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TECHNICAL MEMORANDUM

CRITICALITY OF 30% ENRICHED URANIUM SOLUTIONS IN CYLINDRICAL GEOMETRY-INTERIM REP

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CONTENTS

1. INTRODUCTION

An experimental survey is being carried out jointly by A.W.R.E. and D.E.R.E of the critical parameters of uranium hydrogen mixtures at 30 V enrichment. The D.E.R.E. phase of this survey is concerned with the criticality of aqueous uranium solutions and covers the range in H : U235 from about 50 upwards; the A.W.R.E. phase will make use of solid compacts of UO_2 and paraffin wax at H : U235 between about 6 and 70.

In the D.E.R.E. phase of the work measurements are being made of the critical volumes and masses, as a function of H : U235, of uranyl fluoride (UO_2F_2) solutions contained in stainless steel and / or aluminium cylinders and spheres under various conditions of reflection. Later experiments will extend the data to include single and interacting slabs.

Provisional results are given in this Memorandum of the first series of experiments in which uranyl fluoride solutions were made critical in stainless-steel cylinders of 8, 12, and 16 in. dia. The critical dimensions are given for two conditions of reflection :

(a) with an effectively infinite (> 7-in. thick) radial water reflector.
(b) with no reflection other than that contributed by the vessel walls.

2. EXPERIMENTAL MATERIALS AND CONDITIONS

2.1 Fissile Solutions

Aqueous uranyl fluoride (UO_2F_2), of the concentrations and densities given in Tables I - V.

Isotopic Analysis :

U-235	30.30 ±	0.2%
U-234	0.35 ±	0.02%
U-236	0.07 ±	0.02%
U-238	Balance	

Major impurities in solution :

	p.p.m.*	σ_α (barn)	Relative absorption (arbitrary units relative to Cd.)
Cadmium	97	2450	100
Iron	1350	2.53	2.7
Nickel	240	4.8	0.83
Chromium	320	3.1	0.83
Aluminium	1600	0.23	0.56

* (parts per million UO_2F_2)

The proportion of thermal neutrons absorbed by the impurities will vary between 0.3% and 0.25% as the H : U235 varies between 76 and 600.

2.2 Reactor Core Vessels

The reactor vessels were vertical cylinders without re-entrant tubes or other internal perturbations but with an external projection from the base in the form of a dump line in the case of the 12- and 16-in. dia. cylinders and a $\frac{1}{2}$-in. dia. stainless-steel pipe in the case of the 8-in. dia. cylinder. The bases of the tanks were not of simple geometry; these and other dimensions of the tanks are shown in Figs. 1, 2, and 3. The dump lines of the 12- and 16-in. dia. tanks were connected via a 2-in. Saunders valve, type 'A', to a 10 litre dump tank. The 0.45 litre of solution held in the dump line and the upper portion of the valve are not included in the critical masses and volumes given in Tables I, II, and III.

2.3 Neutron Reflectors

(a) Radially Reflected Systems

Water reflector at the sides, < 7 in. (17.8 cm) in thickness, of the same height as the fissile solution. The stainless steel core vessel base, and to a lesser extent the tank top, act as partial end reflectors.

(b) Unreflected Systems

Stainless-steel walls, bottom and top (Ref. 1) act as partial reflectors.
Concrete floor, walls, and roof of cell at a minimum distance of 33 in.
Slight additional reflection from the supporting structure of the rig, fuel and reflector dump tanks (both empty), reflector tank (30-in. dia., wall thickness 0.64 in. aluminium) and paraffin wax 'long' counters (not closer than 4 ft.).

(c) Cadmium-Screened Systems (12-in. dia. tank)

Stainless-steel encased cadmium cylinder surrounding the curved surface of the cylindrical tank (except for the lowest 2 cm of the tank). An annular gap of 1.0 cm exists between the cadmium cylinder and the core tank. The cadmium cylinder comprised 0.09 cm of cadmium sandwiched between two sheets of 0.16-cm thick stainless steel.

3. EXPERIMENTAL RESULTS

(i) The observed critical heights and the corresponding volumes and masses for cylinders radially reflected by water or unreflected are given in Tables I - III. The results for critical height and critical mass from Tables I - IV are shown in Figs. 4 - 8.

All the critical heights were found by loading the core tank up to or beyond the point of criticality unless otherwise stated. These heights have not been corrected for the effects of the cylinder walls and bases, solution temperature, impurities in the solution, solution contained in the dump line, etc.

The accuracy of the critical height measurements is estimated to be ± 0.05 cm.

(ii) A few measurements of critical dimensions in the 12-in. dia. tank were made with the cadmium cylinder surrounding the core tank either with or without a water reflector. The results are tabulated in Table IV along with the main series of results of Table II where the solution concentration is the same.

(iii) The effect of fuel in the dump line of the 16-in. dia. tank with radial water reflection was measured for two values of H : U235. In each case the critical height was measured with the dump line filled with solution and with the line disconnected and the hole in the base of the tank plugged to produce a smooth base profile. The results are given in Table V.

4. DISCUSSION AND CONCULUSIONS

Measurements have been carried out for reflected and bare tanks of 12- and 16-in. dia. For the 8-in. dia. tank it was not possible to achieve criticality without a water reflector or with a cadmium shield between the core tank and the reflector. The critical approach curves obtained during the experiments suggest that such configurations would remain sub-critical to very considerable heights if not to infinite height.

Some care was taken during the experiments to establish the H : U235 at which the solution had maximum reactivity, i.e. minimum volume. These were :

Cylinder diameter	8 in.	12 in.	16 in
Cylinder reflected at sides by water	110	120	130
Unreflected cylinder	-	130	130

The corresponding H : U235 for minimum mass were:

Cylinder diameter	8 in.	12 in.	16 in.
Cylinder reflected at side by water	200	500	700
Unreflected cylinder	-	350	600

Of the effects for which no correction has been made in the quoted results (see Section 3.1), that of the fuel in the dump line can be assessed at not greater than 1 mm from the results in Table V. The accuracy of these results can be assessed from the reproducibility of the critical height for solution 30F30 which did not vary outside ± 0.025 cm in a repeated series of experiments over a period of a week.

Direct comparison with results for solutions at other enrichments is only possible for the 12-in. dia. core tank as measurements have not been made corresponding to the other two tanks. Table VI presents the more important critical parameters where comparison can be made directly with data at 93 V and 44.6 V.

Figs. 9 and 10 compare the 30 V D.E.R.E. results with the results of O.R.N.L. experiments (Ref. 2) on unreflected cylinders at 93 V; these results are almost directly comparable, the only significant difference in the experimental arrangement being the greater thickness and hence greater reflectivity of the D.E.R.E. tank base (1 cm against 0.16 cm).

In Figs. 11 and 12, the present measurement on radially reflected cylinders are compared with A.E.R.E. results for 44.6 V material (Ref.3). The A.E.R.E. work, was carried out in the same tank at a time when a hollow axial tube (1.6-cm o.d. 0.09 cm 18/8 stainless-steel wall) was fitted and no solution dump pipe existed.

A full report describing these experiments together with later work using core tanks of other sizes will be issued in due course.

REFERCES

1. G. White and A. Grant: Effect of a Stainless Steel End Reflector on the Critical Height of a Cylinder Radially Reflected by Water. IG Memorandum 440 (D), June 1959.

2. C.K. Beck, et al: Critical Mass Studies, Part III, K - 343, April 1949.

3. W.G. Clarke et al: Critical Assemblies of Aqueous Uranyl Fluoride Solutions, Part I - Experimental Techniques and Results. AERE R/R 2051, Sept., 1956.

