

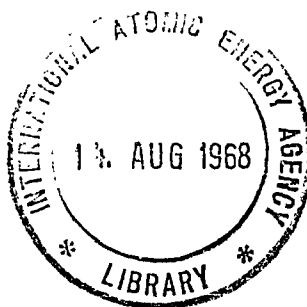


AUSTRALIAN ATOMIC ENERGY COMMISSION
RESEARCH ESTABLISHMENT
LUCAS HEIGHTS

**PRELIMINARY SURVEY OF REQUIREMENTS FOR HEAVY WATER MODERATED
REACTOR LATTICE EXPERIMENTS IN THE PROPOSED CRITICAL FACILITY**

by

A.W. DALTON
D.B. McCULLOCH



February 1968

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PRELIMINARY SURVEY OF REQUIREMENTS FOR
HEAVY WATER MODERATED REACTOR LATTICE EXPERIMENTS
IN THE PROPOSED CRITICAL FACILITY

ERRATA SHEET - AAEC/TM433

(A.W. Dalton and D.B. McCulloch)

Please make corrections as follows:-

TABLE 4

Data line 1:

$\frac{1}{2000}$	10	<u>1.78</u>	<u>87.90</u>	<u>40.63</u>	<u>4.12</u>	<u>5.90</u>
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Data line 8:

$\frac{1}{4000}$	10	1.96	92.45	24.35	4.97	<u>6.93</u>
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TABLE 5

Data line 21:

$\frac{1}{8000}$	100	<u>27.15</u>	85.01	<u>5.73</u>	<u>2.34</u>	<u>29.17</u>
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by

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ABSTRACT

Calculations have been carried out to assess the fuel and control requirements for lattice measurements in heavy water moderated reactor cells, using a 'split-table' type machine with a U235/graphite driver region.

The METHUSELAH code was used to calculate cell-averaged cross-section data for the heavy-water moderated region, and GYMEA for the U235/graphite driver region and the graphite reflector. CRAM calculations in four groups were then made for critical configurations in a range of driver region compositions and assembly geometries.

It was established that for the type of natural uranium steam-generating heavy water reactor lattice considered, an adequately close approximation to the equilibrium neutron spectrum for the critical SGHWR could be established over a

Continued...

ABSTRACT (Continued)

30 cm radius at the centre of the assembly, using approximately one tonne of SGHWR type fuel, 9 kg U235 and 13 tonnes of graphite. The latter two quantities would be somewhat increased if practical packing densities for the machine were taken into account. Adequate reactivity control for operation is available by use of a practicably small number (about 5) of conveniently sized plates 'black' to thermal neutrons.

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1. INTRODUCTION

The proposed critical facility is a 'split-table' type machine on which reactive assemblies up to approximately 12 ft cube and 250 tons total weight may be constructed. For physics studies in heavy water moderated natural uranium reactor lattices, it will be necessary to 'drive' a more or less small section of such a system by surrounding it with a region containing highly enriched fissile material. The present study assesses the fuel, moderator and control requirements for such a reactive assembly, constructed so that the neutron energy spectrum in the centre lattice cell is representative of that which would be found in the corresponding full-scale heavy water power reactor.

2. INITIAL CONSIDERATIONS

For the purpose of the survey, the natural Steam Generating Heavy Water Reactor (SGHWR) reference design proposed by Bicevskis (1967 - A.A.E.C. unpublished) has been taken as typical of the type of lattice likely to be studied experimentally in the facility. Characteristic neutron migration lengths in this type of lattice are of the order of 20 cm. It is therefore likely that the heavy water lattice comprising the central region of the critical assembly will need to have a radius of some 50 cm or more if an asymptotic spectrum is to be established over a reasonable volume at the reactor centre. This radius was selected as a starting point, and varied by 5 cm steps up to 70 cm.

The composition of the U235-aluminium alloy and graphite driver region surrounding the central region must be chosen to keep the fissile material investment to a reasonable level. Any influence of the driver region composition on the neutron energy spectrum at the centre of the reactor must also be investigated. The U235/graphite ratio was therefore varied in the range 1/2,000 to 1/16,000 which embraces the ratio of $\xi\Sigma_s/\Sigma_a$ applicable to the central-region heavy water lattice.

Finally, the graphite reflector thickness was varied to assess the saving in fissile material which could be achieved, and for one configuration with a 70 cm radius central region the effect of absorbers in the driver region was calculated to make some assessment of the number and size of control absorber plates likely to be required for convenient operation of the assembly.

3. DATA PREPARATION

3.1 Central Region

A. Methuselah II (Alpiar 1963, Brinkworth and Griffiths 1966) cell calculation

was carried out in the 5-group option to give cell-averaged cross section data. These were then condensed to 4 groups for use in the CRAM finite difference diffusion code (Hassitt 1962). Principle features of the lattice cell are given in Table 1, and the cell-averaged cross section data in Table 2.

3.2 Driver Region and Reflector

Four-group cross section data for fuel and graphite at each U235/graphite ratio considered (1/2,000, 1/4,000, 1/8,000 and 1/16,000) were prepared using the GYMEA code (Pollard and Robinson 1966). The group boundaries were chosen to be the same as those for the METHUSELAH scheme, and the resulting data are given in Table 3.

4. REACTOR CALCULATIONS

Criticality searches were made in cylindrical geometry using the CRAM one-dimensional diffusion code by varying the thickness of driver region. An axial buckling corresponding to an extrapolated core height of 200 cm was used throughout. The cores studied embraced many of the possible permutations within the ranges of interest for central region radius, driver region composition, and reflector thickness. The critical U235/graphite masses and core dimensions for assemblies with 60 cm and 70 cm radius central regions are given in Tables 4 and 5. The U235 critical mass data are also displayed in Figures 1 and 2.

In order to assess the likely control requirements, the lattice with central region radius of 70 cm, driver region U235/graphite ratio of 1/8,000, and reflector thickness of 40 cm was selected for absorber studies. CRAM calculations of K_{eff} were therefore made with thin (1 cm wide) rings of added 'unit - $\frac{1}{v}$ ' absorber at a number of different concentrations located midway across and at the outer edge of the driver region. The results of these calculations, expressed as reactivity changes, are shown in Figure 6.

5. RESULTS

5.1 Critical Size Searches

In order to ease interpretation of measurements of lattice parameters made in the central cell of the heavy water region of the critical facility, it is important that the neutron spectrum over a volume comparable with that of the heavy water lattice cell, shall be close to that obtaining in the corresponding critical single-region SGHWR.

In anticipation of possible future developments along the lines of heavier

fuel elements and larger lattice pitches, it was decided that a constant spectrum, closely similar to that of the METHUSELAH/CRAM critical SGHWR calculation, must be assured to a radius of 30 cm. It was readily established by inspection of the calculated assembly fluxes that the spectrum over a 30 cm radius region at the centre was for all practical purposes independent of reflector thickness. Furthermore, the data displayed in Figures 1 and 2 for 60 and 70 cm radius SGHWR zones show that whilst there are continuing marked savings in driver region fuel loadings up to a reflector thickness of about 40 cm, there is very little to be gained from any further increase in the size of the reflector. Further examination of data was therefore restricted to those cases with 40 cm graphite reflectors, and the 1/8,000 composition was selected for most detailed study.

