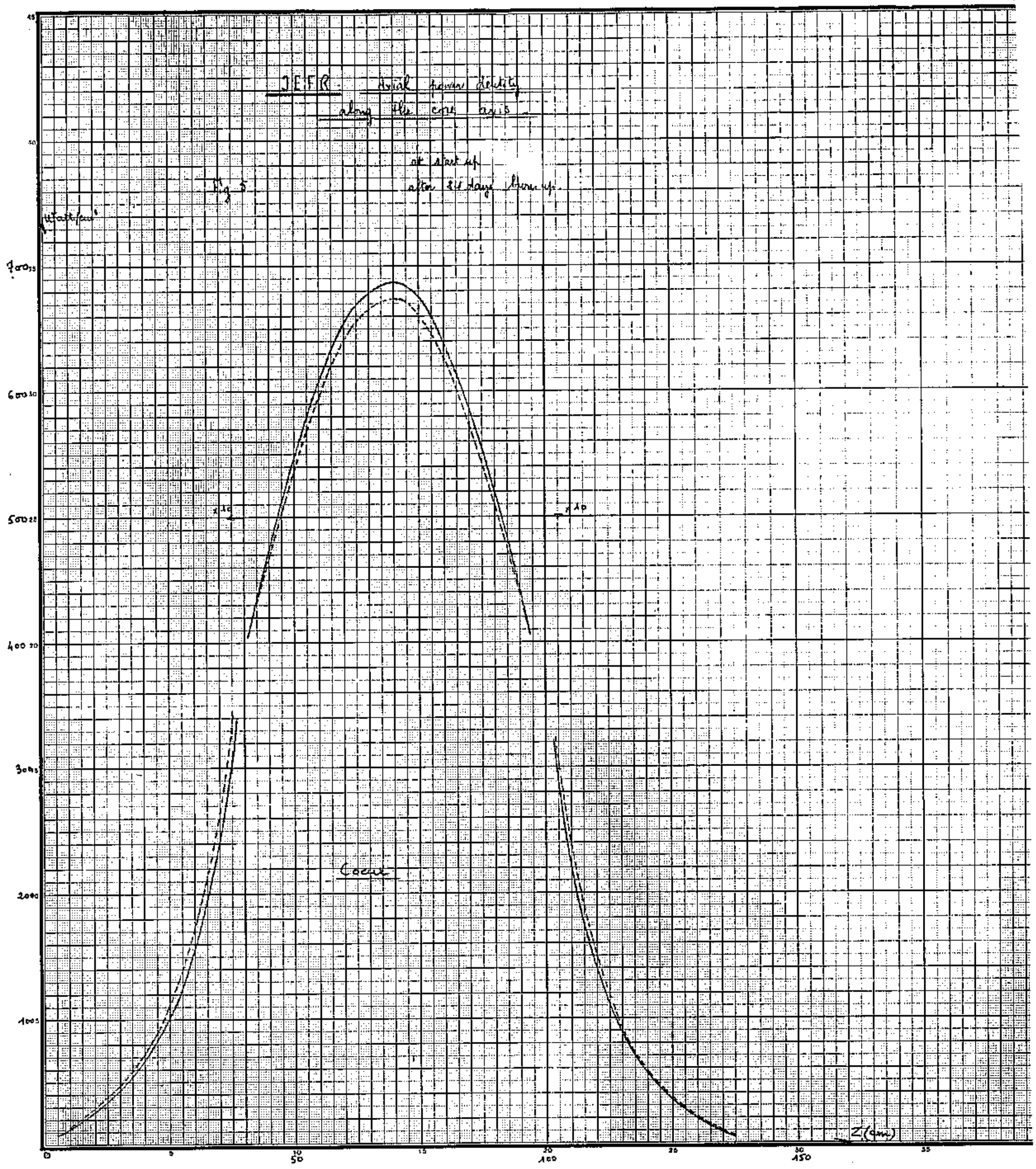
Fig 3

Average neutron flux, versus energy, in the core of JEFR.

25 group Cadarache set, Version II
Spherical S8 Calculation

11 groups set	25 groups set	Energy limits	
1	1	14,5 – 3,68	MeV
2	2	3,68 – 2,23	MeV
	3	2,23 – 1,35	MeV
3	4	1.35 – 0.821	MeV
4	5	0.821 – 0,498	MeV
5	6	498 – 302	KeV
6	7	302 – 183	KeV
	8	183 – 111	KeV
7	9	111 – 67,4	KeV
	10	67,4 – 40,9	KeV
	11	40,9 – 24,8	KeV
	12	24,8 – 15,0	KeV
8	13	15,0 – 9,12	KeV
	14	9,12 – 5,53	KeV
	15	5,53 – 3,36	KeV
9	16	3,36 – 2,04	KeV
	17	2,04 – 1,23	KeV
10	18	1,23 – 0,748	KeV
	19	748 – 454	eV
	20	454 – 275	eV
11	21	275 – 101	eV
	22	101 – 22,6	eV
	23	22,6 – 3,06	eV
	24	3,06 – 0,414	eV
	25	0,414 – thermal	


Watt/cm³
700
600
500
400
300
200
100
J.F.R. Radial power density
at core mid-plane
Fig. 4
at start up
after 84 days burn up
0
10
20
30
40
50
60
70
R (cm)


JEFR axial power density
along the core axis
at start up
Fig 5
Watt/cm
700
600
500
400
300
200
100
Coeur
50
100
150
Z (cm)

I-4 Questionnaire and Answer

(Q1) Calculations by "5245"

Was the 11 group set which was obtained by the group condensation with the weighting spectrum at the core center, used in the control rod, blanket and reflector region too ?

