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Criticality Studies

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Y-12 PLANT NUCLEAR SAFETY HANDBOOK

Compiled By:

J. W. Wachter, Editor
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W. T. Mee
R. H. Pletz
F. G. Welfare
B. J. Youngblood

Y-12 PLANT
Oak Ridge, Tennessee

UNION CARBIDE NUCLEAR COMPANY
DIVISION OF UNION CARBIDE CORPORATION

Operating

- OAK RIDGE GASEOUS DIFFUSION PLANT
- OAK RIDGE Y-12 PLANT
- OAK RIDGE NATIONAL LABORATORY
- PADUCAH GASEOUS DIFFUSION PLANT

for the Atomic Energy Commission

Under U. S. Government Contract W7405 eng 26

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TID-4500 (20th Edition)

UNION CARBIDE NUCLEAR COMPANY
Division of Union Carbide Corporation

Y-12 PLANT

Contract W-7405-eng-26
With the U. S. Atomic Energy Commission

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PREFACE

The field of nuclear safety makes routine use of a wide range of information, most of which is scattered throughout a variety of AEC reports. This handbook is part of a continuing effort to compile into a single volume much of the information needed to solve nuclear safety problems. It is intended for reference use by persons already familiar with the original reports. Indeed, because this information is presented here in a highly condensed form, certain pertinent supporting data may not appear explicitly, so that persons not familiar with the circumstances under which the data were obtained are cautioned against using it without consulting the source material.

No originality is claimed for any portion of the report, save only in the manner of its presentation. Indeed, every effort has been made to refer the reader to the original source of the data and, also, to cite the particular report from which the data here are quoted. Although many tables of nuclear safety limits are included in this report, it is in no sense a "guide" which specifies the acceptable operating limits for the Y-12 Plant. Instead, these tables merely state the limits which are generally accepted in the nuclear safety field, and which have been developed and reported elsewhere.

A word about the arrangement of material: Basically, the information is categorized into 26 divisions, A through Z, whose subject matter ranges from general information, through calculational techniques and nuclear safety limits, to experimental critical data. Within these alphabetical divisions are various sections (eg, G-0, G-1, G-2) into which is gathered information on the same general subject. Tables and figures are each numbered consecutively within a Section and are referenced by giving the Section designation followed by the table (or figure) number, set off by a decimal point. Thus Table G-2.3 is the third table of Section G-2. Certain sections are incomplete in this issue of the report. They will be added to future issues as they become available.

Acknowledgement is due the McGraw-Hill Publishing Company for permission to reproduce material from Nucleonics magazine. Special acknowledgement is made to those whose unpublished work has been incorporated in this handbook, and particularly to A. D. Callihan for much recent experimental data and to H. C. Paxton for the comprehensive curves of Section J-2.

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GLOSSARY OF TERMS

Buckling - A number characteristic of a critical reactor and related to the curvature (or buckling) of the neutron flux. The Material Buckling, B_m^2, is a number which summarizes the material dependence of the nuclear characteristics of a system of fissionable material. The Geometric Buckling, B_g^2, is a number which summarizes the manner in which the nuclear characteristics of a system are dependent upon the size and shape of the system.

Contingency - A possible but unlikely change in the nuclear characteristics of a system of fissionable material which reduces its nuclear safety. Contingencies are independent if they relate to independent nuclear variables and are not caused by the same processing accident or mishap.

Critical - Capable of supporting a fission chain reaction such that the nuetron density at any point is constant in time. If, in the absence of an external source, the neutron density increases with time, the system is Supercritical; if it decreases with time, the system is Subcritical. A Delayed Critical system is one in which the chain reaction is propagated by both prompt and delayed neutrons. A Prompt Critical system is critical by reason of the prompt neutrons alone, and becomes supercritical by the subsequent appearance of delayed neutrons. The k_e for a prompt critical system is 1.0075, corresponding to an excess reactivity of $1, by definition.

Critical Assembly - A system of materials capable of supporting a fission chain reaction.

Critical Condition - The requirement that the effective multiplication factor equal one.

Cross Section - The probability that a particular nuclear event will take place expressed in terms of a fictitious nuclear area within which it is presumed that the event proceeds with 100% certainty and outside of which it is presumed not to occur at all. The neutron cross sections of a nucleus are the probabilities that the nucleus will undergo various interactions with neutrons.

Displacement, d - In an aqueous solution, the number of atoms of hydrogen displaced from pure water by one molecule of the solute.

Double Contingency Criterion - A method for considering the nuclear safety of a system in which the parameters are so arranged that at least two of the possible independent contingencies must occur before the system can become critical.

Enrichment - The isotopic enrichment of the fissile isotope. Usually expressed in weight per cent, E, but occasionally as atom per cent, E_a, or an isotopic ratio, R_a.

Experiment - The determination of critical parameters of a system by test. In a Critical Experiment, criticality is achieved or approached so closely as to remove all doubt as to the critical parameters. A Multiplication Experiment is one in which the values of the critical parameters are inferred from relatively long extrapolations of the reciprocal multiplication as increments of the final system are successively added, and implies absence of remote assembly equipment. An In Situ Experiment is a multiplication experiment carried out on production equipment of a fissile material processing facility and at the location where the equipment is to be used. An Exponential Experiment is one in which the critical parameters (esp. material buckling) of a large system are inferred from a subcritical part by measurements on the steady state neutron flux distribution resulting from an extraneous neutron source. In a Pulsed-Neutron Experiment, critical parameters are inferred from a subcritical system by studying the distribution in time and energy of leakage neutrons resulting from a burst of neutrons generated by a suitable external source.

Extrapolation Length - The distance into the medium surrounding a reactor core at which, for purposes of calculation, the neutron flux may be assumed to be zero.

Fast Fission Factor, ϵ - The increase in the number of fission neutrons due to fissions caused by neutrons with energies higher than thermal.

Fissile - 1. Fissionable. 2. (Proposed Amer Nucl Soc Standard.) The property of a heavy nucleus such that the binding energy of an additional neutron is sufficient to raise the resultant nucleus above the fission threshold. (Disregarding rare cases such as Pu-240 in which measurable fissioning occurs below the fission threshold by the tunnel effect, this definition can be paraphrased to mean fissionable by neutrons of essentially zero kinetic energy. Thus in common usage U-233, U-235, and Pu-239 are fissile because they are fissionable by room temperature thermal neutrons.)

Fission - The division of a nucleus into two or more separate nuclei, the Fission Products, with the release of energy, radiation, and neutrons. Fissions may be categorized by the speed of the neutron which initiated the fission process, as Thermal Fissions or Fast Fissions.

Fissionable - The property of a heavy nucleus such that it can be broken into two nearly equal fragments. Thus U-238 is said to be fissionable by neutrons of energy greater than 1 Mev or by photons of energy greater than 5.31 Mev.

Geometry - The size and shape of a system.

Mishap - That which brings about the occurrence of one or more contingencies, as by human or analytical error, or by a mechanical or process accident.

Moderator - A material capable of slowing high energy neutrons.

Multiplication Factor - The ratio of the number of neutrons present at a given time to the number of neutrons present one neutron generation time earlier. The Infinite Multiplication Factor, k_{oo}, is calculated without regard to the neutrons which escape from the system; the Effective Multiplication Factor, k_e, includes the escapes from the system due to its finite size.

Multiplication, M - The ratio of (a) the external (leakage) neutron flux produced by a neutron source within, or adjacent to, a system containing fissile material to (b) the external neutron flux produced in the absence of the fissile material. In measurements on uranium, the U-235 may, or may not, be replaced in (b) with a U-238 mock-up. Surface Multiplication, M_s, implies that the source is placed external to the material; Self Multiplication, M_c, implies that a mock fission source is placed centrally within the system. In interaction experiments, if a neutron leakage flux C is measured from an array of identical subcritical units clustered about a central unit having $M_c = B/A$; the Overall Multiplication, M_o, is $M_o = C/A$; the Cross Multiplication, M_x, is $M_x = M_o/M_c = C/B$.

Neutron - An uncharged nucleon of rest mass 1.00898 amu. Neutrons are categorized by their energy and mode of appearance in a critical system, thus; Fission Neutrons are neutrons released in fission events and have an average energy of translation of about 2 Mev. Thermal Neutrons are in thermal equilibrium with the surrounding medium and, at room temperatures, have energies distributed in a Maxwell-Boltzman distribution about 0.025 eV. Fast Neutrons have retained some or all of the initial fission energies, and are usually considered to include all neutrons not thermal neutrons, and may be further subdivided to include Epithermal and Intermediate Neutrons. Prompt Neutrons are fission neutrons released in the fission event, while Delayed Neutrons are emitted in the course of the nuclear decay of the fission products and appear subsequent to the fission event itself. The delay times for most delayed neutrons from U-235 fissions are about 5 seconds, and extend up to 1 minute.

Neutron Age - 1/6 of the average square of the crow-flight distance required for neutrons to slow down over a specified neutron energy range. In water, the neutron age from fission energy to thermal energy is approximately 27 cm^2.

Neutron Flux - The product of neutron density and average neutron velocity; the number of neutrons per unit area per unit time; or, the total neutron path length per unit volume per unit time.

Nuclear Safety - The application of experimental and theoretical data to the prevention of accidental criticalities.

Poison - A nonfissile material which absorbs neutrons and thereby tends to stop a fission chain reaction, or the action of adding a nonfissile neutron absorber to a system as a means of controlling criticality.

Reactor - 1. A vessel containing fissionable materials. 2. A system normally comprising a Core containing the fissile material and a Reflector.

Reflector - Material capable of changing the direction of movement of neutrons, thereby causing their return to a system of fissionable material. A Minimal Reflector has a reflecting ability no greater than a thickness of 1/8" of water; a Nominal Reflector has a reflecting ability no greater than that of one inch of water. An Infinite Reflector or a Full Reflector, is sufficiently thick that increasing its thickness does not increase the number or character of neutrons returned to the core.

Resonance Escape Probability, p - The probability that a neutron released by fission will not be absorbed before being slowed to thermal energy.

Resonance Integral, σ_r - The logarithmic integral of the absorption cross section over a range of neutron energy containing absorption resonances. The Effective Resonance Integral, $(\sigma_r)_e$, is such that, experimentally, $p = \exp \{- N (\sigma_r)_e / \xi \Sigma_s \}$.

Ring-Tamper - A reflector completely surrounding two or more subcritical reactors such that no portion of the reflector material lies in the space between the reactors.

Safe Geometry - A correlation of size and/or shape such that the system is safe for a certain material or group of materials.

Safe System - An arrangement of material which satisfies an accepted set of rules governing the amount and/or arrangement of fissionable material.

Safeguard - That which reduces the likelihood of a mishap affecting criticality, whether a technical contrivance to prevent a specific accident, or simply the existing operating procedures or established conditions which tend to reduce the hazard.

Shield - Material surrounding fissionable material to shield equipment or personnel from radiation resulting from fissions or from radioactive decay.

System - An arrangement of fissionable and nonfissionable materials considered from the point of view of nuclear criticality. In a Thermal System, most fissions are caused by thermal neutrons; in a Fast System, most fissions are caused by fast neutrons.

Thermal Diffusion Length - The distance a neutron moves after being thermalized and before being absorbed.

Thermal Utilization, f - The fraction of all thermal neutron absorptions which are absorptions by uranium.

Table B-1.1

CONVERSION FACTORS

To Convert	From	To	Either Multiply By	Or Divide By
Length	Centimeters	Feet	0 03281	30 4801
		Inches	0 39370	2 54
	Feet	Centimeters	30 4801	0 03281
		Inches	12	0 08333
		Meters	0 3048	3 2808
	Inches	Centimeters	2 540005	0 39370
		Feet	0 08333	12
		Meters	0 0254	39 37
	Meters	Feet	3 2808	0 3048
		Inches	39 37	0 0254
Area	Square Centimeters	Square Inches	0 15500	6 4516
		Square Feet	0 001076	929 034
	Square Feet	Square Centimeters	929 0341	0 001076
		Square Inches	144	0 006944
	Square Inches	Square Feet	0 006944	144
		Square Centimeters	6 4516	0 15500
Volume	Cubic Centimeters	Cubic Inches	0 06102	16 3872
		Cubic Feet	0 0000353	28,317
		Gallons	0 0002642	3,785 4
	Cubic Feet	Cubic Centimeters	28,317	0 0000353
		Cubic Meters	0 02832	35 311
		Gallons	7 481	0 13368
		Liters	28 32	0 03531
	Cubic Inches	Cubic Centimeters	16 3872	0 06102
		Cubic Feet	0 0005787	1728
		Gallons	0 004329	231
		Liters	0 01639	61 025
	Gallons	Cubic Centimeters	3,785 4	0 000264
		Cubic Feet	0 13368	7 481
		Cubic Inches	231	0 004329
		Liters	3 7853	0 26418
	Liters	Cubic Feet	0 03531	28 3206
		Cubic Inches	61 025	0 01639
		Gallons	0 26418	3 7853
Mass	Grams	Pounds	0 002205	453 59
	Kilograms	Pounds	2 2046	0 4536
	Pounds	Kilograms	0 4536	2 2046
		Grams	453 59	0 002205

Table B-1.1 (Continued)

To Convert	From	To	Either Multiply By	Or Divide By
Density	Grams/Cubic Centimeter	Pounds/Cubic Inch	0.03613	27.678
		Pounds/Gallon	8.3452	0.11983
		Pounds/Cubic Foot	62.43	0.01602
	Grams/Liter	Pounds/Gallon	.00776	128.8659
	Pounds/Cubic Foot	Grams/Cubic Centimeter	0.01602	62.4220
	Pounds/Gallon	Grams/Cubic Centimeter	0.11983	8.3452
Concentration	Grams/Pound	Grams/Gram	0.002205	
	Kilograms/Ton	Grams/Gram	0.001102	907.18
Flow	Gallons/Second	Liters/Minute	227.118	0.0044
	Liters/Second	Gallons/Minute	15.85	0.06309
	Pounds/Second	Kilograms/Minute	27.18	0.036792
	Pounds/Minute	Kilograms/Hour	27.18	0.036792

Table B-1.2

RECIPROCAL CONVERSION FACTORS

To Convert	From	To	Either Multiply By	Or Divide By
Reciprocal Length	Per Centimeter	Per Foot	30.4801	0.03281
		Per Inch	2.54	0.39370
	Per Foot	Per Centimeter	0.03281	30.4801
		Per Inch	0.08333	12
		Per Meter	3.2808	0.3048
	Per Inch	Per Centimeter	0.39370	2.54
		Per Foot	12	0.08333
		Per Meter	39.37	0.0254
Reciprocal Area	Per Square Centimeter	Per Square Inch	6.4516	0.15500
		Per Square Foot	929.034	0.001076
	Per Square Foot	Per Square Centimeter	0.001076	929.0341
		Per Square Inch	0.006944	144
	Per Square Inch	Per Square Foot	144	0.006944
		Per Square Centimeter	0.15500	6.4516

Table B-1.2 (Continued)

To Convert	From	To	Either Multiply By	Or Divide By
Reciprocal Volume	Per Cubic Centimeter	Per Cubic Inch	16.387	0.06102
		Per Cubic Foot	28,317.0	0.0000353
		Per Gallon	3,785.4	0.0002642
	Per Cubic Foot	Per Cubic Centimeter	0.0000353	28,317
		Per Cubic Meter	35.311	0.02832
		Per Gallon	0.13368	7.481
		Per Liter	0.03531	28.32
	Per Cubic Inch	Per Cubic Centimeter	0.06102	16.3872
		Per Cubic Foot	0.03531	0.0005787
		Per Gallon	231.	0.004329
		Per Liter	61.025	0.01639
	Per Gallon	Per Cubic Centimeter	0.000264	3,785
		Per Cubic Foot	7.481	0.13368
		Per Cubic Inch	0.004329	231
		Per Liter	0.26418	3.7853
	Per Liter	Per Cubic Foot	28.3206	0.0353
		Per Cubic Inch	0.01639	61.025
		Per Gallon	3.7853	0.26418
Reciprocal Mass	Per Gram	Per Pound	453.59	0 002205
	Per Kilogram	Per Pound	0.4536	2.2046
	Per Pound	Per Kilogram	2.2046	0.4536
		Per Gram	0.002205	453.59
Reciprocal Time	Per Hour	Per Minute	0.016667	60
		Per 8-Hour Shift	8	0.125
		Per Day	24	0.0006944
		Per Year	8766	0.0001141

Table B-1.3

VOLUME PER UNIT LENGTH OF
CYLINDRICAL CONTAINERS

Diameter (inches)	Liters (per in)	Liters (per ft)	US Gallons (per in)	US Gallons (per ft)
1.0	0.0129	0.154	0.0033	0.040
1.5	0.0290	0.347	0.0076	0.091
2.0	0.0515	0.618	0.0135	0.163
2.5	0.0804	0.965	0.0212	0.254
3.0	0.1158	1.390	0.0305	0.367
3.5	0.1577	1.892	0.0416	0.499
4.0	0.2059	2.471	0.0543	0.652
4.5	0.2606	3.127	0.0688	0.826
5.0	0.3218	3.861	0.0849	1.019
5.5	0.3893	4.672	0.1028	1.234
6.0	0.4633	5.560	0.1223	1.468
6.5	0.5438	6.525	0.1436	1.723
7.0	0.6306	7.568	0.1665	1.999
7.5	0.7239	8.687	0.1912	2.294
8.0	0.8237	9.884	0.2175	2.611
8.5	0.9299	11.158	0.2456	2.947
9.0	1.0425	12.510	0.2753	3.304
9.5	1.1615	13.938	0.3068	3.682
10.0	1.287	15.44	0.3399	4.079
10.5	1.419	17.03	0.3748	4.498
11.0	1.557	18.69	0.4113	4.936
11.5	1.702	20.42	0.4496	5.395
12.0	1.853	22.24	0.4895	5.875
12.5	2.011	24.13	0.5312	6.374
13.0	2.175	26.10	0.5745	6.895
13.5	2.346	28.15	0.6196	7.435
14.0	2.523	30.27	0.6663	7.996
14.5	2.706	32.47	0.7148	8.578
15.0	2.896	34.75	0.7649	9.179
15.5	3.092	37.11	0.8168	9.802
16.0	3.295	39.54	0.8703	10.444
16.5	3.504	42.05	0.9256	11.107
17.0	3.720	44.64	0.9825	11.791
17.5	3.942	47.30	1.0412	12.494
18.0	4.170	50.04	1.1015	13.219
18.5	4.405	52.86	1.1636	13.963
19.0	4.647	55.76	1.2273	14.728
19.5	4.894	58.73	1.2928	15.514
20.0	5.149	61.78	1.3599	16.319
20.5	5.409	64.91	1.4288	17.146
21.0	5.676	68.12	1.4993	17.992
21.5	5.950	71.40	1.5716	18.859
22.0	6.230	74.76	1.6455	19.747
22.5	6.516	78.20	1.7212	20.654
23.0	6.809	81.71	1.7985	21.583
23.5	7.108	85.30	1.8776	22.531
24.0	7.414	88.97	1.9583	23.500
24.5	7.726	92.72	2.0408	24.490
25.0	8.045	96.54	2.1249	25.499
25.5	8.370	100.44	2.2108	26.530
26.0	8.701	104.42	2.2983	27.580
26.5	9.039	108.47	2.3876	28.651
27.0	9.384	112.61	2.4785	29.743
27.5	9.734	116.81	2.5712	30.854
28.0	10.092	121.10	2.6655	31.987
28.5	10.455	125.47	2.7616	33.139
29.0	10.825	129.91	2.8593	34.312
29.5	11.202	134.42	2.9588	35.506
30.0	11.585	139.02	3.0599	36.719
(30 gal drum)				
18.4	4.356	52.27	1.151	13.81
(55 gal drum)				
22.5	6.516	78.20	1.7212	20.654

Table B-2.1

PHYSICAL CONSTANTS OF URANIUM COMPOUNDS

Compound	Weight Percent Uranium	Crystalline Color	Theoretical Density	Solubility (gms/100 ml)
UCl_4	--	--	4.87[1]	--
UCl_6	--	--	3.59[1]	--
UF_4	0.758	Green	6.7[2]	i/w, s conc a & alk
UF_6	0.676	Pale Yellow	5.06[1]	s/w, s CCl_4
UH_3	--	--	10.92[1]	--
UO_2	0.882	Brown-Black	10.96[1]	i/w, s HNO_3 & conc H_2SO_4
U_3O_8	0.849	Olive Green-Black	8.39[1]	i/w, s HNO_3 & H_2SO_4
UO_3	0.833	Yellow-Red	8.34[1]	i/w, s min a
UO_4	0.786	--	--	--
$UO_4 \cdot 2 H_2O$	0.704	Pale Yellow	--	.0006/w, d HCl
$UO_2(NO_3)_2$	0.604	--	--	--
$UO_2(NO_3)_2 \cdot 6 H_2O$	0.474	Yellow	2.807	170/w, v s org
UO_2SO_4	0.650	--	--	--
$UO_2SO_4 \cdot 3 H_2O$	0.567	Yellow-Green	3.28	20.5/w, 4 al s H_2SO_4
$2 UO_2SO_4 \cdot 7 H_2O$	0.555	Yellow	--	v s/w, s H_2SO_4
UO_2F_2	--	White	6.37[1]	--

Source Handbook of Chemistry and Physics, pp 678-9, 41st Edition, Chemical Rubber Publishing Co., Cleveland, Ohio (1959).
[1] Katz, J. J., The Chemistry of Uranium, First Edition, McGraw-Hill Book Co., New York, New York (1951).
[2] The Condensed Chemical Dictionary, Fifth Edition, Arthur and Elizabeth Rose, State College, Pa., Reinhold Publishing Corp, New York, New York (1956).

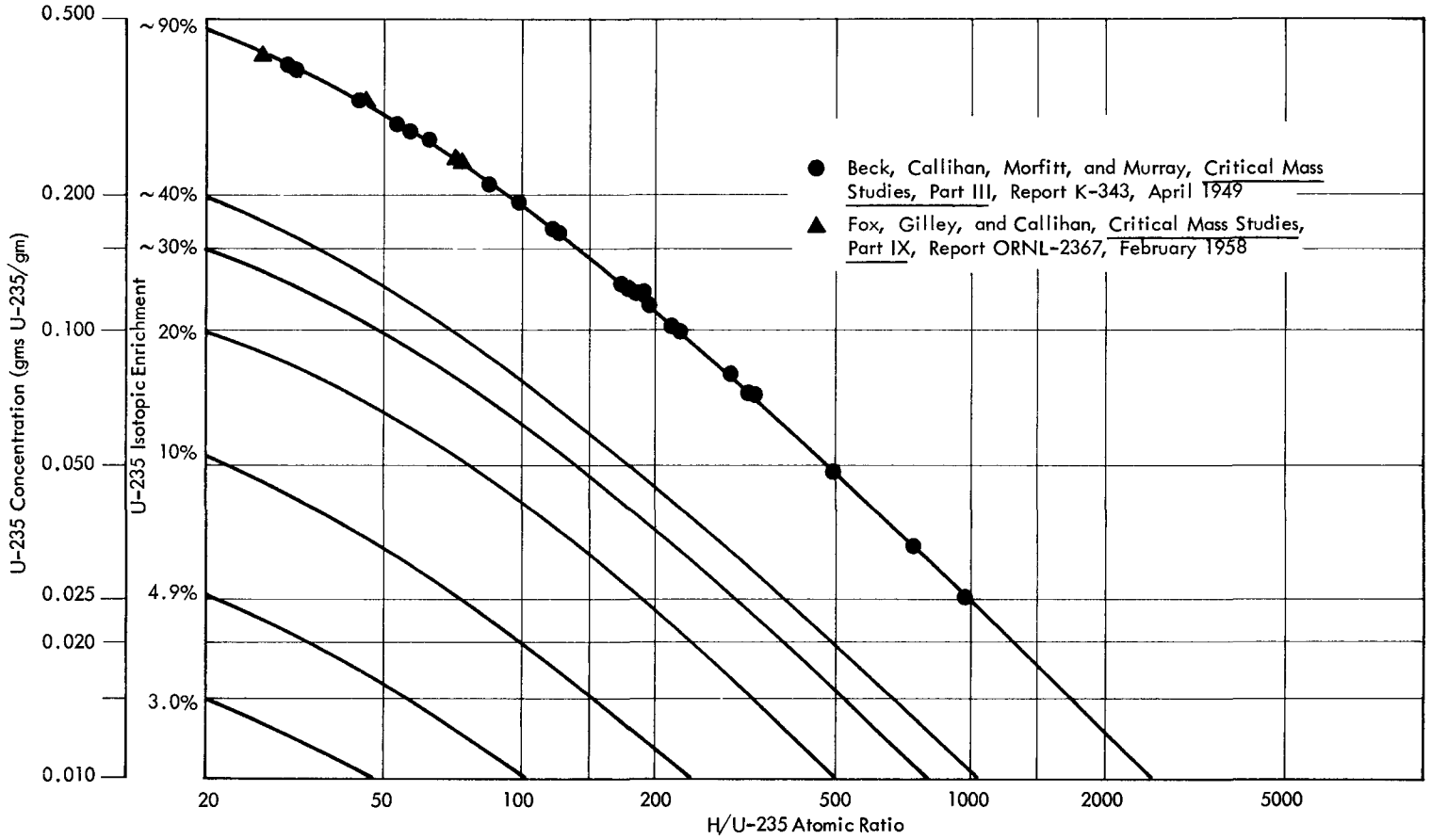


Figure B-3.1. CONCENTRATION OF URANYL FLUORIDE SOLUTION AS A FUNCTION OF THE H/U-235 ATOMIC RATIO. (As Derived from Figures B-3.2 and B-3.3.)

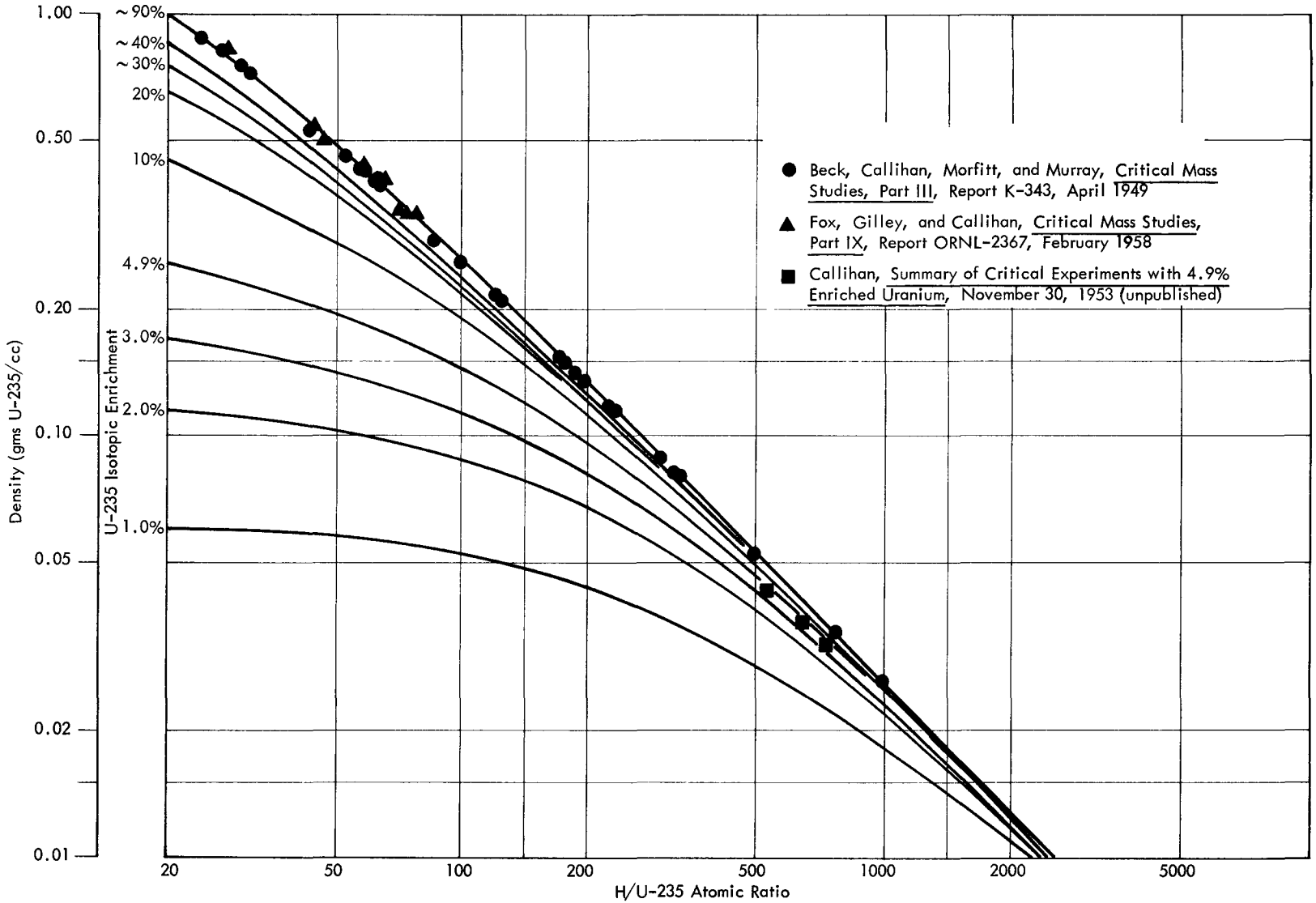


Figure B-3.2. DENSITY OF URANYL FLUORIDE SOLUTION AS A FUNCTION OF THE H/U-235 ATOMIC RATIO ACCORDING TO THE DISPLACEMENT FORMULA. (The Displacement of 4.365 was Chosen to Give the Best Fit to the Experimental Data for ~90% Isotopic Enrichment.)