For these remaining cases the ratios of fluxes in Groups 1, 2 and 3 to that in Group 4 were calculated at a number of mesh points between the assembly centre and 30 cm radius, and compared with those obtained from the single-region METHUSELAH/CRAM critical SGHWR calculation. The results for a range of central region radii and driver region compositions are given in Tables 6 and 7. It is clear that the Group 3 : Group 4 flux ratio is by far the most sensitive and hence is selected for display in Figures 3 and 4. Figure 3 shows that only the 70 cm radius region ensures constancy of spectrum to within 1 per cent over the required volume, whilst Figure 4 shows that for this size of central region the group flux ratios over the required volume are very close to those for the single-region METHUSELAH/CRAM critical SGHWR calculation, and are almost independent of driver region composition. Figure 5 shows the driver region fuel and graphite savings obtainable if a smaller constant spectrum region, and thus a smaller SGHWR central region, were acceptable.

5.2 Control Requirements

The major negative reactivity contribution to safe shutdown for a split-table type critical assembly arises from spatial separation of the moving tables. In-core absorber rods are therefore required to control only rather small amounts of reactivity in order to cater for

- (a) some degree of shutdown, say about 1 per cent at full closure of the tables, and
- (b) a similar amount for divergence to operating power level and to accommodate experimental changes.

A total of some 2 per cent reactivity held at full insertion is therefore required.

Figure 6 shows the reactivity effect in the 70 cm radius central region core

of rings of 'unit $\frac{1}{V}$ ' absorber at a number of concentrations placed at two different radii in the driver region. The curves extend to a total controlled reactivity of about 5 per cent.

These absorber loadings were converted into areas of absorbing plates which are 'black' to Group 4 (thermal) neutrons, using the 'Absorption Area' method of ANL-5800, 2nd Edition. Each absorber loading was converted to the equivalent black body absorption area C, defined as absorption per unit height of black body per unit source intensity in the external medium using

$$C = \frac{\text{(Absorber region only)} \left[\int \phi_4 \Sigma_{a4} dV \right]}{\text{(Driver region)} \left[\int \phi_3 \Sigma_{3 \rightarrow 4} dV \right]} \cdot \frac{1}{V} \text{(Driver region)}$$

Values of C y. reactivity controlled are shown in Figure 7. Figure 8 shows the variation of C with plate width for thin black absorbers in a medium of diffusion length 16.25 cm. This value is appropriate to the driver region loading, and 'variational method' mean data of ANL-5800 were used. It should be noted that the abscissa scale of Figure 5.10 of ANL-5800 is incorrect, and should cover the range 0-5 rather than 0-0.5.

For convenient operation of the critical facility it is likely that absorber plates approximately 4 cm wide by 80 cm long would be suitable. From Figure 8, with a correction factor (0.879) for cosinusoidal axial variation of flux in the assembly, the absorber plate requirements for 2 per cent reactivity control become

- (a) midway position in driver region - 4.4 plates
- (b) outer edge of driver region - 5.6 plates

It should be noted that this method of calculation is approximate, but is adequate at this stage to show that control requirements lie in the practicable range.

6. CONCLUSIONS

1. It has been shown that asymptotic spectrum conditions can be established over a single central heavy water reactor lattice cell of up to 50 cm pitch, provided it is surrounded by similar cells covering a region of about 60 to 70 cm radius. The fuel requirements for such a region would be at the one tonne level. Some reduction in central region radius and therefore fuel loading might be possible by detailed attention to a surrounding spectrum-matching 'buffer zone'.

2. For all the practical configurations considered, the driver region U235 fuel requirements can be met by some 9 kg U235. The practical densities which can be achieved in a 'packed drawer' configuration would lead to some increase in this requirement.

3. Total graphite requirements for driver zone and reflector are of the order of 13 tonnes. Again some increase in this quantity would be required to compensate for practically achievable packing densities.

4. It is estimated that some 5 plates each 80 cm by 4 cm would be required in the driver region to control approximately 2 per cent reactivity in the largest assembly considered. The control problems seem therefore quite practicable.

7. REFERENCES

- Alpiar, R. A. (1963). - AEEW-R135.
- Brinkworth, M. J. and Griffiths, J. A. (1966). - AEEW-R480.
- Hassitt, A. (1962). - TRG-229(R).
- Pollard, J. P. and Robinson, G. S. (1966). - AAEC/E147.

TABLE 1
PRINCIPAL FEATURES OF THE SGHWR LATTICE CELL

<u>Fuel (UO₂)</u>	
Density (g cm ⁻³)	10.216
Rod diameter (cm)	1.684
Rods per cluster	36
Pitch circle radii (cm)	1.886(6 rods)
	3.636(12 rods)
	5.476(18 rods)
Cladding (ZR-2) thickness (cm)	0.046
Rating (w/g fuel)	8.992
(w/g uranium)	10.20
Average temperature (°C)	744
<u>Coolant (H₂O)</u>	
Density (g cm ⁻³)	0.4954
Temperature (°C)	275
Coolant/fuel volume ratios	0.526
<u>Pressure Tube (ZR-2)</u>	
Inside diameter	16.92
Outside diameter	17.53
<u>Moderator (D₂O)</u>	
Purity (% molecular)	99.72
Density (g cm ⁻³)	1.078
Temperature (°C)	77
Lattice pitch (cm)	34.04
Moderator/fuel volume ratio	11.44
" " molecular ratio	16.14

TABLE 2
SGHWR CELL-AVERAGED MACROSCOPIC CROSS SECTIONS

Cross Section Type	Group 1 10 MeV - 821 keV	Group 2 821 keV - 5.53 keV	Group 3 5.53 keV - 0.618 eV	Group 4 0.618 eV - 0.00102 eV
Σ trans	1.4340×10^{-1}	2.5020×10^{-1}	2.5473×10^{-1}	3.7052×10^{-1}
Σ removal	6.3366×10^{-2}	2.9964×10^{-2}	1.9879×10^{-2}	3.9582×10^{-3}
$\nu\Sigma$ fission	7.3633×10^{-3}	8.2587×10^{-5}	6.1151×10^{-4}	4.7444×10^{-5}
Σ scatter (1→g)	0	5.9599×10^{-2}	0	0
" (2→g)	0	0	2.9132×10^{-2}	0
" (3→g)	0	0	0	1.7038×10^{-2}
" (4→g)	0	0	0	0