If not, what kind of the weighting spectrum was used in the group condensation in the control rod, blanket and reflector region ?

(A) The weighting spectra used were drawn from the spherical transport calculation (DTF_4 - S_8), done for our preliminary study of JEFR (item 1). The geometrical configuration was the following :

1 - core

2 - radial blanket

3 - stainless steel reflector

Core spectrum was used to weight the cross sections in the core, in the control rods zone without absorbing material situated in the core and in the control rod zone with absorbing material situated above the core.

Radial blanket spectrum was used to weight the cross sections in the blanket (axial blanket and radial blanket).

Stainless steel reflector spectrum was used to weight the cross sections in the steel reflector.

N.B. -

It must be read on page 2 (last three lines) of the "Nuclear check calculation for JEFR" (item 3) :
"see fig. 3 for the group condensation, where is also given the weighting spectrum for the core, which is the averaged spectrum calculated over the core region" (DTF - S_8 spherical model).

(Q2) Control rod calculations by "DTF 4"

i) How much is the leakage in the axial direction treated by the 1D-transport calculation ?

Is the axial hight used in DTF 4 (84.5 cm) common to core, control rod, blanket and reflector regions ?

ii) Does the control zone with "rod out" medium of item 4 mean the absence of the absorbing material in the upper axial blanket ?

iii) Was the effect of condensation from 25 groups to 11 groups evaluated by diffusion code "524 S" ?

iv) How did you obtain the value of 1500 · 10^{-5} k/k for the difference between transport theory and diffusion theory ?

(A) i) - The 1 D - transport calculations were done by using an axial height of 84.5 cm common to all regions (core, control rod, blanket and reflector region), and deduced from an estimation of the averaged axial buckling, as given by the 2 D-524 S calculation.

ii) - Calculation were done in 1 D - geometrical configuration. So, it is impossible to take into account the presence of the absorbing material in the upper axial blanket, unless by adjusting the reactivity.

iii) - The effect of condensation from 25 groups to 11 groups was done only by 1 D - calculation (code MUDE) with the same buckling ($B^2_{axial} = 1.065\ 10^{-3}$). (This is essentially the effect of the diffusion coefficient values, as calculated from the microscopic 11 g cross sections; with the directly condensed diffusion coefficients from the 25 g values, there is practically no difference in k_{eff} between the 25 g and the 11 g calculations).

iv) - See item 1, where it is stated that there is 1477 10^{-5} $\Delta k/k$ between transport and diffusion calculation done on a spherical model of JEFR.

Ｉ－５　ＡＢＮ set，ＤＴＦ－Ⅳ による制御棒価値の計算

（本項は東芝での計算による）

一次元トラスポートコードＤＴＦ－Ⅳを用いてＪＥＦＲ円筒形体系の炉心中心における制御棒（ＳＡＦＥＴＹ　ＲＯＤ）価値を計算した。群定数はＡＢＮセットを使用し，ＤＴＦ－Ⅳへのマクロ断面積は次のように計算した。

$$\Sigma t = \underset{i}{\mathrm{Sum}}\ N^{i} \times \{ \bar{\sigma}^{i}_{c} + \bar{\sigma}^{i}_{f} + \bar{\sigma}^{i}_{in} + \bar{\sigma}^{i}_{el} (1-\mu^{i}_{e}) \} \quad (1)$$

$$\Sigma j \to j = \underset{i}{\mathrm{Sum}}\ N^{i} \times \{ \sigma^{i}_{in} (j \to j) + \bar{\sigma}^{i}_{el} - \bar{\sigma}^{i}_{d}(e) - \mu^{i}_{e} \times \bar{\sigma}^{i}_{el} \} \quad (2)$$

他のマクロ定数はＥＸＰＡＮＤＡ－２と同様に計算した。

計算は２５群，S_4で行いＤＴＦ－ⅣのＣＯＲＥ　ＨＥＩＧＨＴには８４.５cmを入力した。

計算結果

	ＤＴＦ－Ⅳ（ＡＢＮ）	ＤＴＦ－Ⅳ（Cadarache－2）	ＥＸＰＡＮＤＡ－２（ＡＢＮ）
ＲＯＤ　ＯＵＴ	1.05623	1.02527	0.99510
ＳＡＦＥＴＹ　ＲＯＤ　ＩＮ	0.99810	0.96960	0.93940
$-\Delta R/R$　（％）	5.5035	5.4298	5.5974