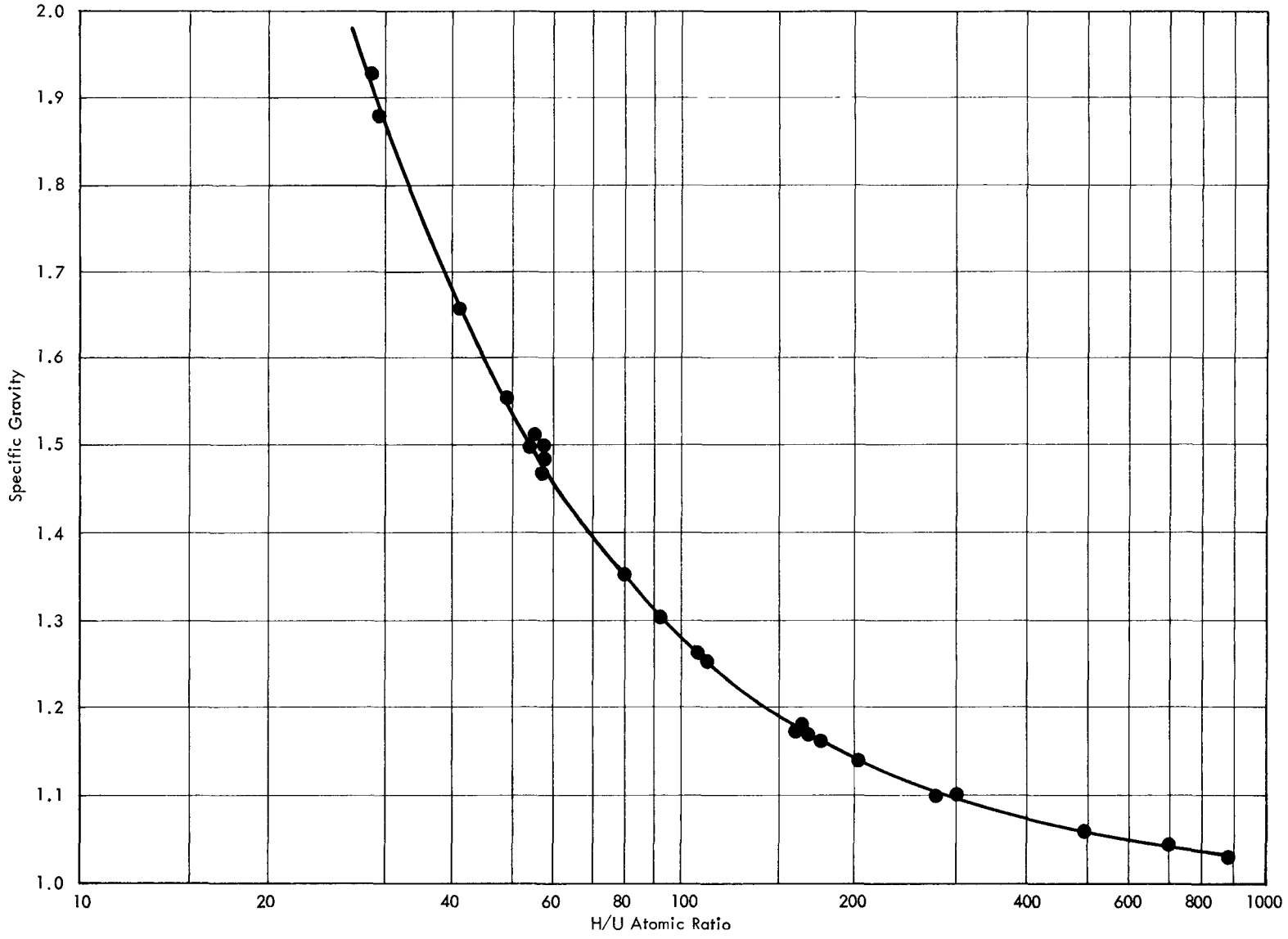


Figure B-3.3. SPECIFIC GRAVITY OF URANYL FLUORIDE SOLUTION AS A FUNCTION OF THE H/U-235 ATOMIC RATIO. (The Curve was Calculated from Data Found in Critical Mass Studies, Part III, by Callihan, Morfitt, and Murray, K-343, April 1949.)

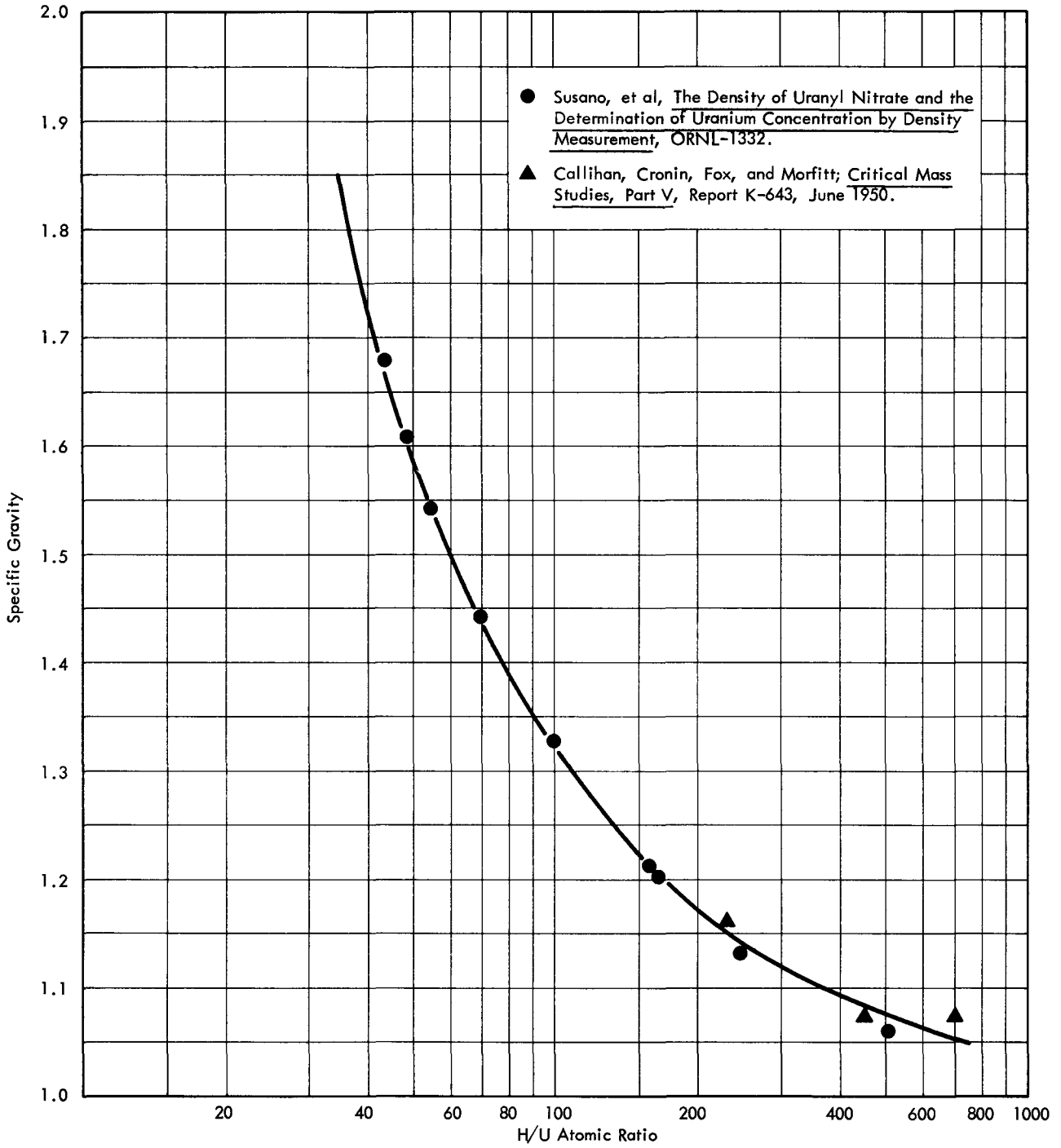


Figure B-3.4. SPECIFIC GRAVITY OF URANYL NITRATE SOLUTION AS A FUNCTION OF THE H/U-235 ATOMIC RATIO. (N/U = 2.86)

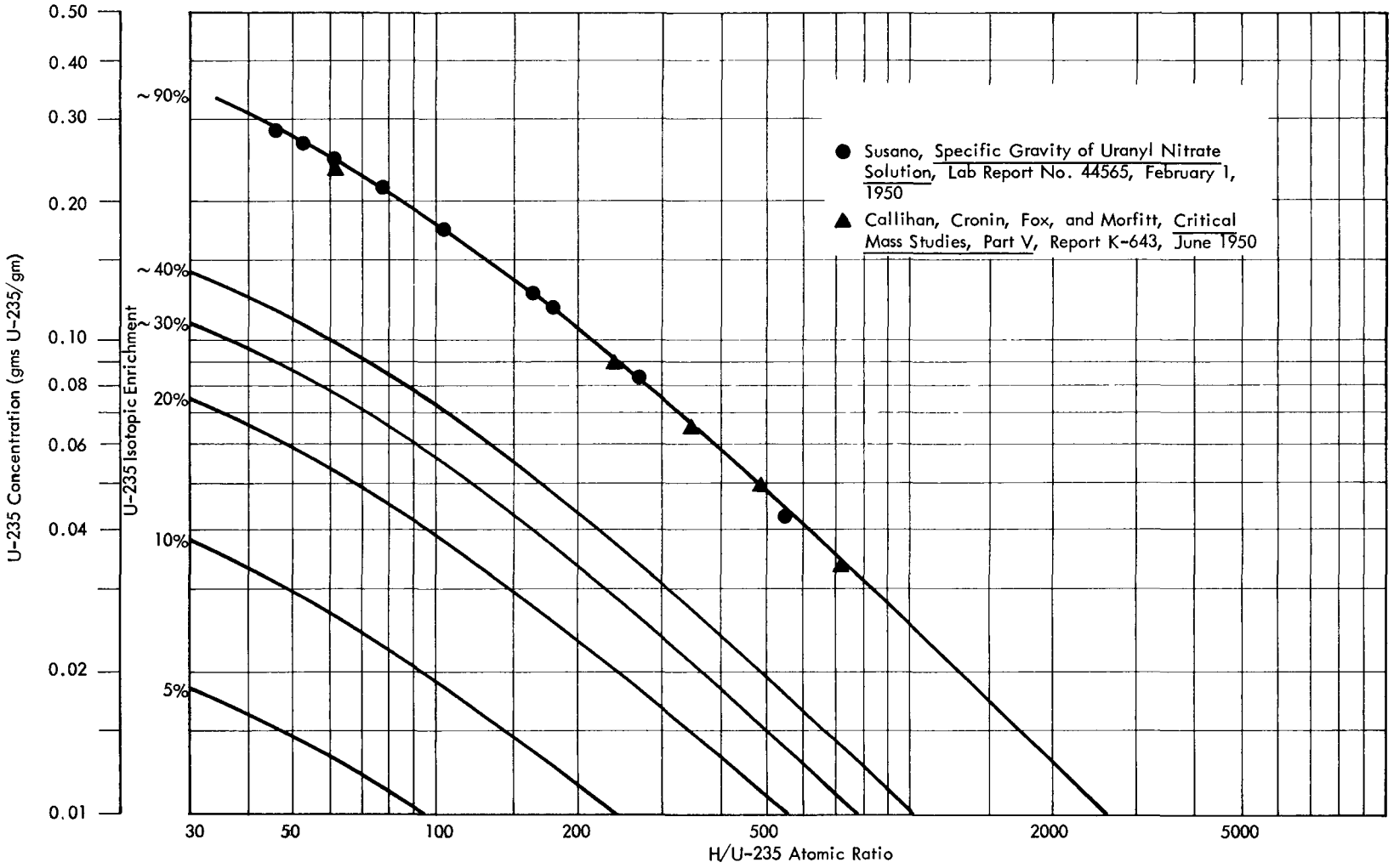


Figure B-3.5. CONCENTRATION OF URANYL NITRATE SOLUTION AS A FUNCTION OF THE H/U-235 ATOMIC RATIO. (As Derived from Figures B-3.4 and B-3.6.)

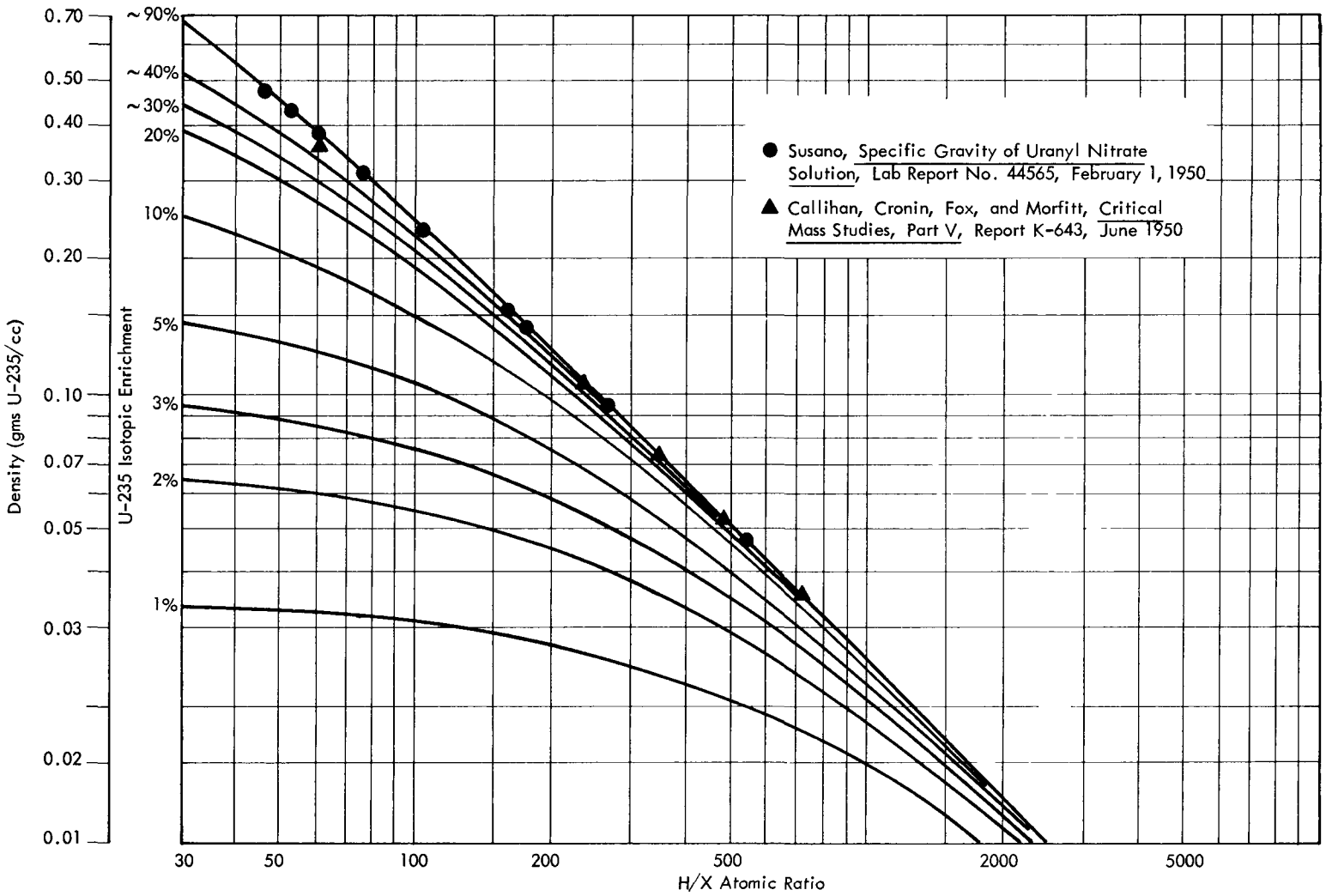


Figure B-3.6. DENSITY OF URANYL NITRATE SOLUTION AS A FUNCTION OF THE H/U-235 ATOMIC RATIO ACCORDING TO DISPLACEMENT FORMULA. (The Displacement of 8.0 was Chosen to Give the Best Fit to the Experimental Data for ~90% Isotopic Enrichment.)

Table C-1.1

THERMAL NEUTRON DATA FOR THE ELEMENT

Cross sections are at 2,200 m/sec and, where necessary, have been corrected to yield effective 1/v cross sections in a Maxwellian thermal neutron flux. For the fissionable elements, for which the moderation area has little meaning, that column contains the microscopic fission cross section. Cross sections given are the absorption (a), scattering (s), and total (t) cross sections.

Atomic No	Element or Compound	Atomic or Mole Wt	Density (gms/cm³)	Nuclei Per Unit Vol ($\times 10^{24}$/cm³)	$1-\mu_o$	ξ	Microscopic Cross Section (barns)			Macroscopic Cross Section (cm⁻¹)			Mean Free Path (cm)			Resonance Integral (barns)	Diffusion Length (cm)	Diffusion Coefficient (cm)	Atomic No
							σ_a	σ_s	σ_t	Σ_a	Σ_s	Σ_t	λ_a	λ_s	λ_t				
1	H	1.008	8.9 (1)	5.3 (1)	0.3386	1.000	0.33	38	38	1.7 (1)	0.002	0.002	0.6 (2)	525	521		1,610	518	1
	H_2O	18.016	1.00	0.0335 (3)	0.676	0.948	0.66	103	103	0.022	3.45	3.45	45	0.290	0.290		2.73 (4)	0.164	
	D_2O	20.030	1.10	0.0331 (3)	0.884	0.570	0.001	13.6	13.6	3.3 (1)	0.449	0.449	0.3 (2)	2.23	2.23		116 (4)	0.62	
2	He	4.003	17.8 (1)	2.6 (1)	0.8334	0.425	0.007	0.8	0.807	0.02 (1)	2.1 (1)	2.1 (1)	50 (2)	4,760	4,760		2.8 (2)	0.16 (2)	2
3	Li	6.940	0.534	0.0463	0.9047	0.268	71	1.4	72.4	3.29	0.065	3.35	0.304	15.4	0.299	28	0.605	1.17	3
4	Be	9.013	1.85	0.1236	0.9259	0.209	0.010	7.0	7.01	124 (1)	0.865	0.865	806	1.16	1.16		22 (4)	0.60	4
	BeO	25.02	3.025	0.0728 (3)	0.939	0.173	0.010	6.8	6.8	73 (1)	0.501	0.501	1,370	2.00	2.00		32 (4)	0.75	
5	B	10.82	2.45	0.1364	0.9394	0.171	755	4	759	103	0.546	104	0.010	1.83	0.010		0.112	1.28	5
6	C	12.011	1.60	0.0803	0.9444	0.158	0.003	4.8	4.80	26 (1)	0.385	0.385	3,845	2.60	2.60		54.4 (4)	0.778	6
7	N	14.008	0.0013	5.3 (1)	0.9524	0.136	1.88	10	11.9	9.9 (1)	50 (1)	60 (1)	0.1 (1)	2,000	1,667		2,710	661	7
8	O	16.000	0.0014	5.3 (1)	0.9583	0.120	20 (1)	4.2	4.2	0.000	21 (1)	21 (1)	$\sim\infty$	4,760	4,760		4.1 (2)	166	8
9	F	19.00	0.0017	5.3 (1)	0.9649	0.102	0.001	3.9	3.90	0.01 (1)	20 (1)	20 (1)	100 (2)	5,000	5,000		1.9 (2)	1,729	9
10	Ne	20.183	0.0009	2.6 (1)	0.9667	0.0968	1	2.4	3.40	2.6 (1)	6.2 (1)	8.9 (1)	0.3 (2)	0.1 (2)	0.1 (2)		0.12 (2)	4,539	10
11	Na	22.991	0.971	0.0254	0.9710	0.0845	0.515	4.0	4.52	0.013	0.102	0.115	76.3	9.80	8.70	0.27	15.8	3.27	11
12	Mg	24.32	1.74	0.0431	0.9722	0.0811	0.063	3.6	3.66	0.003	0.155	0.158	368	6.45	6.33	0.9	28.5	2.21	12
13	Al	26.98	2.699	0.0602	0.9754	0.0723	0.230	1.4	1.63	0.014	0.084	0.098	72.5	11.9	10.2	0.18	20.0	5.52	13
14	Si	28.09	2.42	0.0522	0.9762	0.0698	0.13	1.7	1.83	0.007	0.089	0.096	147	11.3	10.6	0.5	23.7	3.81	14
15	P	30.975	1.82	0.0354	0.9785	0.0632	0.20	5	5.20	0.007	0.177	0.184	141	8.55	5.43	2	16.4	1.90	15
16	S	32.066	2.07	0.0389	0.9792	0.0612	0.49	1.1	1.59	0.019	0.043	0.062	52.4	23.3	16.2	0.6	19.5	7.24	16
17	Cl	35.457	0.0032	5.3 (1)	0.9810	0.0561	32.6	16	48.6	0.002	80 (1)	0.002	625	1,240	417	12	429	294	17
18	A	39.944	0.0018	2.6 (1)	0.9833	0.0492	0.62	1.5	2.12	2.6 (1)	3.9 (1)	5.5 (1)	0.5 (2)	0.2 (2)	0.2 (2)		0.18 (2)	0.63 (2)	18
19	K	39.100	0.87	0.0134	0.9829	0.0504	1.97	1.5	3.47	0.026	0.020	0.047	37.9	49.8	21.5	1.1	22.3	13.1	19
20	Ca	40.08	1.55	0.0233	0.9833	0.0492	0.43	3.0	3.43	0.010	0.070	0.080	100	14.3	12.5	2	21.7	4.70	20
21	Sc	44.96	2.5	0.0335	0.9852	0.0438	23.5	24	47.5	0.787	0.804	1.59	1.29	1.24	0.628	10.7 (5)	0.666	0.349	21
22	Ti	47.90	4.5	0.0566	0.9861	0.0411	5.8	4	9.8	0.328	0.226	0.555	3.05	4.43	1.80	3.0	1.86	1.13	22
23	V	50.95	5.96	0.0704	0.9869	0.0387	5.1	5	10.1	0.359	0.352	0.711	2.79	2.84	1.41	2.2 (5)	1.48	0.786	23
24	Cr	52.01	7.1	0.0822	0.9872	0.0385	2.9	3.0	5.9	0.238	0.247	0.485	4.20	4.05	2.06	1.9	2.18	1.13	24
25	Mn	54.94	7.2	0.0789	0.9878	0.0359	13.2	2.3	15.5	1.04	0.181	1.22	0.962	5.52	0.820	10.8	0.898	0.839	25
26	Fe	55.85	7.86	0.0848	0.9881	0.0353	2.53	11	13.5	0.215	0.933	1.15	4.65	1.07	0.870	2.3	1.27	0.345	26
27	Co	58.94	8.9	0.0910	0.9887	0.0335	37.0	7	44.0	3.37	0.637	4.00	0.297	1.57	0.250	48	0.273	0.251	27
28	Ni	58.71	8.90	0.0913	0.9887	0.0335	4.6	17.5	22.1	0.420	1.60	2.02	2.38	0.63	0.495	4	0.688	0.199	28
29	Cu	63.54	8.94	0.0848	0.9896	0.0309	3.69	7.2	10.9	0.313	0.611	0.924	3.19	1.64	1.08	4	1.26	0.497	29
30	Zn	65.38	7.14	0.0658	0.9897	0.0304	1.06	3.6	4.66	0.070	0.237	0.307	1.43	4.22	0.326	2	4.38	1.34	30
31	Ga	69.72	5.91	0.0511	0.9905	0.0283	2.77	4	6.77	0.142	0.204	0.346	7.04	4.90	2.89	9.2 (5)	3.18	1.44	31
32	Ge	72.60	5.36	0.0445	0.9909	0.0271	2.35	3	5.35	0.105	0.134	0.239	9.52	7.46	4.18		4.53	2.15	32

Table C-1.1 (Continued)

Atomic No	Element or Compound	Atomic or Mole Wt	Density (gms/cm^3)	Nuclei Per Unit Vol ($\times 10^{24}$/cm^3)	$1-\mu_o$	ξ	Microscopic Cross Section (barns)			Macroscopic Cross Section (cm^{-1})			Mean Free Path (cm)			Resonance Integral (barns)	Diffusion Length (cm)	Diffusion Coefficient (cm)	Atomic No
							σ_a	σ_s	σ_t	Σ_a	Σ_s	Σ_t	λ_a	λ_s	λ_t				
33	As	74.91	5.73	0.0461	0.9911	0.0264	4.1	6	10.1	0.189	0.277	0.466	5.29	3.61	2.15	33	2.37	1.06	33
34	Se	78.96	4.8	0.0366	0.9916	0.0251	11.8	11	22.8	0.432	0.403	0.835	2.31	2.48	1.20		1.26	0.686	34
35	Br	79.916	3.12	0.0235	0.9917	0.0247	6.6	6	12.6	0.155	0.141	0.296	6.45	7.09	3.38	147 (5)	3.54	1.94	35
36	Kr	83.80	0.0037	2.6 (1)	0.9921	0.0236	28	7.2	35.2	73 (1)	70 (1)	91 (1)	1,400	3,300	1,100		1,180	1,010	36
37	Rb	85.48	1.53	0.0108	0.9922	0.0233	0.70	12	12.7	0.008	0.130	0.138	132	7.69	72.4		18.3	2.55	37
38	Sr	87.63	2.54	0.0175	0.9925	0.0226	1.16	10	11.2	0.020	0.175	0.195	49.3	5.71	5.13	16	9.62	1.88	38
39	Yt	88.92	5.51	0.0373	0.9925	0.0223	1.3	3	4.3	0.048	0.112	0.160	20.8	8.93	6.25	0.91 (5)	7.57	2.75	39
40	Zr	91.22	6.4	0.0423	0.9927	0.0218	0.180	8	8.2	0.008	0.338	0.346	132	2.96	2.89	3	11.4	0.99	40
41	Nb	92.91	8.4	0.0545	0.9928	0.0214	1.1	5	6.1	0.060	0.272	0.333	16.7	3.70	3.00	8.3	4.43	1.18	41
42	Mo	95.95	10.2	0.0640	0.9931	0.0207	2.5	7	9.5	0.160	0.448	0.608	6.25	2.23	1.64	13	2.09	0.699	42
43	Tc	98			0.9932	0.0203	100												43
44	Ru	101.1	12.2	0.0727	0.9934	0.0197	2.46	6	8.5	0.179	0.436	0.615	5.59	2.30	1.63		1.99	0.709	44
45	Rh	102.91	12.5	0.0732	0.9935	0.0193	150	5	155	11.0	0.360	11.4	0.091	2.78	.088	575	0.107	0.126	45
46	Pd	106.4	12.16	0.0689	0.9937	0.0187	8	3.6	11.6	0.551	0.248	0.799	1.81	4.03	1.25	23	1.30	0.931	46
47	Ag	107.88	10.5	0.0586	0.9938	0.0184	62	6	68	3.63	0.352	3.98	0.275	2.84	0.251	600	0.290	0.305	47
48	Cd	112.41	8.65	0.0464	0.9940	0.0178	3,315	7	3,322	154	0.325	154	0.007	3.08	0.007		0.0083	0.011	48
49	In	114.82	7.28	0.0382	0.9942	0.0173	190	2.2	192	7.26	0.084	7.34	0.138	11.9	0.136	2,570 (5)	0.171	0.212	49
50	Sn	118.70	6.5	0.0330	0.9944	0.0167	0.6	4	4.6	0.020	0.132	0.152	50.0	7.58	6.58	4.3	11.0	2.42	50
51	Sb	121.76	6.69	0.0331	0.9945	0.0163	5.5	4.3	9.8	0.182	0.142	0.324	5.49	7.04	3.09	115	3.21	1.87	51
52	Te	127.61	6.24	0.0295	0.9948	0.0155	4.5	5	9.5	0.133	0.148	0.281	7.52	6.76	3.56	36	3.79	1.91	52
53	I	126.91	4.93	0.0234	0.9948	0.0157	6.7	3.6	10.3	0.157	0.084	0.241	6.37	11.9	4.15	130	4.29	2.89	53
54	Xe	131.30	0.0059	2.7 (1)	0.9949	0.0152	35	4.3	39.3	0.001		0.001	1,053	9,091	909		1,012	972	54
55	Cs	132.91	1.873	0.0085	0.9950	0.0150	29	20	49	0.246	0.170	0.416	4.07	5.88	2.40		2.49	1.52	55
56	Ba	137.36	3.5	0.0154	0.9951	0.0145	1.17	8	9.2	0.018	0.123	0.141	55.6	8.13	7.09	7.5	12.1	2.64	56
57	La	138.92	6.19	0.0268	0.9952	0.0143	8.9	15	24	0.239	0.403	0.642	4.18	2.47	1.57	11	1.77	0.746	57
58	Ce	140.13	6.78	0.0292	0.9952	0.0142	0.7	9	9.7	0.021	0.262	0.283	4.89	3.82	3.53		7.82	1.25	58
59	Pr	140.92	6.78	0.0290	0.9953	0.0141	11.2	4	15.2	0.324	0.116	0.440	3.08	8.62	2.27	7	2.38	1.84	59
60	Nd	144.27	6.95	0.0290	0.9954	0.0138	46	16	62	1.33	0.464	1.79	0.752	2.16	0.559	40	0.586	0.457	60
61	Pm	145			0.9954	0.0137	60												61
62	Sm	150.35	7.7	0.0309	0.9956	0.0133	8,250	5	8,255	255	0.155	255	0.004	6.45	0.004	1,750 (5)	0.005	0.006	62
	Sm_2O_3	348.70	7.43	0.0128 (3)	0.974	0.076	16,500	22.6	16,500	211	0.289	211	0.005	3.46	0.005				
63	Eu	152.0	5.22	0.0207	0.9956	0.0131	4,370	8	4,378	90.5	0.166	90.6	0.011	6.02	0.011	950 (5)	0.0138	0.0172	63
	Eu_2O_3	352.00	7.42	0.0127 (3)	0.978	0.063	8,740	30.2	8,770	111	0.383	111	0.009	2.61	0.009				
64	Gd	157.26	7.95	0.0305	0.9958	0.0127	3,900			1,190			0.001						64
65	Tb	158.93	8.33	0.0316	0.9958	0.0125	44			1.39			0.725						65
66	Dy	162.51	8.56	0.0317	0.9959	0.0122	1,100	100	1,200	34.9	3.17	38.1	0.029	0.315	0.026		0.096	0.323	66
	Dy_2O_3	372.92	7.81	0.0126 (3)	0.993	0.019	2,200	214	2,414	27.7	2.7	30.4	0.036	0.37	0.033				
67	Ho	164.94	8.76	0.0320	0.9960	0.0121	64			2.05			0.489						67
68	Er	167.27	9.16	0.0330	0.9960	0.0119	166	15	181	5.44	0.495	5.98	0.182	2.02	0.167		0.194	0.207	68
69	Tm	168.94	9.35	0.0333	0.9961	0.0118	118			3.93			0.255						69
70	Yb	173.04	7.01	0.0244	0.9961	0.0115	36	12	48	0.878	0.293	1.17	1.14	3.41	0.852		0.899	0.710	70
71	Lu	174.99	9.74	0.0335	0.9962	0.0114	108			3.62			0.278			720			

Table C-1.1 (Continued)

Atomic No	Element or Compound	Atomic or Mole Wt	Density (gms/cm³)	Nuclei Per Unit Vol ($\times 10^{24}$/cm³)	$1-\mu_0$	ξ	Microscopic Cross Section (barns)			Macroscopic Cross Section (cm⁻¹)			Mean Free Path (cm)			Resonance Integral (barns)	Diffusion Length (cm)	Diffusion Coefficient (cm)	Atomic No
							σ_a	σ_s	σ_t	Σ_a	Σ_s	Σ_t	λ_a	λ_s	λ_t				
72	Hf	178.5	13.3	0.0449	0.9963	0.0112	105	8	113	4.71	0.359	5.07	0.212	2.79	0.197	2,800	0.232	0.253	72
73	Ta	180.95	16.6	0.0553	0.9963	0.0110	21.3	5	26.3	1.18	0.277	1.46	0.847	3.61	0.685	590 (5)	0.738	0.643	73
74	W	183.86	19.3	0.0632	0.9964	0.0108	19.2	5	24.2	1.21	0.316	1.53	0.826	3.16	0.654	170	0.698	0.590	74
75	Re	186.22	20.53	0.0664	0.9964	0.0107	84	14	98	5.58	0.930	6.51	0.180	1.08	0.015	620 (5)	0.170	0.162	75
76	Os	190.2	22.48	0.0712	0.9965	0.0105	14.7	11	25.7	1.05	0.783	1.83	0.952	1.28	0.546		0.556	0.336	76
77	Ir	192.2	22.42	0.0703	0.9965	0.0104	430			30.2				.033		2,190 (5)			77
78	Pt	195.09	21.37	0.0660	0.9966	0.0102	8.1	10	18.1	0.535	0.660	1.19	1.87	1.52	0.840	69	0.905	0.438	78
79	Au	197	19.32	0.0591	0.9966	0.0101	98	9.3	107.3	5.79	0.550	6.34	0.173	1.82	0.158	1,558 (5)	0.183	0.194	79
80	Hg	200.61	13.55	0.0407	0.9967	0.0099	360	20	380	14.7	0.814	15.5	0.068	1.23	0.065	73	0.077	0.088	80
81	Tl	204.39	11.85	0.0349	0.9967	0.0098	3.3	14	17.3	0.115	0.489	0.604	8.70	2.04	1.66	38 (5)	2.38	0.651	81
82	Pb	207.21	11.35	0.0330	0.9968	0.0096	0.170	11	11.2	0.006	0.363	0.369	179	2.75	2.71	0.1	12.8	0.918	82
83	Bi	209.00	9.747	0.0281	0.9968	0.0095	0.032	9.4	9.4	0.001	0.264	0.265	909	3.79	3.77	0.5	32.0	1.126	83
84	Po	210	9.24	0.0265	0.9968	0.0095													84
85	At	211			0.9968	0.0094													85
86	Rn	222	0.0097	2.6 (1)	0.9970	0.0090	0.7												86
87	Fr	223			0.9980	0.0089													87
88	Ra	226.05	5	0.0133	0.9971	0.0088	20			0.266			3.76						88
89	Ac	227			0.9971	0.0088	510												89
90	Th	232.05	11.3	0.0293	0.9971	0.0086	7	12.5	19.5	0.205	0.366	0.571	4.88	2.73	1.75	69.8 (5)	2.7	1.49	90
91	Pa	231	15.4	0.0402	0.9971	0.0086	260			10.4			0.096						91
92	U	238.07	18.9	0.04783	0.9972	0.0084	7.6	8.3	15.9	0.364	0.397	0.761	2.75	2.52	1.31	290 (5)	1.37	0.683	92
	UO_2	270.07	10	0.0223 (3)	0.9776	0.036	7.6	16.7	24.3	0.169	0.372	0.542	5.92	2.70	1.85		1.897	0.615	
93	Np	237			0.9972	0.0084	170												93
94	Pu	239	19.74	0.0498	0.9972	0.0083	1,145	9.6	1,155	57.0	0.478	57.5	0.018	2.09	0.012	250	0.0708	0.286	94
95	Am	242			0.9973	0.0082	8,000												95
96	Cm	245			0.9973	0.0081													96
97	Bk	249			0.9973	0.0081	500												97
98	Cf	249			0.9973	0.0079	900												98
99	E	253			0.9974	0.0079	160												99
100	Fm	256			0.9974	0.0078													100
101	Mv	260			0.9974	0.0077													101

(1) $\times 10^5$
(2) $\times 10^{-5}$
(3) Molecules/cm³
(4) Measured
(5) Activation integral
Source: Davis and Hauser, Nucleonics 16, (3) pp 87-9, March 1958.