TABLE 3
DRIVER REGION MACROSCOPIC CROSS SECTION DATA FOR FUEL TO MODERATOR ATOM RATIOS OF 1/2, 000 TO 1/16, 000

Fuel to Moderator Atomic Ratios	Cross Section Type	FUEL				MODERATOR			
		Group 1	Group 2	Group 3	Group 4	Group 1	Group 2	Group 3	Group 4
1/2000	Σ trans	2.8108×10^{-3}	5.2015×10^{-3}	3.8176×10^{-3}	1.5757×10^{-2}	1.4180×10^{-1}	3.0474×10^{-1}	3.5706×10^{-1}	3.5747×10^{-1}
	Σ removal	6.1378×10^{-5}	1.2258×10^{-4}	1.5073×10^{-3}	1.3419×10^{-2}	2.3731×10^{-2}	1.0101×10^{-2}	5.0550×10^{-3}	7.2018×10^{-4}
	$\nu \Sigma$ fission	1.4260×10^{-4}	2.2148×10^{-4}	1.9765×10^{-3}	2.7129×10^{-2}	0	0	0	0
	Σ scatter (1-g)	0	0	0	0	0	2.3731×10^{-2}	0	0
	Σ " (2-g)	0	0	0	0	0	0	1.0101×10^{-2}	0
	Σ " (3-g)	0	0	0	0	0	0	0	5.0446×10^{-3}
	Σ " (4-g)	0	0	0	0	0	0	5.7911×10^{-4}	0
	Σ trans	1.4054×10^{-3}	2.6065×10^{-3}	1.9342×10^{-3}	9.2735×10^{-3}	1.4179×10^{-1}	3.0477×10^{-1}	3.5706×10^{-1}	3.5752×10^{-1}
Σ removal	3.0696×10^{-5}	6.2853×10^{-5}	7.7196×10^{-4}	8.0852×10^{-3}	2.3732×10^{-2}	1.0134×10^{-2}	5.4727×10^{-3}	5.4567×10^{-4}	
1/4000	$\nu \Sigma$ fission	7.1318×10^{-5}	1.1082×10^{-4}	1.0087×10^{-3}	1.6387×10^{-2}	0	0	0	0
	Σ scatter (1-g)	0	0	0	0	0	2.3732×10^{-2}	0	0
	Σ " (2-g)	0	0	0	0	0	0	1.0134×10^{-2}	0
	Σ " (3-g)	0	0	0	0	0	0	0	5.4618×10^{-3}
	Σ " (4-g)	0	0	0	0	0	0	3.7951×10^{-4}	0
	Σ trans	7.0281×10^{-4}	1.3049×10^{-3}	9.7384×10^{-4}	5.2355×10^{-3}	1.4179×10^{-1}	3.0478×10^{-1}	3.5707×10^{-1}	3.5757×10^{-1}
	Σ removal	1.5348×10^{-5}	3.1439×10^{-5}	3.9079×10^{-4}	4.6289×10^{-3}	2.3732×10^{-2}	1.0150×10^{-2}	5.6949×10^{-3}	4.3664×10^{-4}
	$\nu \Sigma$ fission	3.5659×10^{-5}	5.5426×10^{-5}	5.0967×10^{-4}	9.3981×10^{-3}	0	0	0	0
1/8000	Σ scatter (1-g)	0	0	0	0	0	2.3732×10^{-2}	0	0
	Σ " (2-g)	0	0	0	0	0	0	1.0150×10^{-2}	0
	Σ " (3-g)	0	0	0	0	0	0	0	5.6638×10^{-3}
	Σ " (4-g)	0	0	0	0	0	0	2.4901×10^{-4}	0
	Σ trans	3.5140×10^{-4}	6.5278×10^{-4}	4.8866×10^{-4}	2.8313×10^{-3}	1.4179×10^{-1}	3.0479×10^{-1}	3.5707×10^{-1}	3.5760×10^{-1}
	Σ removal	7.6727×10^{-6}	1.5720×10^{-5}	1.9866×10^{-4}	2.5242×10^{-3}	2.3732×10^{-2}	1.0158×10^{-2}	5.8095×10^{-3}	3.7208×10^{-4}
	$\nu \Sigma$ fission	1.7826×10^{-5}	2.7712×10^{-5}	2.5620×10^{-4}	5.1280×10^{-3}	0	0	0	0
	Σ scatter (1-g)	0	0	0	0	0	2.3732×10^{-2}	0	0
1/16000	Σ " (2-g)	0	0	0	0	0	0	1.0158×10^{-2}	0
	Σ " (3-g)	0	0	0	0	0	0	0	5.7983×10^{-3}
	Σ " (4-g)	0	0	0	0	0	0	1.6913×10^{-4}	0

TABLE 4

CHARACTERISTICS OF CRITICAL ASSEMBLIES FOR A CENTRAL SGHWR REGION OF 60 cm RADIUS

Fuel to Moderator Atom Ratios	Reflector Zone		Driver Zone			Total Graphite Mass (tonnes)
	Thickness (cm)	Graphite Mass (tonnes)	Radius (cm)	U235 Mass (kg)	Graphite Mass (tonnes)	
1/2000	10	2.02	97.06	44.51	4.54	6.60
	20	3.58	78.95	25.93	2.65	6.23
	30	5.24	73.41	16.75	1.72	6.96
	40	7.21	69.67	12.35	1.26	8.47
	60	11.69	66.91	8.63	0.88	12.57
	80	17.05	66.00	7.44	0.76	17.81
	100	23.26	65.67	7.01	0.72	23.97
1/4000	10	1.96	92.45	24.35	4.97	4.93
	20	3.78	83.98	17.00	3.47	7.25
	30	5.60	77.92	12.17	2.48	8.09
	40	7.58	74.21	9.39	1.92	9.49
	60	12.16	70.81	6.96	1.42	13.58
	80	17.63	69.62	6.13	1.25	18.88
	100	23.96	69.12	5.84	1.19	25.16
1/8000	10	2.12	100.46	15.98	6.53	8.65
	20	4.10	91.99	11.97	4.89	8.99
	30	6.08	85.76	9.24	3.77	9.85
	40	8.18	81.68	7.56	3.09	11.27
	60	12.98	77.61	5.96	2.44	15.42
	80	18.67	76.07	5.38	2.20	20.87
	100	25.23	75.70	5.17	2.11	27.34
1/16000	10	2.40	114.29	11.65	9.51	11.91
	20	4.65	105.74	9.33	7.62	12.28
	30	6.89	99.23	7.69	6.28	13.17
	40	9.23	94.76	6.62	5.41	14.64
	60	14.47	90.00	5.53	4.52	18.99
	80	20.59	87.98	5.10	4.16	24.75
	100	27.58	87.17	4.92	4.02	31.60

TABLE 5

CHARACTERISTICS OF CRITICAL ASSEMBLIES WITH A CENTRAL SGHWR REGION OF 70 cm RADIUS

Fuel to Moderator Atom Ratios	Reflector Zone		Driver Zone			Moderator Total Mass (tonnes)
	Thickness (cm)	Graphite Mass (tonnes)	Radius (cm)	U235 Mass (kg)	Graphite Mass (tonnes)	
$\frac{1}{2000}$	10	2.05	97.06	44.51	4.54	6.60
	20	3.96	88.56	28.98	2.96	6.92
	30	5.89	82.67	19.04	1.94	7.84
	40	7.99	79.36	13.76	1.41	9.40
	60	12.87	76.65	9.60	0.98	13.85
	80	18.62	75.76	8.27	0.84	19.46
	100	25.22	75.44	7.80	0.80	26.02
$\frac{1}{4000}$	10	2.15	101.98	27.08	5.53	7.68
	20	4.16	93.52	18.94	3.87	8.03
	30	6.18	87.48	13.55	2.77	8.95
	40	8.35	83.80	10.45	2.13	10.48
	60	13.32	80.44	7.73	1.58	14.90
	80	19.19	79.27	6.81	1.39	20.58
	100	25.91	78.86	6.49	1.33	27.23
$\frac{1}{8000}$	10	2.31	109.89	17.66	7.21	9.52
	20	4.48	101.42	13.26	5.42	9.90
	30	6.65	95.19	10.24	4.18	10.83
	40	8.94	91.13	8.38	3.42	12.36
	60	14.13	87.09	6.61	2.70	16.82
	80	20.20	85.57	5.96	2.44	22.63
	100	27.01	85.01	5.81	2.35	29.36
$\frac{1}{16000}$	10	2.58	123.53	12.75	10.42	13.00
	20	5.03	114.98	10.24	8.36	13.39
	30	7.45	108.47	8.45	6.90	14.35
	40	9.97	104.00	7.28	5.95	15.92
	60	15.59	99.21	6.08	4.97	20.56
	80	22.08	97.25	5.61	4.58	26.66
	100	29.45	96.46	5.42	4.43	33.88