以上から

1. 中心制御棒価値に対するSn 計算と拡散計算の差は比較的小さい。
2. Cadareche －２セットを用いたフランスの計算結果とも良く一致している。

Σt の計算方法

前回（燃料ラックの核的検討）＊ の時は

$$\Sigma_t = \frac{1}{3D}$$

$$= \underset{i}{\mathrm{Sum}}\ N^{i} \times \{ (\bar{\sigma}^{i}_{t} - \sigma^{i}_{in} - \bar{\sigma}^{i}_{c} - \bar{\sigma}^{i}_{f}) \times (1-\mu^{i}_{e}) + \bar{\sigma}^{i}_{in} + \bar{\sigma}^{i}_{c} + \bar{\sigma}^{i}_{f} \} \quad (3)$$

$$\Sigma_{j \to j} = \Sigma_t - \Sigma_a - (\underset{k=j+1}{\mathrm{Sum}} \Sigma_{j-k}) \qquad (4)$$

と計算したが，Σ_t を(3)式で計算するとCORE 領域（Group＝25）で

$$\Sigma_t < \Sigma_a$$

となり $\Sigma_{j \to j}$ が負になる。

これはPu^{239}の25群でのself － shielding factor と(3)式に問題があると考えられる。

Σ_t を(1)式で計算するとKeffは0.5％～1％程度大きくなる。

＊）Ⅱ　燃料ラックの核的検討を参照

Ⅱ　燃料ラックの核的検討

Ⅱ－1. はじめに

炉内燃料貯蔵ラック内炉心燃料集合体の発熱を検討するため，その核的検討を東芝および日本原子力研究所の協力を得て行なつた。

ここにその結果をとりまとめて示す。

II－2. 輸送計算による検討

燃料ラックの出力計算における拡散計算と輸送計算の相違を比較した。

1次元拡散コード：EXPANDA－2　（25群，78 mesh）

1次元輸送コード：DTF－IV　（25群，S_4，78 mesh）

WDSN　（25群，S_4，110 mesh）

群定数：　ABNセット

1. 計算体系は第1図に示す円筒形状で，各領域の原子数密度を第1表に示す。ここで，燃料ラック領域は新燃料26本が貯蔵されているとした。

2. 各コードでの固有値および燃料ラック領域の発生中性子数割合を下表に示す。

	EXPANDA－2	DAF－IV	WDSN
固有値	1.0844	1.0932	1.1063
発生中性子数割合	3.283×10^{-2}	3.293×10^{-2}	

DTF－IV，WDSNにおける transpor 補正は次のとおり。

1) DTF－IV

$$\Sigma_t(\mathrm{DTF-IV}) = \Sigma_{tr}(\mathrm{EXPANDA-2}) + DB^2$$

$$\Sigma_a(\mathrm{DTF-IV}) = \Sigma_a(\mathrm{EXPANDA-2}) + DB^2$$

$$\Sigma_{i\to i+1}(\mathrm{DTF-IV}) = \Sigma_{in}^{i\to i+1}(\mathrm{EXPANDA-2}) + \Sigma_r(\mathrm{EXPANDA-2})$$

$$\Sigma_{i\to i}(\mathrm{DTF-IV}) = \Sigma_t(\mathrm{DTF-IV}) - \Sigma_a(\mathrm{DTF-IV}) - \int_{j\neq i} \Sigma_{i\to j}(\mathrm{EXPANDA-2}) - \Sigma_f(\mathrm{DTF-IV})$$

$$\Sigma_{i\to j}(\mathrm{DTF-IV}) = \Sigma_{in}^{i\to j}(\mathrm{EXPANDA-2}) - (j=i+2,\ j+3, \cdots, i+9)$$

$$\Sigma_f(\mathrm{DTF-IV}) = \Sigma_f(\mathrm{EXPANDA-2})$$

2) ＷＤＳＮ

$$\Sigma_t(\mathrm{WDSN}) = \Sigma_t(\mathrm{EXPANDA-2}) + DB^2 - \Sigma_{s1}^{i\to i}\ (\mathrm{EXPANDA-2})$$

$$\Sigma_{so}^{i\to i}(\mathrm{WDSN}) = \Sigma_{so}^{i\to i}(\mathrm{EXPANDA-2}) - \Sigma_{s1}^{i\to i}\ (\mathrm{EXPANDA-2})$$