Table C-1.2

THERMAL MICROSCOPIC CROSS SECTIONS
OF THE FISSIONABLE ISOTOPES

The reaction cross sections for some fissionable isotopes are shown for 2200 m/s neutrons.

	Microscopic Cross Section (barns)		
Isotope	σ_a	σ_f	σ_s
U-233	585 ± 10	533 ± 10	
U-235	689 ± 7	584 ± 10	10 ± 2
U-238	2.71 ± .02	< 0.0005	
Pu-239	1025 ± 15	748 ± 15	9.6 ± .5

Source: Hughes and Schwartz, BNL-325, Second Edition.

Table D-1 1

VALUES OF THE INFINITE MULTIPLICATION FACTOR (K_∞) FOR URANYL FLUORIDE SOLUTION vs H/U-235 ATOMIC RATIO

The uranium is assumed enriched to ~ 90% U 235 K_∞ is calculated from the values of Table D-1 4 for η = 2 12 and ignoring resonance capture These values are intended for field use in conjunction with the tables of Section E 1 to yield values of k_{eff} which are conservative when compared with the experimental data of Callihan, et al (K 343) and Fox, Gilley, and Callihan (ORNL-2367)

H/X	0	1	2	3	4	5	6	7	8	9
10	2 1107	2 1097	2 1088	2 1079	2 1070	2 1061	2 1051	2 1042	2 1033	2 1024
20	2 1015	2 1005	2 0996	2 0987	2 0978	2 0969	2 0959	2 0950	2 0941	2 0932
30	2 0923	2 0914	2 0905	2 0896	2 0887	2 0878	2 0869	2 0860	2 0851	2 0842
40	2 0833	2 0824	2 0815	2 0806	2 0797	2 0788	2 0779	2 0770	2 0761	2 0752
50	2 0743	2 0734	2 0725	2 0716	2 0707	2 0698	2 0689	2 0680	2 0671	2 0662
60	2 0654	2 0645	2 0636	2 0627	2 0618	2 0610	2 0601	2 0592	2 0583	2 0574
70	2 0566	2 0557	2 0548	2 0539	2 0531	2 0522	2 0513	2 0505	2 0496	2 0487
80	2 0479	2 0470	2 0461	2 0452	2 0444	2 0435	2 0426	2 0418	2 0409	2 0400
90	2 0392	2 0383	2 0374	2 0366	2 0357	2 0349	2 0340	2 0331	2 0323	2 0314
100	2 0306	2 0297	2 0289	2 0280	2 0272	2 0263	2 0255	2 0246	2 0238	2 0229
110	2 0221	2 0212	2 0204	2 0195	2 0187	2 0178	2 0170	2 0161	2 0153	2 0144
120	2 0136	2 0127	2 0119	2 0110	2 0102	2 0094	2 0085	2 0077	2 0068	2 0060
130	2 0052	2 0043	2 0035	2 0027	2 0018	2 0010	2 0002	1 9993	1 9985	1 9977
140	1 9969	1 9960	1 9952	1 9944	1 9936	1 9928	1 9919	1 9911	1 9903	1 9895
150	1 9887	1 9878	1 9870	1 9862	1 9854	1 9846	1 9837	1 9829	1 9821	1 9813
160	1 9805	1 9796	1 9788	1 9780	1 9772	1 9764	1 9756	1 9748	1 9740	1 9732
170	1 9724	1 9716	1 9708	1 9700	1 9692	1 9684	1 9676	1 9668	1 9660	1 9652
180	1 9644	1 9636	1 9628	1 9620	1 9612	1 9604	1 9596	1 9588	1 9580	1 9572
190	1 9564	1 9556	1 9548	1 9540	1 9532	1 9524	1 9516	1 9508	1 9500	1 9492
200	1 9485	1 9477	1 9469	1 9461	1 9453	1 9445	1 9437	1 9429	1 9421	1 9413
210	1 9406	1 9398	1 9390	1 9382	1 9374	1 9367	1 9359	1 9351	1 9343	1 9335
220	1 9328	1 9320	1 9312	1 9304	1 9297	1 9289	1 9281	1 9274	1 9266	1 9258
230	1 9251	1 9243	1 9235	1 9228	1 9220	1 9213	1 9205	1 9197	1 9190	1 9182
240	1 9175	1 9167	1 9159	1 9152	1 9144	1 9137	1 9129	1 9121	1 9114	1 9106
250	1 9099	1 9091	1 9083	1 9076	1 9068	1 9061	1 9053	1 9045	1 9038	1 9030
260	1 9023	1 9015	1 9008	1 9000	1 8993	1 8985	1 8978	1 8970	1 8963	1 8955
270	1 8948	1 8940	1 8933	1 8925	1 8918	1 8911	1 8903	1 8896	1 8888	1 8881
280	1 8874	1 8866	1 8859	1 8851	1 8844	1 8837	1 8829	1 8822	1 8814	1 8807
290	1 8800	1 8792	1 8785	1 8778	1 8770	1 8763	1 8756	1 8748	1 8741	1 8734
300	1 8727	1 8719	1 8712	1 8705	1 8698	1 8691	1 8683	1 8676	1 8669	1 8662
310	1 8655	1 8647	1 8640	1 8633	1 8626	1 8619	1 8611	1 8604	1 8597	1 8590
320	1 8583	1 8575	1 8568	1 8561	1 8554	1 8547	1 8540	1 8533	1 8526	1 8519
330	1 8512	1 8504	1 8497	1 8490	1 8483	1 8476	1 8469	1 8462	1 8455	1 8448
340	1 8441	1 8433	1 8426	1 8419	1 8412	1 8405	1 8398	1 8391	1 8384	1 8377
350	1 8370	1 8363	1 8356	1 8349	1 8342	1 8335	1 8328	1 8321	1 8314	1 8307
360	1 8301	1 8294	1 8287	1 8280	1 8273	1 8266	1 8259	1 8252	1 8245	1 8238
370	1 8231	1 8224	1 8217	1 8210	1 8203	1 8197	1 8190	1 8183	1 8176	1 8169
380	1 8163	1 8156	1 8149	1 8142	1 8135	1 8128	1 8121	1 8114	1 8107	1 8100
390	1 8094	1 8087	1 8080	1 8073	1 8067	1 8060	1 8053	1 8047	1 8040	1 8033

Table D-1.1 (Continued)

H/X	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
400	1.8027	1.8020	1.8013	1.8006	1.8000	1.7993	1.7986	1.7980	1.7973	1.7966
410	1.7960	1.7953	1.7946	1.7939	1.7933	1.7926	1.7919	1.7913	1.7906	1.7899
420	1.7893	1.7886	1.7879	1.7873	1.7866	1.7860	1.7853	1.7846	1.7840	1.7833
430	1.7827	1.7820	1.7813	1.7807	1.7800	1.7794	1.7787	1.7780	1.7774	1.7767
440	1.7761	1.7754	1.7748	1.7741	1.7735	1.7728	1.7722	1.7715	1.7709	1.7702
450	1.7696	1.7689	1.7683	1.7676	1.7670	1.7663	1.7657	1.7650	1.7644	1.7637
460	1.7631	1.7624	1.7618	1.7611	1.7605	1.7599	1.7592	1.7586	1.7579	1.7573
470	1.7567	1.7560	1.7554	1.7547	1.7541	1.7535	1.7528	1.7522	1.7515	1.7509
480	1.7503	1.7496	1.7490	1.7483	1.7477	1.7471	1.7464	1.7458	1.7451	1.7445
490	1.7439	1.7432	1.7426	1.7420	1.7414	1.7408	1.7401	1.7395	1.7389	1.7383
500	1.7377	1.7370	1.7364	1.7358	1.7351	1.7345	1.7339	1.7332	1.7326	1.7320
510	1.7314	1.7307	1.7301	1.7295	1.7289	1.7283	1.7276	1.7270	1.7264	1.7258
520	1.7252	1.7245	1.7239	1.7233	1.7227	1.7221	1.7215	1.7209	1.7203	1.7197
530	1.7191	1.7184	1.7178	1.7172	1.7166	1.7160	1.7153	1.7147	1.7141	1.7135
540	1.7129	1.7123	1.7117	1.7111	1.7105	1.7099	1.7093	1.7087	1.7081	1.7075
550	1.7069	1.7062	1.7056	1.7050	1.7044	1.7038	1.7032	1.7026	1.7020	1.7014
560	1.7008	1.7002	1.6996	1.6990	1.6984	1.6978	1.6972	1.6966	1.6960	1.6954
570	1.6949	1.6943	1.6937	1.6931	1.6925	1.6919	1.6913	1.6907	1.6901	1.6895
580	1.6889	1.6883	1.6877	1.6871	1.6865	1.6859	1.6853	1.6847	1.6841	1.6835
590	1.6830	1.6824	1.6818	1.6812	1.6806	1.6801	1.6795	1.6789	1.6783	1.6777

H/X	0	10	20	30	40	50	60	70	80	90
600	1.6772	1.6713	1.6656	1.6598	1.6541	1.6485	1.6429	1.6373	1.6317	1.6262
700	1.6207	1.6153	1.6099	1.6046	1.5992	1.5939	1.5887	1.5835	1.5783	1.5731
800	1.5680	1.5629	1.5579	1.5528	1.5478	1.5429	1.5380	1.5331	1.5282	1.5234
900	1.5186	1.5138	1.5091	1.5043	1.4997	1.4950	1.4904	1.4858	1.4812	1.4767
1000	1.4722	1.4677	1.4632	1.4588	1.4544	1.4500	1.4457	1.4413	1.4370	1.4328
1100	1.4285	1.4243	1.4201	1.4159	1.4118	1.4077	1.4036	1.3995	1.3954	1.3914
1200	1.3874	1.3834	1.3794	1.3755	1.3716	1.3677	1.3638	1.3600	1.3561	1.3523
1300	1.3486	1.3448	1.3410	1.3373	1.3336	1.3299	1.3263	1.3226	1.3190	1.3154
1400	1.3118	1.3083	1.3047	1.3012	1.2977	1.2942	1.2907	1.2873	1.2839	1.2805
1500	1.2771	1.2737	1.2703	1.2670	1.2637	1.2604	1.2571	1.2538	1.2505	1.2473
1600	1.2441	1.2409	1.2377	1.2345	1.2314	1.2282	1.2251	1.2220	1.2189	1.2158
1700	1.2128	1.2097	1.2067	1.2037	1.2007	1.1977	1.1947	1.1918	1.1888	1.1859
1800	1.1830	1.1801	1.1772	1.1743	1.1715	1.1686	1.1658	1.1630	1.1602	1.1574
1900	1.1546	1.1519	1.1491	1.1464	1.1437	1.1410	1.1383	1.1356	1.1329	1.1303

Table D-1.2

FERMI AGE TO THERMAL (τ) FOR URANYL FLOURIDE SOLUTION vs H/U-235 ATOMIC RATIO

The uranium is assumed enriched to ~ 90% U-235. The calculational method of Bell (LA-1548) was followed in which factors are applied to the assumed value of 27 cm^2 to take some account of changes in slowing down and in the average λ_{tr}. This table is intended for field use in conjunction with the buckling tables of Section E-2 to yield estimates of k_{eff} which are conservative when compared with the experimental data of Callihan, et al, (K-343) and Fox, Gilley, and Callihan (ORNL-2367).

H/X	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
10	28.213	28.160	28.107	28.054	28.001	27.948	27.895	27.842	27.789	27.736
20	27.683	27.661	27.639	27.617	27.596	27.574	27.552	27.531	27.509	27.487
30	27.466	27.454	27.442	27.430	27.418	27.407	27.395	27.383	27.371	27.359
40	27.348	27.340	27.333	27.325	27.318	27.311	27.303	27.296	27.288	27.281
50	27.274	27.268	27.263	27.258	27.253	27.248	27.243	27.238	27.233	27.228
60	27.223	27.219	27.215	27.211	27.208	27.204	27.200	27.197	27.193	27.189
70	27.186	27.183	27.180	27.177	27.174	27.171	27.168	27.165	27.162	27.159
80	27.157	27.154	27.152	27.150	27.148	27.146	27.143	27.141	27.139	27.137
90	27.135	27.133	27.131	27.129	27.127	27.126	27.124	27.122	27.120	27.118
100	27.117	27.115	27.114	27.112	27.111	27.109	27.108	27.106	27.105	27.103
110	27.102	27.100	27.099	27.098	27.097	27.096	27.094	27.093	27.092	27.091
120	27.090	27.088	27.087	27.086	27.085	27.084	27.083	27.082	27.081	27.080
130	27.079	27.078	27.077	27.076	27.075	27.074	27.073	27.072	27.071	27.070
140	27.070	27.069	27.068	27.067	27.066	27.066	27.065	27.064	27.063	27.062
150	27.062	27.061	27.060	27.059	27.059	27.058	27.057	27.057	27.056	27.055
160	27.055	27.054	27.053	27.053	27.052	27.052	27.051	27.050	27.050	27.049
170	27.049	27.048	27.047	27.047	27.046	27.046	27.045	27.044	27.044	27.043
180	27.043	27.042	27.042	27.041	27.041	27.041	27.040	27.040	27.039	27.039
190	27.039	27.038	27.038	27.037	27.037	27.036	27.036	27.035	27.035	27.034
200	27.034	27.033	27.033	27.032	27.032	27.032	27.031	27.031	27.030	27.030
210	27.030	27.029	27.029	27.028	27.028	27.028	27.027	27.027	27.026	27.026
220	27.026	27.025	27.025	27.025	27.024	27.024	27.024	27.023	27.023	27.023
230	27.023	27.022	27.022	27.022	27.021	27.021	27.021	27.020	27.020	27.020
240	27.020	27.019	27.019	27.019	27.018	27.018	27.018	27.017	27.017	27.017
250	27.017	27.016	27.016	27.016	27.015	27.015	27.015	27.014	27.014	27.014
260	27.014	27.013	27.013	27.013	27.013	27.013	27.012	27.012	27.012	27.012
270	27.012	27.011	27.011	27.011	27.011	27.011	27.010	27.010	27.010	27.010
280	27.010	27.009	27.009	27.009	27.009	27.009	27.008	27.008	27.008	27.008
290	27.008	27.007	27.007	27.007	27.007	27.007	27.006	27.006	27.006	27.006
300	27.006	27.005	27.005	27.005	27.005	27.005	27.004	27.004	27.004	27.004
310	27.004	27.003	27.003	27.003	27.003	27.003	27.002	27.002	27.002	27.002
320	27.002	27.001	27.001	27.001	27.001	27.001	27.001	27.001	27.001	27.001
330	27.001	27.000	27.000	27.000	27.000	27.000	26.999	26.999	26.999	26.999
340	26.999	26.998	26.998	26.998	26.998	26.998	26.998	26.998	26.998	26.998

Table D-1 2 (Continued)

H/X	0	1	2	3	4	5	6	7	8	9
350	26 998	26 997	26 997	26 997	26 997	26 997	26 996	26 996	26 996	26 996
360	26 996	26 995	26 995	26 995	26 995	26 995	26 995	26 995	26 995	26 995
370	26 995	26 994	26 994	26 994	26 994	26 994	26 994	26 994	26 994	26 994
380	26 994	26 993	26 993	26 993	26 993	26 993	26 993	26 993	26 993	26 993
390	26 993	26 992	26 992	26 992	26 992	26 992	26 991	26 991	26 991	26 991
400	26 991	26 990	26 990	26 990	26 990	26 990	26 990	26 990	26 990	26 990
410	26 990	26 989	26 989	26 989	26 989	26 989	26 989	26 989	26 989	26 989
420	26 989	26 988	26 988	26 988	26 988	26 988	26 988	26 988	26 988	26 988
430	26 988	26 987	26 987	26 987	26 987	26 987	26 987	26 987	26 987	26 987
440	26 987	26 987	26 987	26 987	26 987	26 987	26 987	26 987	26 987	26 987
450	26 987	26 986	26 986	26 986	26 986	26 986	26 986	26 986	26 986	26 986
460	26 986	26 985	26 985	26 985	26 985	26 985	26 985	26 985	26 985	26 985
470	26 985	26 984	26 984	26 984	26 984	26 984	26 984	26 983	26 983	26 983
480	26 984	26 983	26 983	26 983	26 983	26 983	26 983	26 983	26 983	26 983
490	26 983	26 983	26 983	26 983	26 983	26 983	26 983	26 983	26 983	26 983
500	26 983	26 982	26 982	26 982	26 982	26 982	26 982	26 982	26 982	26 982
510	26 982	26 981	26 981	26 981	26 981	26 981	26 981	16 981	26 981	26 981
520	26 981	26 981	26 981	26 981	26 981	26 981	26 981	26 981	26 981	26 981
530	26 981	26 980	26 980	26 980	26 980	26 980	26 980	26 980	26 980	26 980
540	26 980	26 980	26 980	26 980	26 980	26 980	26 980	26 980	26 980	26 980
550	26 980	26 979	26 979	26 979	26 979	26 979	26 979	26 979	26 979	26 979
560	26 979	26 979	26 979	26 979	26 979	26 979	26 979	26 979	26 979	26 979
570	26 979	26 978	26 978	26 978	26 978	26 978	26 978	26 978	26 978	26 978
580	26 978	26 978	26 978	26 978	26 978	26 978	26 978	26 978	26 978	26 978
590	26 978	26 977	26 977	26 977	26 977	26 977	26 977	26 977	26 977	26 977

H/X	0	10	20	30	40	50	60	70	80	90
600	26 977	26 977	26 976	26 976	26 975	26 975	26 974	26 974	26 974	26 973
700	26 973	26 973	26 972	26 972	26 972	26 971	26 971	26 971	26 970	26 970
800	26 970	26 970	26 969	26 969	26 969	26 969	26 968	26 968	26 968	26 968
900	26 967	26 967	26 967	26 967	26 967	26 966	26 966	26 966	26 966	26 966
1000	26 965	26 965	26 965	26 965	26 965	26 965	26 964	26 964	26 964	26 964
1100	26 964	26 964	26 964	26 963	26 963	26 963	26 963	26 963	26 963	26 963
1200	26 963	26 962	26 962	26 962	26 962	26 962	26 962	26 962	26 962	26 962
1300	26 961	26 961	26 961	26 961	26 961	26 961	26 961	26 961	26 961	26 961
1400	26 960	26 960	26 960	26 960	26 960	26 960	26 960	26 960	26 960	26 960
1500	26 960	26 960	26 959	26 959	26 959	26 959	26 959	26 959	26 959	26 959
1600	26 959	26 959	26 959	26 959	26 959	26 959	26 958	26 958	26 958	26 958
1700	26 958	26 958	26 958	26 958	26 958	26 958	26 958	26 958	26 958	26 958
1800	26 958	26 958	26 958	26 958	26 957	26 957	26 957	26 957	26 957	26 957
1900	26 957	26 957	26 957	26 957	26 957	26 957	26 957	26 957	26 957	26 957

Table D-1.3

VALUES OF DIFFUSION LENGTH SQUARED (L^2) FOR URANYL FLUORIDE SOLUTION vs H/U-235 ATOMIC RATIO

The uranium is assumed enriched to ~ 90% U-235. The value of 8.1225 cm^2 for pure water has been corrected by the factor (1 - f) where f is taken from Table D-1.4. This table is intended for field use in conjunction with the buckling tables of Section E-2 to yield estimates of k_{eff} which are conservative when compared with the experimental data of Callihan, et al, (K-343) and Fox, Gilley, and Callihan (ORNL-2367).

H/X	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
10	0.03558	0.03910	0.04263	0.04616	0.04968	0.05321	0.05674	0.06026	0.06379	0.06732
20	0.07085	0.07434	0.07784	0.08134	0.08483	0.08833	0.09183	0.09532	0.09882	0.10232
30	0.10582	0.10928	0.11275	0.11621	0.11968	0.12315	0.12661	0.13008	0.13354	0.13701
40	0.14048	0.14391	0.14735	0.15078	0.15422	0.15766	0.16109	0.16453	0.16796	0.17140
50	0.17484	0.17824	0.18165	0.18506	0.18846	0.19187	0.19528	0.19868	0.20209	0.20550
60	0.20891	0.21228	0.21566	0.21904	0.22242	0.22580	0.22917	0.23255	0.23593	0.23931
70	0.24269	0.24604	0.24939	0.25274	0.25609	0.25944	0.26279	0.26614	0.26949	0.27284
80	0.27619	0.27951	0.28283	0.28615	0.28947	0.29279	0.29611	0.29943	0.30275	0.30607
90	0.30939	0.31268	0.31597	0.31926	0.32256	0.32585	0.32914	0.33244	0.33573	0.33902
100	0.34232	0.34558	0.34885	0.35211	0.35538	0.35864	0.36191	0.36517	0.36844	0.37170
110	0.37497	0.37820	0.38144	0.38468	0.38792	0.39116	0.39439	0.39763	0.40087	0.40411
120	0.40735	0.41056	0.41377	0.41698	0.42019	0.42340	0.42661	0.42982	0.43303	0.43624
130	0.43946	0.44264	0.44583	0.44901	0.45220	0.45538	0.45857	0.46175	0.46494	0.46812
140	0.47131	0.47446	0.47762	0.48078	0.48394	0.48710	0.49025	0.49341	0.49657	0.49973
150	0.50289	0.50602	0.50915	0.51228	0.51541	0.51855	0.52168	0.52481	0.52794	0.53107
160	0.53421	0.53731	0.54042	0.54353	0.54663	0.54974	0.55285	0.55595	0.55906	0.56217
170	0.56528	0.56836	0.57144	0.57452	0.57760	0.58068	0.58376	0.58684	0.58992	0.59300
180	0.59609	0.59914	0.60220	0.60525	0.60831	0.61137	0.61442	0.61748	0.62053	0.62359
190	0.62665	0.62968	0.63271	0.63574	0.63877	0.64180	0.64483	0.64786	0.65089	0.65392
200	0.65696	0.65996	0.66297	0.66598	0.66898	0.67199	0.67500	0.67800	0.68101	0.68402
210	0.68703	0.69001	0.69299	0.69597	0.69896	0.70194	0.70492	0.70791	0.71089	0.71387
220	0.71686	0.71981	0.72277	0.72573	0.72869	0.73165	0.73461	0.73757	0.74053	0.74349
230	0.74645	0.74938	0.75232	0.75525	0.75819	0.76113	0.76406	0.76700	0.76993	0.77287
240	0.77581	0.77872	0.78163	0.78454	0.78745	0.79037	0.79328	0.79619	0.79910	0.80201
250	0.80493	0.80781	0.81070	0.81359	0.81648	0.81937	0.82226	0.82515	0.82804	0.83093
260	0.83382	0.83668	0.83955	0.84241	0.84528	0.84815	0.85101	0.85388	0.85674	0.85961
270	0.86248	0.86532	0.86816	0.87101	0.87385	0.87670	0.87954	0.88238	0.88523	0.88807
280	0.89092	0.89374	0.89656	0.89938	0.90220	0.90503	0.90785	0.91067	0.91349	0.91631
290	0.91914	0.92194	0.92474	0.92754	0.93034	0.93314	0.93594	0.93874	0.94154	0.94434
300	0.94714	0.94991	0.95269	0.95547	0.95825	0.96103	0.96380	0.96658	0.96936	0.97214
310	0.97492	0.97766	0.98041	0.98316	0.98591	0.98866	0.99140	0.99415	0.99690	0.99965
320	1.0024	1.0051	1.0078	1.0106	1.0133	1.0161	1.0188	1.0215	1.0243	1.0270
330	1.0298	1.0325	1.0352	1.0379	1.0406	1.0433	1.0460	1.0487	1.0514	1.0541
340	1.0569	1.0596	1.0623	1.0650	1.0677	1.0704	1.0731	1.0758	1.0785	1.0812

Table D-1.3 (Continued)

H/X	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
350	1.0839	1.0865	1.0892	1.0919	1.0945	1.0972	1.0999	1.1025	1.1052	1.1079
360	1.1106	1.1132	1.1159	1.1185	1.1212	1.1239	1.1265	1.1292	1.1318	1.1345
370	1.1372	1.1398	1.1424	1.1450	1.1477	1.1503	1.1529	1.1556	1.1582	1.1608
380	1.1635	1.1661	1.1687	1.1713	1.1739	1.1765	1.1791	1.1817	1.1843	1.1869
390	1.1896	1.1922	1.1948	1.1974	1.2000	1.2026	1.2052	1.2078	1.2104	1.2130
400	1.2156	1.2181	1.2207	1.2233	1.2258	1.2284	1.2310	1.2335	1.2361	1.2387
410	1.2413	1.2438	1.2464	1.2489	1.2515	1.2541	1.2566	1.2592	1.2617	1.2643
420	1.2669	1.2694	1.2719	1.2744	1.2770	1.2795	1.2820	1.2846	1.2871	1.2896
430	1.2922	1.2947	1.2972	1.2997	1.3022	1.3048	1.3073	1.3098	1.3123	1.3148
440	1.3174	1.3199	1.3224	1.3249	1.3274	1.3299	1.3324	1.3349	1.3374	1.3399
450	1.3424	1.3448	1.3473	1.3498	1.3523	1.3548	1.3572	1.3597	1.3622	1.3647
460	1.3672	1.3696	1.3721	1.3745	1.3770	1.3795	1.3819	1.3844	1.3868	1.3893
470	1.3918	1.3942	1.3967	1.3991	1.4016	1.4040	1.4065	1.4089	1.4114	1.4138
480	1.4163	1.4187	1.4211	1.4235	1.4260	1.4284	1.4308	1.4333	1.4357	1.4381
490	1.4406	1.4430	1.4454	1.4478	1.4502	1.4526	1.4550	1.4574	1.4598	1.4622
500	1.4647	1.4670	1.4694	1.4718	1.4742	1.4766	1.4790	1.4814	1.4838	1.4862
510	1.4886	1.4909	1.4933	1.4957	1.4980	1.5004	1.5028	1.5051	1.5075	1.5099
520	1.5123	1.5146	1.5170	1.5193	1.5217	1.5241	1.5264	1.5288	1.5311	1.5335
530	1.5359	1.5382	1.5405	1.5429	1.5452	1.5476	1.5499	1.5522	1.5546	1.5569
540	1.5593	1.5616	1.5639	1.5662	1.5686	1.5709	1.5732	1.5756	1.5779	1.5802
550	1.5826	1.5849	1.5872	1.5895	1.5918	1.5941	1.5964	1.5987	1.6010	1.6033
560	1.6057	1.6079	1.6102	1.6125	1.6148	1.6171	1.6194	1.6217	1.6240	1.6263
570	1.6286	1.6308	1.6331	1.6354	1.6377	1.6400	1.6422	1.6445	1.6468	1.6491
580	1.6514	1.6536	1.6559	1.6581	1.6604	1.6627	1.6649	1.6672	1.6694	1.6717
590	1.6740	1.6762	1.6784	1.6807	1.6829	1.6852	1.6874	1.6896	1.6919	1.6941

H/X	0	10	20	30	40	50	60	70	80	90
600	1.6964	1.7187	1.7409	1.7628	1.7847	1.8064	1.8279	1.8493	1.8705	1.8916
700	1.9126	1.9334	1.9541	1.9746	1.9950	2.0153	2.0354	2.0554	2.0753	2.0951
800	2.1147	2.1342	2.1535	2.1728	2.1919	2.2109	2.2297	2.2485	2.2671	2.2856
900	2.3040	2.3223	2.3405	2.3585	2.3765	2.3943	2.4120	2.4296	2.4471	2.4645
1000	2.4818	2.4990	2.5161	2.5331	2.5499	2.5667	2.5834	2.5999	2.6164	2.6328
1100	2.6491	2.6652	2.6813	2.6973	2.7132	2.7290	2.7447	2.7604	2.7759	2.7913
1200	2.8067	2.8219	2.8371	2.8522	2.8672	2.8821	2.8970	2.9117	2.9264	2.9410
1300	2.9555	2.9699	2.9842	2.9985	3.0127	3.0268	3.0408	3.0548	3.0686	3.0824
1400	3.0962	3.1098	3.1234	3.1369	3.1503	3.1637	3.1769	3.1902	3.2033	3.2164
1500	3.2294	3.2423	3.2552	3.2680	3.2807	3.2934	3.3060	3.3185	3.3310	3.3434
1600	3.3557	3.3680	3.3802	3.3924	3.4045	3.4165	3.4284	3.4404	3.4522	3.4640
1700	3.4757	3.4874	3.4990	3.5105	3.5220	3.5335	3.5448	3.5562	3.5674	3.5786
1800	3.5898	3.6009	3.6120	3.6229	3.6339	3.6448	3.6556	3.6664	3.6771	3.6878
1900	3.6984	3.7090	3.7195	3.7300	3.7404	3.7508	3.7611	3.7714	3.7817	3.7918

Table D-1 4

THERMAL UTILIZATION (f) FOR URANYL FLUORIDE SOLUTION vs H/U 235 ATOMIC RATIO

The uranium is assumed enriched to ~90% U 235 Thermal utlization has been calculated using the following thermal cross sections Absorptions by materials other than hydrogen and U 235 were ignored A "not 1/v factor" of 0 981 was applied to the U-235 absorption cross section