TABLE 6

VARIATION OF FLUX RATIOS WITH SIZE OF SGHWR REGION

(DRIVER REGION FUEL TO MODERATOR RATIO = 1/8,000 REFLECTOR THICKNESS 40 cm)

SGHWR Radius (cm)	Mesh Location (cm)	Flux Relative to Group 4		
		Group 1 ($\times 10^{-2}$)	Group 2 ($\times 10^{-1}$)	Group 3 ($\times 10^{-1}$)
50	2	6.330	1.686	2.465
	6	6.330	1.686	2.470
	10	6.331	1.689	2.480
	14	6.333	1.693	2.498
	18	6.341	1.701	2.527
	22	6.361	1.716	2.640
	26	6.404	1.743	2.743
60	30	6.496	1.792	2.896
	2	6.336	1.685	2.444
	6	6.336	1.686	2.445
	10	6.335	1.686	2.448
	14	6.334	1.686	2.454
	18	6.335	1.687	2.462
	22	6.339	1.690	2.476
70	26	6.350	1.695	2.498
	30	6.378	1.706	2.533
	2	6.339	1.686	2.439
	6	6.339	1.686	2.439
	10	6.339	1.686	2.440
	14	6.338	1.686	2.441
	18	6.337	1.686	2.444
-	22	6.337	1.686	2.448
	26	6.336	1.687	2.455
	30	6.336	1.689	2.466
	2 to 30 *	6.341 *	1.687 *	2.438 *

* Values for critical single-region SGHWR

TABLE 7

VARIATION OF FLUX RATIOS WITH FUEL/MODERATOR RATIO

FOR A SGHWR REGION OF RADIUS 70 cm AND REFLECTOR THICKNESS 40 cm

Fuel to Moderator (cm)	Mesh Location Ratio	Flux Relative to Group 4		
		Group 1 ($\times 10^{-2}$)	Group 2 ($\times 10^{-1}$)	Group 3 ($\times 10^{-1}$)
$\frac{1}{2000}$	2	6.338	1.696	2.440
	6	6.338	1.695	2.441
	10	6.338	1.695	2.442
	14	6.337	1.696	2.443
	18	6.336	1.696	2.443
	22	6.335	1.697	2.446
	26	6.335	1.689	2.469
	30	6.336	1.692	2.486
	2	6.339	1.696	2.440
	6	6.339	1.695	2.440
$\frac{1}{4000}$	10	6.338	1.686	2.441
	14	6.337	1.686	2.443
	18	6.337	1.686	2.447
	22	6.336	1.687	2.452
	26	6.335	1.688	2.462
	30	6.336	1.691	2.477
	2	6.339	1.686	2.439
	6	6.339	1.686	2.439
	10	6.339	1.686	2.440
	14	6.338	1.686	2.441
$\frac{1}{8000}$	18	6.337	1.686	2.444
	22	6.337	1.685	2.448
	26	6.336	1.687	2.455
	30	6.336	1.689	2.466
	2	6.340	1.687	2.438
	6	6.340	1.687	2.438
	10	6.340	1.687	2.439
	14	6.339	1.686	2.440
	18	6.339	1.686	2.441
	22	6.338	1.686	2.443
$\frac{1}{16000}$	26	6.337	1.687	2.447
	30	6.337	1.688	2.454
	2 to 30 *	6.341 *	1.687 *	2.438 *

* Values for critical single-region SGHWR

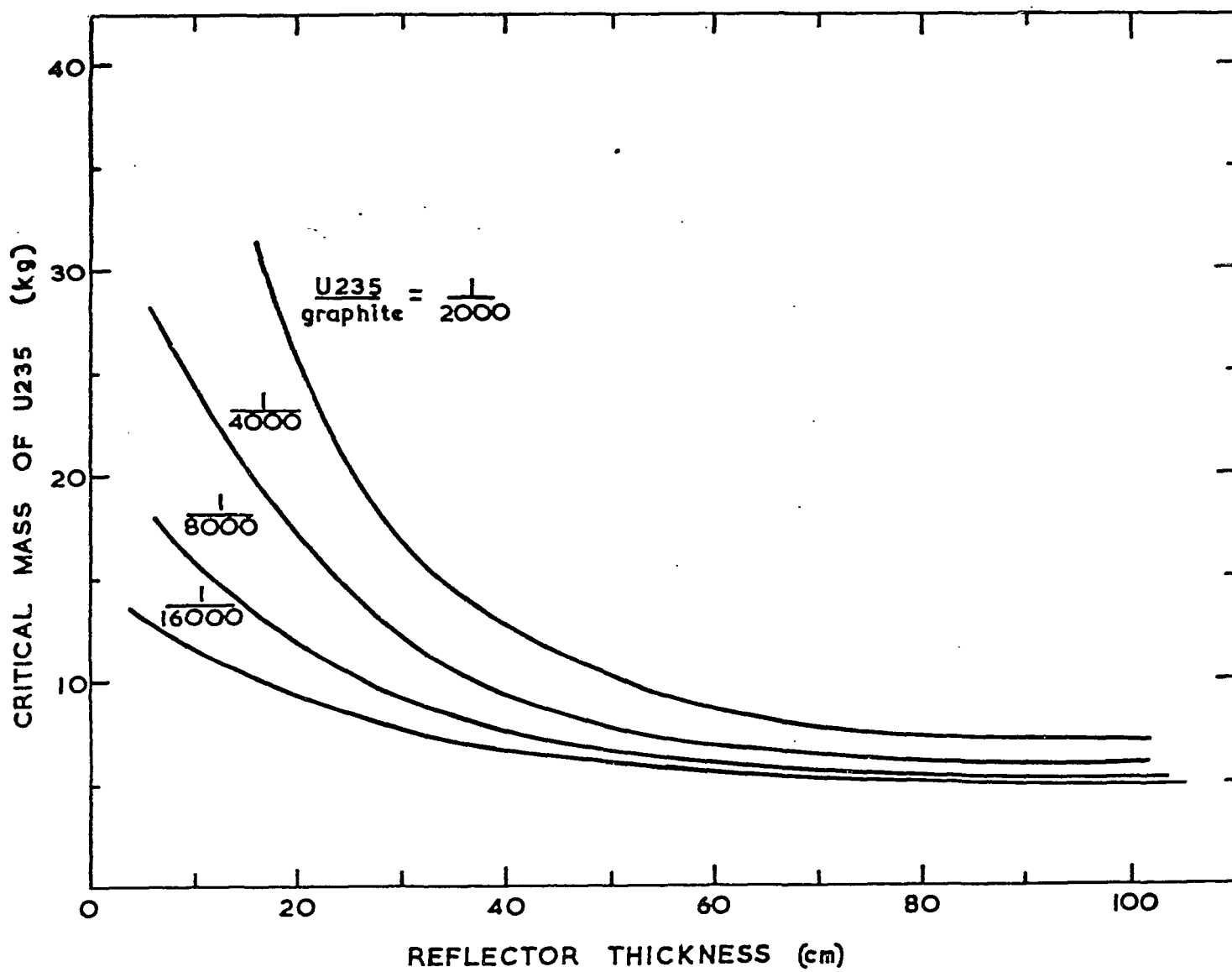


FIGURE 1. VARIATION OF CRITICAL MASS OF U235 IN THE DRIVER REGION FOR DIFFERENT FUEL TO MODERATOR ATOMIC RATIOS, WITH SGHWR CENTRE REGION OF RADIUS 60cm