3. 中性子エネルギースペクトル，中性子束分布

炉心中央と燃料ラック中央位置における中性子エネルギースペクトルを第3図，第4図に示す。

炉内の中性子束分布を第5図に示す。燃料ラック領域でＷＤＳＮはＥＸＰＡＮＤＡ−2，ＤＴＦ−Ⅳより低い分布を示している。

第6図に炉心中央における全中性子束と燃料ラック各点における全中性子束との比を示す。

4. 燃料ラック領域の非均質効果

これまでの計算は燃料ラック領域中の燃料を均質化して行なつたが，非均質の取扱い（第2図）では次の結果となる。

（ＥＸＰＡＮＤＡ−2による）

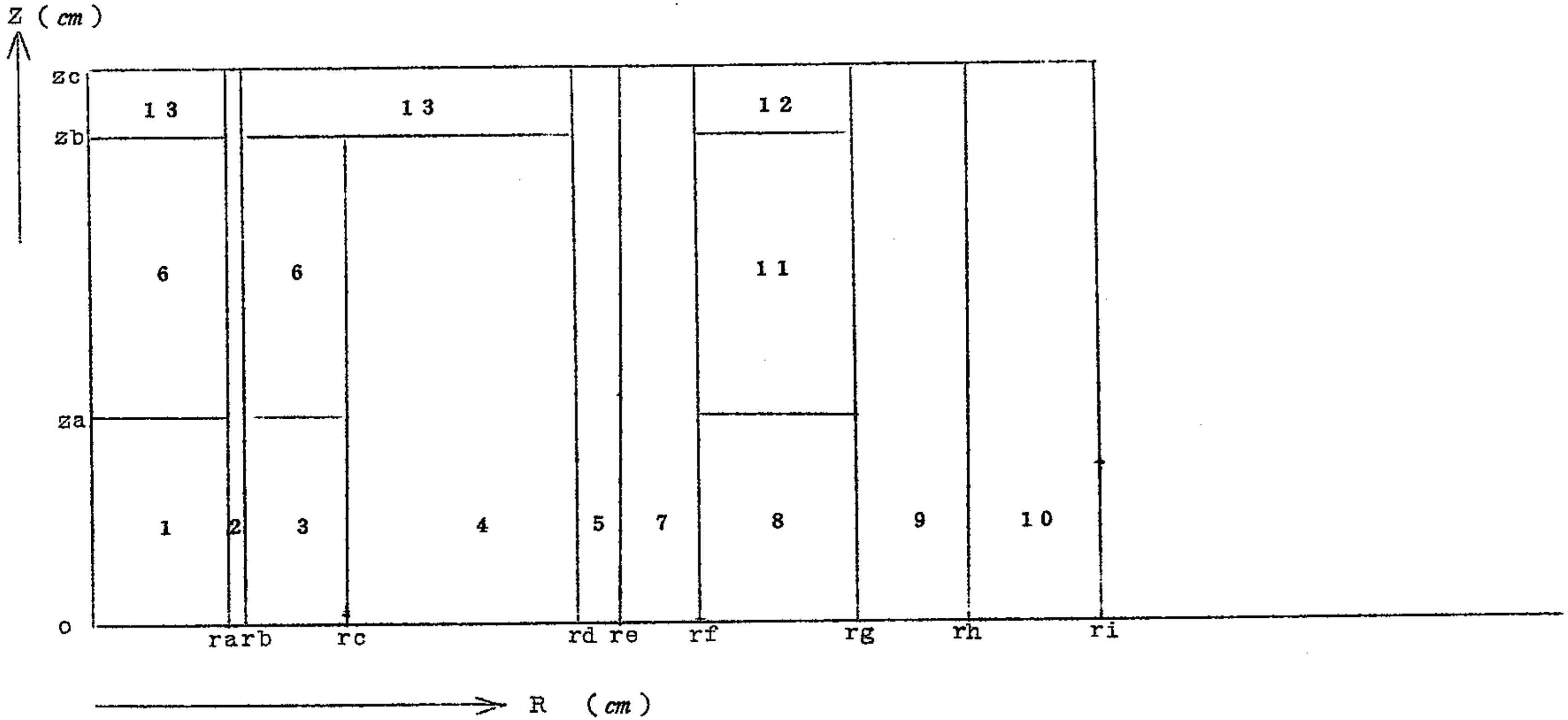
	均　質	非均質	変化高
発生中性子割合	3.2834×10^{-2}	2.7000×10^{-2}	-0.5834×10^{-2} （17.8％）

第1表　原子数密度

（単位 10^{22} /cm³）

核種＼領域	炉心	制御棒	半径方向ブランケット	反射体	鋼板	燃料ラック	遮蔽体	ナトリウム
Pu 239	0.1093					0.01149		
Pu 240	0.03905					0.0041		
Pu 241	0.00781					0.00082		
U 235	0.1665		0.00279			0.0175		
U 238	0.5505		1.10			0.05784		
O	1.729		2.206			0.1817		
Na	0.9212	1.900	0.7304	0.4536	1.435	1.899	0.7073	2.269
Cr	0.3563	0.2838	0.3086	1.468	0.6749	0.2323	1.263	
Fe	1.161	0.925	1.006	4.853	2.231	0.7678	4.176	
Ni	0.1993	0.1588	0.1727	0.5853	0.269	0.09259	0.5035	
Mo	0.002514	0.02024	0.02201					