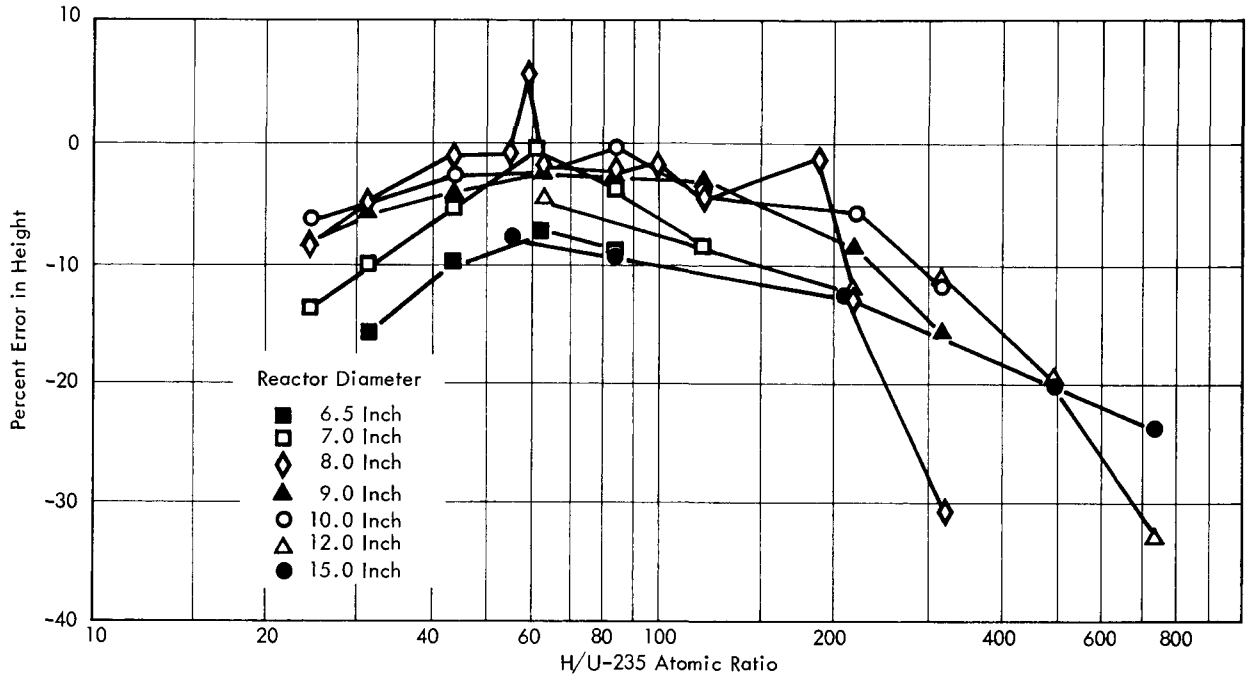
$\sigma_a^{25} = 689$ $\sigma_a^{H} = 0\ 33$

H/X	0	1	2	3	4	5	6	7	8	9
10 00	0 99514	0 99465	0 99417	0 99369	0 99321	0 99272	0 99224	0 99176	0 99128	0 99080
20 00	0 99032	0 98985	0 98937	0 98889	0 98841	0 98794	0 98746	0 98698	0 98651	0 98603
30 00	0 98556	0 98509	0 98461	0 98414	0 98367	0 98319	0 98272	0 98225	0 98178	0 98131
40 00	0 98084	0 98037	0 97990	0 97943	0 97896	0 97850	0 97803	0 97756	0 97710	0 97663
50 00	0 97617	0 97570	0 97524	0 97477	0 97431	0 97384	0 97338	0 97292	0 97246	0 97200
60 00	0 97153	0 97107	0 97061	0 97015	0 96969	0 96924	0 96878	0 96832	0 96786	0 96740
70 00	0 96695	0 96649	0 96604	0 96558	0 96513	0 96467	0 96422	0 96376	0 96331	0 96286
80 00	0 96240	0 96195	0 96150	0 96105	0 96060	0 96015	0 95970	0 95925	0 95880	0 95835
90 00	0 95790	0 95746	0 95701	0 95656	0 95612	0 95567	0 95522	0 95478	0 95433	0 95389
100 00	0 95344	0 95300	0 95256	0 95211	0 95167	0 95123	0 95079	0 95035	0 94991	0 94947
110 00	0 94903	0 94859	0 94815	0 94771	0 94727	0 94683	0 94640	0 94596	0 94552	0 94509
120 00	0 94465	0 94421	0 94378	0 94334	0 94291	0 94248	0 94204	0 94161	0 94118	0 94074
130 00	0 94031	0 93988	0 93945	0 93902	0 93859	0 93816	0 93773	0 93730	0 93687	0 93644
140 00	0 93602	0 93559	0 93516	0 93473	0 93431	0 93388	0 93346	0 93303	0 93261	0 93218
150 00	0 93176	0 93133	0 93091	0 93049	0 93007	0 92964	0 92922	0 92880	0 92838	0 92796
160 00	0 92754	0 92712	0 92670	0 92628	0 92586	0 92544	0 92502	0 92461	0 92419	0 92377
170 00	0 92336	0 92294	0 92252	0 92211	0 92169	0 92128	0 92087	0 92045	0 92004	0 91963
180 00	0 91921	0 91880	0 91839	0 91798	0 91757	0 91715	0 91674	0 91633	0 91592	0 91551
190 00	0 91511	0 91470	0 91429	0 91388	0 91347	0 91307	0 91266	0 91225	0 91185	0 91144
200 00	0 91104	0 91063	0 91023	0 90982	0 90942	0 90901	0 90861	0 90821	0 90780	0 90740
210 00	0 90700	0 90660	0 90620	0 90580	0 90540	0 90500	0 90460	0 90420	0 90380	0 90340
220 00	0 90300	0 90260	0 90221	0 90181	0 90141	0 90102	0 90062	0 90022	0 89983	0 89943
230 00	0 89904	0 89864	0 89825	0 89786	0 89746	0 89707	0 89668	0 89628	0 89589	0 89550
240 00	0 89511	0 89472	0 89433	0 89394	0 89355	0 89316	0 89277	0 89238	0 89199	0 89160
250 00	0 89121	0 89083	0 89044	0 89005	0 88967	0 88928	0 88889	0 88851	0 88812	0 88774
260 00	0 88735	0 88697	0 88659	0 88620	0 88582	0 88544	0 88505	0 88467	0 88429	0 88391
270 00	0 88353	0 88314	0 88276	0 88238	0 88200	0 88162	0 88124	0 88087	0 88049	0 88011
280 00	0 87973	0 87935	0 87898	0 87860	0 87822	0 87785	0 87747	0 87709	0 87672	0 87634
290 00	0 87597	0 87559	0 87522	0 87485	0 87447	0 87410	0 87373	0 87335	0 87298	0 87261
300 00	0 87224	0 87187	0 87150	0 87113	0 87075	0 87038	0 87002	0 86965	0 86928	0 86891
310 00	0 86854	0 86817	0 86780	0 86744	0 86707	0 86670	0 86634	0 86597	0 86560	0 86524
320 00	0 86487	0 86451	0 86414	0 86378	0 86341	0 86305	0 86269	0 86232	0 86196	0 86160
330 00	0 86124	0 86087	0 86051	0 86015	0 85979	0 85943	0 85907	0 85871	0 85835	0 85799
340 00	0 85763	0 85727	0 85691	0 85655	0 85619	0 85584	0 85548	0 85512	0 85477	0 85441

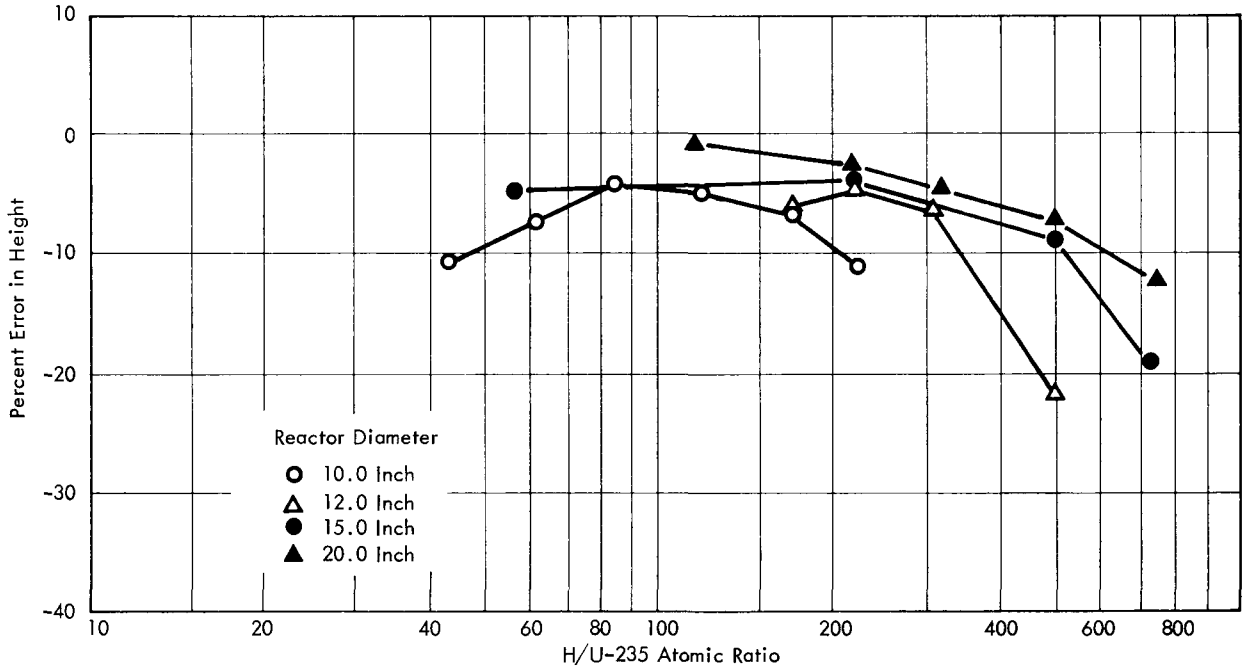
Table D-1.4 (Continued)

H/X	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
350.00	0.85405	0.85370	0.85334	0.85299	0.85263	0.85228	0.85192	0.85157	0.85121	0.85086
360.00	0.85051	0.85015	0.84980	0.84945	0.84910	0.84874	0.84839	0.84804	0.84769	0.84734
370.00	0.84699	0.84664	0.84629	0.84594	0.84559	0.84524	0.84489	0.84454	0.84420	0.84385
380.00	0.84350	0.84315	0.84281	0.84246	0.84211	0.84177	0.84142	0.84108	0.84073	0.84039
390.00	0.84004	0.83970	0.83935	0.83901	0.83867	0.83832	0.83798	0.83764	0.83729	0.83695
400.00	0.83661	0.83627	0.83593	0.83559	0.83525	0.83491	0.83456	0.83423	0.83389	0.83355
410.00	0.83321	0.83287	0.83253	0.83219	0.83185	0.83152	0.83118	0.83084	0.83050	0.83017
420.00	0.82983	0.82950	0.82916	0.82882	0.82849	0.82815	0.82782	0.82748	0.82715	0.82682
430.00	0.82648	0.82615	0.82582	0.82548	0.82515	0.82482	0.82449	0.82415	0.82382	0.82349
440.00	0.82316	0.82283	0.82250	0.82217	0.82184	0.82151	0.82118	0.82085	0.82052	0.82019
450.00	0.81987	0.81954	0.81921	0.81888	0.81856	0.81823	0.81790	0.81758	0.81725	0.81692
460.00	0.81660	0.81627	0.81595	0.81562	0.81530	0.81497	0.81465	0.81432	0.81400	0.81368
470.00	0.81335	0.81303	0.81271	0.81239	0.81206	0.81174	0.81142	0.81110	0.81078	0.81046
480.00	0.81014	0.80982	0.80950	0.80918	0.80886	0.80854	0.80822	0.80790	0.80758	0.80726
490.00	0.80695	0.80663	0.80631	0.80599	0.80568	0.80536	0.80504	0.80473	0.80441	0.80409
500.00	0.80378	0.80346	0.80315	0.80283	0.80252	0.80220	0.80189	0.80158	0.80126	0.80095
510.00	0.80064	0.80032	0.80001	0.79970	0.79939	0.79907	0.79876	0.79845	0.79814	0.79783
520.00	0.79752	0.79721	0.79690	0.79659	0.79628	0.79597	0.79566	0.79535	0.79504	0.79473
530.00	0.79443	0.79412	0.79381	0.79350	0.79320	0.79289	0.79258	0.79227	0.79197	0.79166
540.00	0.79136	0.79105	0.79075	0.79044	0.79014	0.78983	0.78953	0.78922	0.78892	0.78861
550.00	0.78831	0.78801	0.78770	0.78740	0.78710	0.78680	0.78649	0.78619	0.78589	0.78559
560.00	0.78529	0.78499	0.78469	0.78439	0.78409	0.78379	0.78349	0.78319	0.78289	0.78259
570.00	0.78229	0.78199	0.78169	0.78139	0.78110	0.78080	0.78050	0.78020	0.77991	0.77961
580.00	0.77931	0.77902	0.77872	0.77842	0.77813	0.77783	0.77754	0.77724	0.77695	0.77665
590.00	0.77636	0.77606	0.77577	0.77548	0.77518	0.77489	0.77460	0.77430	0.77401	0.77372
600.00	0.77343	0.77313	0.77284	0.77255	0.77226	0.77197	0.77168	0.77139	0.77110	0.77081

H/X	0	10	20	30	40	50	60	70	80	90
600.00	0.77343	0.77052	0.76763	0.76476	0.76192	0.75909	0.75629	0.75351	0.75075	0.74801
700.00	0.74528	0.74258	0.73990	0.73724	0.73459	0.73197	0.72936	0.72677	0.72420	0.72165
800.00	0.71912	0.71660	0.71410	0.71162	0.70916	0.70671	0.70428	0.70187	0.69947	0.69709
900.00	0.69472	0.69238	0.69004	0.68773	0.68543	0.68314	0.68087	0.67861	0.67637	0.67415
1000.0	0.67193	0.66974	0.66755	0.66538	0.66323	0.66109	0.65896	0.65685	0.65475	0.65266
1100.0	0.65059	0.64853	0.64648	0.64445	0.64243	0.64042	0.63842	0.63644	0.63447	0.63251
1200.0	0.63056	0.62863	0.62670	0.62479	0.62289	0.62100	0.61912	0.61726	0.61540	0.61356
1300.0	0.61173	0.60991	0.60810	0.60630	0.60451	0.60273	0.60096	0.59920	0.59745	0.59571
1400.0	0.59399	0.59227	0.59056	0.58886	0.58718	0.58550	0.58383	0.58217	0.58052	0.57888
1500.0	0.57725	0.57562	0.57401	0.57241	0.57081	0.56923	0.56765	0.56608	0.56452	0.56297
1600.0	0.56142	0.55989	0.55836	0.55684	0.55533	0.55383	0.55234	0.55085	0.54938	0.54791
1700.0	0.54645	0.54499	0.54354	0.54211	0.54068	0.53925	0.53784	0.53643	0.53503	0.53363
1800.0	0.53224	0.53087	0.52949	0.52813	0.52677	0.52542	0.52407	0.52274	0.52141	0.52008
1900.0	0.51876	0.51745	0.51615	0.51485	0.51356	0.51228	0.51100	0.50973	0.50846	0.50720
2000.0	0.50595	0.50470	0.50346	0.50223	0.50100	0.49978	0.49856	0.49735	0.49614	0.49495
2100.0	0.49375	0.49257	0.49138	0.49021	0.48904	0.48787	0.48671	0.48556	0.48441	0.48327
2200.0	0.48213	0.48100	0.47987	0.47875	0.47763	0.47652	0.47542	0.47431	0.47322	0.47213
2300.0	0.47104	0.46996	0.46888	0.46781	0.46675	0.46569	0.46463	0.46358	0.46253	0.46149



(a) Water-Reflected Stainless Steel Cylinders of Uranyl Fluoride



(b) Unreflected Stainless Steel Cylinders of Uranyl Fluoride

Figure E-0.1. ERRORS INVOLVED IN USING THE BUCKLING TABLES OF SECTION E TO ESTIMATE THE CRITICAL HEIGHT OF EXPERIMENTAL STAINLESS STEEL REACTORS CONTAINING URANYL FLUORIDE SOLUTION. (Given the Atomic Ratio and the Reactor Diameter. Plotted Points Relate to the Experimental Data of Callihan, et al, as Reported in K-343 and ORNL-2367, and Quoted in Section K-1.)

Table E-1 1

MATERIAL BUCKLINGS FOR UO_2F_2 vs H/U-235 ATOMIC RATIO

Calculated by the method of Bell (LA 1548) assuming no resonance capture See Section E 0 for errors involved in the use of this table in conjunction with the tables of Section E 2 Buckling is given in m^{-2}, to convert to cm^{-2} shift decimal point four places to the left

H/X	0	1	2	3	4	5	6	7	8	9
30	267 7	267 6	267 5	267 4	267 4	267 3	267 2	267 2	267 1	267 0
40	267 0	266 8	266 7	266 6	266 5	266 4	266 2	266 1	266 0	265 9
50	265 8	265 6	265 5	265 3	265 2	265 1	264 9	264 8	264 6	264 5
60	264 4	264 2	264 0	263 9	263 7	263 6	263 4	263 2	263 1	262 9
70	262 8	262 6	262 4	262 3	262 1	262 0	261 8	261 6	261 5	261 3
80	261 2	261 0	260 8	260 7	260 5	260 4	260 2	260 0	259 9	259 7
90	259 6	259 4	259 2	259 0	258 9	258 7	258 5	258 4	258 2	258 0
100	257 9	257 7	257 5	257 3	257 2	257 0	256 8	256 7	256 5	256 3
110	256 2	256 0	255 8	255 6	255 5	255 3	255 1	255 0	254 8	254 6
120	254 5	254 3	254 1	253 9	253 8	253 6	253 4	253 3	253 1	252 9
130	252 8	252 6	252 4	252 2	252 1	251 9	251 7	251 6	251 4	251 2
140	251 1	250 9	250 7	250 5	250 4	250 2	250 0	249 9	249 7	249 5
150	249 4	249 2	249 0	248 8	248 7	248 5	248 3	248 2	248 0	247 8
160	247 7	247 5	247 3	247 1	247 0	246 8	246 6	246 5	246 3	246 1
170	246 0	245 8	245 6	245 4	245 3	245 1	244 9	244 8	244 6	244 4
180	244 3	244 1	243 9	243 7	243 6	243 4	243 2	243 1	242 9	242 7
190	242 6	242 4	242 2	242 0	241 9	241 7	241 5	241 4	241 2	241 0
200	240 9	240 7	240 5	240 3	240 2	240 0	239 8	239 7	239 5	239 3
210	239 2	239 0	238 8	238 6	238 5	238 3	238 1	238 0	237 8	237 6
220	237 5	237 3	237 1	237 0	236 8	236 7	236 5	236 3	236 2	236 0
230	235 9	235 7	235 5	235 3	235 2	235 0	234 8	234 7	234 5	234 3
240	234 2	234 0	233 8	233 7	233 5	233 4	233 2	233 0	232 9	232 7
250	232 6	232 4	232 2	232 0	231 9	231 7	231 5	231 4	231 2	231 0
260	230 9	230 7	230 5	230 4	230 2	230 1	229 9	229 7	229 6	229 4
270	229 3	229 1	228 9	228 8	228 6	228 5	228 3	228 1	228 0	227 8
280	227 7	227 5	227 3	227 2	227 0	226 9	226 7	226 5	226 4	226 2
290	226 1	225 9	225 7	225 6	225 4	225 3	225 1	224 9	224 8	224 6
300	224 5	224 3	224 1	224 0	223 8	223 7	223 5	223 3	223 2	223 0
310	222 9	222 7	222 5	222 4	222 2	222 1	221 9	221 7	221 6	221 4
320	221 3	221 1	220 9	220 8	220 6	220 5	220 3	220 1	220 0	219 8
330	219 7	219 5	219 4	219 2	219 1	218 9	218 8	218 6	218 5	218 3
340	218 2	218 0	217 8	217 7	217 5	217 4	217 2	217 0	216 9	216 7
350	216 6	216 4	216 3	216 1	216 0	215 8	215 7	215 5	215 4	215 2
360	215 1	214 9	214 7	214 6	214 4	214 3	214 1	213 9	213 8	213 6
370	213 5	213 3	213 2	213 0	212 9	212 7	212 6	212 4	212 3	212 1
380	212 0	211 8	211 7	211 5	211 4	211 2	211 1	210 9	210 8	210 6
390	210 5	210 3	210 2	210 0	209 9	209 7	209 6	209 4	209 3	209 1

Table E-1.1 (Continued)

H/X	0	1	2	3	4	5	6	7	8	9
400	209 0	208 8	208 7	208 5	208 4	208 2	208 1	207 9	207 8	207 6
410	207 5	207 3	207 2	207 0	206 9	206 7	206 6	206 4	206 3	206 1
420	206 0	205 8	205 7	205 5	205 4	205 2	205 1	204 9	204 8	204 6
430	204 5	204 3	204 2	204 0	203 9	203 7	203 6	203 4	203 3	203 1
440	203 0	202 8	202 7	202 5	202 4	202 3	202 1	202 0	201 8	201 7
450	201 6	201 4	201 3	201 1	201 0	200 8	200 7	200 5	200 4	200 2
460	200 1	199 9	199 8	199 6	199 5	199 3	199 2	199 0	198 9	198 7
470	198 6	198 4	198 3	198 1	198 0	197 9	197 7	197 6	197 4	197 3
480	197 2	197 0	196 9	196 7	196 6	196 5	196 3	196 2	196 0	195 9
490	195 8	195 6	195 5	195 3	195 2	195 0	194 9	194 7	194 6	194 4
500	194 3	194 1	194 0	193 8	193 7	193 6	193 4	193 3	193 1	193 0
510	192 9	192 7	192 6	192 4	192 3	192 2	192 0	191 9	191 7	191 6
520	191 5	191 3	191 2	191 0	190 9	190 8	190 6	190 5	190 3	190 2
530	190 1	189 9	189 8	189 6	189 5	189 4	189 2	189 1	188 9	188 8
540	188 7	188 5	188 4	188 2	188 1	188 0	187 8	187 7	187 5	187 4
550	187 3	187 1	187 0	186 8	186 7	186 6	186 4	186 3	186 1	186 0
560	185 9	185 7	185 6	185 4	185 3	185 2	185 0	184 9	184 7	184 6
570	184 5	184 3	184 2	184 1	183 9	183 8	183 7	183 5	183 4	183 3
580	183 2	183 0	182 9	182 7	182 6	182 5	182 3	182 2	182 0	181 9
590	181 8	181 6	181 5	181 4	181 2	181 1	181 0	180 8	180 7	180 6

H/X	0	10	20	30	40	50	60	70	80	90
600	180 5	179 1	177 8	176 5	175 1	173 8	172 5	171 2	169 9	168 6
700	167 3	166 0	164 8	163 5	162 2	161 0	159 7	158 5	157 3	156 0
800	154 8	153 6	152 4	151 2	150 0	148 8	147 6	146 4	145 2	144 0
900	142 9	141 7	140 6	139 4	138 3	137 1	136 0	134 8	133 7	132 6
1000	131 5	130 4	129 3	128 2	127 1	126 0	124 9	123 8	122 7	121 6
1100	120 6	119 5	118 5	117 4	116 3	115 3	114 2	113 2	112 2	111 1
1200	110 1	109 1	108 1	107 1	106 1	105 0	104 0	103 0	102 0	101 1
1300	100 1	99 1	98 1	97 1	96 2	95 2	94 2	93 3	92 3	91 4
1400	90 4	89 5	88 5	87 6	86 6	85 7	84 8	83 9	82 9	82 0
1500	81 1	80 2	79 3	78 4	77 5	76 6	75 7	74 8	73 9	73 0
1600	72 1	71 2	70 4	69 5	68 6	67 7	66 9	66 0	65 1	64 3
1700	63 4	62 6	61 7	60 9	60 0	59 2	58 4	57 5	56 7	55 9
1800	55 0	54 2	53 4	52 6	51 8	50 9	50 1	49 3	48 5	47 7
1900	46 9	46 1	45 3	44 5	43 7	43 0	42 2	41 4	40 6	39 8

Table E-2.1

GEOMETRIC BUCKLING FOR UO_2F_2 SOLUTIONS IN STAINLESS STEEL CONTAINERS

(Water-Reflected Cylinder Diameter in Inches)

The calculational method of Bell (LA-1548) was followed except that an extrapolation length of (7.0) (1 + 1/D) was used, where D ≈ cylinder diameter in inches, to achieve conservative results with respect to experimental data. Buckling is given in m^{-2}, to convert to cm^{-2}, shift decimal point four places to the left.

Diameter	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
1	475.7	476.6	477.6	478.5	479.5	480.4	481.4	482.3	483.3	484.2
2	485.2	478.7	472.2	465.7	459.2	452.8	446.3	439.8	433.3	426.8
3	420.4	413.8	407.2	400.6	394.1	387.5	380.9	374.4	367.8	361.2
4	354.7	349.1	343.6	338.0	332.5	327.0	321.4	315.9	310.3	304.8
5	299.3	294.8	290.3	285.8	281.3	276.8	272.3	267.8	263.3	258.8
6	254.3	250.6	247.0	243.4	239.8	236.2	232.5	228.9	225.3	221.7
7	218.1	215.1	212.2	209.2	206.3	203.4	200.4	197.5	194.5	191.6
8	188.7	186.3	183.9	181.5	179.1	176.7	174.3	171.9	169.5	167.1
9	164.7	162.7	160.7	158.7	156.7	154.8	152.8	150.8	148.8	146.8
10	144.9	143.2	141.6	139.9	138.3	136.6	135.0	133.3	131.7	130.0
11	128.4	127.0	125.6	124.2	122.8	121.4	120.0	118.6	117.2	115.8
12	114.5	113.3	112.1	110.9	109.7	108.6	107.4	106.2	105.0	103.8
13	102.7	101.7	100.7	99.7	98.7	97.7	96.7	95.7	94.7	93.7
14	92.7	91.8	90.9	90.0	89.2	88.3	87.4	86.6	85.7	84.8
15	84.0	83.2	82.5	81.7	81.0	80.2	79.5	78.7	78.0	77.2
16	76.5	75.8	75.1	74.5	73.8	73.2	72.5	71.8	71.2	70.5
17	69.9	69.3	68.7	68.1	67.6	67.0	66.4	65.9	65.3	64.7
18	64.2	63.6	63.1	62.6	62.1	61.6	61.1	60.6	60.1	59.6
19	59.1	58.6	58.2	57.7	57.3	56.8	56.4	55.9	55.5	55.0
20	54.6	54.2	53.8	53.4	53.0	52.6	52.2	51.8	51.4	51.0
21	50.6	50.2	49.8	49.5	49.1	48.8	48.4	48.0	47.7	47.3
22	47.0	46.6	46.3	46.0	45.7	45.4	45.0	44.7	44.4	44.1
23	43.8	43.5	43.2	42.9	42.6	42.3	42.0	41.7	41.4	41.1
24	40.9	40.6	40.3	40.1	39.8	39.6	39.3	39.0	38.8	38.5
25	38.3	38.0	37.8	37.5	37.3	37.1	36.8	36.6	36.3	36.1
26	35.9	35.6	35.4	35.2	35.0	34.8	34.5	34.3	34.1	33.9
27	33.7	33.5	33.3	33.1	32.9	32.7	32.5	32.3	32.1	31.9
28	31.7	31.5	31.3	31.1	30.9	30.8	30.6	30.4	30.2	30.0
29	29.9	29.7	29.5	29.4	29.2	29.1	28.9	28.7	28.6	28.4

	0	1	2	3	4	5	6	7	8	9
30	28.3	26.7	25.3	24.0	22.8	21.7	20.7	19.7	18.8	18.0
40	17.2	16.5	15.8	15.2	14.5	14.0	13.4	12.9	12.5	12.0
50	11.6	11.2	10.8	10.4	10.1	9.7	9.4	9.1	8.8	8.6
60	8.3	8.0	7.8	7.6	7.4	7.2	7.0	6.8	6.6	6.4
70	6.2	6.1	5.9	5.8	5.6	5.5	5.3	5.2	5.1	5.0
80	4.9	4.7	4.6	4.5	4.4	4.3	4.2	4.1	4.0	4.0
90	3.9	3.8	3.7	3.6	3.6	3.5	3.4	3.4	3.3	3.3

Table E-2.2

GEOMETRIC BUCKLING FOR UO_2F_2 SOLUTIONS IN STAINLESS STEEL CONTAINERS

(Water-Reflected Length or Height in Inches)

The calculational method of Bell (LA-1548) was followed using a constant extrapolation length of 7.0 cm. Buckling is given in m^{-2}; to convert to cm^{-2}, shift decimal point four places to the left.

Height	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
1	360.8	349.9	339.6	329.7	320.2	311.2	302.5	294.1	286.1	278.5
2	271.1	264.0	257.2	250.7	244.4	238.3	232.5	226.9	221.4	216.2
3	211.1	206.3	201.6	197.0	196.6	188.4	184.3	180.3	176.4	172.7
4	169.1	165.6	162.2	158.9	155.7	152.6	149.6	146.7	143.9	141.1
5	138.4	135.8	133.3	130.9	128.5	126.2	123.9	121.7	119.6	117.5
6	115.4	113.5	111.5	109.6	107.8	106.0	104.3	102.6	100.9	99.3
7	97.7	96.2	94.7	93.2	91.8	90.4	89.0	87.6	86.3	85.0
8	83.8	82.6	81.4	80.2	79.0	77.9	76.8	75.7	74.7	73.7
9	72.6	71.7	70.7	69.7	68.8	67.9	67.0	66.1	65.3	64.4
10	63.6	62.8	62.0	61.2	60.4	59.7	58.9	58.2	57.5	56.8
11	56.1	55.4	54.8	54.1	53.5	52.9	52.2	51.6	51.0	50.5
12	49.9	49.3	48.8	48.2	47.7	47.2	46.6	46.1	45.6	45.1
13	44.6	44.2	43.7	43.2	42.8	42.3	41.9	41.4	41.0	40.6
14	40.2	39.8	39.4	39.0	38.6	38.2	37.8	37.4	37.1	36.7
15	36.4	36.0	35.7	35.3	35.0	34.7	34.3	34.0	33.7	33.4
16	33.1	32.8	32.5	32.2	31.9	31.6	31.3	31.0	30.7	30.5
17	30.2	29.9	29.7	29.4	29.1	28.9	28.6	28.4	28.2	27.9
18	27.7	27.4	27.2	27.0	26.8	26.5	26.3	26.1	25.9	25.7
19	25.5	25.3	25.1	24.8	24.7	24.5	24.3	24.1	23.9	23.7
20	23.5	23.3	23.1	23.0	22.8	22.6	22.4	22.3	22.1	21.9
21	21.8	21.6	21.4	21.3	21.1	21.0	20.8	20.7	20.5	20.4
22	20.2	20.1	19.9	19.8	19.6	19.5	19.4	19.2	19.1	19.0
23	18.8	18.7	18.6	18.4	18.3	18.2	18.1	17.9	17.8	17.7
24	17.6	17.4	17.3	17.2	17.1	17.0	16.9	16.8	16.6	16.5
25	16.4	16.3	16.2	16.1	16.0	15.9	15.8	15.7	15.6	15.5
26	15.4	15.3	15.2	15.1	15.0	14.9	14.8	14.7	14.7	14.6
27	14.5	14.4	14.3	14.2	14.1	14.0	14.0	13.9	13.8	13.7
28	13.6	13.5	13.5	13.4	13.3	13.2	13.1	13.1	13.0	12.9
29	12.8	12.8	12.7	12.6	12.6	12.5	12.4	12.3	12.3	12.2

	0	1	2	3	4	5	6	7	8	9
30	12.1	11.5	10.9	10.3	9.8	9.3	8.9	8.5	8.1	7.7
40	7.4	7.1	6.8	6.5	6.2	6.0	5.8	5.5	5.3	5.1
50	5.0	4.8	4.6	4.5	4.3	4.2	4.0	3.9	3.8	3.7
60	3.6	3.5	3.4	3.3	3.2	3.1	3.0	2.9	2.8	2.8
70	2.7	2.6	2.5	2.5	2.4	2.4	2.3	2.2	2.2	2.1
80	2.1	2.0	2.0	2.0	1.9	1.9	1.8	1.8	1.7	1.7
90	1.7	1.6	1.6	1.6	1.5	1.5	1.5	1.5	1.4	1.4

Table E-2 3

GEOMETRIC BUCKLING FOR UO_2F_2 SOLUTIONS IN STAINLESS STEEL CONTAINERS

(Unreflected Cylinder Diameter in Inches)

The calculational method of Bell (LA-548) was followed except that an extrapolation length of (4.3) (1 + 1/D) was used, where D ≈ cylinder diameter in inches, to achieve conservative results with respect to experimental data. Buckling is given in m^{-2}, to convert to cm^{-2}, shift decimal point four places to the left.