TABLE I

CRITICAL PARAMETERS OF 30% ENRICHED AQUEOUS UO_2F_2 SOLUTIONS IN 16-in. (40.6-cm.) DIAMETER STAINLESS STEEL CYLINDERS

Soln. No.	H:U235 atomic ratio	Uranium Conc'n (mg/ml)	U-235 Conc'n. (mg/ml	Solution Density (g/ml)	Radially Reflected by Water				Unreflected			
					Crit Height (cm)	Crit Mass (kgU235)	Crit Volume (litre)	Height / Diameter	Crit Height (cm)	Crit Mass (kg U235)	Crit Volume (litre)	Height / Diameter
30F1	76.7	960	288	2.090	18.10	6.74	23.4	0.45	20.27	7.55	26.2	0.50
30F2	110.4	704	211	1.805	17.70	4.83	22.9	0.44	19.62	5.41	25.4	0.48
30F3	173	470	141	1.548	17.95	3.27	23.2	0.44	19.90	3.66	25.8	0.49
30F4	269	310	93.0	1.358	19.25	2.32	24.9	0.47	21.40	2.60	27.7	0.53
30F5	439	193	57.9	1.223	22.60	1.70	29.3	0.56	25.52	1.92	33.0	0.63
30F6	657	130	39.0	1.149	29.54	1.49	38.2	0.73	35.72	1.82	46.2	0.88
30F7	815	105	31.5	1.119	37.42	1.52	48.4	0.92	50.10	2.05	64.8	0.23
30F8	942	91	27.3	1.102	48.70	1.72	63.0	1.20	82*	2.89*	106*	2.02*

* Estimated by extrapolation of neutron multiplication measurements from a height of 67.5 cm and a mass of 2.42 kg U-235

TABLE II

CRITICAL PARAMETERS OF 30.3% ENRISHED AQUEOUS UO_2F_2 SOLUTIONS IN 12-in. (30.5-cm) DIAMETER STAINLESS STEEL CYLINDERS

Soln. No.	H:U235 atomic ratio	Uranium conc'n (mg/cm^3)	U235 conc'n (mg/cm^3)	Solution Density (g/cm^3)	Radially Reflected by Water				Unreflected			
					Crit. Height (cm.)	Crit. Mass (kgU235)	Crit. Volume (litre)	Height/Diameter	Crit. Height. (cm)	Crit. Mass (kg U235	Crit. Volume (litre)	Height/Diameter
30F9	81.9	905	272	2.03	22.6	4.48	16.05	0.74				
30F10	82.4	900	270	2.02	22.55	4.44	16.42	0.74	32.05	6.32	23.39	1.05
30F11	106	725	218	1.823	22.12	3.52	16.15	0.725	30.62	4.87	22.35	1.005
30F12	135	585	176	1.670	22.15	2.84	16.17	0.725	30.3	3.89	22.12	0.995
30F13	167	483	145	1.554	22.5	2.38	16.42	0.74	30.77	3.26	22.46	1.07
30F14	257	323	96.9	1.373	24.45	1.73	17.85	0.80	34.65	2.45	25.23	1.14
30F15	378	223	66.9	1.258	28.62	1.40	20.89	0.94	45.7	2.44	33.36	1.45
30F17	440	192	57.6	1.221	31.65	1.33	23.10	1.04	57.2	2.41	41.75	1.88
30F16	532	160	48.0	1.186	37.42	1.31	27.31	1.23	>65*			
30F18	622	137	41.1	1.158	47.0	1.41	34.31	1.54				
30F19	651	131	39.3	1.150	51.27	1.47	37.42	1.68				

*Multiplication of 2 at height of 65 cm. No accurate extrapolation to critical height possible

TABLE III

CRITICAL PARAMETERS OF 30% ENRICHED AQUEOUS UO_2F_2 SOLUTIONS
IN 8-in. (20.3-cm) DIAMETER STAINLESS STEEL CYLINDERS

					Radially Reflected by Water			
Soln. No.	H:U235 atomic ratio	U conc'n (mg/ml)	U-235 conc'n (mg/ml)	Soln. density (g/ml)	Crit. Height (cm)	Crit. Mass (kgU235)	Crit. Volume (litre)	Height / Diameter
30F20	82.4	905	272	2.033	51.9	4.60	16.9	2.55
30F23	94.2	807.5	242	1.924	50.5	4.00	16.4	2.48
30F21	105.6	734	220	1.844	50.15	3.59	16.3	2.47
30F22	114.8	678	203	1.775	50.22	3.31	16.3	2.47
30F24	140.8	565	170	1.648	52.03	2.87	16.9	2.56
30F25	160.5	502	151	1.578	54.82	2.69	17.8	2.70
$30F_26$	195	418	125	1.480	63.03	2.56	20.5	3.10

Criticality could not be achieved in bare cylinders with the cylinder heights available in the experimental rig.

TABLE IV

CRITICAL PARAMETERS OF 30.3% ENRICHED AQUEOUS UO_2F_2 SOLUTIONS
IN 12-in. (30.5 cm.) DIAMETER STAINLESS STEEL CYLINDERS
EFFECT OF REFLECTER CONDITIONS

Soln. No.	H:U235 atomic ratio	U conc'n (mg/cm3)	U-235 conc'n (mg/cm3)	Soln. density (g/cm3)	Reflector Conditions (see Sec. 2.3)	Critical Parameters: Height (cm.)	Mass (kg U235	Volume (litre)	Height / Diameter
30F12	135	585	176	1.670	Water	22.15	2.84	16.17	0.725
					Water+Cadmium	24.2	3.27	17.68	0.795
					Cadmium only	29.8	3.84	21.75	0.98
					Bare	30.3	3.89	22.12	0.995
30F15	378	223	67.0	1.258	Water	28.62	1.40	20.89	0.94
					Water+Cadmium	32.2	1.52	23.48	1.06
					Cadmium only	-	-	-	-
					Bare	45.7	2.24	33.36	1.45
30F17	440	192	57.7	1.221	Water	31.65	1.33	23.10	1.04
					Water+Cadmium	-	-	-	-
					Cadmium only	54.13	2.12	31.75	1.77
					Bare	57.2	2.41	41.75	1.88

TABLE V

EFFECT OF FUEL IN THE DUMP LINE ON CRITICAL HEIGHT

Soln. No.	H:U-235	Critical Height with Dump Line	Critical Height without Dump Line
30F26	195	18.41 cm	18.50 cm
30F30	749	33.62 cm	33.63 cm

TABLE VI

COMPARISONS BETWEEN CRITICAL PARAMETERS OF UO_2F_2 SOLUTIONS IN 12-in (30.5-cm) DIAMETER CYLINDERS AT VARIOUS ENRICHMENTS.

			Minimum Critical		H:U-235 Ratio at Minimum Critical	
Enrichment (%U-235)	Reflector Conditions	System Differences (See Notes)	Volume (litre)	Mass (kgU-235)	Volume	Mass
93.4	Unreflected	(a)	15.8	1.7	~50	400
30.3	Unreflected	(b)	22.1	2.23	130	350
44.6	Infinite Water (Radial only)	(c)	-	1.25	-	500
30.3	Infinite Water (Radial only)	(d)	16.1	1.30	120	500

NOTES : Dissimiliarities Between Critical Systems

(a) Tank bottom thickness : 0.16 cm (1/16 inch) (Ref. 2) Solution dump pipe, 7.6-cm diameter, on centre line.