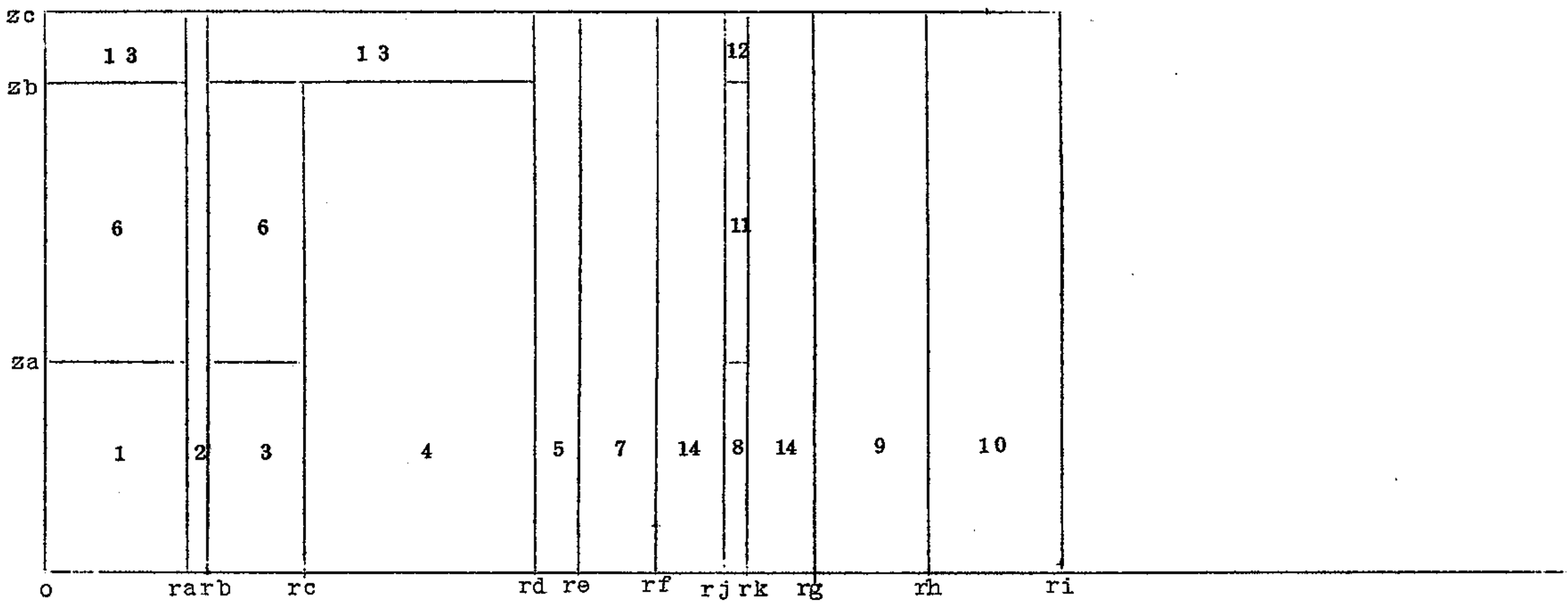
（20℃時，但しNaのみは370℃とする）



ra＝2 0.2 8 9cm　za＝3 0cm
rb＝2 2.8 3 7 〃　zb＝7 0 〃
rc＝3 6.5 6 0 〃　zc＝8 0 〃
rd＝6 9.6 5 8 〃
re＝7 5.7 0 4 〃
rf＝8 7.0 0 0 〃
rg＝110.00 〃
rh＝126.00 〃
ri＝145.00 〃

1　内部炉心
2　制御棒領域
3　外部炉心
4　半径方向ブランケット
5　半径方向反射体
6　軸方向ブランケット
7　SUS, ナトリウム混成領域
8　燃料ラック領域炉心燃料部
9　シヤヘイ板ゾーン
10　ナトリウム領域
11　燃料ラック領域 ブランケット燃料部
12　〃　スリーブ部
13　スリーブ