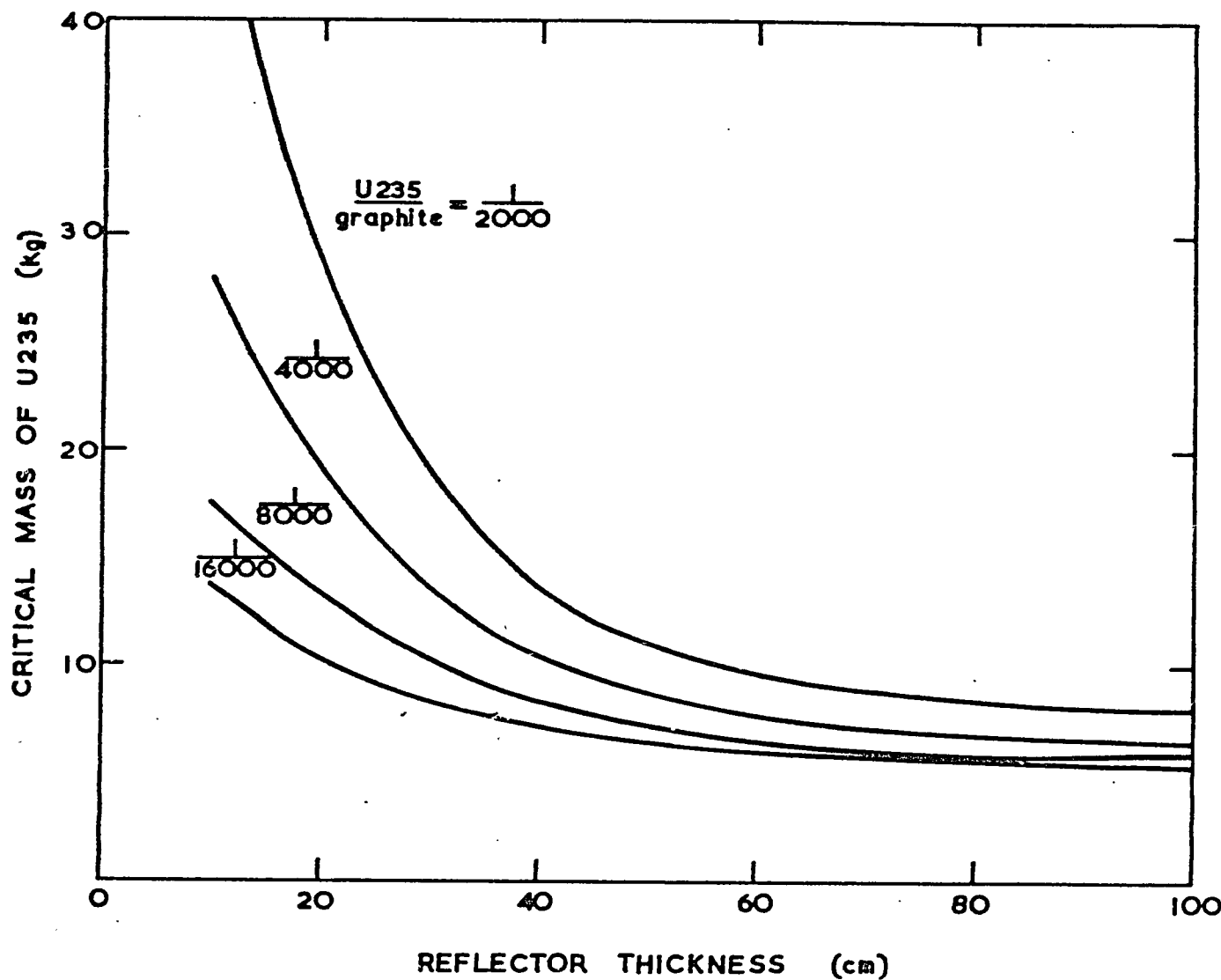


FIGURE 2. VARIATION OF CRITICAL MASS OF U235 IN DRIVER REGION FOR DIFFERENT FUEL TO MODERATOR ATOMIC RATIOS WITH SGHWR CENTRE REGION OF RADIUS 70cm