(b) Tank bottom thickness : 1.0 cm average (Ref. 1).

(c) Solution dump pipe, 5.4-cm diameter (see section 2.2 and Fig 2)

(d) Hollow stainless steel tube, 1.6-cm. o.d., 0.09-cm wall thickness, along axis of core tank (Ref. 3).

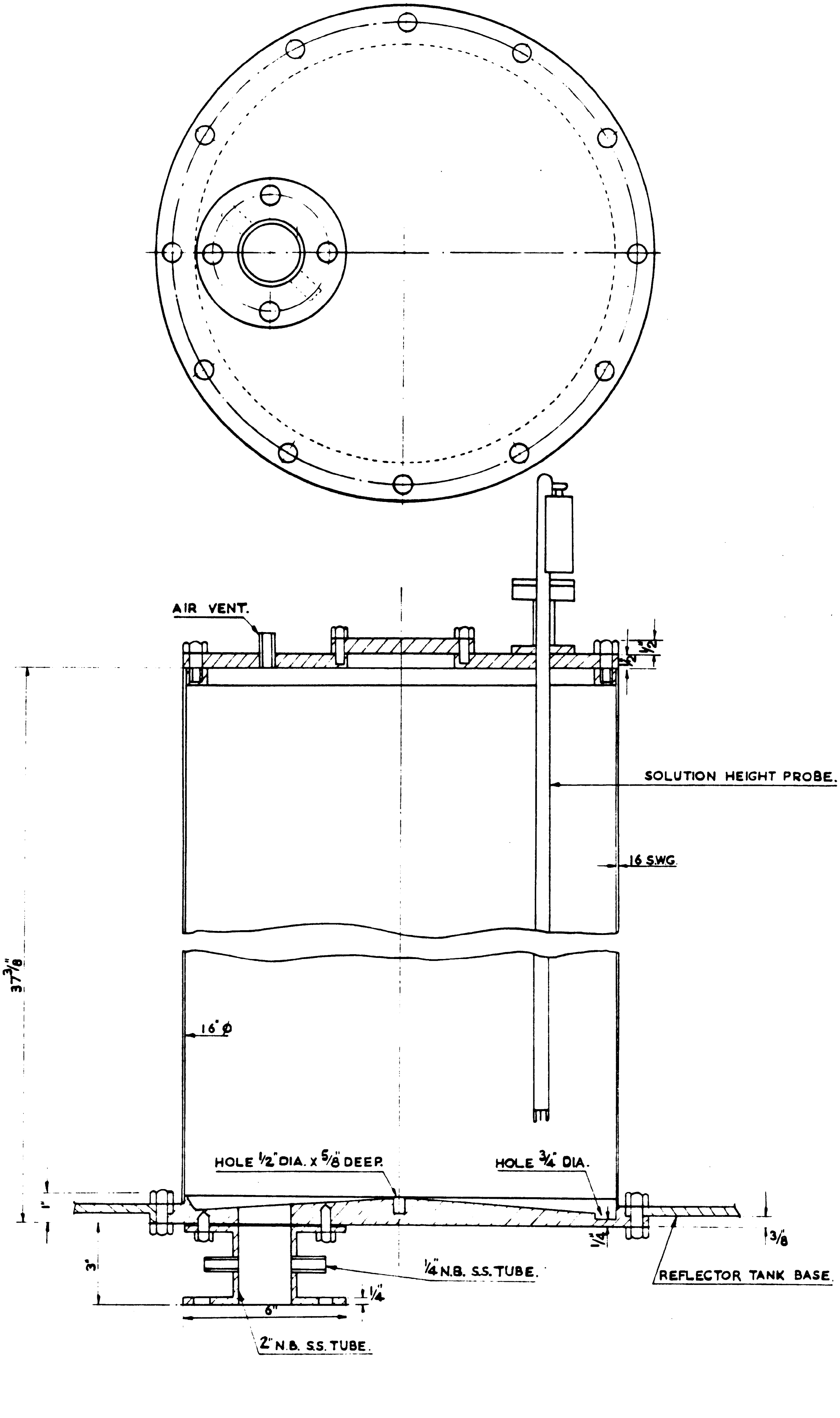

FIG. 1. 16-INCH CORE TANK (SCALE: 1/4)

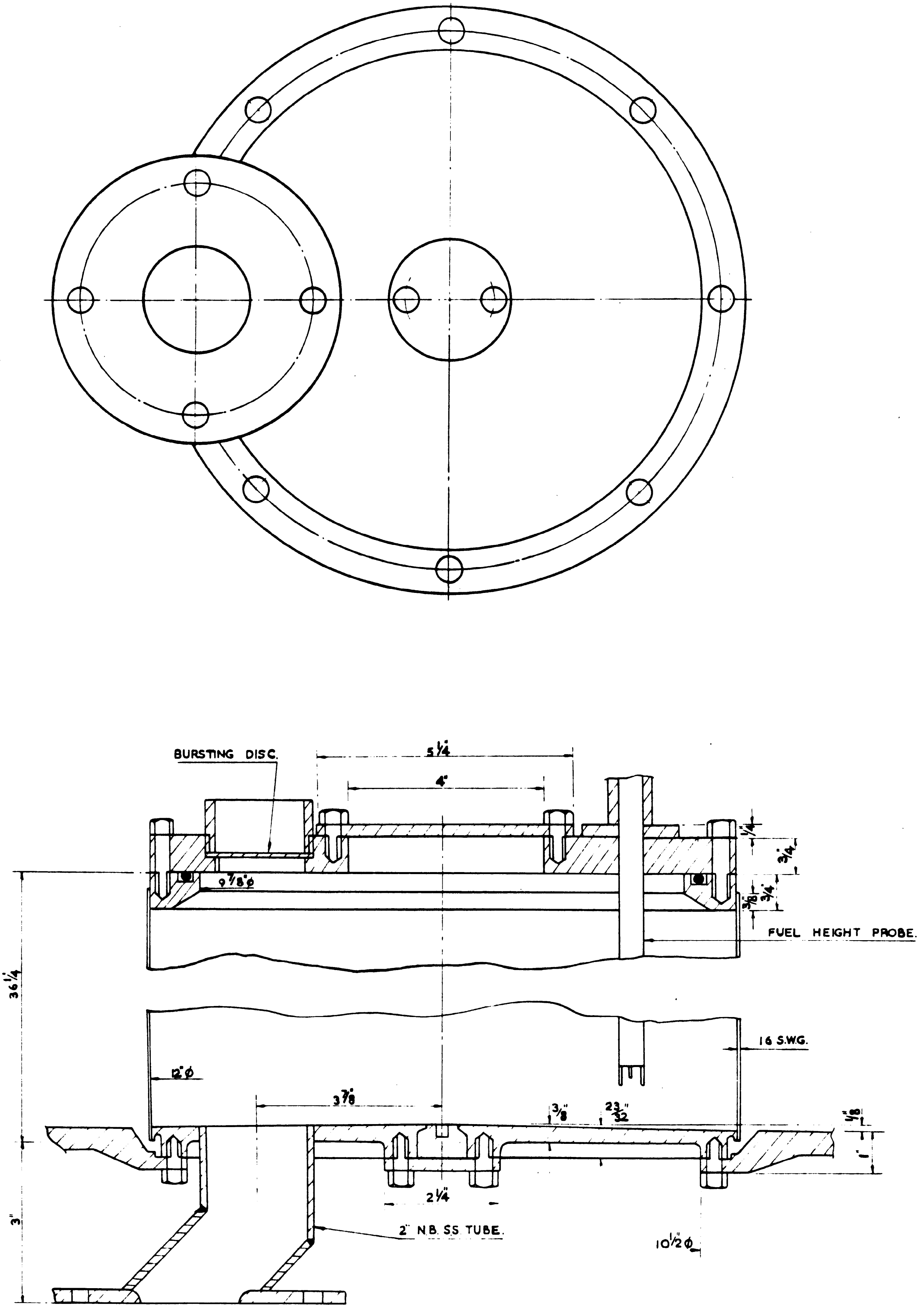

FIG. 2. 12-INCH CORE TANK. (SCALE 1:2)