図 1　円筒形炉心形状　（HOMOGENEOUS case）

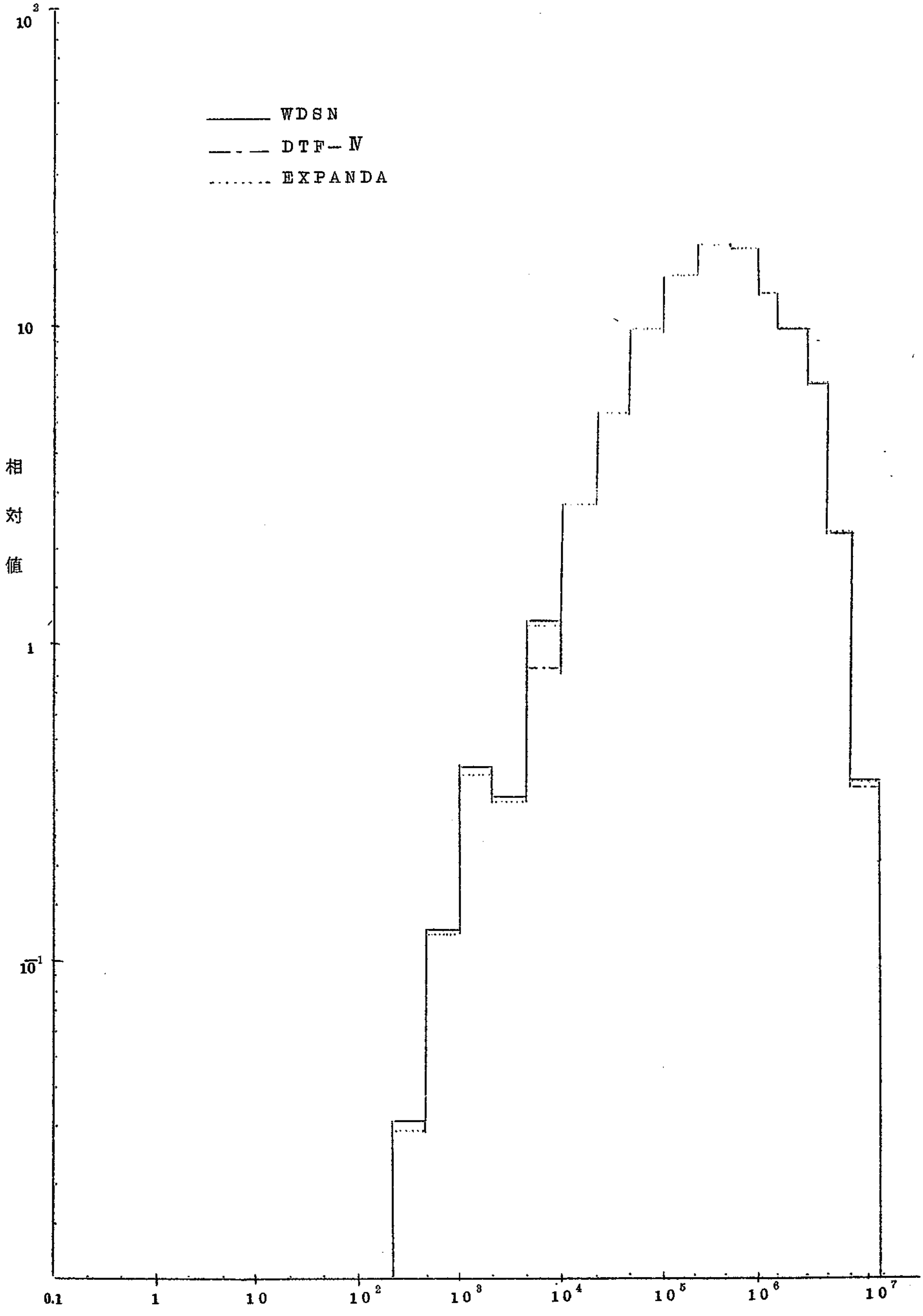


ra = 20.289 cm
rb = 22.837 〃
rc = 36.560 〃
rd = 69.658 〃
re = 75.704 〃
rf = 87.000 〃
rj = 97.292 〃
rk = 99.708 〃
rg = 110.00 〃