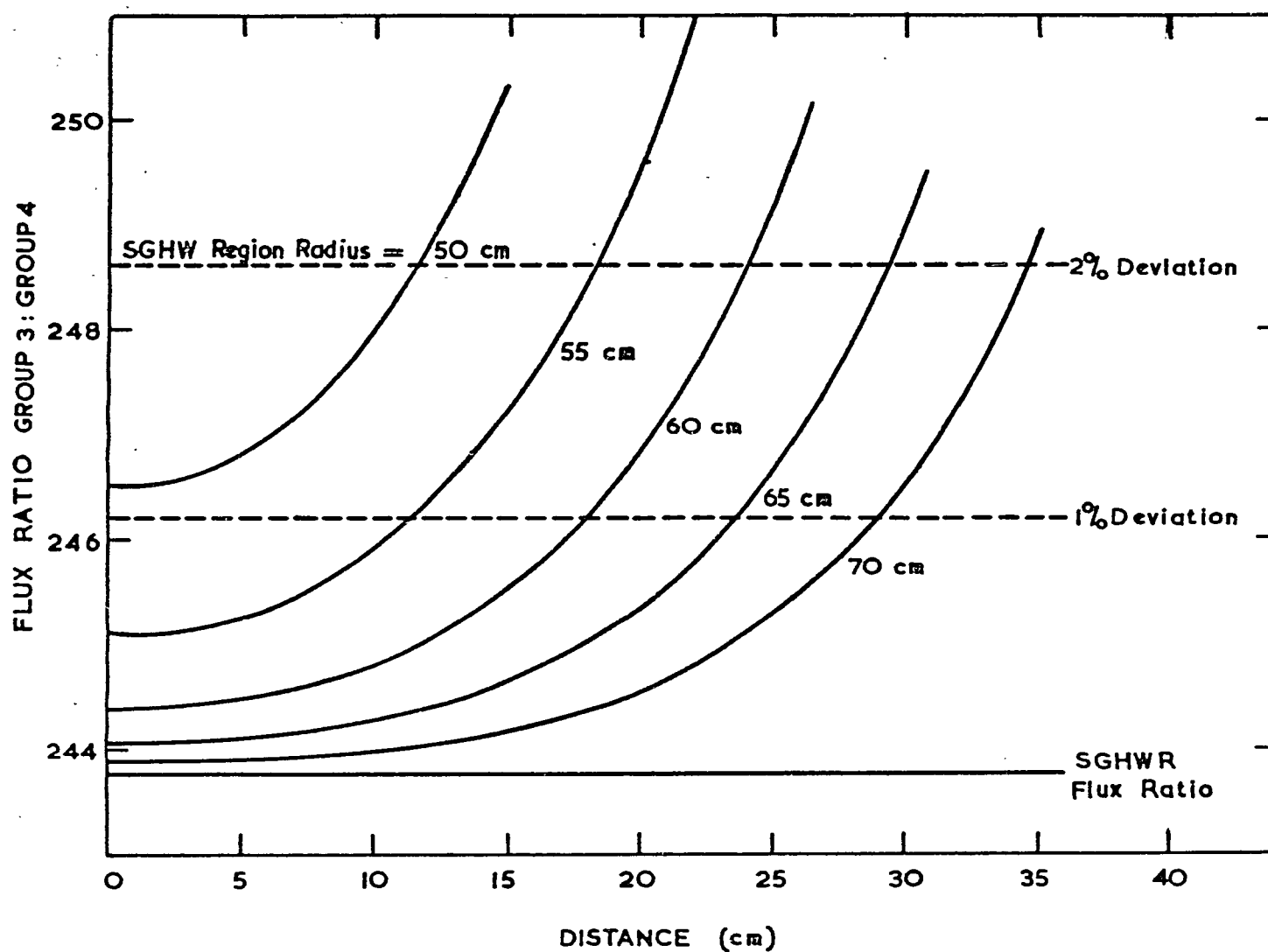


FIGURE 3. VARIATION OF FLUX RATIO (GROUP 3/GROUP 4) WITH DISTANCE FROM CENTRE OF SGHWR REGIONS OF DIFFERENT RADII (DRIVER REGION U235/GRAPHITE, ATOMIC RATIO 1/8000, REFLECTOR 40cm THICK)

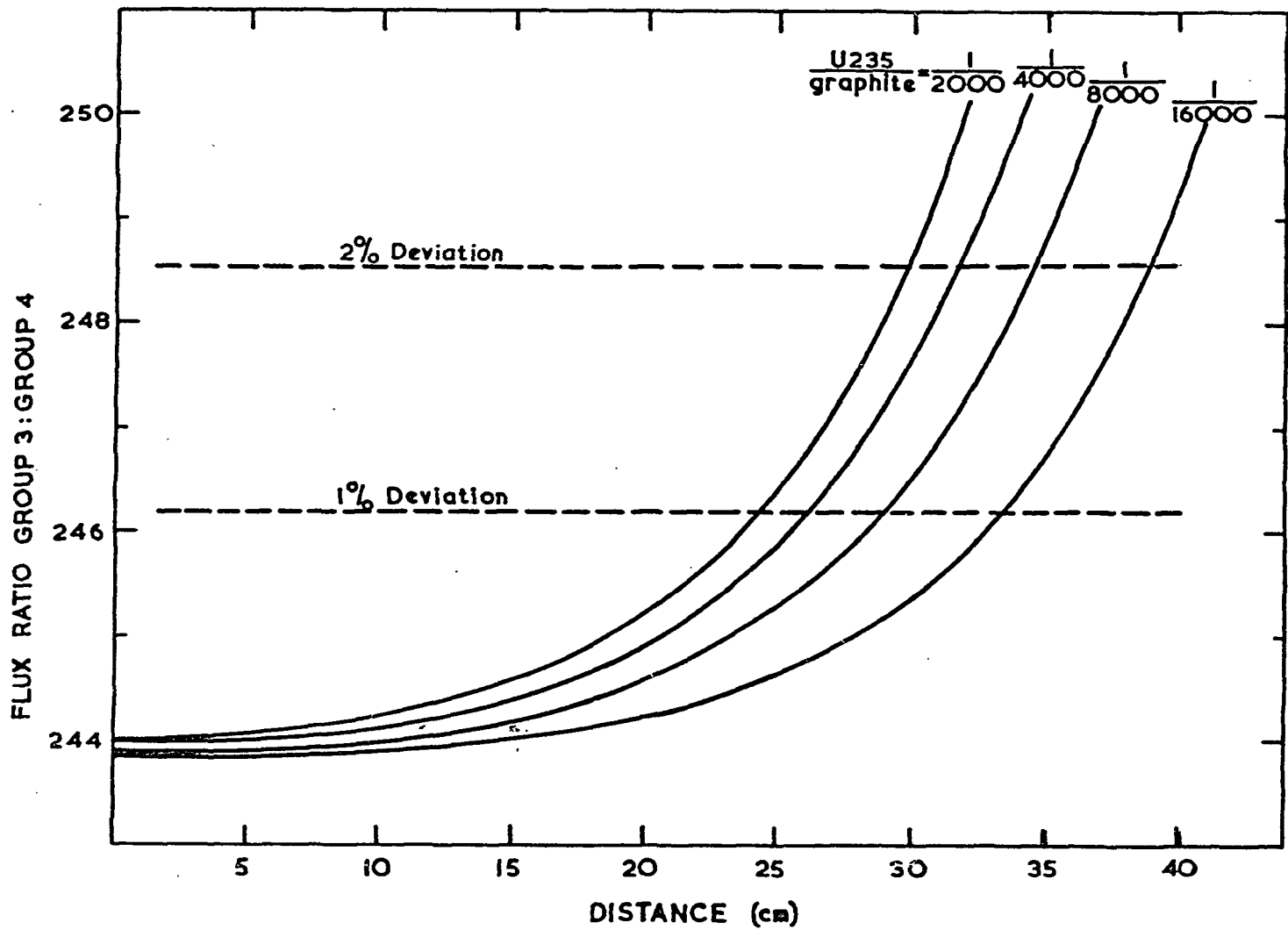


FIGURE 4. VARIATION OF FLUX RATIO WITH DISTANCE FROM CENTRE OF 70cm RADIUS SGHW REGION FOR DIFFERENT DRIVER REGION FUEL/MODERATOR ATOMIC RATIOS. REFLECTOR THICKNESS 40cm