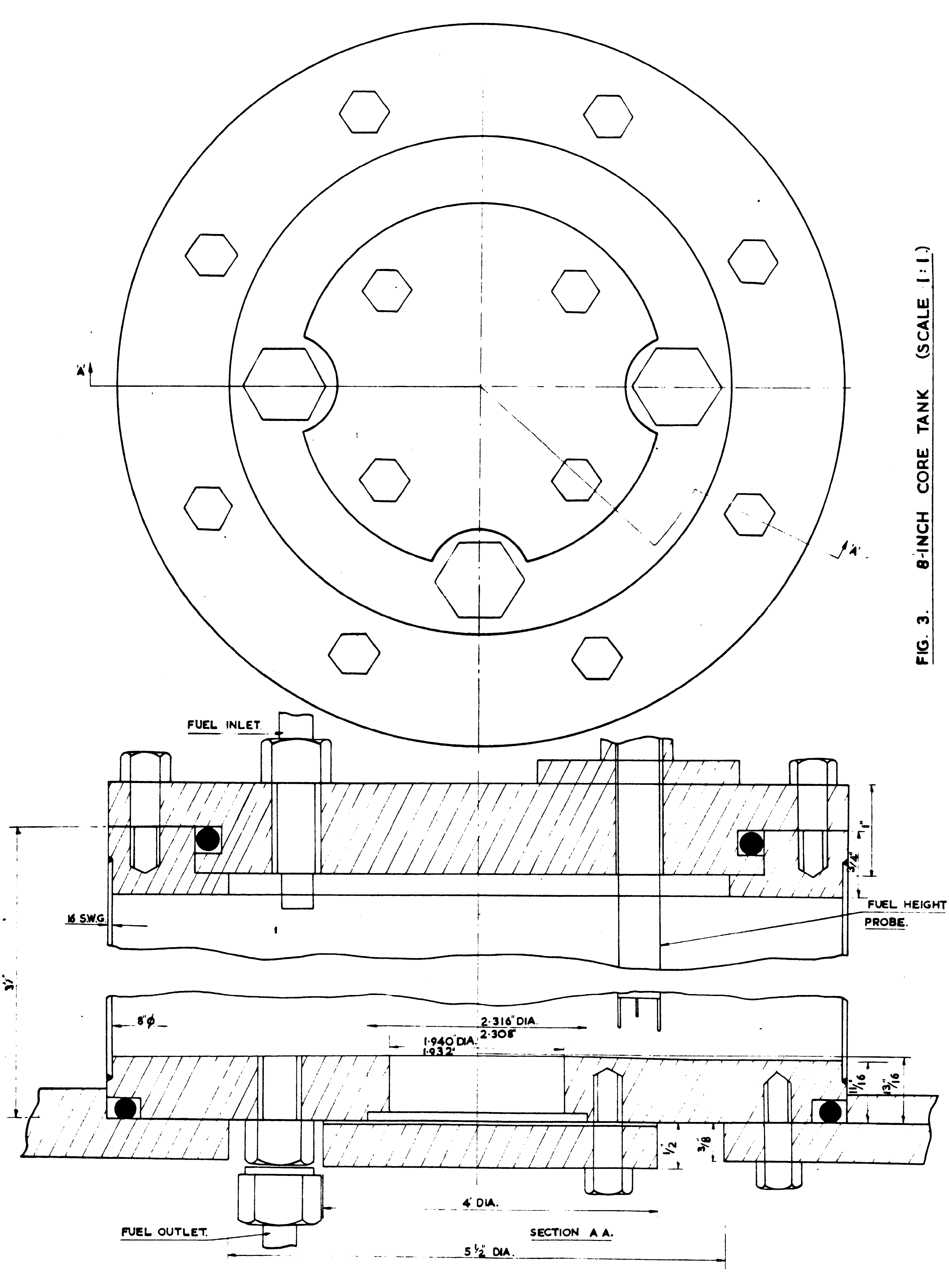

FIG. 3. 8-INCH CORE TANK (SCALE 1:1)

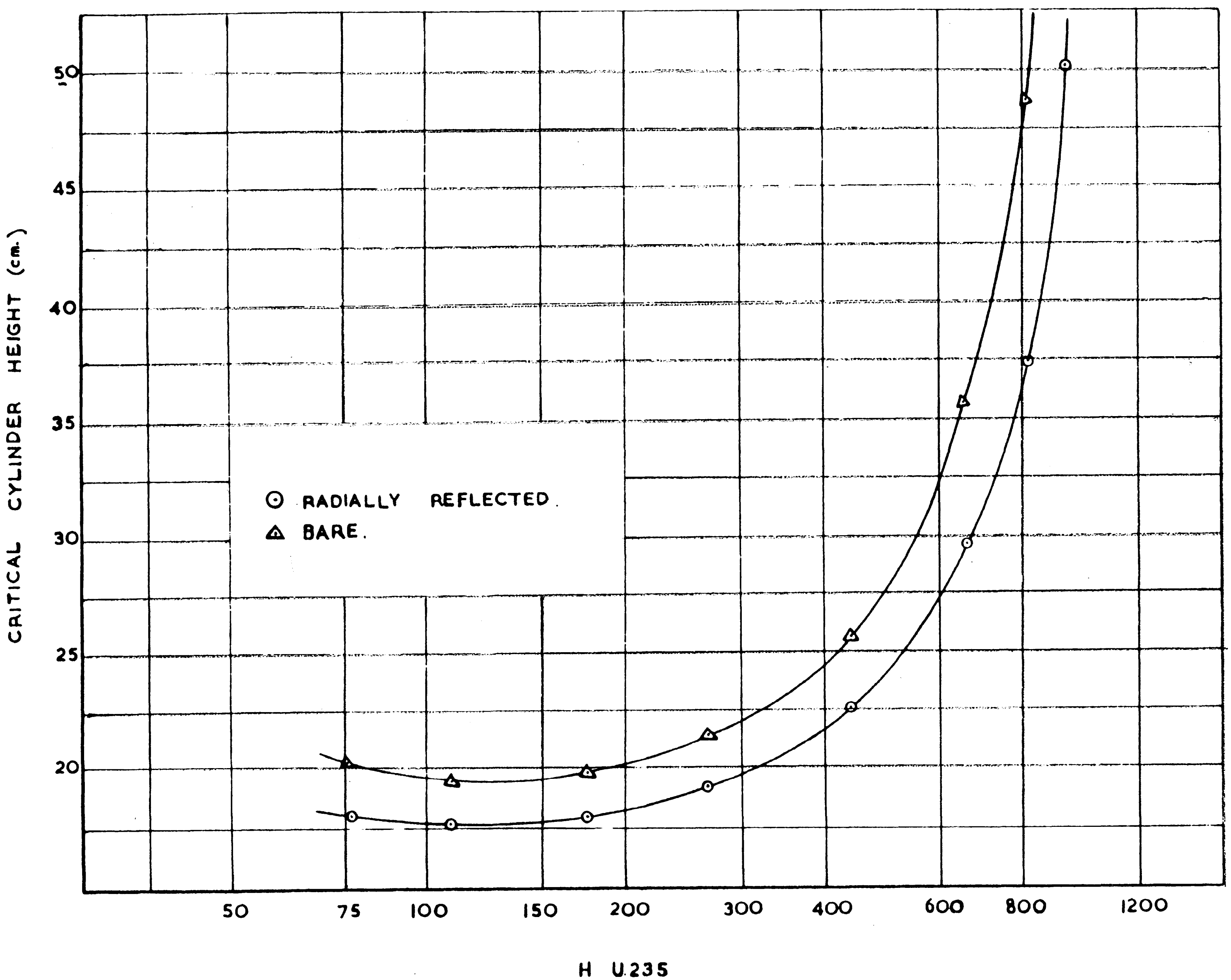

FIG. 4 HEIGHT OF CRITICAL 16-IN. DIA. CYLINDERS.