Diameter	0	1	2	3	4	5	6	7	8	9
1	1096 4	1084 6	1072 9	1061 1	1049 4	1037 6	1025 9	1014 1	1002 4	990 6
2	978 9	957 8	936 8	915 8	894 8	873 8	852 7	831 7	810 7	789 7
3	768 7	752 0	735 3	718 6	701 9	685 2	668 5	651 8	635 1	618 4
4	601 8	589 5	577 2	564 9	552 6	540 4	528 1	515 8	503 5	491 2
5	479 0	469 9	460 8	451 8	442 7	433 7	424 6	415 5	406 5	397 4
6	388 4	381 6	374 8	368 0	361 2	354 4	347 6	340 8	334 0	327 2
7	320 5	315 3	310 1	304 9	299 7	294 6	289 4	284 2	279 0	273 8
8	268 7	264 6	260 6	256 5	252 5	248 4	244 4	240 3	236 3	232 2
9	228 2	225 0	221 8	218 6	215 4	212 2	209 0	205 8	202 6	199 4
10	196 2	193 6	191 0	188 4	185 8	183 2	180 6	178 0	175 4	172 8
11	170 3	168 2	166 1	164 0	161 9	159 8	157 7	155 6	153 5	151 4
12	149 3	147 5	145 8	144 0	142 3	140 6	138 8	137 1	135 3	133 6
13	131 9	130 4	128 9	127 5	126 0	124 6	123 1	121 6	120 2	118 7
14	117 3	116 0	114 8	113 6	112 3	111 1	109 9	108 6	107 4	106 2
15	105 0	103 9	102 9	101 8	100 8	99 8	98 7	97 7	96 6	95 6
16	94 6	93 7	92 8	91 9	91 0	90 1	89 2	88 3	87 4	86 5
17	85 6	84 8	84 0	83 2	82 4	81 7	80 9	80 1	79 3	78 5
18	77 8	77 1	76 4	75 7	75 1	74 4	73 7	73 1	72 4	71 7
19	71 1	70 5	69 9	69 3	68 7	68 1	67 5	66 9	66 3	65 7
20	65 1	64 5	64 0	63 5	63 0	62 5	61 9	61 4	60 9	60 4
21	59 9	59 4	58 9	58 5	58 0	57 6	57 1	56 6	56 2	55 7
22	55 3	54 8	54 4	54 0	53 6	53 2	52 8	52 4	52 0	51 6
23	51 2	50 8	50 4	50 1	49 7	49 4	49 0	48 6	48 3	47 9
24	47 6	47 2	46 9	46 6	46 2	45 9	45 6	45 2	44 9	44 6
25	44 3	44 0	43 7	43 4	43 1	42 8	42 5	42 2	41 9	41 6
26	41 3	41 0	40 7	40 5	40 2	40 0	39 7	39 4	39 2	38 9
27	38 7	38 4	38 2	37 9	37 7	37 4	37 2	36 9	36 7	36 4
28	36 2	35 9	35 7	35 5	35 3	35 1	34 8	34 6	34 4	34 2
29	34 0	33 8	33 6	33 4	33 2	33 0	32 8	32 6	32 4	32 2

	0	1	2	3	4	5	6	7	8	9
30	32 0	30 2	28 5	27 0	25 6	24 2	23 0	21 9	20 9	19 9
40	19 0	18 1	17 3	16 6	15 9	15 2	14 6	14 1	13 5	13 0
50	12 5	12 1	11 6	11 2	10 8	10 5	10 1	9 8	9 5	9 2
60	8 9	8 6	8 3	8 1	7 8	7 6	7 4	7 2	7 0	6 8
70	6 6	6 4	6 3	6 1	5 9	5 8	5 6	5 5	5 4	5 2
80	5 1	5 0	4 9	4 8	4 6	4 5	4 4	4 3	4 2	4 2
90	4 1	4 0	3 9	3 8	3 7	3 7	3 6	3 5	3 4	3 4

Table E-2.4

GEOMETRIC BUCKLING FOR UO_2F_2 SOLUTIONS IN STAINLESS STEEL CONTAINERS

(Unreflected Length or Height in Inches)

The calculational method of Bell (LA-1548) was followed using a constant extrapolation length of 4.3 cm. Buckling is given in m^{-2}; to convert to cm^{-2}, shift decimal point four places to the left.

Height	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
1	795.3	760.2	727.4	696.7	667.9	640.9	615.4	591.4	568.9	547.5
2	527.4	508.3	490.3	473.2	457.0	441.6	427.0	413.0	399.8	387.2
3	375.1	363.7	352.7	342.2	332.2	322.6	313.5	304.7	296.3	288.2
4	280.4	273.0	265.8	259.0	252.4	246.0	239.9	234.0	228.3	222.8
5	217.5	212.4	207.5	202.8	198.2	193.7	189.5	185.3	181.3	177.4
6	173.7	170.0	166.5	163.1	159.7	156.5	153.4	150.4	147.4	144.6
7	141.8	139.1	136.5	134.0	131.5	129.1	126.8	124.5	122.3	120.1
8	118.0	116.0	114.0	112.0	110.1	108.3	106.5	104.7	103.0	101.4
9	99.7	98.1	96.6	95.1	93.6	92.1	90.7	89.3	88.0	86.7
10	85.4	84.1	82.9	81.7	80.5	79.3	78.2	77.1	76.0	75.0
11	73.9	72.9	71.9	70.9	70.0	69.0	68.1	67.2	66.3	65.5
12	64.6	63.8	63.0	62.2	61.4	60.6	59.9	59.1	58.4	57.7
13	57.0	56.3	55.6	54.9	54.3	53.7	53.0	52.4	51.8	51.2
14	50.6	50.0	49.5	48.9	48.4	47.8	47.3	46.8	46.3	45.8
15	45.3	44.8	44.3	43.8	43.3	42.9	42.4	42.0	41.6	41.1
16	40.7	40.3	39.9	39.5	39.1	38.7	38.3	37.9	37.5	37.2
17	36.8	36.5	36.1	35.8	35.4	35.1	34.7	34.4	34.1	33.8
18	33.4	33.1	32.8	32.5	32.2	31.9	31.6	31.4	31.1	30.8
19	30.5	30.3	30.0	29.7	29.5	29.2	29.0	28.7	28.5	28.2
20	28.0	27.7	27.5	27.3	27.0	26.8	26.6	26.4	26.2	25.9
21	25.7	25.5	25.3	25.1	24.9	24.7	24.5	24.3	24.1	23.9
22	23.7	23.6	23.4	23.2	23.0	22.8	22.7	22.5	22.3	22.1
23	22.0	21.8	21.6	21.5	21.3	21.2	21.0	20.9	20.7	20.5
24	20.4	20.2	20.1	20.0	19.8	19.7	19.5	19.4	19.3	19.1
25	19.0	18.9	18.7	18.6	18.5	18.3	18.2	18.1	18.0	17.8
26	17.7	17.6	17.5	17.4	17.2	17.1	17.0	16.9	16.8	16.7
27	16.6	16.5	16.4	16.2	16.1	16.0	15.9	15.8	15.7	15.6
28	15.5	15.4	15.3	15.2	15.1	15.0	15.0	14.9	14.8	14.7
29	14.6	14.5	14.4	14.3	14.2	14.1	14.1	14.0	13.9	13.8

	0	1	2	3	4	5	6	7	8	9
30	13.7	12.9	12.2	11.6	10.9	10.4	9.9	9.4	8.9	8.5
40	8.1	7.8	7.4	7.1	6.8	6.5	6.3	6.0	5.8	5.6
50	5.4	5.2	5.0	4.8	4.6	4.5	4.3	4.2	4.1	3.9
60	3.8	3.7	3.6	3.5	3.4	3.3	3.2	3.1	3.0	2.9
70	2.8	2.8	2.7	2.6	2.6	2.5	2.4	2.4	2.3	2.3
80	2.2	2.1	2.1	2.0	2.0	2.0	1.9	1.9	1.8	1.8
90	1.8	1.7	1.7	1.6	1.6	1.6	1.5	1.5	1.5	1.5

Table E-2.5

GEOMETRIC BUCKLING FOR UO_2F_2 SOLUTIONS IN STAINLESS STEEL CONTAINERS

("Bottom-Reflected" Length or Height in Inches)

The calculational method of Bell (LA-1548) was followed using constant extrapolation lengths of 7.0 cm for one end and 4.3 cm for the other (11.3 cm total). Buckling is given in m^{-2}; to convert to cm^{-2}, shift decimal point four places to the left.

Height	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
1	515.3	496.9	479.4	462.9	447.2	432.3	418.1	404.6	391.8	379.5
2	367.9	356.7	346.1	335.9	326.1	316.8	307.9	299.3	291.1	283.3
3	275.7	268.5	261.5	254.8	248.3	242.1	236.1	230.4	224.8	219.5
4	214.3	209.3	204.5	199.9	195.4	191.0	186.8	182.8	178.8	175.0
5	171.3	167.8	164.3	161.0	157.7	154.6	151.5	148.5	145.6	142.8
6	140.1	137.5	134.9	132.4	130.0	127.6	125.3	123.1	120.9	118.8
7	116.7	114.7	112.7	110.8	109.0	107.1	105.4	103.6	102.0	100.3
8	98.7	97.1	95.6	94.1	92.7	91.2	89.8	88.5	87.2	85.9
9	84.6	83.3	82.1	80.9	79.8	78.6	77.5	76.4	75.3	74.3
10	73.3	72.3	71.3	70.3	69.4	68.5	67.6	66.7	65.8	64.9
11	64.1	63.3	62.5	61.7	60.9	60.1	59.4	58.7	57.9	57.2
12	56.5	55.9	55.2	54.5	53.9	53.3	52.6	52.0	51.4	50.8
13	50.2	49.7	49.1	48.6	48.0	47.5	47.0	46.4	45.9	45.4
14	44.9	44.5	44.0	43.5	43.1	42.6	42.2	41.7	41.3	40.9
15	40.4	40.0	39.6	39.2	38.8	38.4	38.1	37.7	37.3	36.9
16	36.6	36.2	35.9	35.5	35.2	34.9	34.5	34.2	33.9	33.6
17	33.3	32.9	32.6	32.3	32.0	31.8	31.5	31.2	30.9	30.6
18	30.4	30.1	29.8	29.6	29.3	29.0	28.8	28.5	28.3	28.1
19	27.8	27.6	27.4	27.1	26.9	26.7	26.5	26.2	26.0	25.8
20	25.6	25.4	25.2	25.0	24.8	24.6	24.4	24.2	24.0	23.8
21	23.6	23.4	23.3	23.1	22.9	22.7	22.5	22.4	22.2	22.0
22	21.9	21.7	21.5	21.4	21.2	21.1	20.9	20.8	20.6	20.5
23	20.3	20.2	20.0	19.9	19.7	19.6	19.4	19.3	19.2	19.0
24	18.9	18.8	18.6	18.5	18.4	18.3	18.1	18.0	17.9	17.8
25	17.6	17.5	17.4	17.3	17.2	17.1	16.9	16.8	16.7	16.6
26	16.5	16.4	16.3	16.2	16.1	16.0	15.9	15.8	15.7	15.6
27	15.5	15.4	15.3	15.2	15.1	15.0	14.9	14.8	14.7	14.6
28	14.5	14.4	14.4	14.3	14.2	14.1	14.0	13.9	13.8	13.8
29	13.7	13.6	13.5	13.4	13.4	13.3	13.2	13.1	13.0	13.0

	0	1	2	3	4	5	6	7	8	9
30	12.9	12.2	11.5	10.9	10.3	9.8	9.4	8.9	8.5	8.1
40	7.7	7.4	7.1	6.8	6.5	6.3	6.0	5.8	5.6	5.4
50	5.2	5.0	4.8	4.6	4.5	4.3	4.2	4.1	3.9	3.8
60	3.7	3.6	3.5	3.4	3.3	3.2	3.1	3.0	2.9	2.8
70	2.8	2.7	2.6	2.6	2.5	2.4	2.4	2.3	2.3	2.2
80	2.1	2.1	2.0	2.0	2.0	1.9	1.9	1.8	1.8	1.8
90	1.7	1.7	1.6	1.6	1.6	1.5	1.5	1.5	1.5	1.4

Table E-2.6

GEOMETRIC BUCKLING FOR UNREFLECTED URANIUM METAL CYLINDER

(Diameter in Inches)

The geometric buckling concept has been employed using the empirical constants of Gwin and Mee (Y-1248) who use an assumed material buckling of 720.1 m^{-2}, and an extrapolation length of 2.745 cm. Buckling is given in m^{-2}, to convert to cm^{-2}, shift decimal point four places to the left.

Diameter	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
1	3588.0	3371.4	3173.8	2993.0	2827.3	2675.0	2534.6	2405.1	2285.2	2174.0
2	2070.8	1974.8	1885.2	1801.7	1723.5	1650.4	1581.8	1517.4	1456.8	1399.8
3	1346.1	1295.4	1247.6	1202.3	1159.4	1118.8	1080.3	1043.8	1009.1	976.1
4	944.6	914.7	886.2	858.9	833.0	808.1	784.4	761.7	740.0	719.2
5	699.2	680.1	661.8	644.1	627.2	610.9	595.3	580.3	565.8	551.8
6	538.4	525.4	512.9	500.9	489.2	478.0	467.2	456.7	446.5	436.7
7	427.3	418.1	409.2	400.6	392.3	384.2	376.4	368.8	361.4	354.2
8	347.3	340.6	334.0	327.7	321.5	315.5	309.7	304.0	298.5	293.2
9	287.9	282.8	277.8	273.0	268.3	263.7	259.2	254.9	250.6	246.5
10	242.5	238.5	234.7	230.9	227.3	223.7	220.2	216.8	213.5	210.2
11	207.0	203.9	200.9	197.9	195.0	192.1	189.4	186.6	184.0	181.4
12	178.8	176.3	173.9	171.5	169.1	166.8	164.6	162.4	160.2	158.1
13	156.0	154.0	152.0	150.0	148.1	146.2	144.4	142.5	140.8	139.0
14	137.3	135.6	134.0	132.3	130.7	129.2	127.6	126.1	124.7	123.2
15	121.8	120.4	119.0	117.6	116.3	115.0	113.7	112.4	111.2	109.9
16	108.7	107.5	106.4	105.2	104.1	103.0	101.9	100.8	99.7	98.7
17	97.7	96.7	95.7	94.7	93.7	92.8	91.8	90.9	90.0	89.1
18	88.2	87.4	86.5	85.7	84.8	84.0	83.2	82.4	81.6	80.8
19	80.1	79.3	78.6	77.9	77.1	76.4	75.7	75.0	74.4	73.7
20	73.0	72.4	71.7	71.1	70.5	69.8	69.2	68.6	68.0	67.4
21	66.8	66.3	65.7	65.1	64.6	64.1	63.5	63.0	62.5	61.9
22	61.4	60.9	60.4	59.9	59.4	59.0	58.5	58.0	57.6	57.1
23	56.6	56.2	55.8	55.3	54.9	54.5	54.0	53.6	53.2	52.8
24	52.4	52.0	51.6	51.2	50.8	50.4	50.1	49.7	49.3	49.0
25	48.6	48.3	47.9	47.6	47.2	46.9	46.5	46.2	45.9	45.5
26	45.2	44.9	44.6	44.3	44.0	43.7	43.4	43.1	42.8	42.5
27	42.2	41.9	41.6	41.3	41.0	40.8	40.5	40.2	39.9	39.7
28	39.4	39.2	38.9	38.6	38.4	38.1	37.9	37.7	37.4	37.2
29	36.9	36.7	36.5	36.2	36.0	35.8	35.5	35.3	35.1	34.9
	0	1	2	3	4	5	6	7	8	9
30	34.7	32.6	30.7	29.0	27.4	26.0	24.6	23.4	22.2	21.2
40	20.2	19.2	18.4	17.6	16.8	16.1	15.5	14.8	14.3	13.7
50	13.2	12.7	12.2	11.8	11.4	11.0	10.6	10.2	9.9	9.6
60	9.3	9.0	8.7	8.4	8.2	8.0	7.7	7.5	7.3	7.1
70	6.9	6.7	6.5	6.3	6.2	6.0	5.9	5.7	5.6	5.4
80	5.3	5.2	5.1	4.9	4.8	4.7	4.6	4.5	4.4	4.3
90	4.2	4.1	4.0	4.0	3.9	3.8	3.7	3.6	3.6	3.5

Table E-2.7

GEOMETRIC BUCKLING FOR UNREFLECTED URANIUM METAL

(Length and Height in Inches)

The geometric buckling concept has been employed using the empirical constants of Gwin and Mee (Y-1248) who use an assumed material buckling of 720.1 m^{-2}, and an extrapolation length of 2.745 cm. Buckling is given in m^{-2}; to convert to cm^{-2}, shift decimal point four places to the left.

Height	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
1	1530.6	1438.2	1353.9	1276.8	1206.1	1141.1	1081.3	1026.0	974.8	927.4
2	883.4	842.4	804.2	768.6	735.2	704.0	674.8	647.3	621.5	597.2
3	574.2	552.6	532.2	512.9	494.6	477.3	460.9	445.3	430.5	416.4
4	403.0	390.2	378.0	366.4	355.3	344.7	334.6	324.9	315.7	306.8
5	298.3	290.1	282.3	274.8	267.6	260.6	254.0	247.5	241.4	235.4
6	229.7	224.1	218.8	213.7	208.7	203.9	199.3	194.8	190.5	186.3
7	182.3	178.4	174.6	170.9	167.3	163.9	160.5	157.3	154.2	151.1
8	148.2	145.3	142.5	139.8	137.1	134.6	132.1	129.7	127.3	125.0
9	122.8	120.6	118.5	116.5	114.4	112.5	110.6	108.7	106.9	105.2
10	103.4	101.8	100.1	98.5	97.0	95.4	93.9	92.5	91.1	89.7
11	88.3	87.0	85.7	84.4	83.2	82.0	80.8	79.6	78.5	77.4
12	76.3	75.2	74.2	73.1	72.1	71.2	70.2	69.3	68.3	67.4
13	66.6	65.7	64.8	64.0	63.2	62.4	61.6	60.8	60.0	59.3
14	58.6	57.9	57.1	56.5	55.8	55.1	54.5	53.8	53.2	52.6
15	51.9	51.3	50.8	50.2	49.6	49.0	48.5	48.0	47.4	46.9
16	46.4	45.9	45.4	44.9	44.4	43.9	43.5	43.0	42.5	42.1
17	41.7	41.2	40.8	40.4	40.0	39.6	39.2	38.8	38.4	38.0
18	37.6	37.3	36.9	36.5	36.2	35.8	35.5	35.2	34.8	34.5
19	34.2	33.8	33.5	33.2	32.9	32.6	32.3	32.0	31.7	31.4
20	31.1	30.9	30.6	30.3	30.1	29.8	29.5	29.3	29.0	28.8
21	28.5	28.3	28.0	27.8	27.6	27.3	27.1	26.9	26.6	26.4
22	26.2	26.0	25.8	25.6	25.4	25.2	25.0	24.8	24.6	24.4
23	24.2	24.0	23.8	23.6	23.4	23.2	23.1	22.9	22.7	22.5
24	22.4	22.2	22.0	21.8	21.7	21.5	21.4	21.2	21.0	20.9
25	20.7	20.6	20.4	20.3	20.1	20.0	19.8	19.7	19.6	19.4
26	19.3	19.2	19.0	18.9	18.8	18.6	18.5	18.4	18.2	18.1
27	18.0	17.9	17.7	17.6	17.5	17.4	17.3	17.2	17.0	16.9
28	16.8	16.7	16.6	16.5	16.4	16.3	16.2	16.1	16.0	15.9
29	15.8	15.7	15.6	15.5	15.4	15.3	15.2	15.1	15.0	14.9

	0	1	2	3	4	5	6	7	8	9
30	14.8	13.9	13.1	12.4	11.7	11.1	10.5	10.0	9.5	9.0
40	8.6	8.2	7.8	7.5	7.2	6.9	6.6	6.3	6.1	5.8
50	5.6	5.4	5.2	5.0	4.9	4.7	4.5	4.4	4.2	4.1
60	4.0	3.8	3.7	3.6	3.5	3.4	3.3	3.2	3.1	3.0
70	2.9	2.9	2.8	2.7	2.6	2.6	2.5	2.4	2.4	2.3
80	2.3	2.2	2.2	2.1	2.1	2.0	2.0	1.9	1.9	1.8
90	1.8	1.8	1.7	1.7	1.7	1.6	1.6	1.6	1.5	1.5

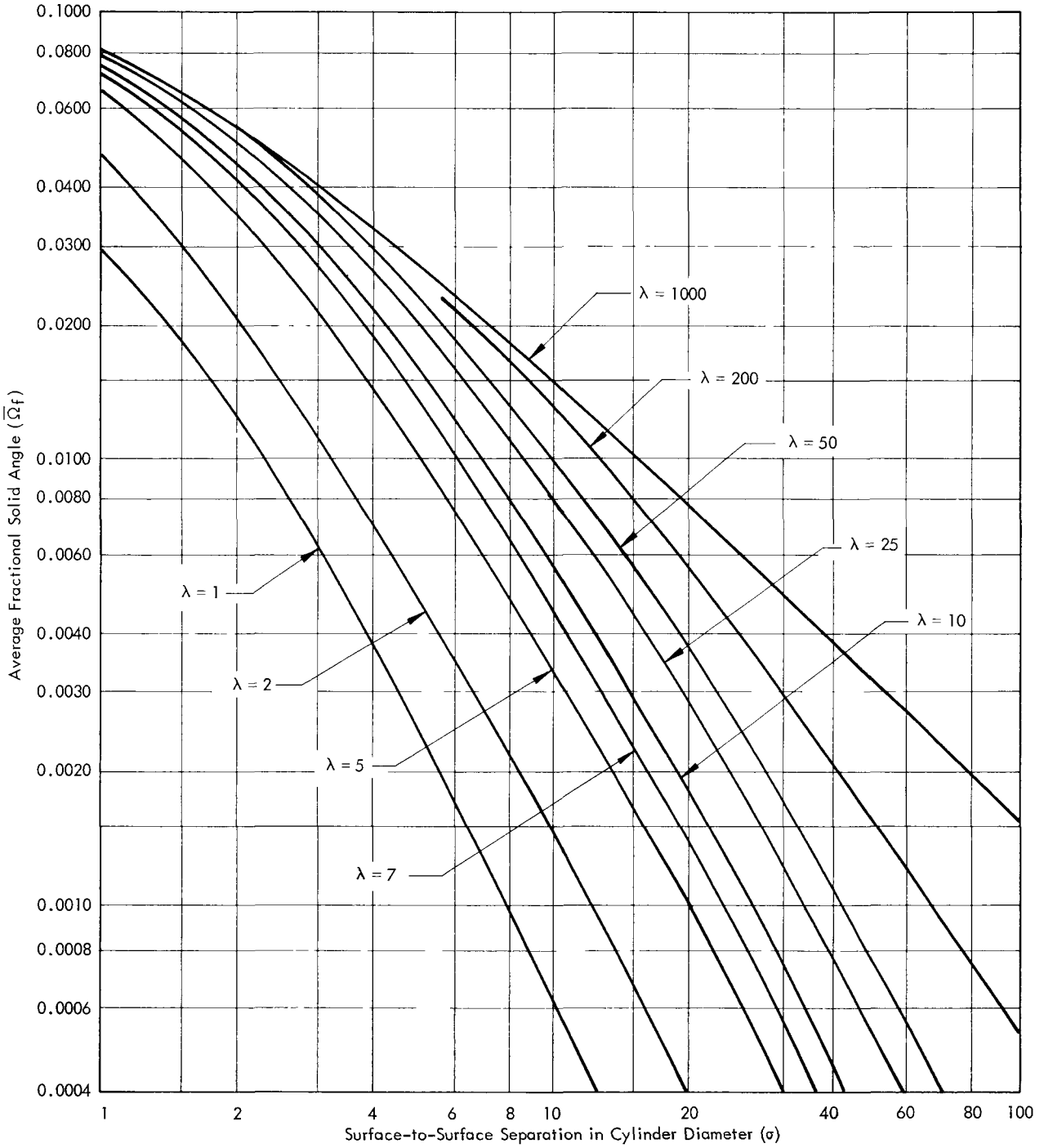


Figure F-1.1. AVERAGE FRACTIONAL SOLID ANGLE BETWEEN SIMILAR AND PARALLEL CYLINDERS AS A FUNCTION OF THE SURFACE-TO-SURFACE SEPARATION IN CYLINDER DIAMETERS. (Extended to Surface-to-Surface Separations greater than 1.0 by the Formulas Presented in GAT-DM-455.)

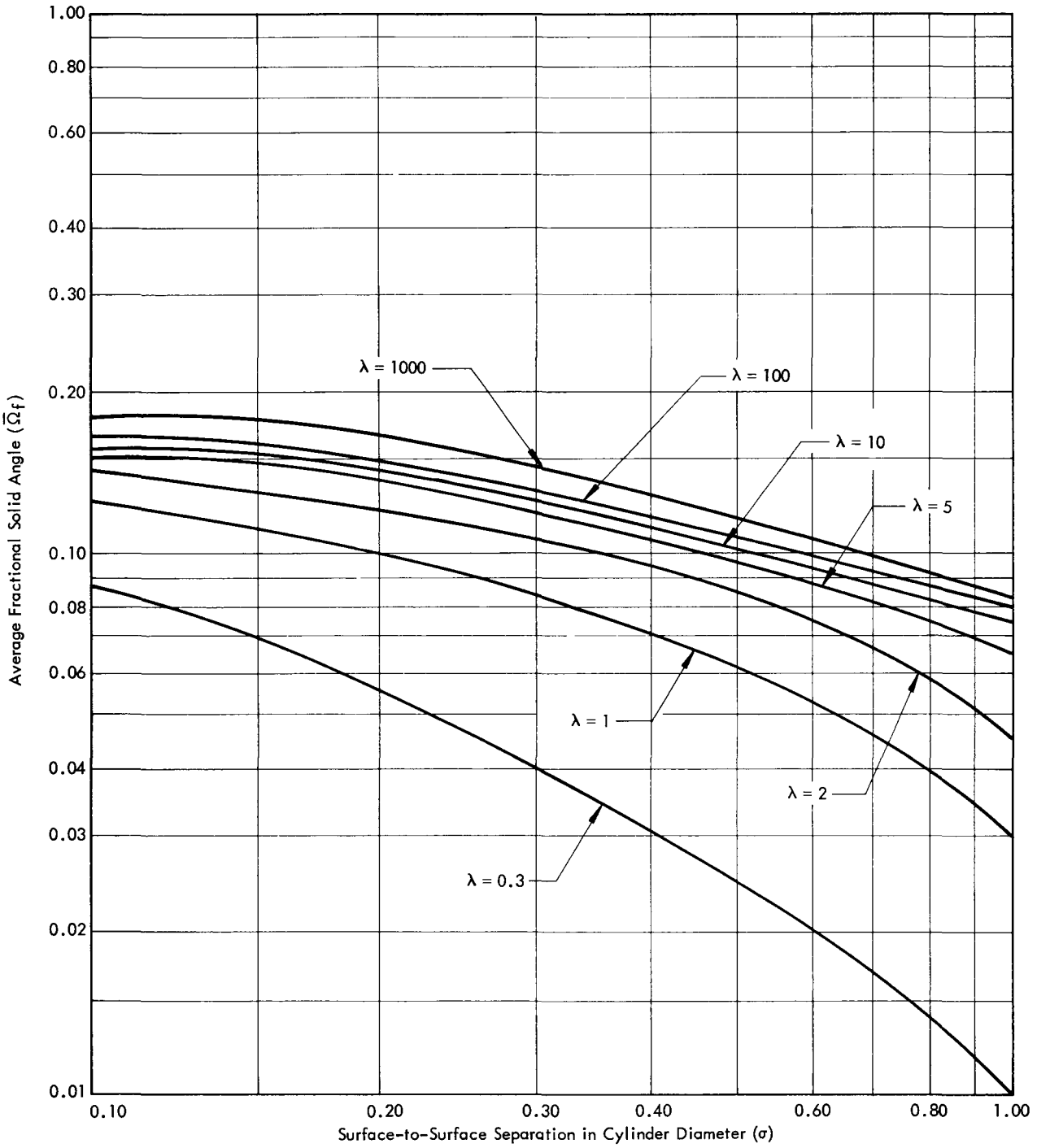


Figure F-1.2. AVERAGE FRACTIONAL SOLID ANGLE BETWEEN SIMILAR AND PARALLEL CYLINDERS AS A FUNCTION OF THE SURFACE-TO-SURFACE SEPARATION IN CYLINDER DIAMETERS. (Extended to Surface-to-Surface Separations less than 1.0 by the Formulas Presented in GAT-DM-455.)