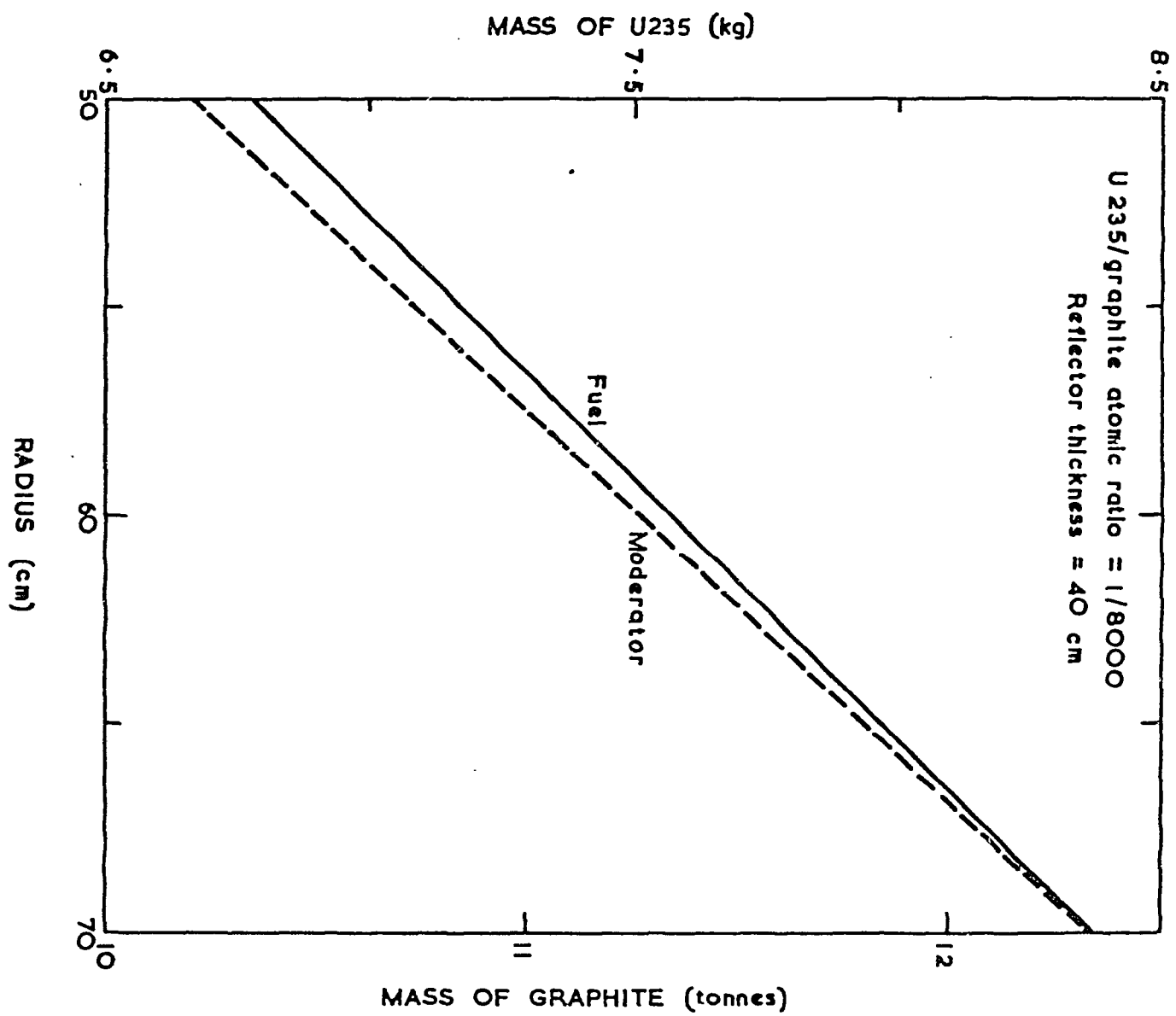


FIGURE 5. VARIATION IN THE MASSES OF FUEL AND MODERATOR IN DRIVER REGION WITH RADIUS OF SGHW REGION FOR CRITICAL ASSEMBLIES