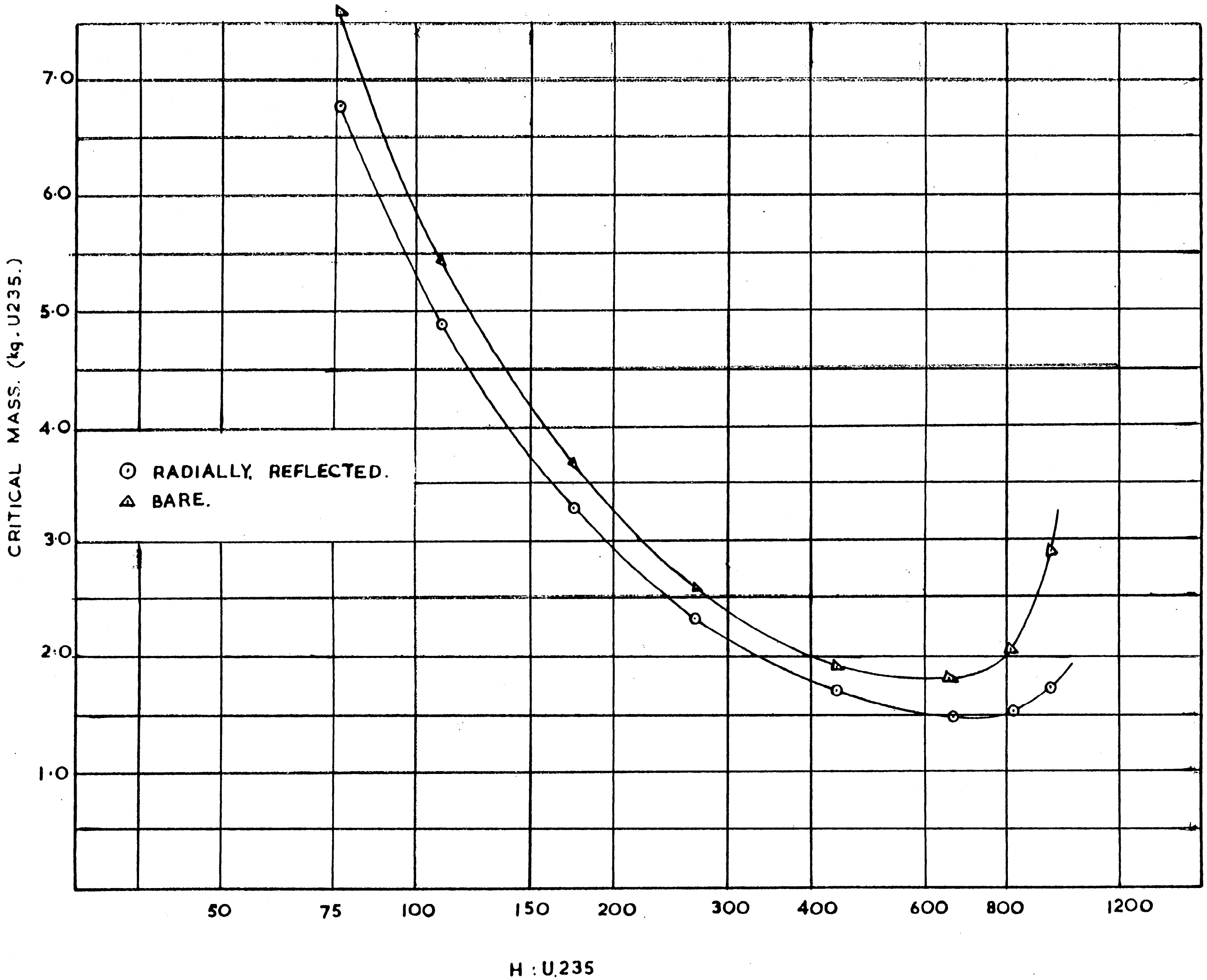

FIG. 5 CRITICAL MASS OF U.235 IN 16-IN. DIA. CYLINDERS.