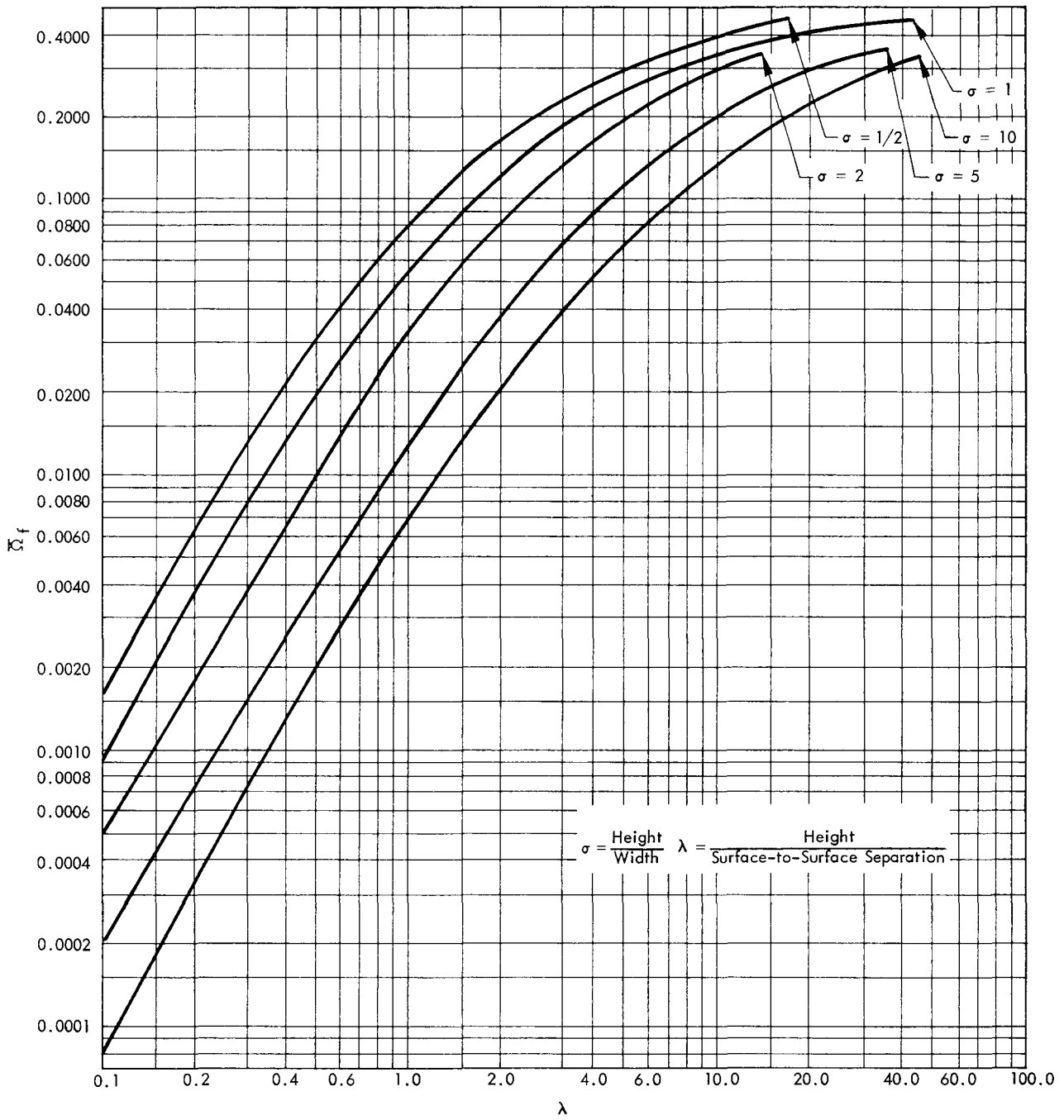


Figure F-1.3. **AVERAGE FRACTIONAL SOLID ANGLE BETWEEN SIMILAR AND PARALLEL SLABS AS A FUNCTION OF THE SLAB HEIGHT, λ.** (Measured in Units of the Surface-to-Surface Separations. Pond, J. A., Private Communication.)

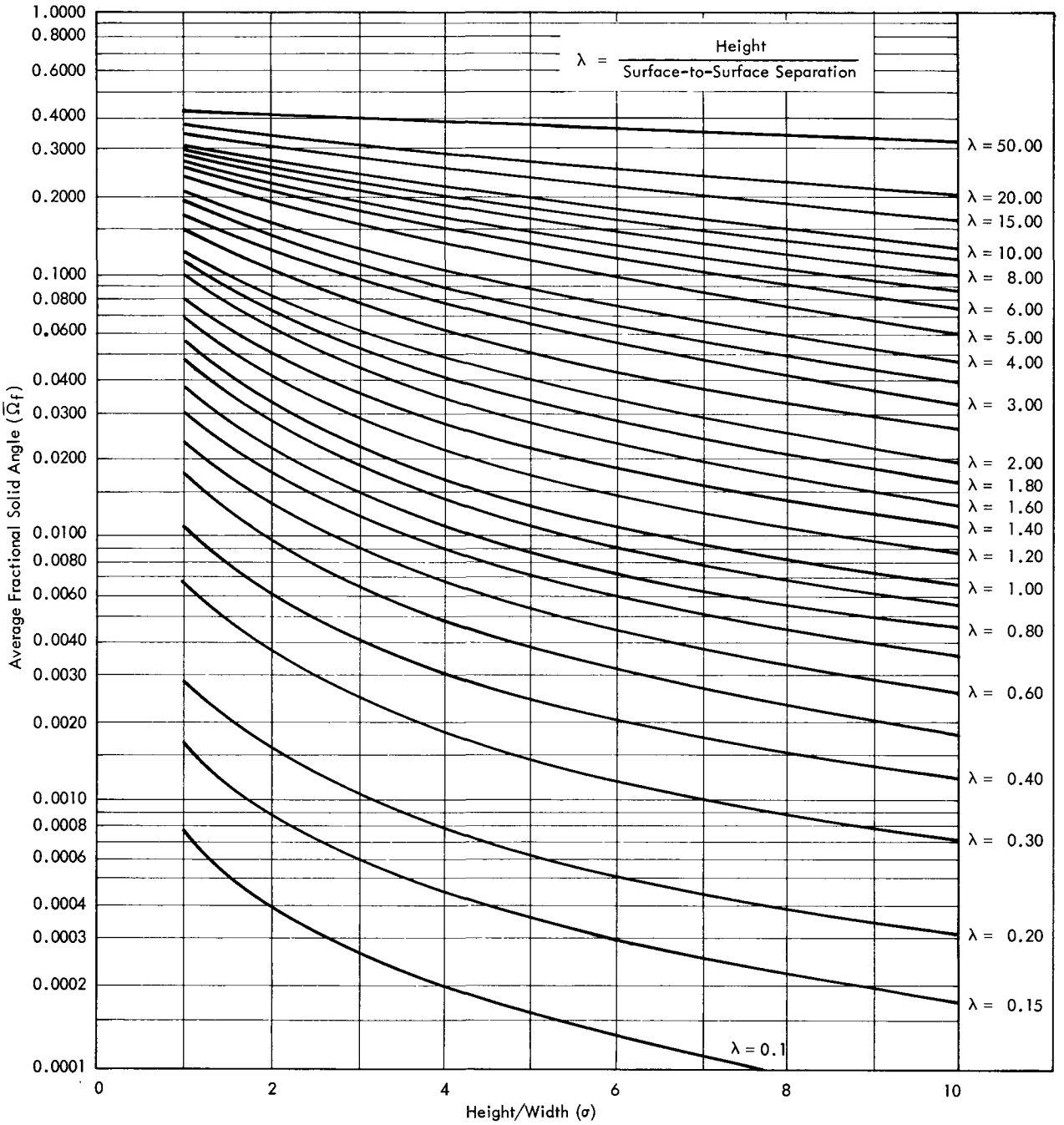


Figure F-1.4. AVERAGE FRACTIONAL SOLID ANGLE BETWEEN SIMILAR AND PARALLEL SLABS AS A FUNCTION OF THE SLAB HEIGHT-TO-WIDTH RATIO. (Pond, J. A., Private Communication.)

Table G-0 1

SUMMARY OF SAFE LIMIT GROUPS

Group	Requires Control Over Interaction and	Typical Applications	Equivalent Nomenclature
I	Safe Parameter (as tabulated)	Metal Pickling and Dissolving Baths	Nuclearly Safe
II	Safe Parameter and Moderating Components (whether metal, solution or other moderator)	Solution Processing Equipment, Metal Handling	"Always Safe" Metal Safe Solution Safe Nuclearly Safe
III	Safe Parameter, Moderating Components, and One Other Variable	Low Isotopic Enrichment, Alloys, Dry Box Operation	"Limited Safe" Nuclearly Safe
IV	Safe Parameter, Moderating Components, and Two (or more) Other Variables	All the Above	Basic Limits Nuclearly Safe

Table G-1.1

GROUP I SAFE LIMITS FOR INDIVIDUAL SYSTEMS OF U-235, U-233, AND Pu-239

Dimensional limits apply to the maximum size of the fissionable material or the inside dimensions of the containing vessel, and apply to any physical form (metal, solution, salt, or combination) of the fissionable material. "Reactor compositions" such as dilute fissionable material in heavy water, Be, or C (having D X, Be/X, or C X of greater than about 100) are excluded, as are systems with thick reflectors of these materials. See Tables J-1.1 and O-1.1 for comparable minimum critical values.

Fissionable Isotope X	Cylinder Diameter (inches)	Slab Thickness (inches)	Volume (liters)	Volume (cubic inches)	Concentration (gms X/liter)	Mass (gms of X)
U-235	2.5	0.6	0.13	36	5.0	350
U-233	1.5	0.2	0.16	9.8	4.7	250
Pu-239	1.4	0.2	0.13	7.9	3.2	250

Source: Derived from Henry, Mallett, and Newlon, K-1019, and Callihan, et al, TID-7016.

Table G-2.1

GROUP II SAFE LIMITS FOR INDIVIDUAL SYSTEMS OF HOMOGENEOUS U-235, U-233, AND Pu-239 SOLUTIONS

Solutions are defined by Figure G-2.2 and the density corrections thereof must be applied to these tabulated values, if applicable. "Reactor compositions" such as dilute fissionable material in heavy water, are excluded (see Table G-1.1). Table J-1.1 gives comparable critical data.

Fissionable Isotope X	Cylinder Diameter (inches)	Slab Thickness (inches)	Volume (liters)	Volume (gals)	Concentration (gms X/liter)	Mass (gms of X)
U-235	5.0	1.4	4.8	1.27	5.0	350
U-233	3.7	0.5	2.0	0.53	4.7	250
Pu-239	4.5	1.5	3.3	0.87	3.2	250

Source: Henry, Mallett, and Newlon, K-1019, and Callihan, et al, TID-7016.

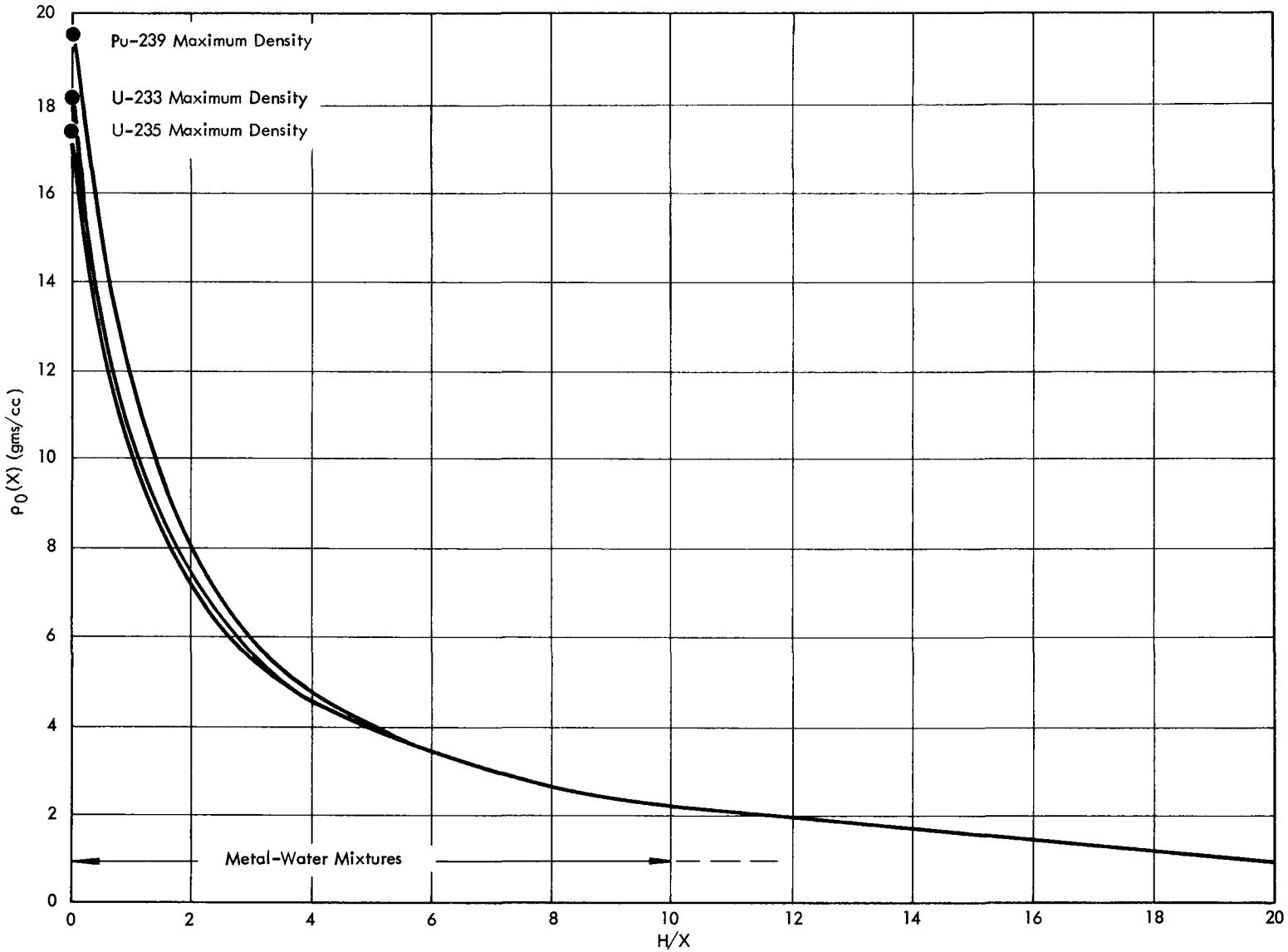


Figure G-2.1. ASSUMED DENSITIES OF X (U-235, U-233, or Pu-239) AT H/X LESS THAN 20. (If a Material Density Exceeds the Indicated Value by the Ratio n, Reduce the Mass Limits by the Factor $1/n^2$, Volume Limits by $1/n^3$, and Linear Dimension Limits by $1/n$. No Relaxation is Allowed for Material Densities below the Indicated Value (except for the special case of small air voids cited in Figure G-3.3). Figure 1 of Callihan, et al, TID-7016.)

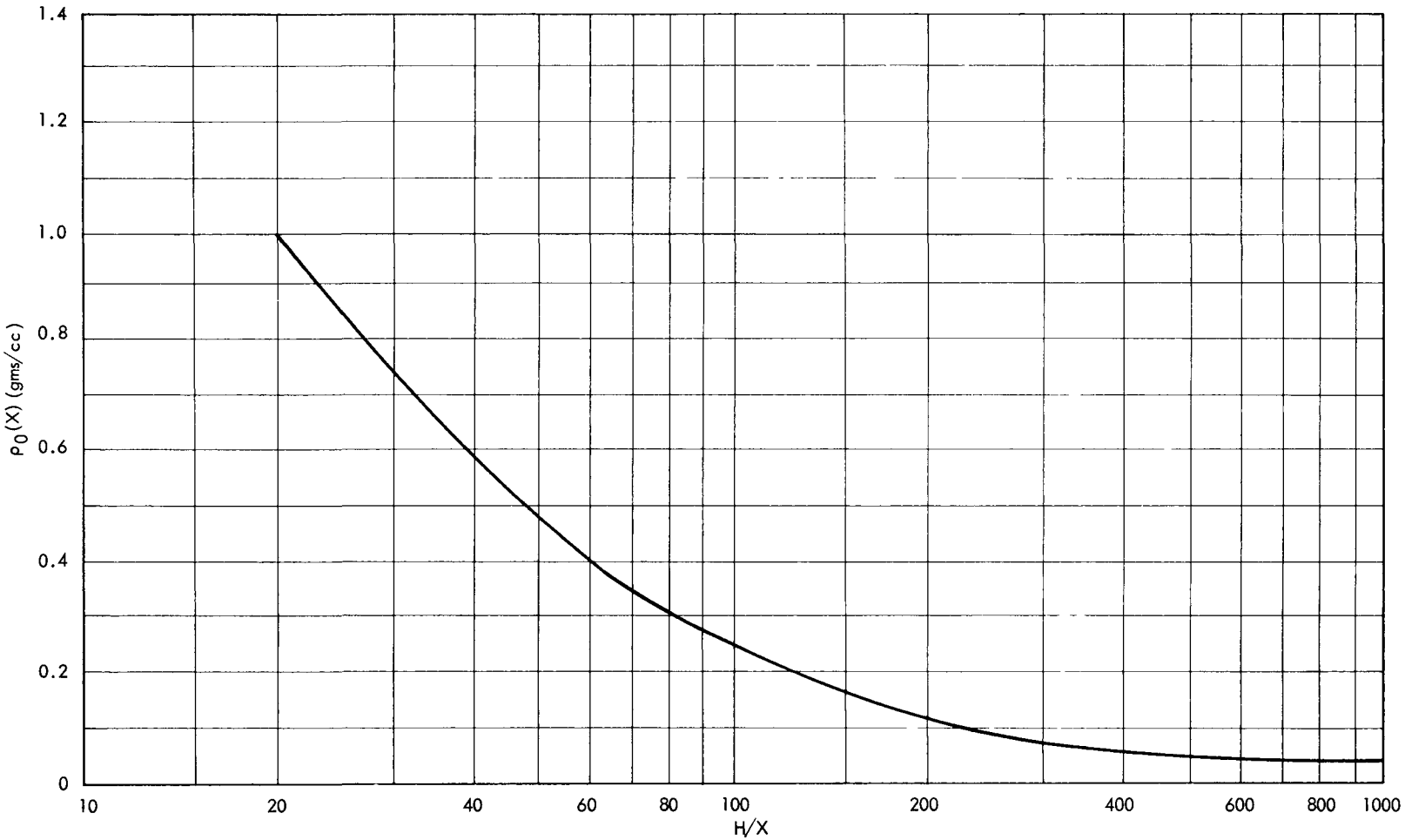


Figure G-2.2. ASSUMED DENSITIES OF X (U-235, U-233, or Pu-239) AT H/X GREATER THAN 20. (If a Material Density Exceeds the Indicated Value by the Ratio n, Reduce the Mass Limits by the Factor $1/n^2$, Volume Limits by $1/n^3$, and Linear Dimension Limits by $1/n$. No Relaxation is Allowed for Material Densities below the Indicated Value (except for the special case of small air voids cited in Figure G-3.3). Figure 2 of Callihan, et al, TID-7016.)

Table G-2.2

GROUP II SAFE VALUES FOR INDIVIDUAL U-235, U-233, AND Pu-239 METAL UNITS

Tabulated values are applicable to homogeneous metal pieces and alloys and to high-density systems which conform to Figure G-2.1). "Reactor compositions" and heavy reflectors are excluded (see Table G-1.1). Table O-1 1 gives comparable critical data.

Fissionable Isotope X	Cylinder Diameter (inches)	Slab Thickness (inch)	Volume (cubic inches)	Mass (kgs of X)
U-235	2.5	0.6	36	11.0
U-233	1.5	0.2	9.8	3.0
Pu-239	1.4	0.2	7.9	2.6

Source Callihan, et al, TID-7016.

Table G-3.1

GROUP III SAFE LIMITS FOR INDIVIDUAL SYSTEMS OF HOMOGENEOUS U-235 SOLUTIONS FOR VARIOUS ISOTOPIC COMPOSITIONS

Tabulated values give the maximum allowable inside dimensions of the containing vessel or the maximum allowable mass or internal volume. They apply to homogeneous aqueous solutions and do not apply to "reactor compositions" (see Tables G-2.1 and G-2.2). The table below should not be used where heterogeneity of the material could occur. See Section J-3 for comparison of these limits with critical data.

U-235 Assay (wt % U-235)	Volume (liters)	Volume (gals)	Infinite Cylinder Diameter (inches)	Infinite Slab Thickness (inches)	Mass U-235 (kgs)	Mass U (kgs)
94	4.8	1.16	5.0	1.5	0.350	0.370
75	5.0	1.32	5.2	1.6	0.360	0.480
50	6.0	1.58	5.7	1.9	0.390	0.780
40	6.7	1.77	6.0	2.0	0.410	1.03
30	7.7	2.03	6.3	2.2	0.440	1.47
20	9.5	2.50	6.9	2.7	0.480	2.40
15	11.0	2.90	7.4	3.1	0.520	3.47
12	12.5	3.30	7.8	3.4	0.560	4.67
10	14.0	3.69	8.2	3.6	0.600	6.00
8.0	16.0	4.22	8.7	3.9	0.650	8.13
6.0	20.5	5.41	9.6	4.5	0.740	12.3
5.0	27.0	7.13	10.25	5.0	0.800	16.0
4.0	33.8	8.92	11.2	5.5	0.940	23.9
3.5	40.0	10.6	12.0	6.0	1.05	30.0
3.0	49.2	13.0	12.8	6.5	1.20	40.0
2.5	64.6	17.1	14.0	7.1	1.50	60.0
2.0	95.1	25.1	16.0	8.7	2.00	100
1.75	126	33.3	17.6	9.6	2.75	157
1.5	186	49.1	20.0	11.0	3.60	240
1.25	308	81.3	24.0	13.5	6.40	512
1.1	524	138	29.0	17.1	12.0	1070
1.0	1300	343	39.6	24.0	22.7	2270
0.90[1]	∞	∞	∞	∞	∞	∞

[1] The minimum assay value was increased to 0.95.

Source Henry, Mallett, and Newlon, K-1019, Newlon, KSA-128. Interpolations were made from the source data as plotted in Figure J-3.1 (reciprocal mass vs log U-235 isotopic concentration).

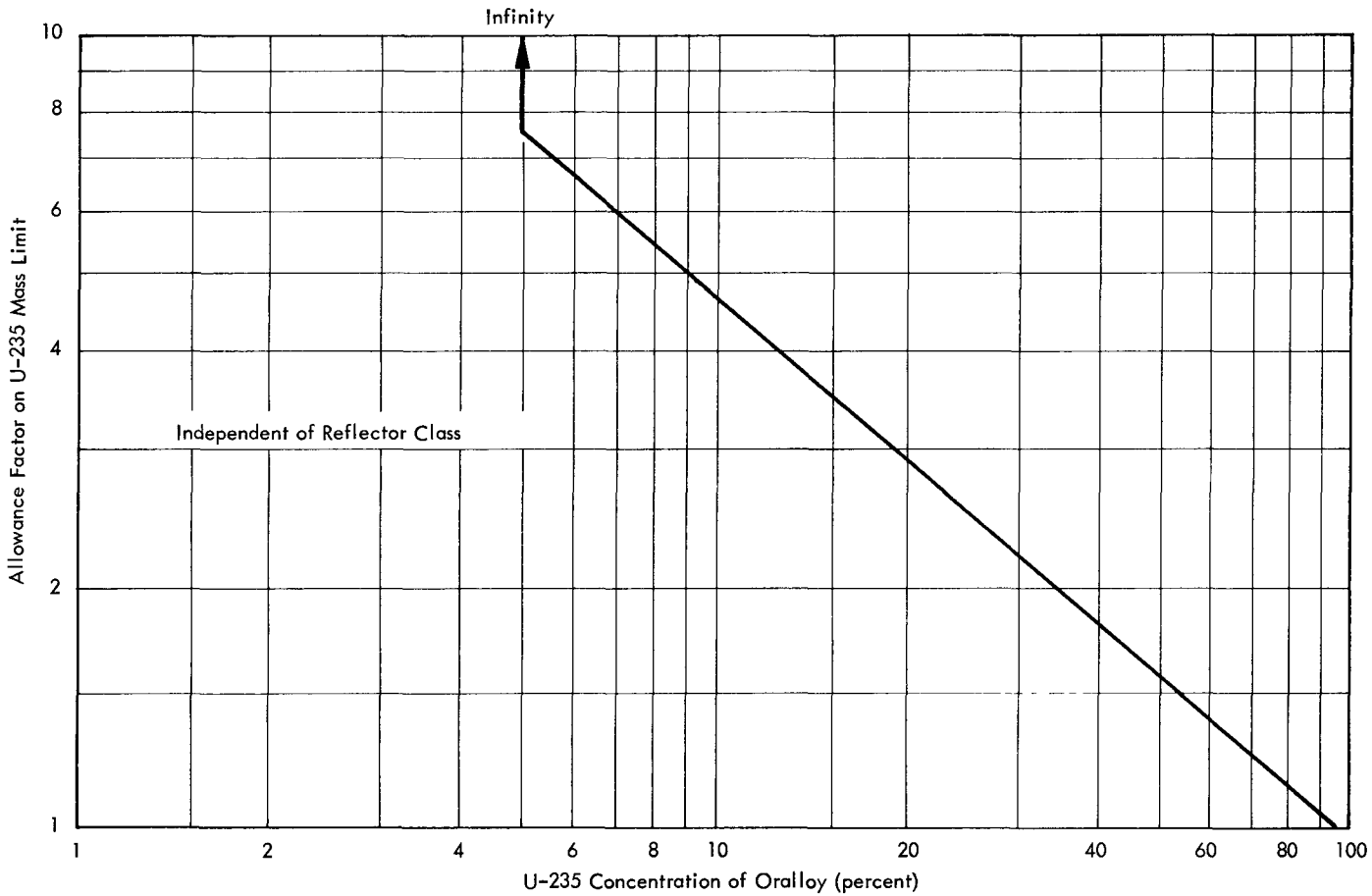


Figure G-3.1. MASS ALLOWANCE FACTOR FOR U-235 ISOTOPIC COMPOSITION. (These Values may be Applied to the Mass Limits of Table G-2.2 to Obtain Group III Values, and to the Mass Limits of Table G-4.4 to Obtain Group IV Values. Figure 6 of Callihan, et al, TID-7016.)

Table G-3.2

GROUP III SAFE VALUES FOR INDIVIDUAL U-235, U-233, AND Pu-239 HOMOGENEOUS SOLUTIONS UNDER VARIOUS CONDITIONS OF CONTROLLED REFLECTION

Tabulated values give the maximum allowable inside dimensions of the containing vessel or the maximum allowable mass or internal volume. Thick water is assumed to be the most effective reflector encountered in normal production operations. "Nominal reflector" refers to water no more than one-inch thick or its equivalent. "Minimal reflector" refers to no more than 1/8-inch-thick stainless steel, or the same thickness of other common metals including iron, copper, nickel, or titanium. See Section K for water and minimal reflector critical data, Section N-2 for various nominal reflectors.

Fissionable Isotope X	Degree of Reflection	Cylinder Diameter (inches)	Slab Thickness (inches)	Volume (liters)	Volume (gals)	Mass (kgs of X)
U-235	Thick Water	5.0	1.5	4.8	1.27	0.35
	Nominal (≤ 1 inch water)	5.8	2.4	6.0	1.58	0.43
	Minimal (≤ 1/8 inch SS)	6.7	3.3	8.1	2.14	0.55
U-233	Thick Water	3.7	0.5	2.0	0.53	0.25
	Nominal (≤ 1 inch water)	4.7	1.7	3.0	0.79	0.33
	Minimal (≤ 1/8 inch SS)	5.7	2.5	4.0	1.0	0.45
Pu-239	Thick Water	4.5	1.5	3.3	0.87	0.25
	Nominal (≤ 1 inch water)	5.7	2.6	5.0	1.32	0.32
	Minimal (≤ 1/8 inch SS)	6.8	3.6	6.6	1.74	0.43

Source: Callihan, et al, TID-7016

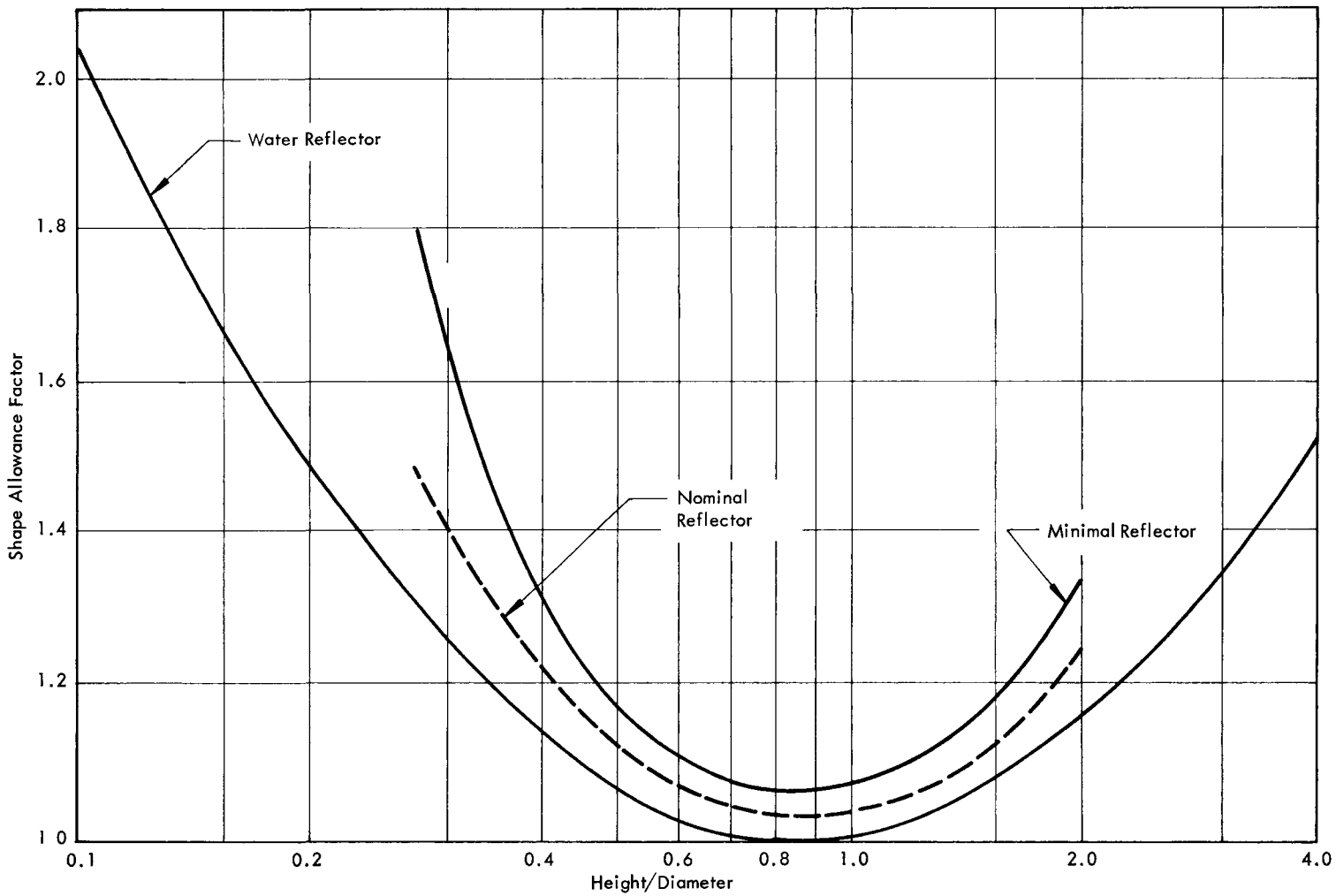


Figure G-3.2. SHAPE ALLOWANCE FACTOR FOR VARIOUS CYLINDER HEIGHT-TO-DIAMETER RATIOS. (These Factors may be Applied to the Mass and Volume Limits of Tables G-2.1 and G-2.2 to Obtain Group III Limits, and to the Values of Tables G-4.3 and G-4.4 to Obtain Group IV Limits. Figure 3 of Callihan, et al, TID-7016.)