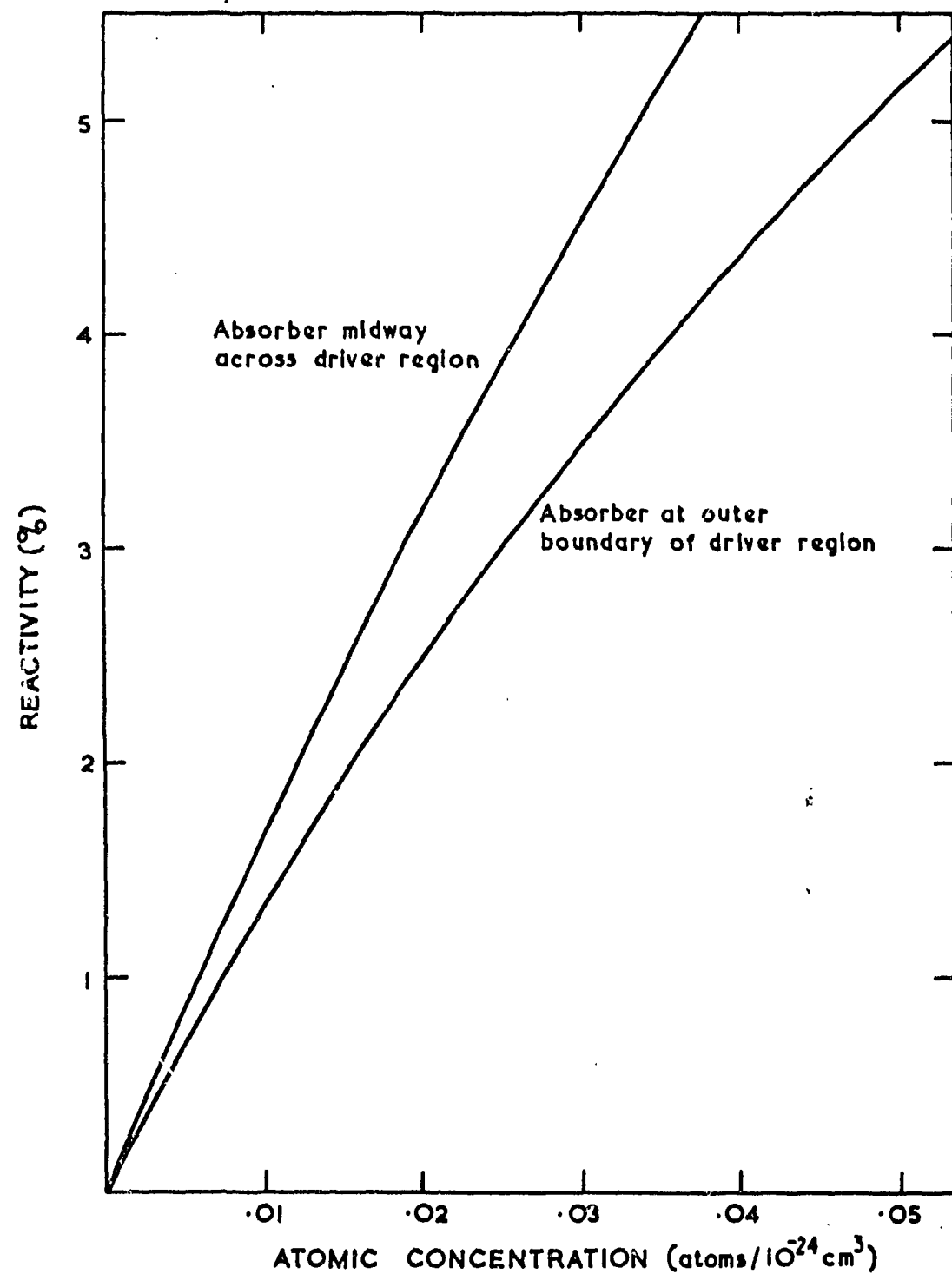


FIGURE 6. VARIATION OF CONTROLLED REACTIVITY WITH ABSORBER CONCENTRATION

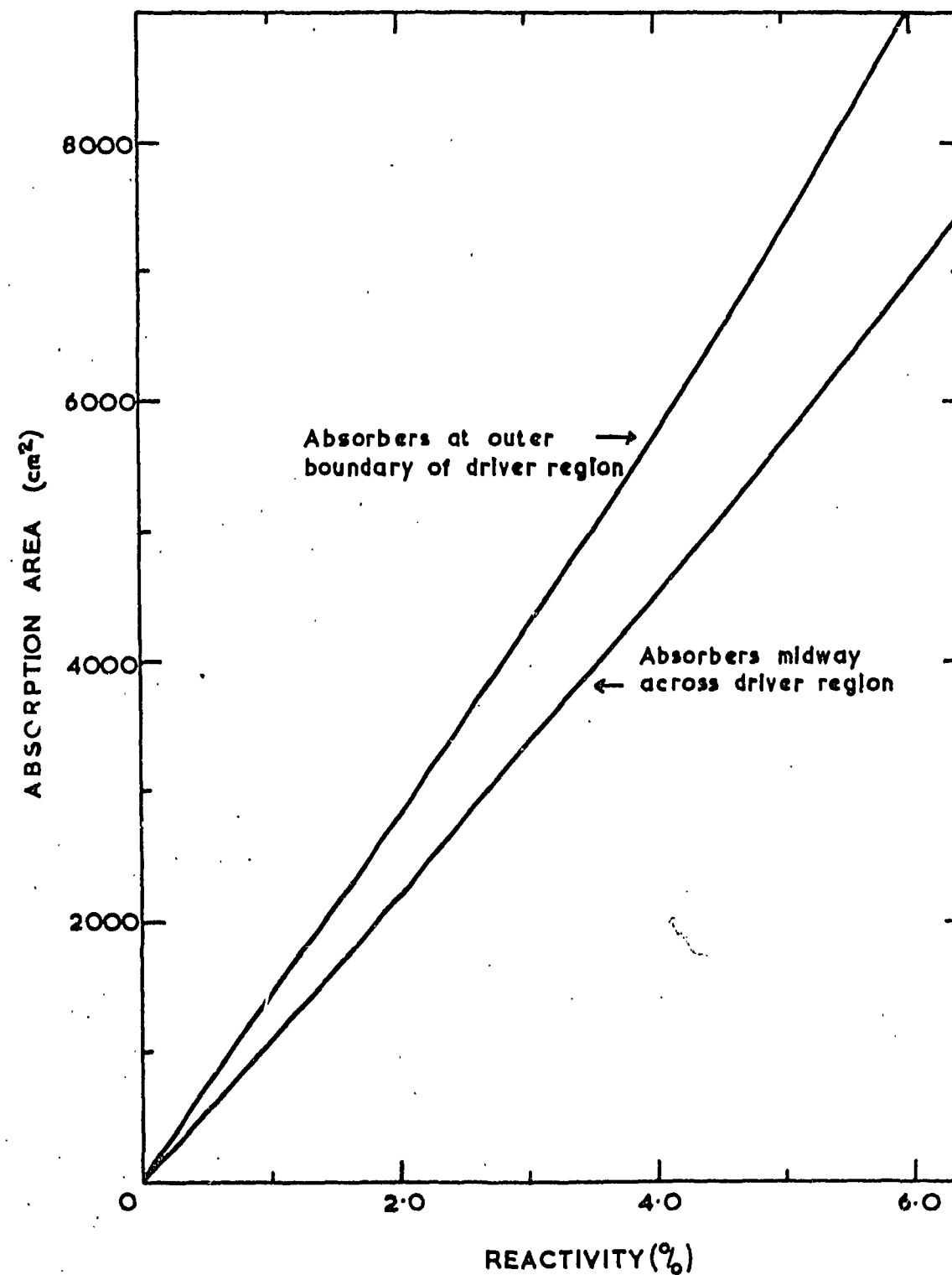


FIGURE 7. ABSORPTION AREA v. CONTROLLED REACTIVITY FOR BLACK ABSORBERS

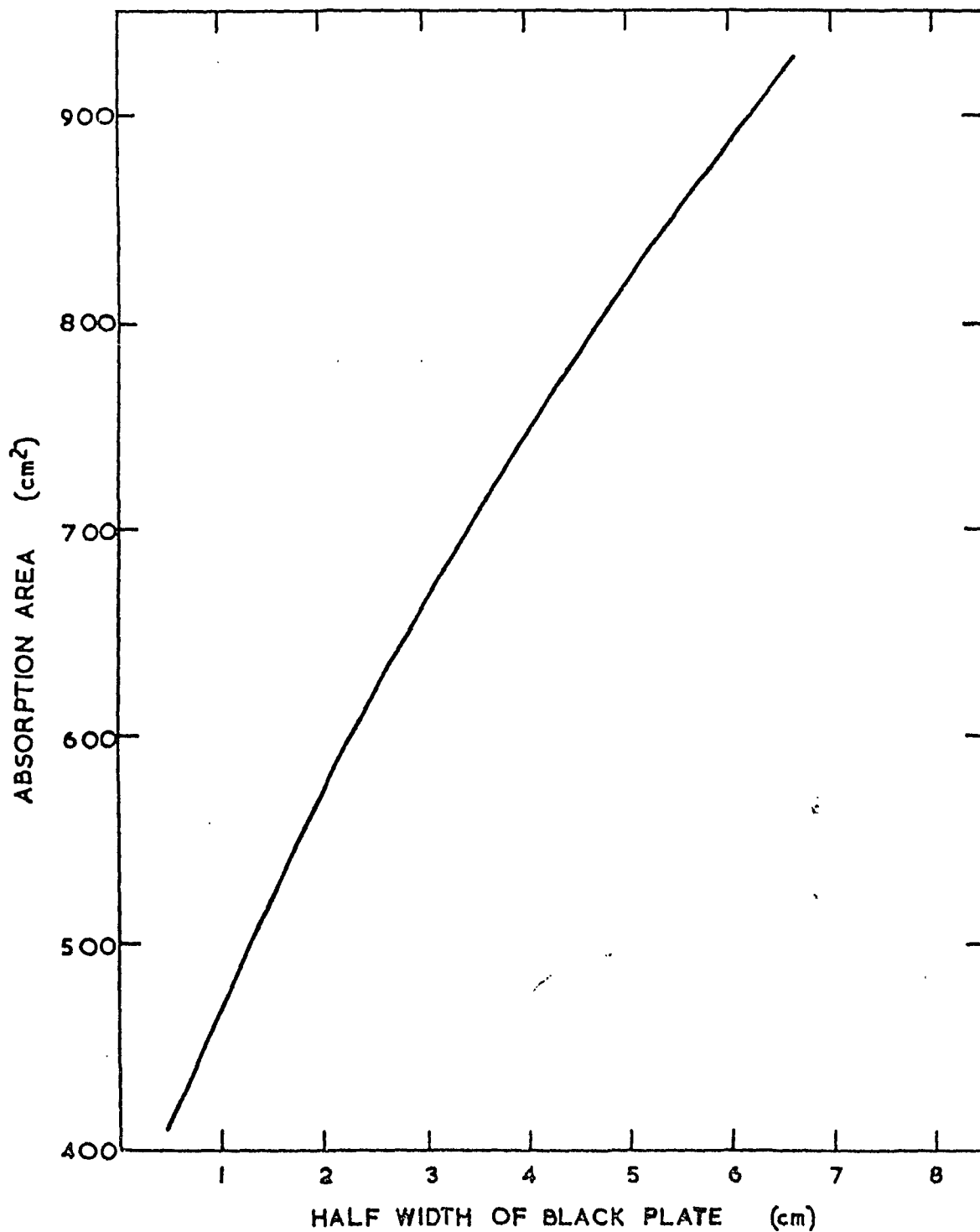


FIGURE 8. ABSORPTION AREA OF A BLACK PLATE IN A MEDIUM OF
DIFFUSION LENGTH 16.25cm