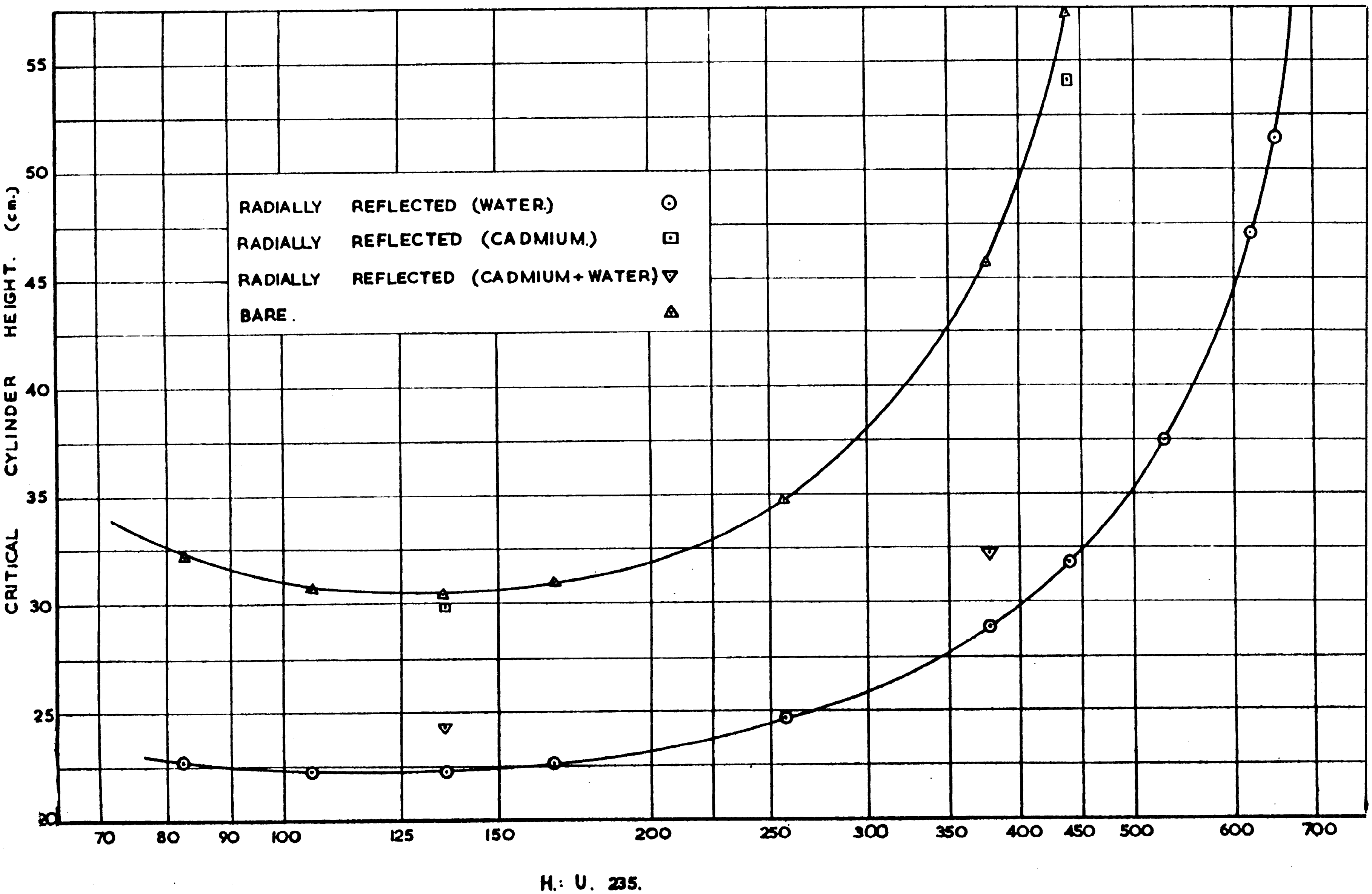

FIG. 6. HEIGHT OF CRITICAL 12-IN. DIA. CYLINDERS.

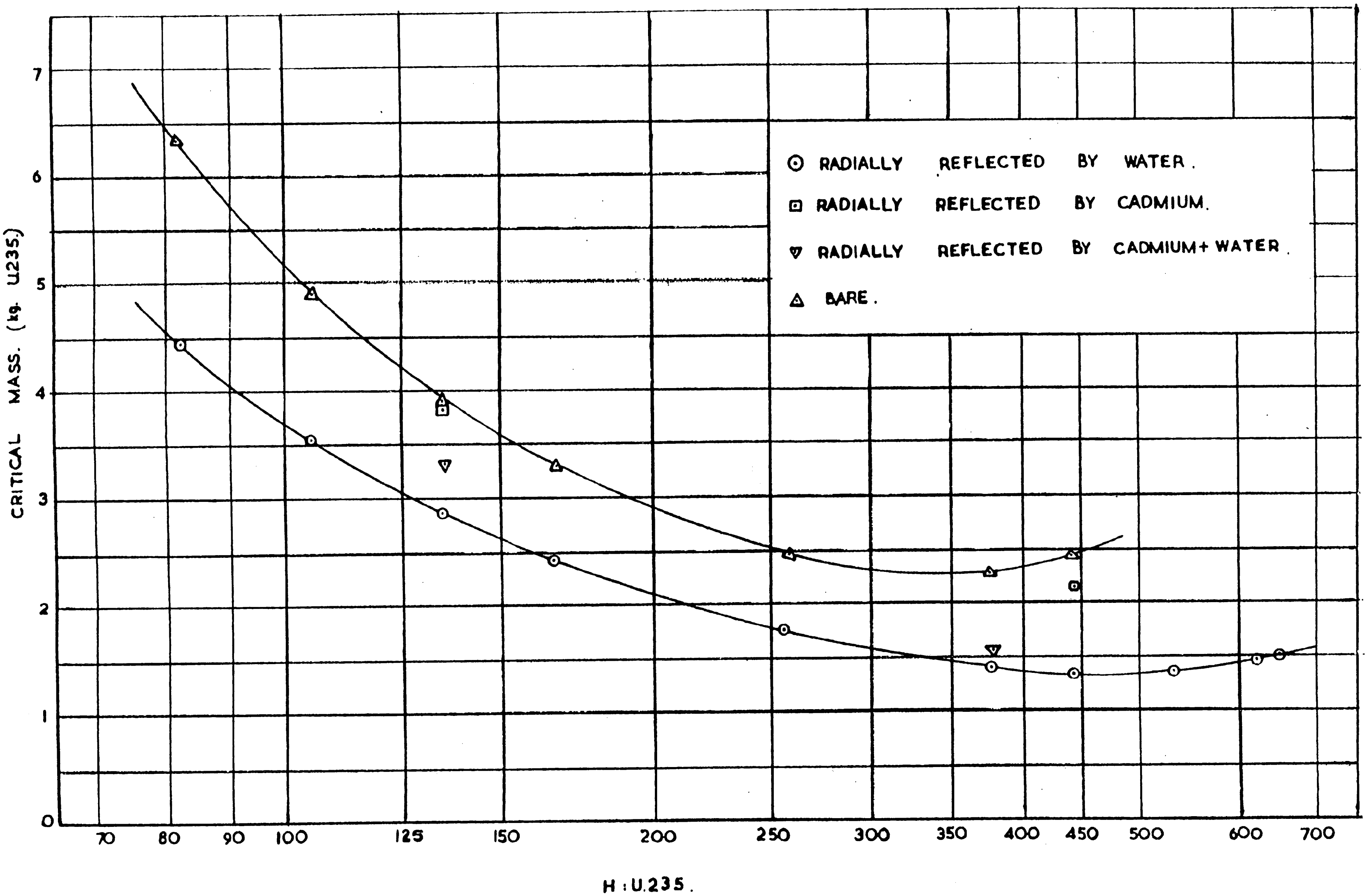

FIG. 7 CRITICAL MASS OF U.235 IN 12-IN. DIA. CYLINDERS.