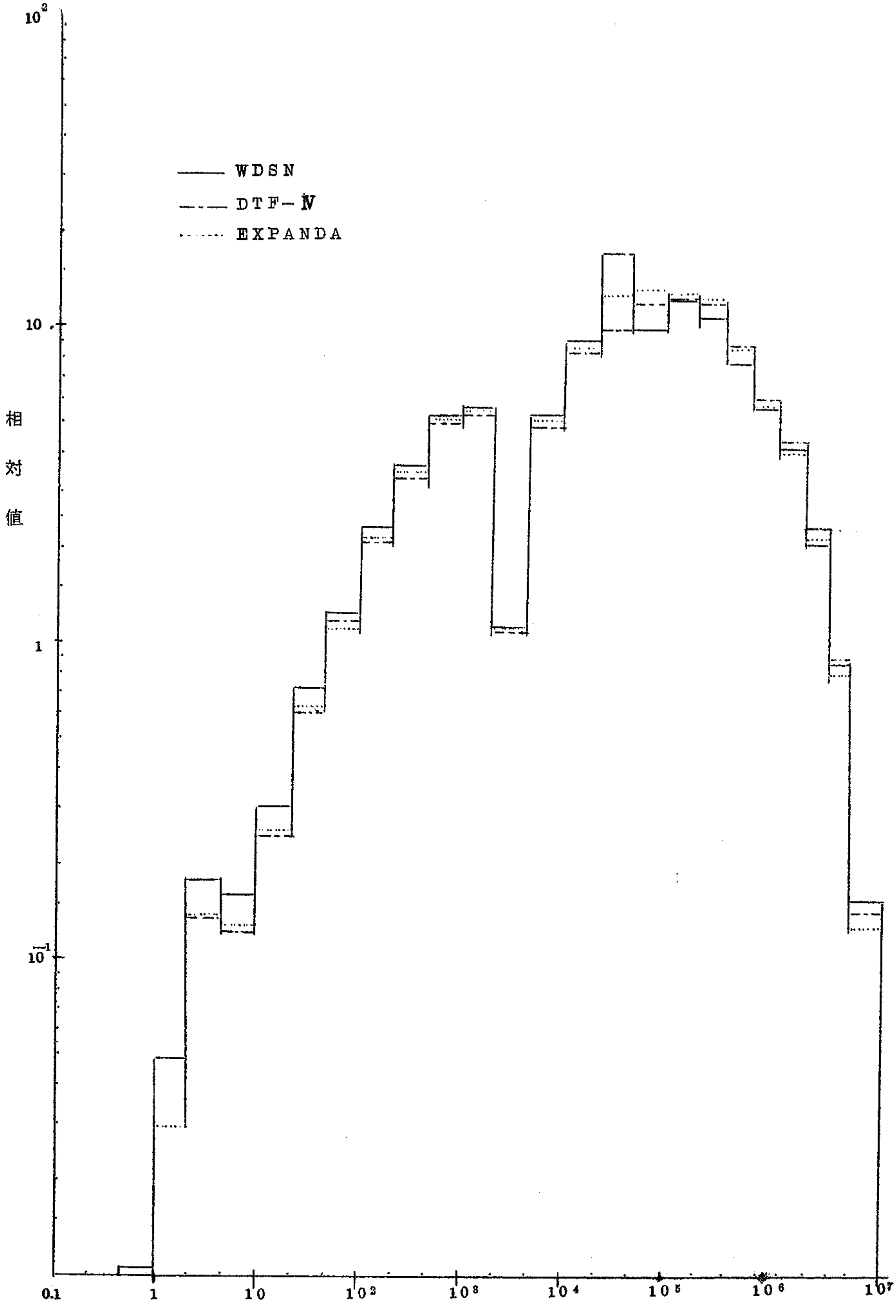
rh = 126.00 cm
ri = 145.00 cm

za = 30.0 cm
zb = 70.0 cm
zc = 80.0 cm

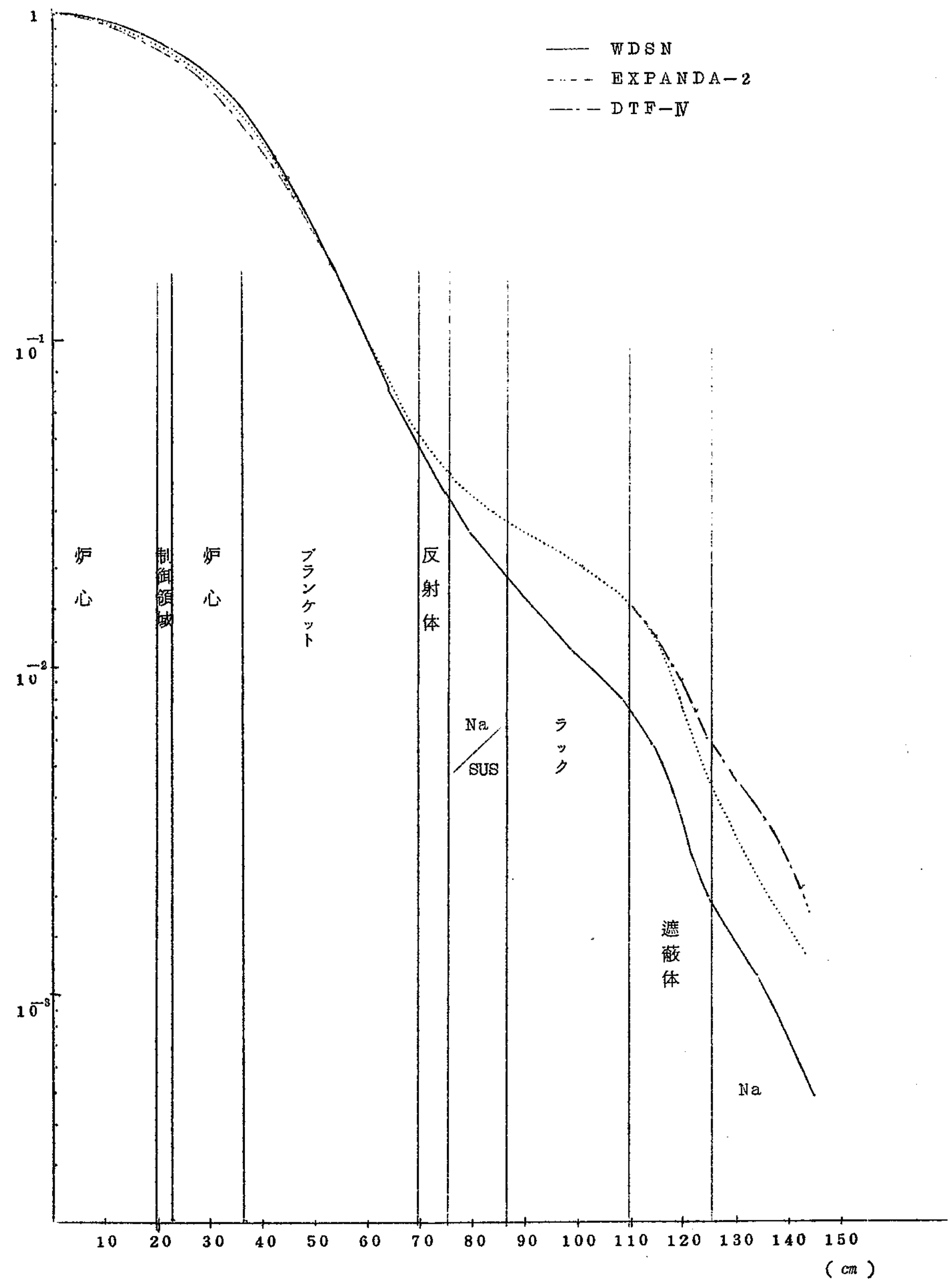
図 2　円筒形炉心形状　（HETEROGENEOUS case）



第３図　中性子スペクトル（炉心中央）

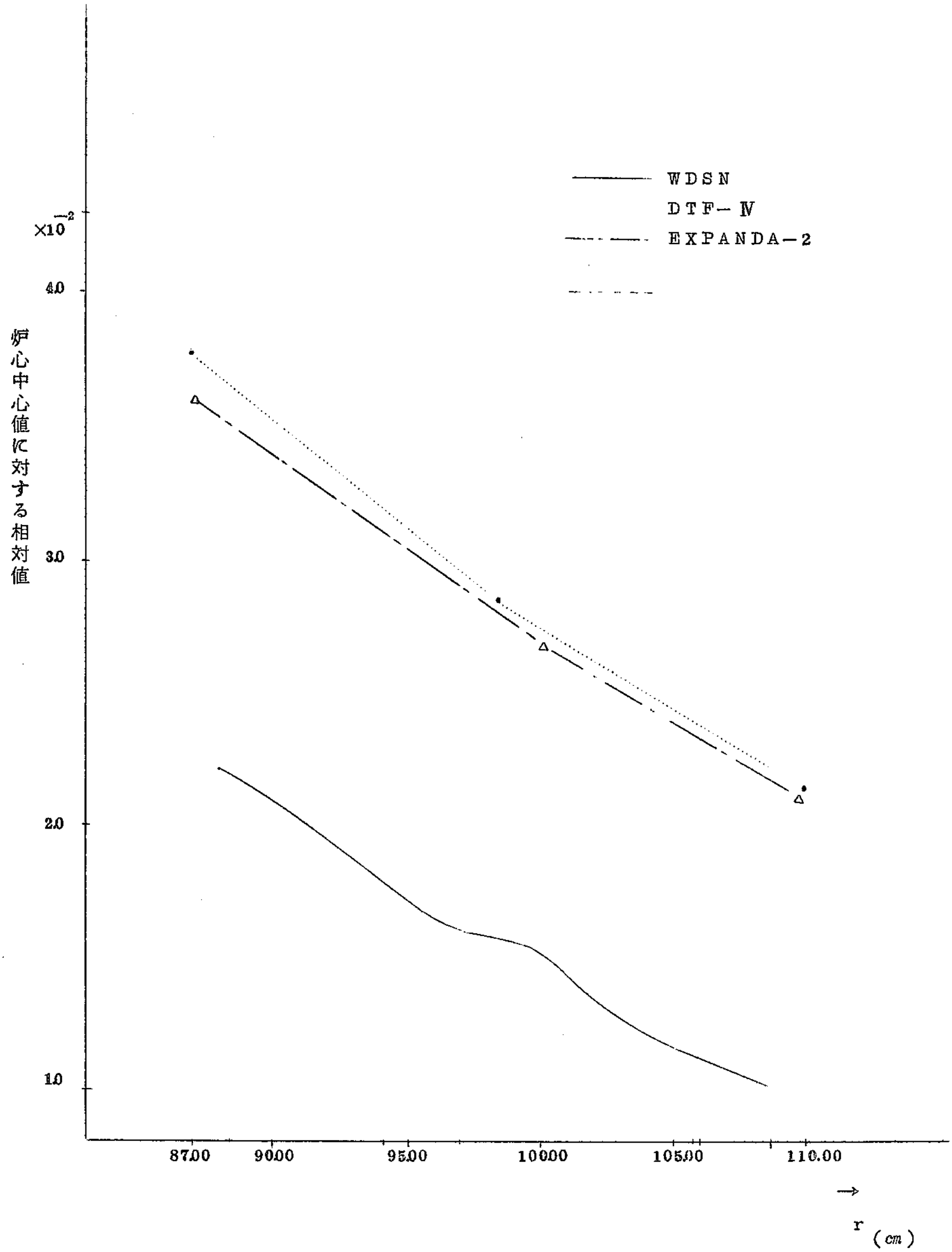


第4図　中性子スペクトル（燃料ラック中央）



1
10^{-1}
10^{-2}
10^{-3}
WDSN
EXPANDA−2
DTF−Ⅳ
炉心
制御領域
炉心
ブランケット
反射体
Na/SUS
ラック
遮蔽体
Na
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
（cm）
→半径

第5図　φ（u）　g=8



第6図　燃料ラック領域での $\int_i \phi_i(u)du_i$