Table G-3.4

GROUP III SAFE VALUES FOR INDIVIDUAL U-235, U-233, AND Pu-239 METAL PIECES UNDER VARIOUS CONDITIONS OF CONTROLLED REFLECTION

Thick water is assumed to be the most effective reflector encountered in normal production operations. "Nominal reflector" refers to water no more than one-inch thick or its equivalent. "Minimal reflector" refers to no more than 1/8-inch-thick stainless steel, or the same thickness of other common metals including iron, copper, nickel, or titanium. See Figure R-1.1 for comparable critical data.

Fissionable Isotope X	Degree of Reflection	Cylinder Diameter (inches)	Slab Thickness (inches)	Volume (cubic inches)	Mass (kgs of X)
U-235	Thick Water	2.5	0.6	36	11.0
	Nominal ($\leq$ 1 inch water)	3.0	1.2	51	15.0
	Minimal ($\leq$ 1/8 inch water)	3.8	2 0	61	22.0
U-233	Thick Water	1.5	0.2	9.7	3.0
	Nominal ($\leq$ 1 inch water)	1.9	0.5	13	4.1
	Minimal ($\leq$ 1/8 inch water	2.3	1.0	20	6.0
Pu-239	Thick Water	1.4[1]	0.2[1]	7.9	2.6[2]
	Nominal ($\leq$ 1 inch water)	1.7[1]	0.5[1]	10	3.3[2]
	Minimal ($\leq$ 1/8 inch water)	2.0[1]	0.9[1]	13	4.4[2]

[1] These limits apply to Pu metal at a density of 19.6 gms/cc. See discussion on assumed density used in preparing limits.

[2] These limits apply to Pu metal at a density of 19.6 gms/cc: for alloys (ρ = 15.8 gms/cc) the corresponding limits are 3.5 kgs with thick water reflector, 4.8 kgs with nominal reflector, and 7.0 kgs with minimal reflector. See discussion on assumed density used in preparing table.

Source: Callihan, et al, TID-7016.

Table G-3.5

GROUP III SAFE VALUES FOR INDIVIDUAL U-235, U-233, AND Pu-239 HOMOGENEOUS SOLUTIONS UNDER VARIOUS CONDITIONS OF CONTROLLED MODERATION

Tabulated values apply only to aqueous solutions which conform to Figures G-2.1 and G-3.1, and refer to internal dimensions of the containing vessel. Reactor compositions (see Table G-1.1) are excluded. Moderation must be rigidly controlled. See Section J-2 for comparable critical values.

Fissionable Isotope X	Degree of Moderation	Cylinder Diameter (inches)	Slab Thickness (inches)	Volume (liters)	Volume (gals)	Mass (gms of X)
U-235	$20 \leq H/X \leq 100$	5 0	1 5	4.8	1 27	800[1]
	$100 \leq H/X \leq 400$	5 0	1.5	4.8	1.27	350
	$400 \leq H/X \leq 800$	6.9	2 5	9.5	2.5	350
	$800 \leq H/X \leq 2300$	9 1	4 0	20.0	5.28	350
	$2300 \leq H/X$	∞	∞	∞	∞	∞
U-233	$20 \leq H/X \leq 100$	3.7	0.5	2.0	0.53	330
	$100 \leq H/X \leq 400$	3.7	0.5	2.0	0.53	250
	$400 \leq H/X \leq 800$	5.8	1.9	6 0	1 58	250
	$800 \leq H/X \leq 2300$	7.4	2.9	12.0	3. 17	250
	$2300 \leq H/X$	∞	∞	∞	∞	∞
Pu-239	$20 \leq H/X \leq 100$	4.5	1.5	3.3	0.87	480
	$100 \leq H/X \leq 400$	4.5	1.5	3.3	0.87	250
	$400 \leq H/X \leq 800$	6.1	2.5	6 8	1.80	250
	$800 \leq H/X \leq 3600$	7.4	3.3	11.4	3.01	250
	$3600 \leq H/X$	∞	∞	∞	∞	∞

[1] Further relaxations of limits for UF_6 can be found in K-1019.

Source Callihan, et al, TID-7016.

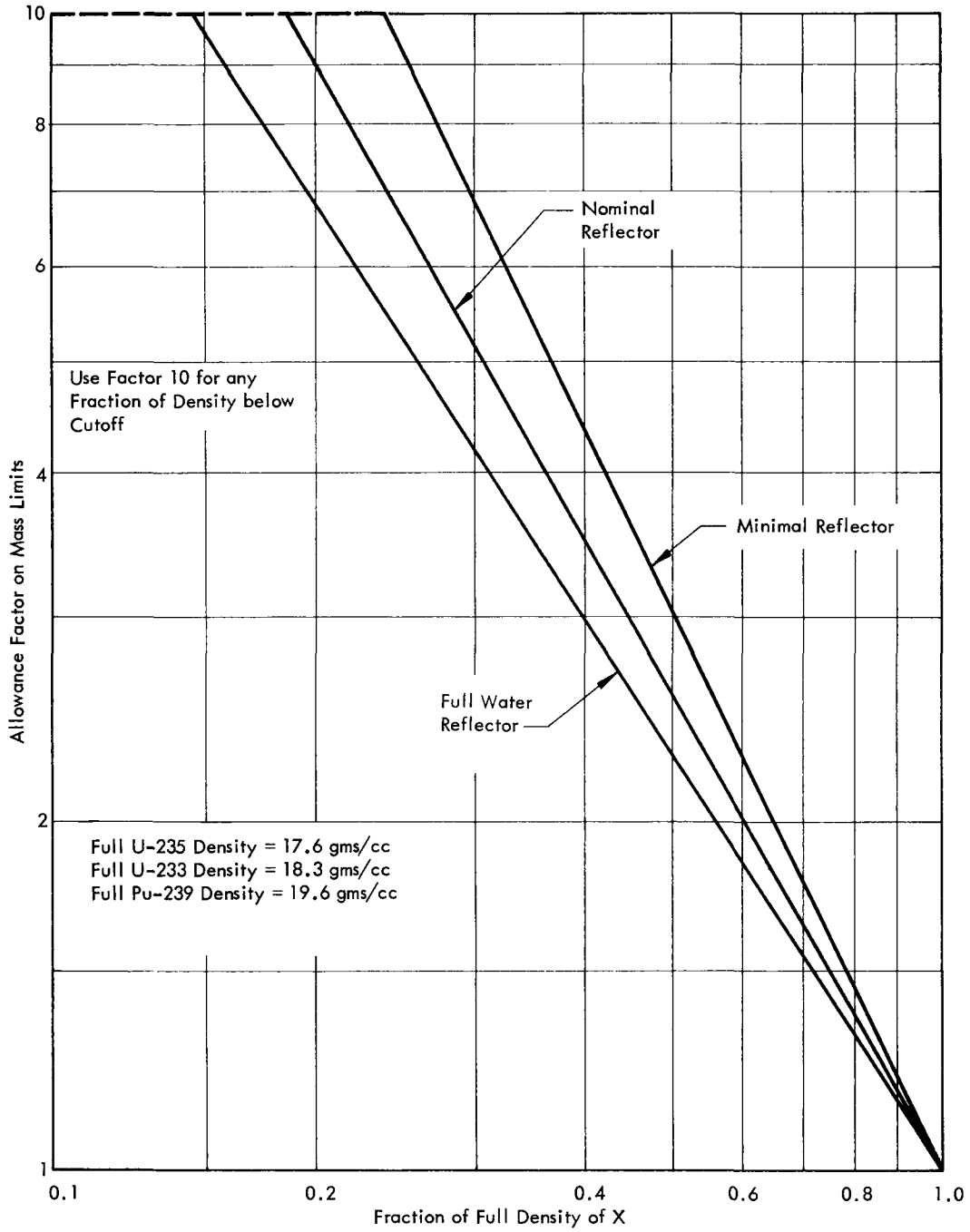


Figure G-3.3. MASS ALLOWANCE FACTORS FOR REDUCED DENSITY OF U-235, U-233, AND Pu-239 AS METAL ONLY. (These Factors may be Applied to the Mass Limits of Table G-2.2 to Obtain Group III Safe Values, and to the Mass Limits of Table G-4.4 to Obtain Group IV Safe Values. When Used for Metal of ~90% Isotopic Enrichment, the above Density Fractions Refer to Total Uranium. Extension to Aqueous Solutions is Allowed under Special Conditions of Small Air Voids. See Reference: Figure 4 of Callihan, et al, TID-7016.)

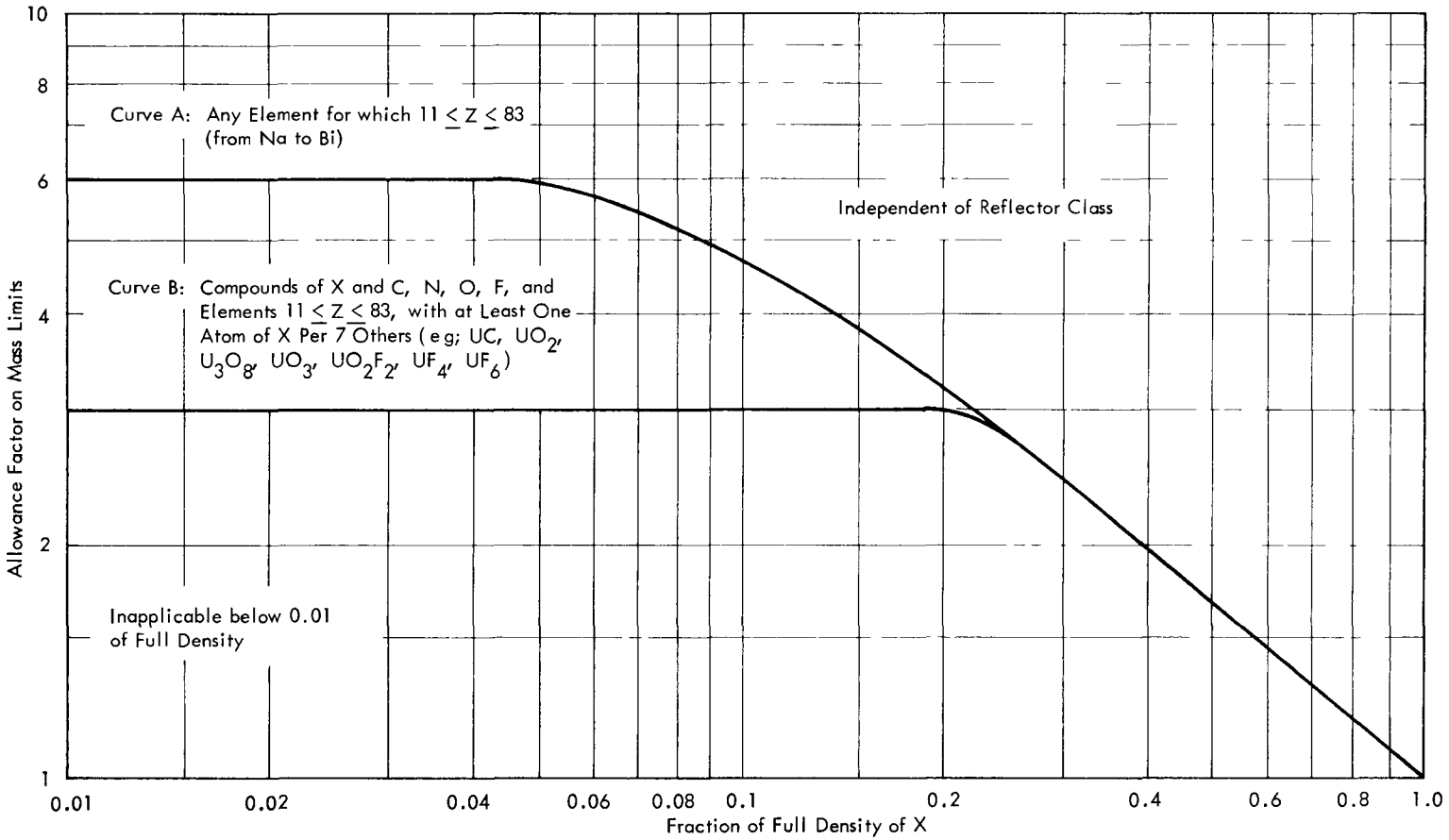


Figure G-3.4. MASS ALLOWANCE FACTORS FOR REDUCED DENSITY OF U-235, U-233, AND Pu-239 MIXED HOMOGENEOUSLY WITH THE ELEMENTS LISTED. (Full Density of X is that Given in Figure G-3.3. These Values may be Applied to the Mass Limits of Table G-2.2 to Obtain the Corresponding Group III Safe Values, and to the Limits of Table G-4.4 to Obtain Group IV Safe Values. Figure 5 Callihan, et al, TID-7016.)

Table G-4.1

GROUP IV SAFE CYLINDER DIAMETERS FOR INDIVIDUAL SYSTEMS
OF U-235, U-233, AND Pu-239

Tabulated values give maximum safe dimensional limits in inches and assume rigid control over reflection and moderation. They specify the maximum size of the fissile material or the inside dimensions of the containing vessel. The material must conform to Tables G-2.1 and G-2.2. Reflection classes are defined in Table G-3.2. These limits may not be used unless the material density is less than that given in Figures G-2.1 and G-2.2. See tables of Section G-3 for critical data references.

Fissionable Isotope X	Degree of Reflection	Metal at Full Density	Principally Solutions		
			$20 \leq H/X$	$400 \leq H/X$	$800 \leq H/X$
U-235	Thick Water	2.5	5.0	6.9	9.1
	Nominal ($\leq$ 1 inch water)	3.0	5 8	7.7	10.2
	Minimal ($\leq$ 1/8 inch water)	3.8	6.7	8.5	11.0
U-233	Thick Water	1 5	3.7	5.8	7.4
	Nominal ($\leq$ 1 inch water)	1.9	4.7	6.9	8.4
	Minimal ($\leq$ 1/8 inch water)	2.3	5.7	8.1	9.4
Pu-239	Thick Water	1.4(1)	4.5	6.1	7.4
	Nominal ($\leq$ 1 inch water)	1.7(1)	5.7	7.2	8.5
	Minimal ($\leq$ 1/8 inch water)	2.0(1)	6.8	8.3	9.6

(1) Limits apply to Pu metal (ρ = 19.6 gms/cc), also used for alloys at reduced density. See discussion on assumed density used to prepare table.
Source Callihan, et al, TID-7016.

Table G-4.2

GROUP IV SAFE SLAB THICKNESSES FOR INDIVIDUAL SYSTEMS
OF U-235, U-233, AND Pu-239

Tabulated values give maximum safe dimensional limits in inches and assume rigid control over reflection and moderation. They specify the maximum size of the fissile material or the inside dimensions of the containing vessel. The material must conform to Tables G-2.1 and G-2.2. Reflection classes are defined in Table G-3.2. These limits may not be used unless the material density is less than that given in Figures G-2.1 and G-2.2. See tables of Section G-3 for critical data references.

Fissionable Isotope X	Degree of Reflection	Metal at Full Density	Principally Solutions		
			$20 \leq H/X$	$400 \leq H/X$	$800 \leq H/X$
U-235	Thick Water	0.6	1.4	2 5	4.0
	Nominal ($\leq$ 1 inch water)	1.2	2.4	3.6	5.2
	Minimal ($\leq$ 1/8 inch SS)	2.0	3.3	4.4	6.1
U-233	Thick Water	0.2	0.5	1.9	2.9
	Nominal ($\leq$ 1 inch water)	0.5	1.7	3.2	4.2
	Minimal ($\leq$ 1/8 inch SS)	1.0	2.5	4.2	5.1
Pu-239	Thick Water	0.2(1)	1.5	2.5	3.3
	Nominal ($\leq$ 1 inch water)	0.5(1)	2.6	3.7	4 6
	Minimal ($\leq$ 1/8 inch SS)	0.9(1)	3.6	4.8	5.6

(1) Limits apply to Pu metal (ρ = 19.6 gms/cc), also used for alloys at reduced density. See discussion on assumed density used to prepare tables.
Source Callihan, et al, TID-7016.

Table G-4.3

GROUP IV SAFE VOLUME LIMITS FOR INDIVIDUAL SYSTEMS OF U-235, U-233, AND Pu-239

Tabulated values give maximum safe volume limits in liters and assume rigid control over reflection and moderation. They specify the maximum size of the fissile material or the internal volume of the containing vessel The material must conform to Tables G-2.1 and G-2.2. Reflector classes are defined in Table G-3.2. The volume limit reductions of Figures G-2.1 and G-2.2 must be used, if applicable. The shape allowance factor of Figure G-3 2 may be applied to these values See tables of Section G-3 for critical data references.

Fissionable Isotope X	Degree of Reflection	Principally Solutions		
		$20 \leq H/X$	$400 \leq H/X$	$800 \leq H/X$
U-235	Thick Water	4.8	9 5	20.0
	Nominal ($\leq$ 1 inch water)	6.0	11.3	24.0
	Minimal ($\leq$ 1/8 inch SS)	8.0	14.0	30.0
U-233	Thick Water	2.0	6.0	12.0
	Nominal ($\leq$ 1 inch water)	3.0	8.4	14.4
	Minimal ($\leq$ 1/8 inch SS)	4.0	12.0	18.0
Pu-239	Thick Water	3.3	6.8	11.4
	Nominal ($\leq$ 1 inch water)	5.0	9.3	14.7
	Minimal ($\leq$ 1/8 inch SS)	6.6	13.0	19.7

Source Callihan, et al, TID-7016.

Table G-4.4

GROUP IV SAFE MASS LIMITS FOR INDIVIDUAL SYSTEMS OF U-235, U-233, AND Pu-239

Tabulated values give maximum mass limits in kgs of X and assume rigid control over reflection and moderation. They apply only to materials conforming to Tables G-2.1 and G-2.2. The mass limit reductions of Figures G-2.1 and G-2.2 must be used, if applicable[1]. See Table G-3.2 for reflector classes. The allowance factors of Figures G-3.1 (isotopic enrichment), G-3.2 (shape), G-3.3 (reduced density), and G-3.4 (poor moderation) may be applied (simultaneously) to these values if rigid safeguards exist for each such condition. See tables of Section G-3 for critical data references.

Fissionable Isotope X	Degree of Reflection	Metal, Low H Mixtures, Compounds $0 \leq H/X \leq 2$	Principally Hydrogeneous Compounds, Mixtures $H/X \geq 20$	Principally Solutions $H/X \leq 100$	Principally Solutions H/X Unlimited[1]
U-235	Thick Water	11.0	2.5	0.8	0.35
	Nominal ($\leq$ 1 inch water)	15.0	3.5	1.04	0.43
	Minimal ($\leq$ 1/8 inch SS)	22.0	5.0	1.40	0.55
U-233	Thick Water	3.0	1.3	0.48	0.25
	Nominal ($\leq$ 1 inch water	4.1	1.7	0.69	0.33
	Minimal ($\leq$ 1/8 inch SS)	6.0	2.3	0.90	0.45
Pu-239	Thick Water	2.6[2]	2.2	0.50	0.25
	Nominal ($\leq$ 1 inch water)	3.3[2]	3.2	0.70	0.32
	Minimal ($\leq$ 1/8 inch SS)	4.4[2]	4.8	1.00	0.43

(1) See Table G-3.5 for values of H/X beyond which basic limits are not required.

(2) Limits apply to Pu metal at a density of 19.6 gms/cc, for alloys (of density 15.8 gms/cc), the corresponding limits are 3.5 kgs with thick water reflector, 4.8 kgs with nominal reflector, and 7.0 kgs with minimal reflector.

Source: Callihan, et al, LA-2063.

Table H-1 1

MAXIMUM RECOMMENDED SIZES OF STORAGE OR TRANSPORTATION UNITS

Containers are assumed to be of light construction (nominal reflectors) and secure against leakage and water inleakage. "Reactor compositions" and certain reflecting materials are excluded (see Table G-1.1), and the limit reductions of Figures G-2 1 and G-2.2 must be applied. Limits may be increased by the allowance factors of Figures G-3 1(isotopic composition), G-3.2 (shape), G-3.3 (metal density), and G-3.4 (poor moderators). See Table H-1 2 for required spacing and storage limits for these units.

Fissionable Isotope X	Metal, Compounds, or Mixtures, $H/X < 2$, Mass Limits [1] (kgs)	Hydrogenous Compounds or Mixtures $2 \leq H/X \leq 20$, Mass Limits [1] (kgs)	Solutions, or Hydrogenous Mixtures, $H/X \geq 20$, In "Nonsafe" Containers[2] Volume Limits (liters)
U-235	18.5[3]	4.5	4.0
U-233	4.5	2.5	2.0
Pu-239	4.5[4]	4.5	4 0

[1] Material volume of unit is not to exceed 4.5 liters.
[2] For "safe" containers defined by Table G-3.4, there is no mass or volume limit for stable solutions ($H/X \geq 20$).
[3] This corresponds to 20 kgs of Oy (~93%).
[4] This limit holds for Pu metal at a density of 19.6 gms/cc, for the alloy at a density of 15.8 gms/cc, the corresponding limit is 6.0 kgs.
Source Callihan, et al, LA-2063.

Table H-1.2

SPACING AND STORAGE LIMITS FOR ARRAYS OF UNITS DEFINED IN TABLE H-1.1

Separations must be guaranteed and arrays must be in a room (concrete walls assumed) greater than 9 feet in smallest dimension. "Isolated" implys edge-to-edge array separation of at least 12 feet of air or 8 inches of concrete. Two-plane or cubic arrays having edge-to-edge separations between units of either the maximum dimensions of one array or 12 feet, whichever is greater, are isolated. Arrays are "associated" if the minimum edge-to-edge spacing between units is at least 7.5 feet.

Type of Array	Minimum Center-to-Center Spacing of Units Within Array[1] (inches)	Storage Limit per Array (number of maximum storage units)[2]
Isolated Linear or Plane Array	≥ 16	No Limit
Isolated Cubic Array	36	200
	30	120
	24	80
	20	50
Two Associated Plane Arrays	30	120/array, 240 total[3]
	24	90/array, 180 total[3]
	20	50/array, 100 total[3]

[1] Edge-to-edge separation of units must be at least 12 inches.
[2] In the case of "safe" containers for solutions ($H/X \geq 20$) defined by Table G-3.4, there is no limit for a parallel in-line array at a minimum axis-to-axis spacing of 24, or for two associated in-line arrays where the spacing in each array is 24.
[3] The same total storage limit applies to more than two associated arrays.
Source Callihan, et al, LA-2063.

Table H-1.3

SPACING LIMITS FOR RAIL, MOTOR, AND AIRPLANE SHIPMENTS OF URANIUM-235
(Any U-235 Enrichment)

Limits	Unmoderated Uranium-235 H/U-235 < 2	Moderated Uranium-235 (Solutions, Hydrogenous Compounds, or Mixtures) 20 > H/U-235 > 2		H/U-235 > 20	
Maximum Shipping Unit	11 kgs U-235[1]	2.5 kgs U-235	4.4 liters[2]	5 inch ID Cylinder[2]	
Maximum Average Density as Established by Shipping Containers[3]	4 kgs U-235/ft^3	1 kg U-235/ft^3	0.8 liter content/ft^3	[4]	
Carload Limit	925 kgs U-235/car	225 kgs U-235/car	225 liters/car	[5]	

[1] For shipments having exclusive use of vehicle shipping space, this value can be 18.5 kgs U-235.

[2] Geometrically safe units. (This volume of solution may be placed in a larger container.)

[3] In this table, a shipping container is considered to include both the physical case holding the unit of fissionable material itself and the arrangements made to maintain spacing between these units. "Birdcages" as well as other spacers are thus considered basic parts of the containers. The average density is defined as $\frac{\text{mass of unit}}{\text{container volume}}$.

Except as otherwise noted, shipping containers, in contact, should define at least one foot side-to-side separation between units of fissionable material.

Each unit case shall be sealed against inleakage of water.

[4] Shipping containers define at least 1.5 feet side-to-side spacing between cylinders.

[5] Treat in accord with other criteria.

Source Callihan, et al, TID-7016

Table I-2.1

CATEGORY DESCRIPTION FOR PARAMETERS FOR SALVAGE STORAGE

Category	Class Number	Title	Description
a	AE	Recastable Metal	Includes solid pieces of metal Includes briquetted chips, but does not include unbriquetted chips. Does not include clad or plated metal or alloys, whether with SS materials or non-SS materials.
b	BE	Canned Metal	Includes unalloyed solid metal pieces which can be considered as Class AE after removal of a jacket or plating of non-SS material.
c	CE	Other Metal	Includes alloys, chips, and turnings, and other metallic masses in which uranium is a major constituent (1% U or more).
d	DE	Compounds	Pure or mixed compounds and oxides. Does not include impure compounds or mixtures of SS materials. Specify the identity of the compound(s).
e	EE	Solutions	Includes all solutions regardless of purity or concentration. Use of this single class, however, does not imply that differing solvents may be mixed. Wherever practical, solutions differing in solvent, purity, or concentration should be kept separate.
f	FE	Combustibles	Materials which can be reduced to an ash prior to recovery by bleaching or dissolving.
g	GE	Noncombustibles	Materials which can not readily be reduced to ash prior to leaching.
h	HE	Process Residues	Includes such items as salt baths, filter cakes, and dust filters.

Source Recovery of Source of Special Nuclear Materials, AEC 7430-01.

Table I-2.2

PARAMETERS FOR SALVAGE STORAGE[1]

Type Container	Mass Limit of U-235[2] (grams)	Comments	Area Limits[3]	Category
Standard Birdcage[4]	≤ 18,500		4/pallet, 3 × 8 pallet array	a,b,d
Slotted Angle Type Birdcage[5]	2,000	Inner container volume must be < 4 liters	4/pallet, 3 × 8 pallet array	d,c,e
Special Drum[6] Solution Container	~5,000[7]	Inner container 5 1/8-inch ID	4/pallet, 3 × 8 pallet array	e
Special Drum[6] Scrap Container	2,000	Inner container 6-inch ID	4/pallet, 3 × 8 pallet array	c
55-Gallon Drum	≤ 350	--	4/pallet, 3 × 8 pallet array	e,f,g,h
30-Gallon Drum	≤ 100	Specific application	Any convenient array	e,f,g,h
	≤ 350	--	4/pallet, 3 × 8 pallet array	
Other Containers	≤ 100	Specific application	Any convenient array	c,d,e,h
(> than 1 gallon)	200-350	--	One diameter separation, 4/pallet, 3 × 8 pallet array	
	≤ 200	--	1 kg/pallet[8], 3 × 8 pallet array	
Other Containers	≤ 200	--	100 gms/sq ft shelf[9]	
(1 gallon or less)	< 350	--	100 gms/sq ft shelf[9]	c,d,e,h
MAC Special Container	< 500	One container per 20-inch box	2 kgs/pallet, 3 × 8 pallet array	c

(1) Due to the complexity of the critical variables, a simple table cannot outline all safe limits. Although nonconformities to this table may be safe, each must have a special evaluation.

(2) When Be or D_2O are contaminants, special evaluation is required.

(3) There should be a four-foot minimum separation between all arrays

(4) Standard birdcage provides a minimum center-to-center separation of 20-inches.

(5) This may be a single or multiple unit cage. It must provide a minimum of 20 inches center-to-center separation between units.

(6) Modified 55-gallon drum.

(7) About 5 kgs is maximum for optimum solution at H/X – 45. Any outside container that provides the same separation as a 55-gallon drum has the same limits.

(8) Whenever possible, maximum separation should be utilized.

(9) Shelves are on a minimum 18-inch vertical separation.

Table I-2 3

PROPOSED SCRAP MATERIAL SHIPPING GUIDE
(Basic Limits are Given in Section H-1.)

Description (category)	Physical Condition	U-235 Mass[1] (grams)	Type Container
Uranium Metal or Alloys (a,b,c)	Solid Masses	18,500	Standard 20 inch Birdcage[2]
Uranium Compounds (d)	Oxide or Salts (dry)	18,500	Standard 20 inch Birdcage[2]
Uranium Metal or Alloys (c)	Foil, Fines, or Turnings (under oil)	< 2,000	Standard 20 inch Birdcage or Special Drum Scrap Container[3]
Fuel Elements (a,b,c)	Metal Pieces (dry)	< 2,000	Standard 20 inch Birdcage or Special Drum Scrap Container[3]
Heterogeneous Mixtures (c,e)	Slag, Fines (wet or dry)	2,000	Standard 20 inch Birdcage or Special Drum Scrap Container[3]
Processing Solutions (e)	Concentrated Solutions	> 2 gms/l	Standard 20 inch Birdcage or Special Drum Solution Container[3]
Salvage Solutions (e)	Dilute Solutions	< 2 gms/l	55-gallon Drum
Combustibles (f)	Miscellaneous (dry)	< 250	55-gallon Drum
Noncombustibles (g)	Miscellaneous (dry)	< 250	55-gallon Drum
Residues (h)	Miscellaneous (wet or dry)	< 200	55-gallon Drum

(1) When Be or D_2O are contaminates, other criteria may apply.
(2) Maximum of 50 cages in contact or array.
(3) Maximum of 60 special drum containers in two-dimensional array.
Source Henry, H. F., et al, Guide to Shipment of U-235 Enriched Uranium Materials, TID-7019, June 1959.

Table I-3.1

PROPOSED SAFE MASS LIMITS FOR HETEROGENEOUS OR HOMOGENEOUS URANIUM SYSTEMS

The tabulated values have been proposed to the Criticality Working Committee of the ORO-AEC as suitable for application to any system of arbitrary degree of heterogeneity. The safe mass values of Tables G-3.1 apply for isotopic compositions of 4% U-235 and above.

Isotopic Composition (% U-235)	Safe Mass Value U-235 (kgs)	U (kgs)	U (lbs)
4[1]	0.930[1]	23[1]	51[1]
3	1.03	34.5	76
2	1.36	68	150
1	6.85	680	1500
0.9	12.5	1400	3080
0.8	30.0	3750	8250
0.7	$\sim$	∞	∞

[1] From Table G-3.1.

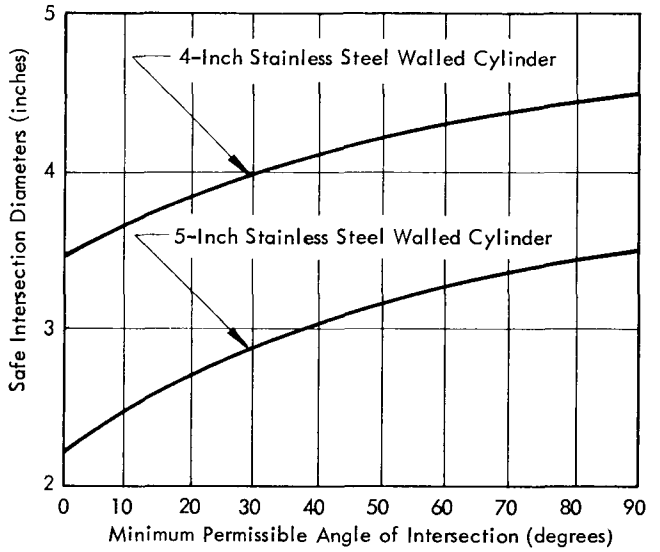


Figure I-4.1. MINIMUM PERMISSIBLE ANGLE FOR PIPES INTERSECTING FOUR FOUR AND FIVE-INCH-DIAMETER STAINLESS STEEL PIPES. (Graph 17 of Schuske, Y-853.)