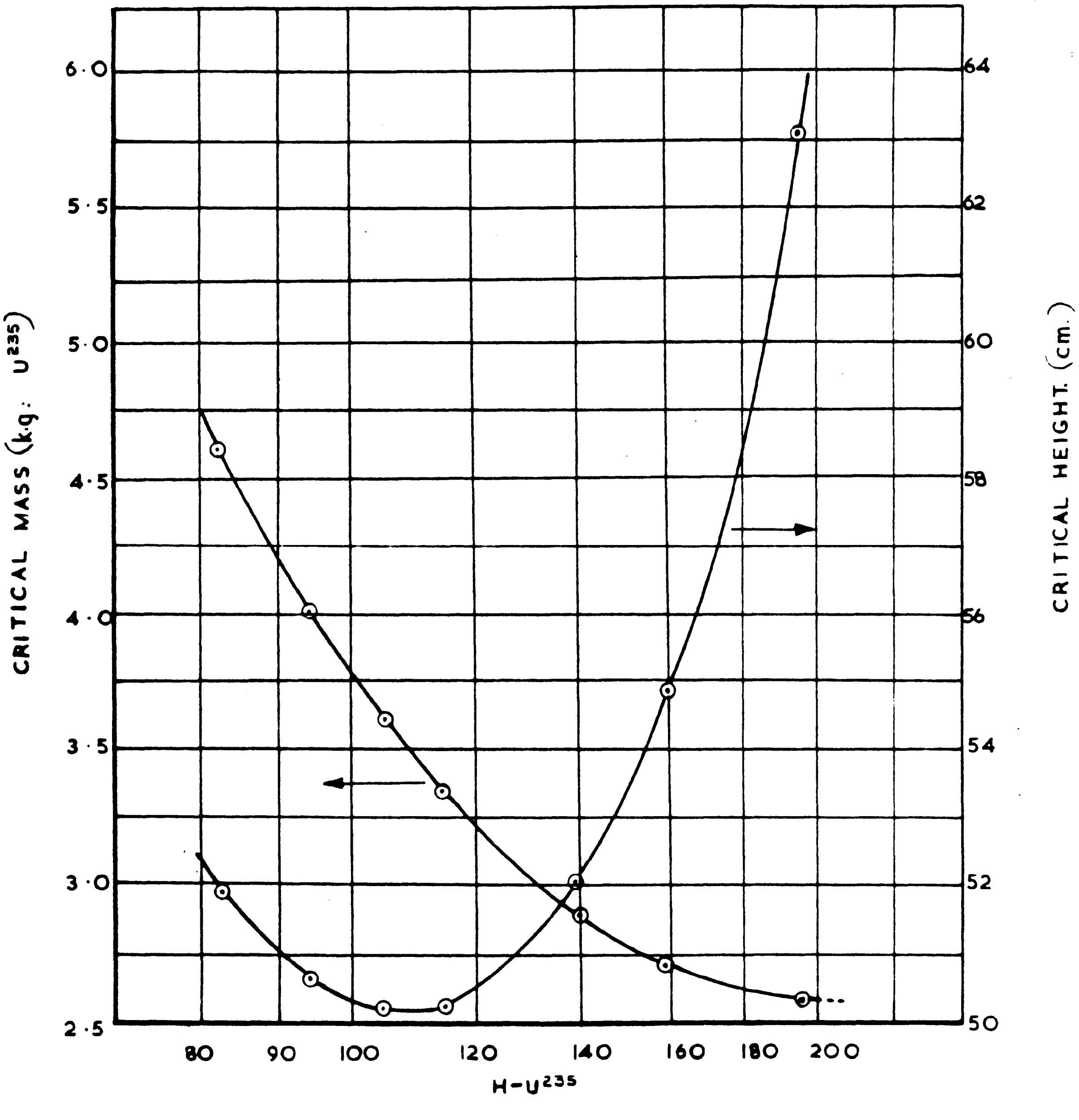

FIG.8. CRITICAL VALUES FOR 30V. URANYL FLUORIDE AQUEOUS SOLUTIONS IN 8-IN. (20·3cm) DIA. CYLINDERS RADIALLY REFLECTED.

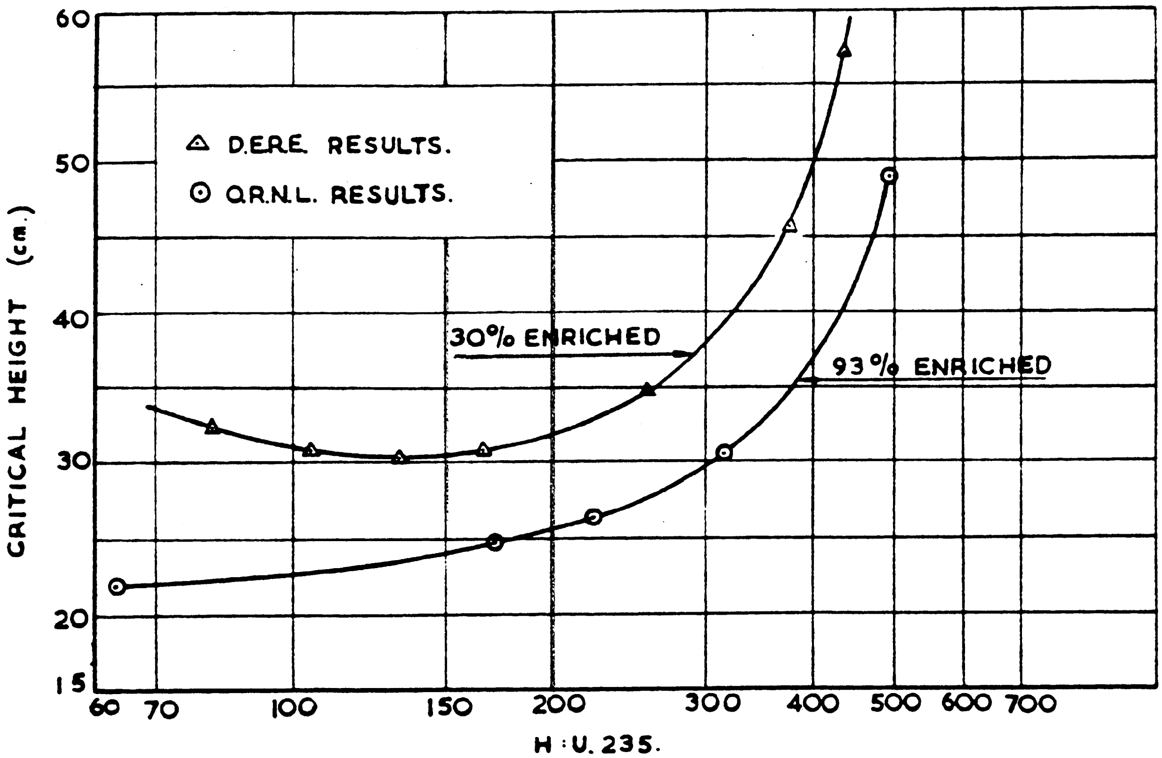

FIG. 9.

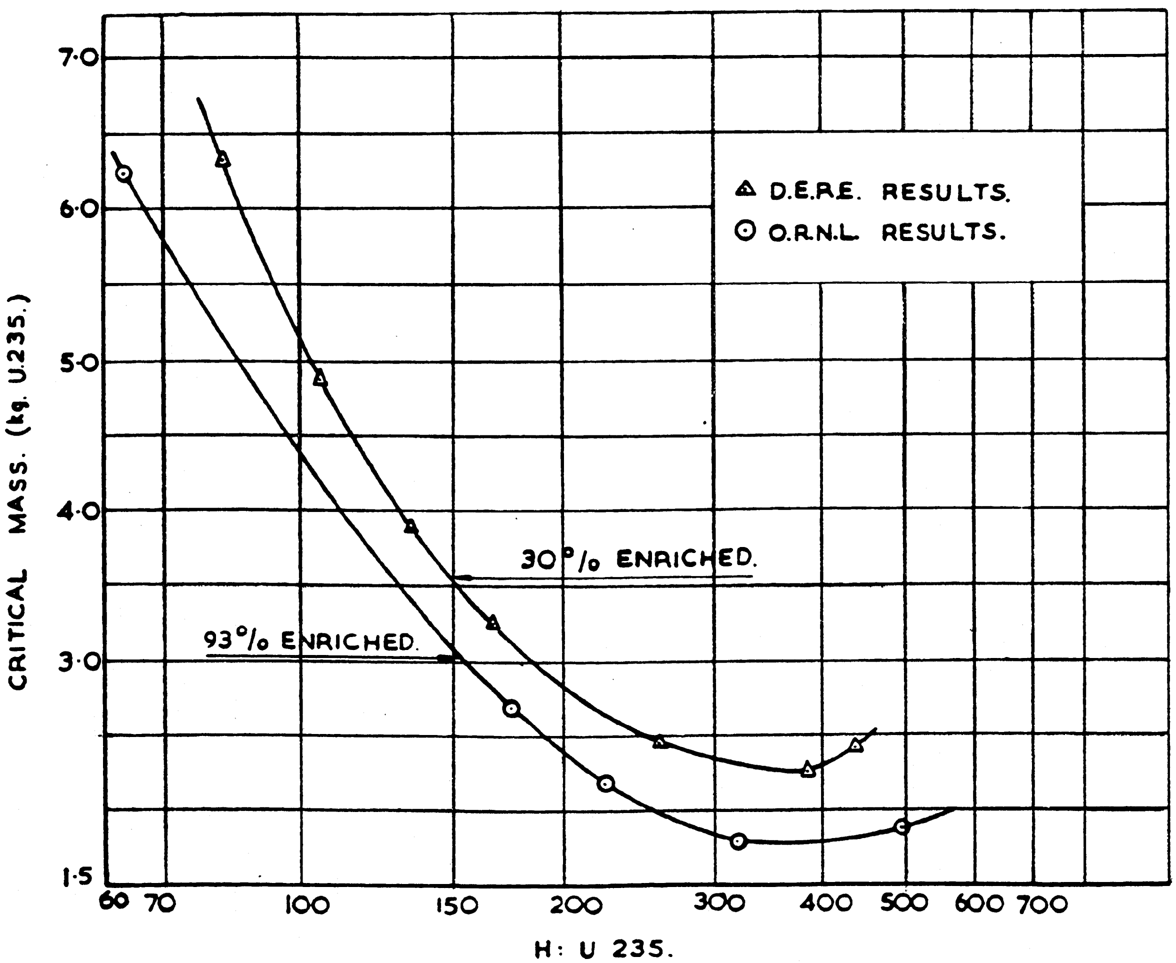

FIG. 10.

COMPARISON OF D.E.R.E. AND O.R.N.L. RESULTS FOR THE CRITICAL PARAMETERS OF A BARE 12 IN. DIA. CYLINDER.

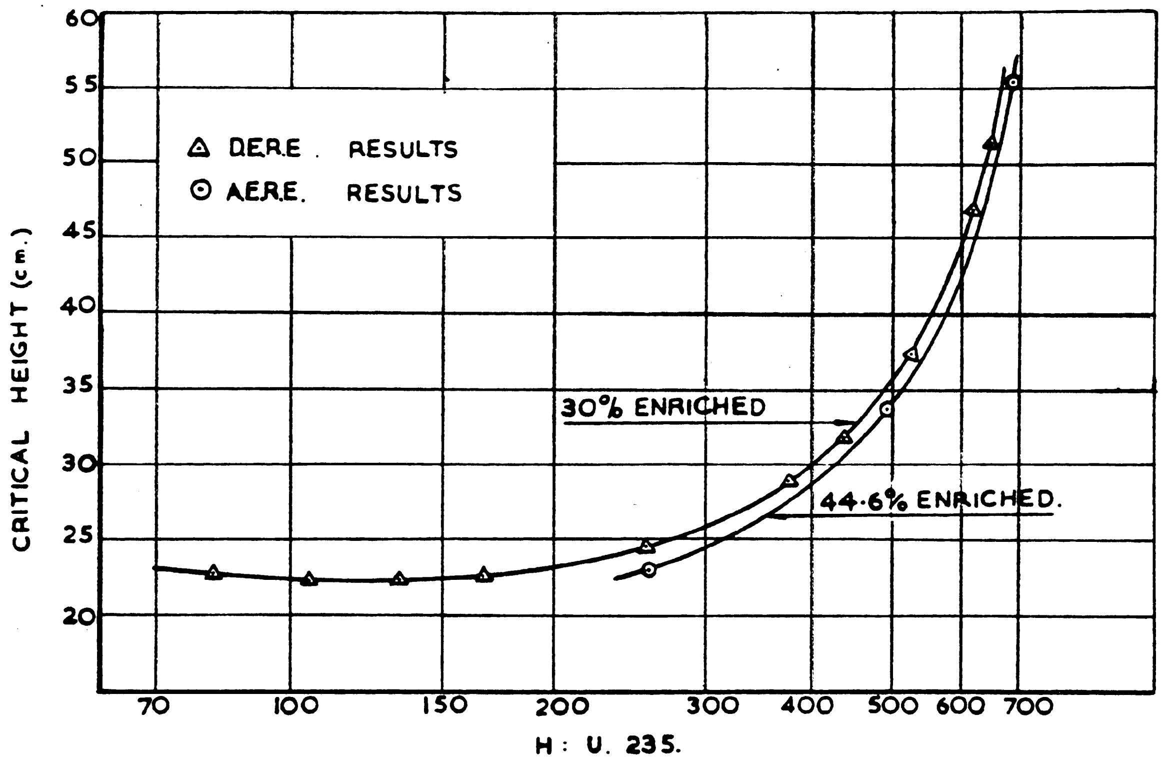

FIG. 11.

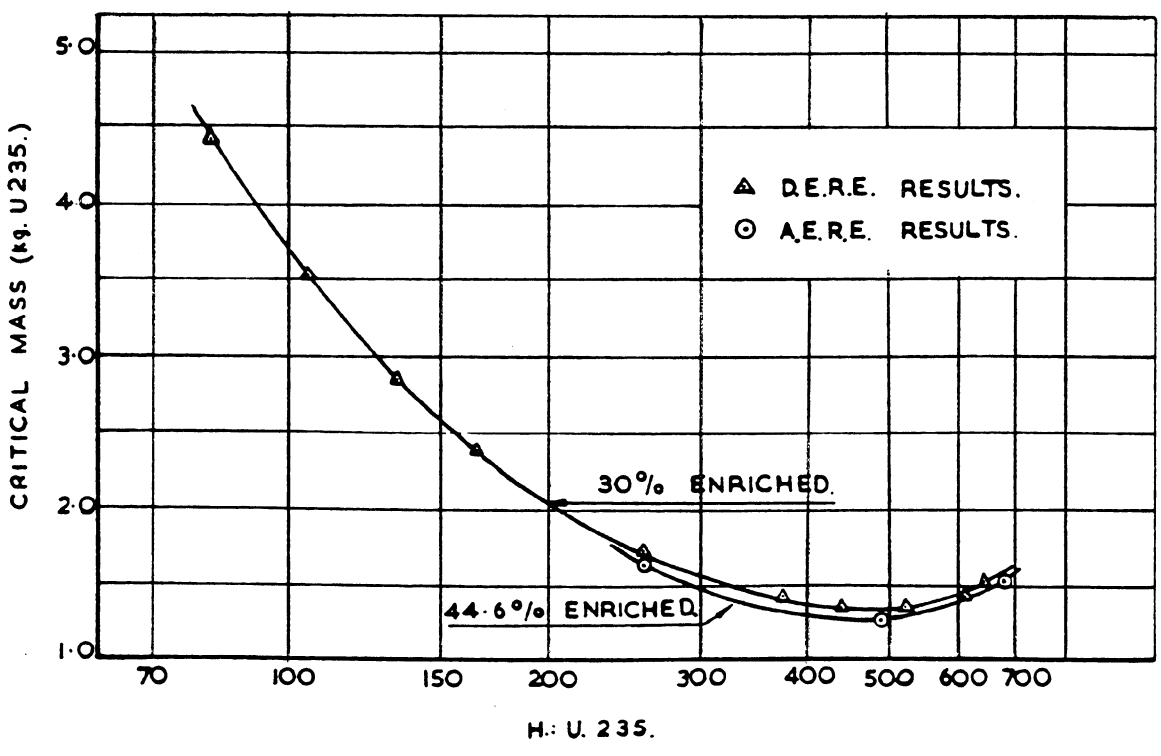

FIG. 12.

COMPARISON OF D.E.R.E. AND A.E.R.E. RESULTS FOR THE CRITICAL PARAMETERS OF A 12 IN. DIA. CYLINDER, RADIALLY REFLECTED BY WATER.