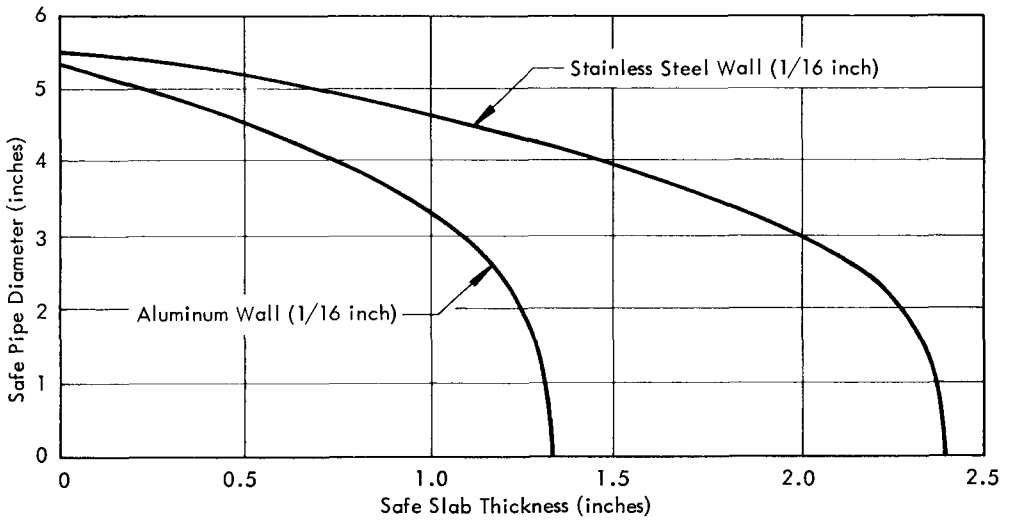


Figure I-4.2. MAXIMUM PERMISSIBLE PIPE DIAMETERS FOR SLAB-PIPE INTERSECTIONS WHERE THE ANGLE OF INTERSECTION IS 90 DEGREES. (Graph 16 of Schuske, Y-853.)

Table J-1.1

MINIMUM CRITICAL PARAMETERS FOR INDIVIDUAL SYSTEMS OF AQUEOUS SOLUTIONS

All values refer to pure fissionable materials having a thick reflector of water or its nuclear equivalent only. In general they are extensions of experimental data to conditions of greatest reactivity for the conditions concerned, eg, spherical geometry is implied for mass and volume data.

Basic Nuclear Parameter	Minimum Critical Values		
	U-235	U-233	Pu-239
Mass (kg)	0.79	0.59	0.51
Infinite Cylinder Diameter (in)	5.5	4.5	5.0
Infinite Slab Thickness (in)	1.7	--	--
Volume (l)	5.9	3.5	5.0
Concentration (gms/l)	11.6	10.9	7.3

Source: Callihan, A. D., "Values of Nuclear Variables" Memorandum, June 25, 1958.

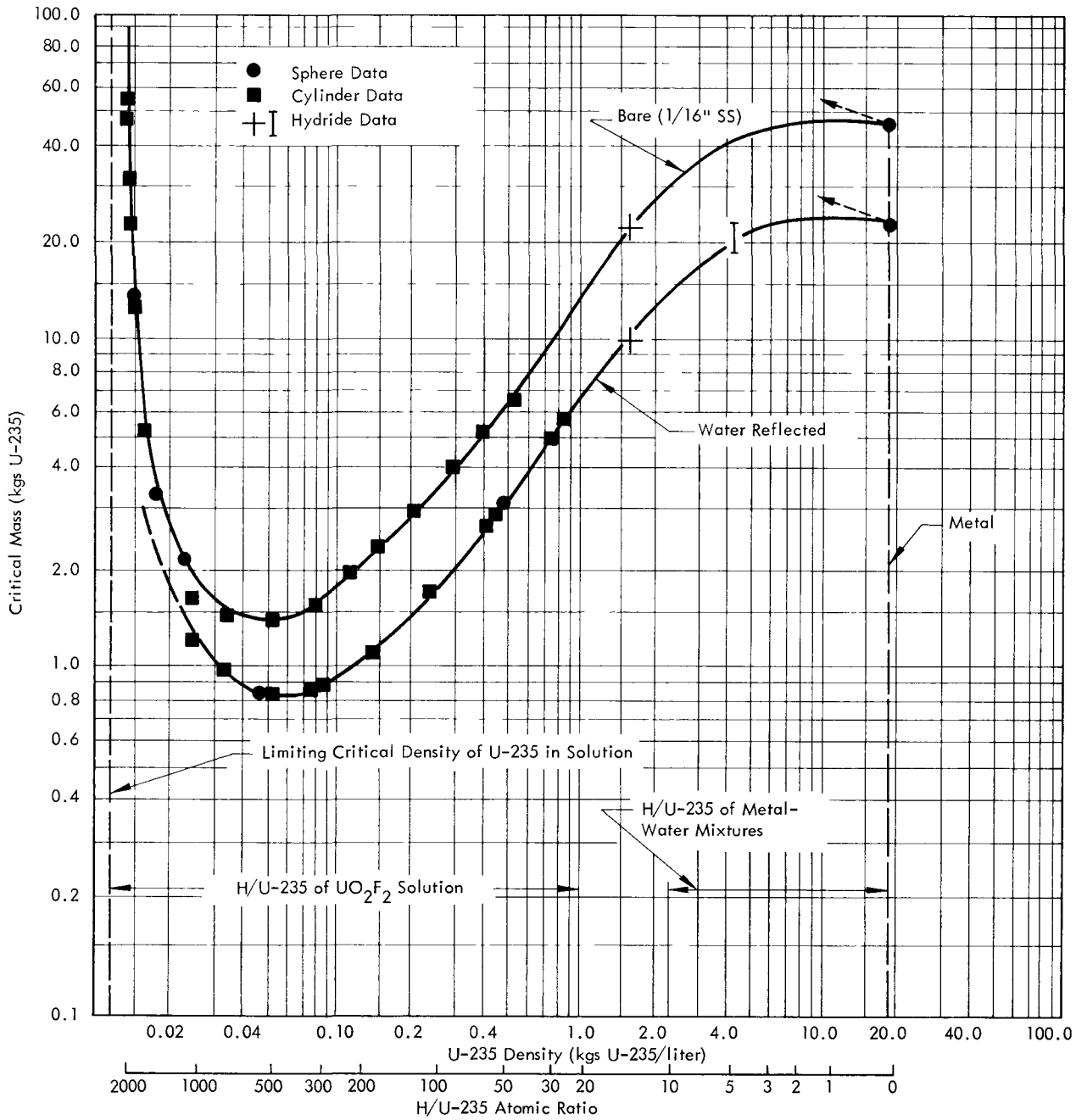


Figure J-2.1. MINIMUM MASS FOR HOMOGENEOUS U-235 SYSTEMS. (Critical Masses of Water-Moderated Spheres of Homogeneous U-235 (93.2%) material. Cylindrical Data for Uranyl Fluoride Solutions were Converted from Nearly Equilateral Cylinders Using Extrapolation Lengths of 5.5 Centimeters (water reflected) and 2.2 Centimeters (bare). Density and Reflector Corrections were Applied to Hydride Data. Figure 1 of Paxton, LAMS-2415.)

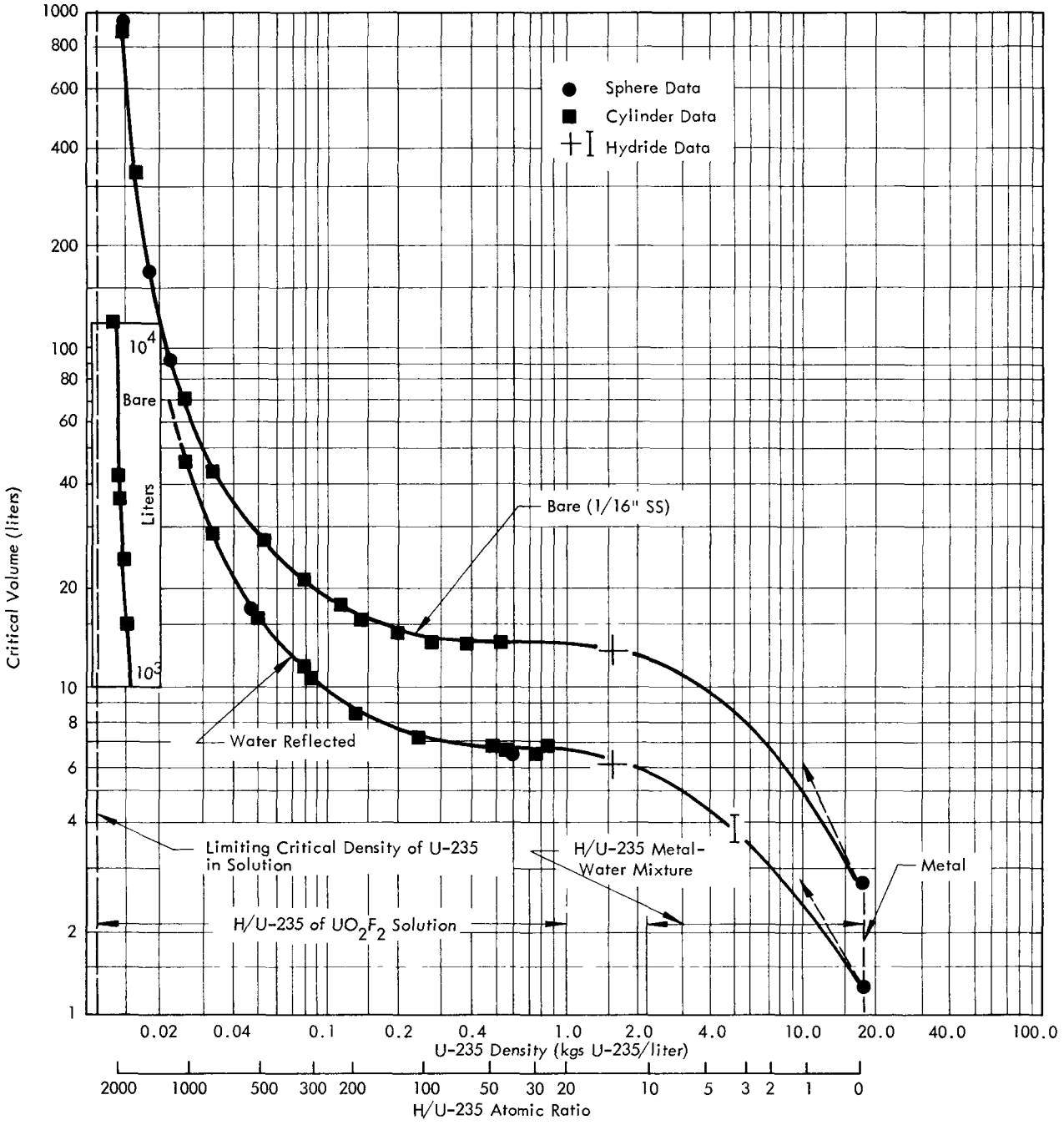


Figure J-2.2. MINIMUM VOLUMES FOR HOMOGENEOUS U-235 SYSTEMS. (Critical Volumes of Water-Moderated Spheres of Homogeneous U-235 (93.2%) Material. Cylindrical Data for Uranyl Fluoride Solutions were Converted from Nearly Equilateral Cylinders Using Extrapolation Lengths of 5.5 Centimeters (water reflected) and 2.2 Centimeters (bare). Density and Reflector Corrections were Applied to Hydride Data. Figure 2 of Paxton, LAMS-2415.)

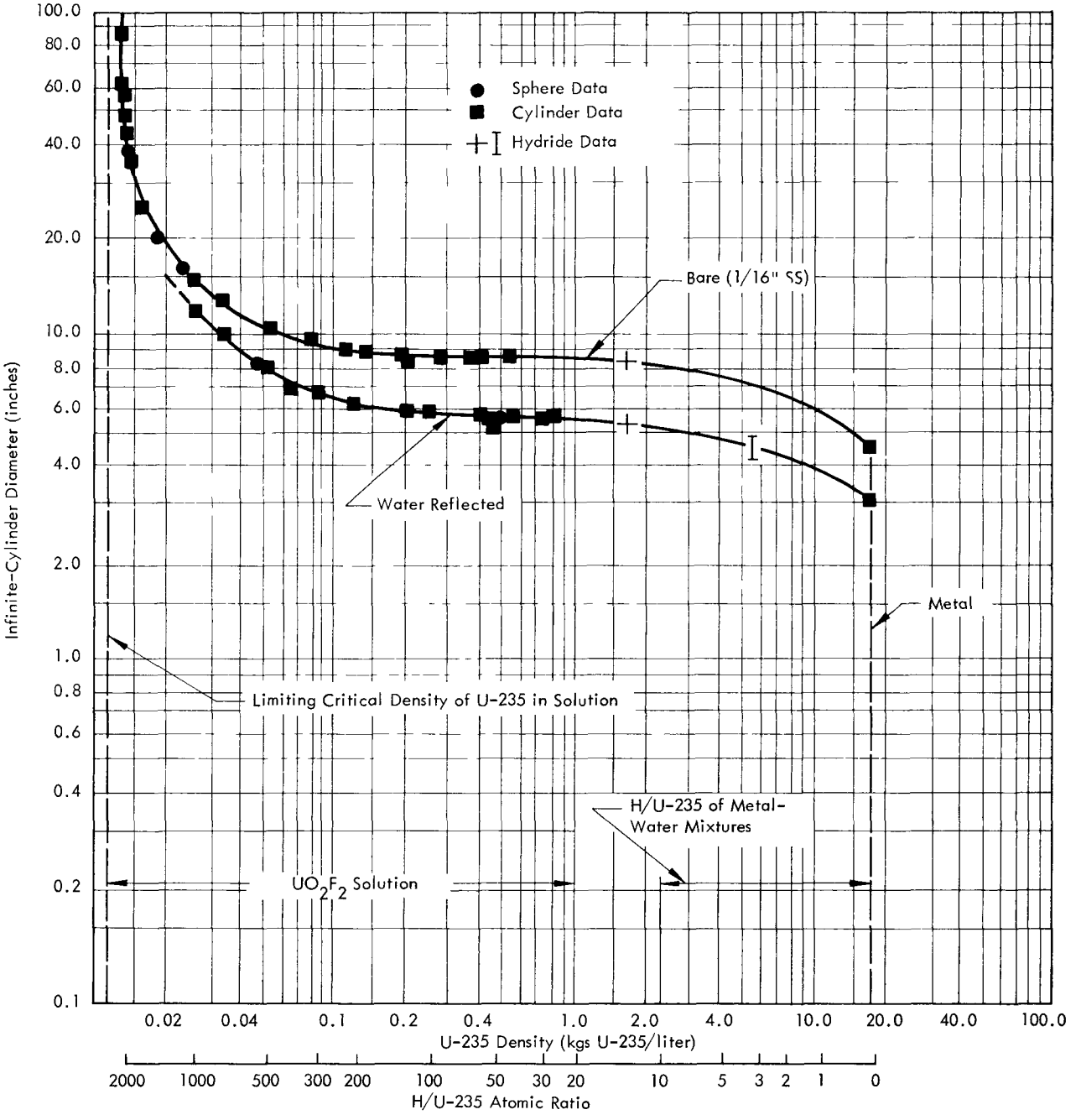


Figure J-2.3. **MINIMUM INFINITE CYLINDER DIAMETER FOR HOMOGENEOUS U-235.** (Estimated Diameters of Infinite Cylinders of Homogeneous Water-Moderated Uranium at an Isotopic Composition of 93.2% U-235. Figure 3 of Paxton, et al, LAMS-2415.)

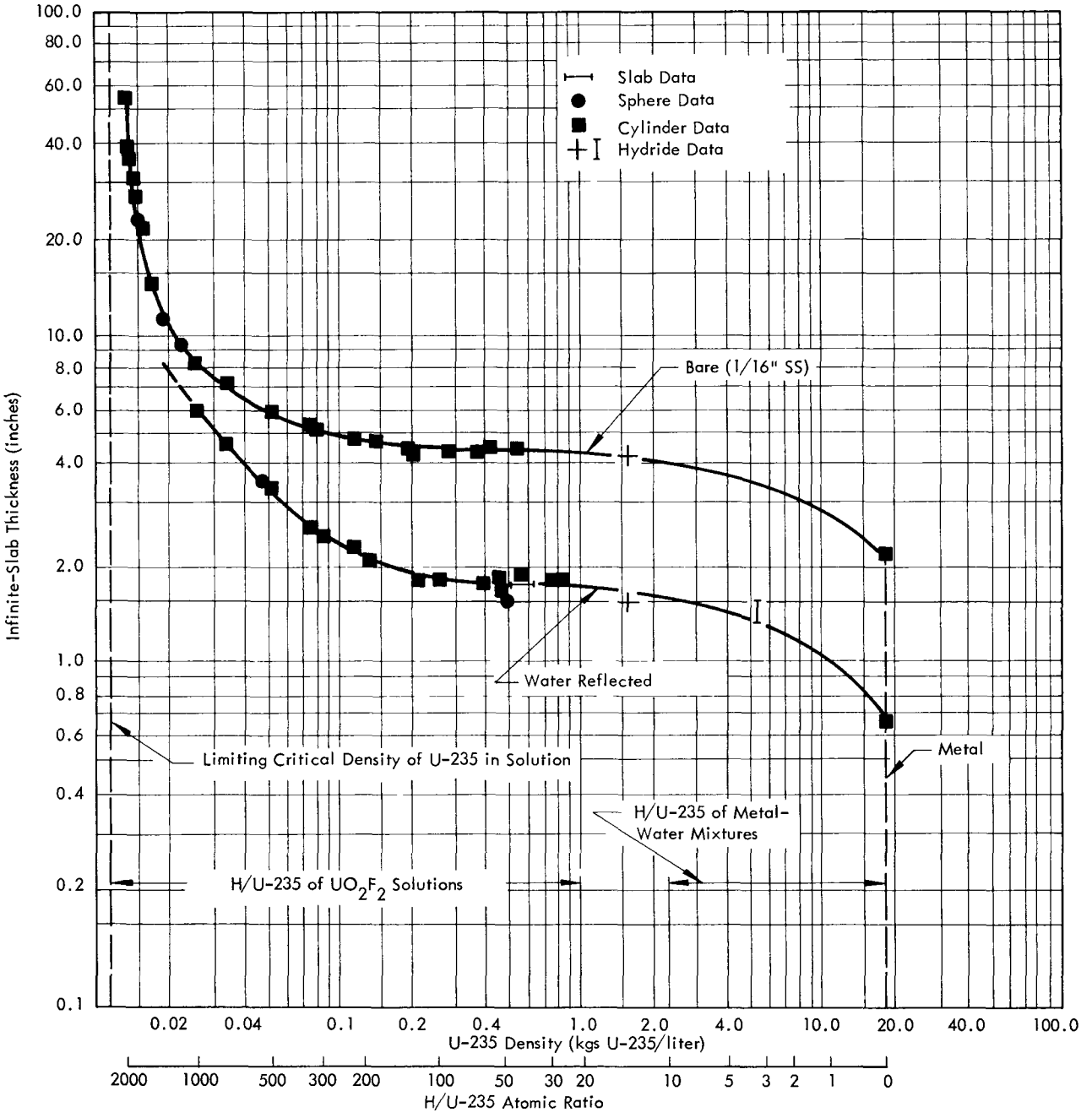


Figure J-2.4. MINIMUM INFINITE SLAB THICKNESS OF HOMOGENEOUS U-235 SYSTEM. (Estimated Thickness of Infinite Slabs of Homogeneous Water-Moderated Uranium at an Isotopic Enrichment of 93.2% U-235. Figure 4 of Paxton, et al, LAMS-2415.)

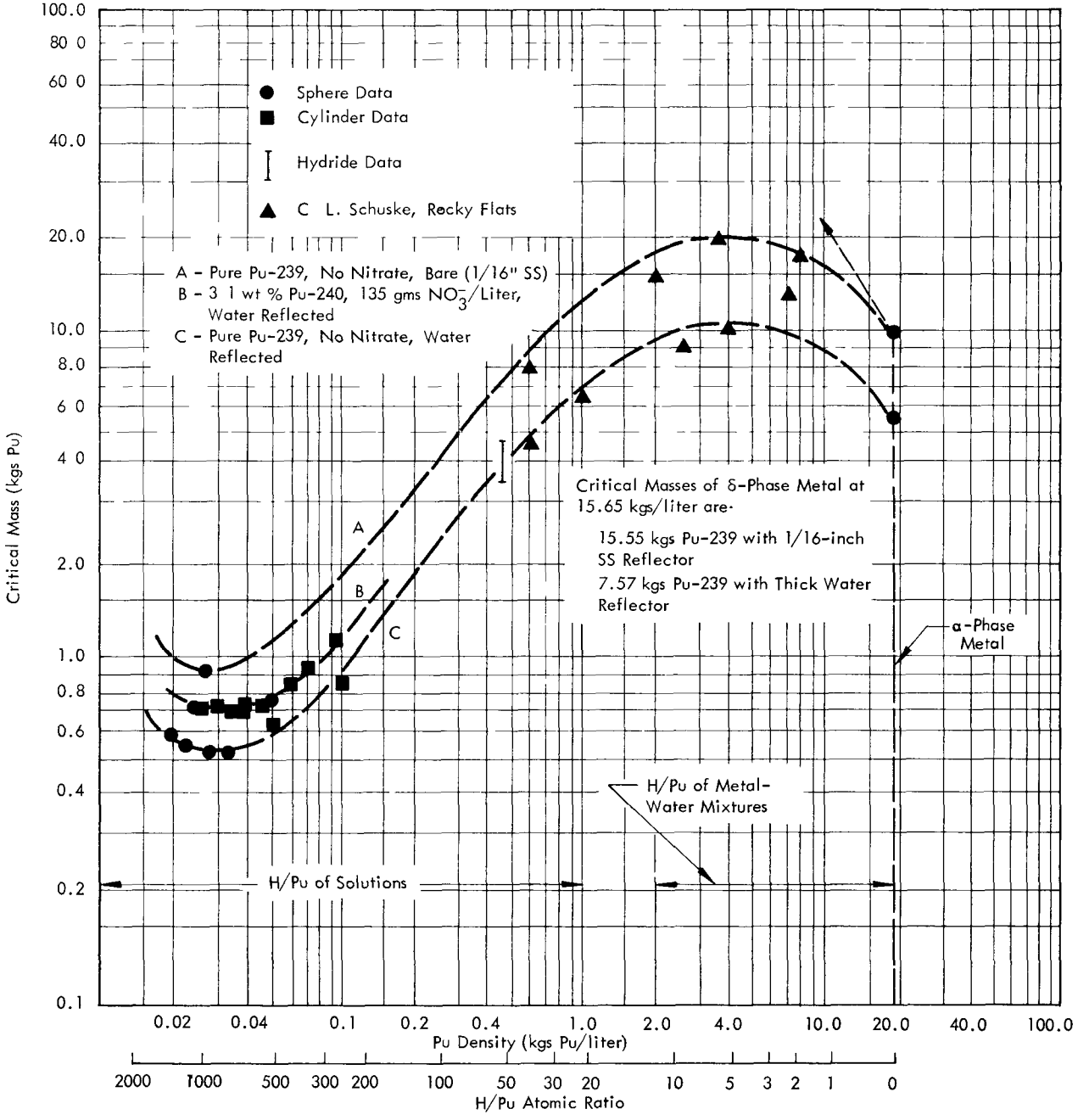


Figure J-2.5. CRITICAL MASSES OF HOMOGENEOUS WATER-MODERATED Pu-239 SPHERES. (Figure 5 of Paxton, et al, LAMS-2415.)

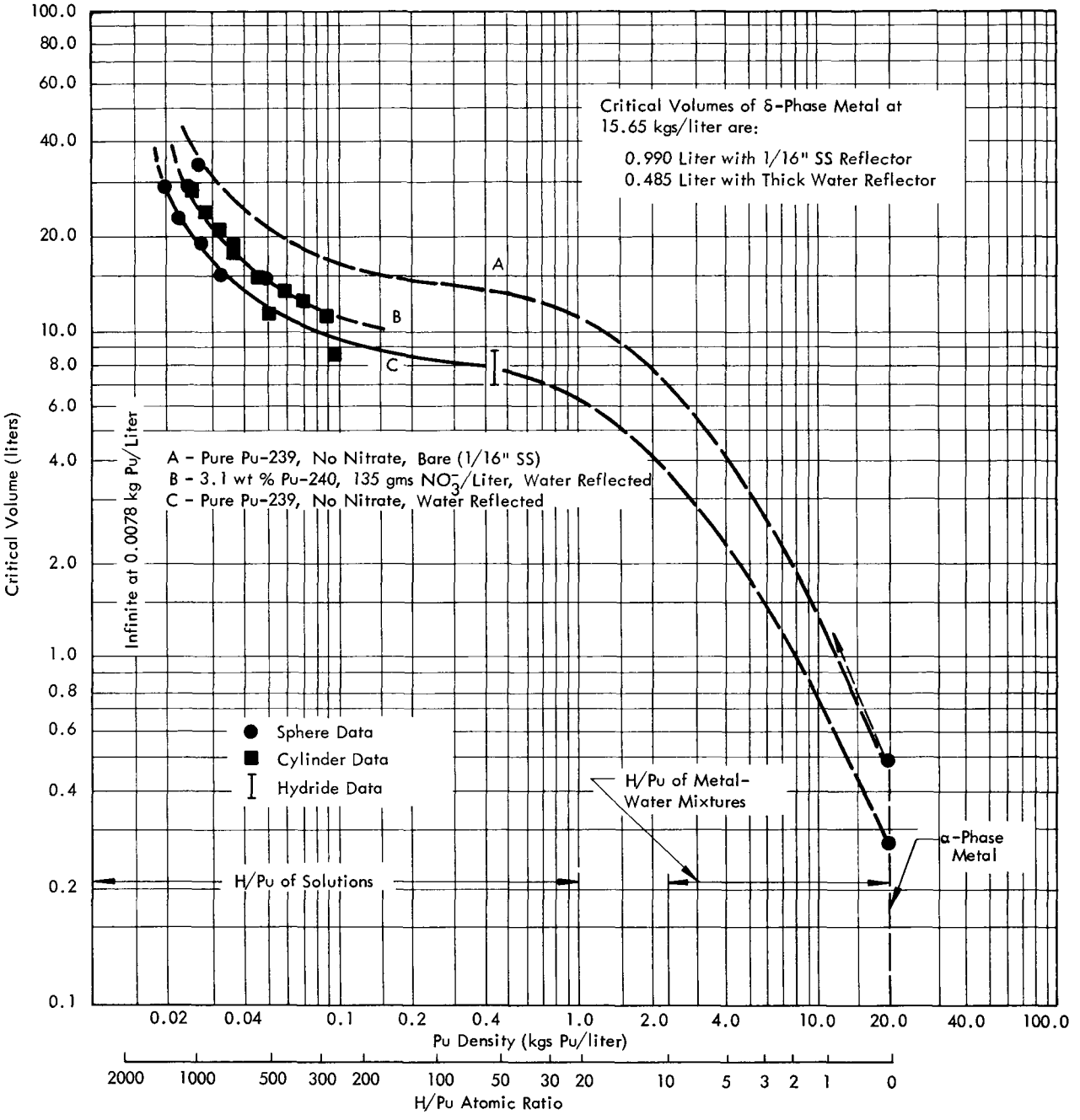


Figure J-2.6. CRITICAL VOLUMES OF HOMOGENEOUS WATER-MODERATED Pu-239 SPHERES. (Figure 6 of Paxton, et al, LAMS-2415.)

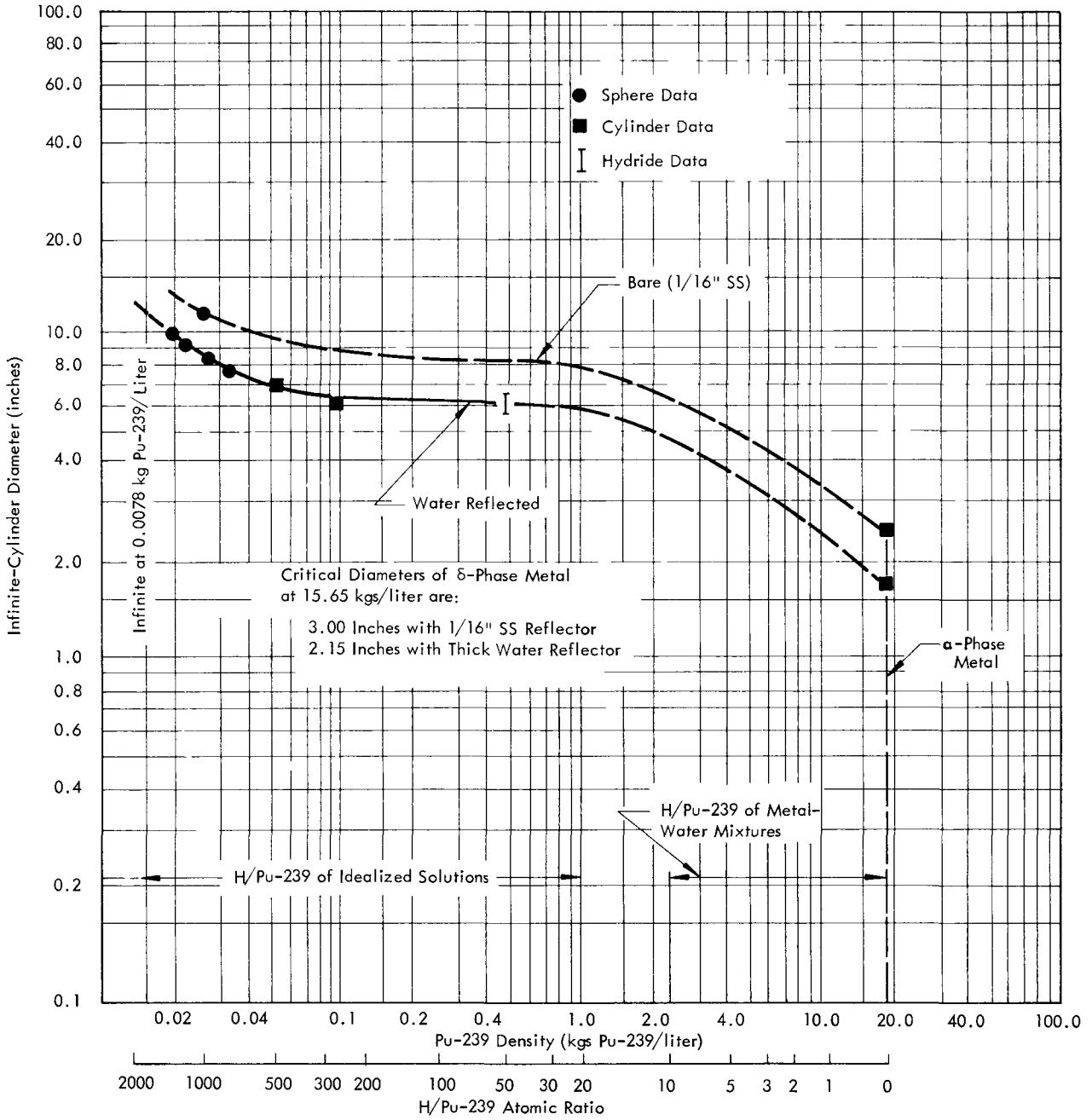


Figure J-2.7. MINIMUM INFINITE CYLINDER DIAMETER FOR HOMOGENEOUS Pu-239 SYSTEMS. (Estimated Critical Diameters of Infinite Cylinders of Water-Moderated Pu-239 in the Absence of NO_3^- and Pu-240. Figure 7 of Paxton, et al, LAMS-2415.)

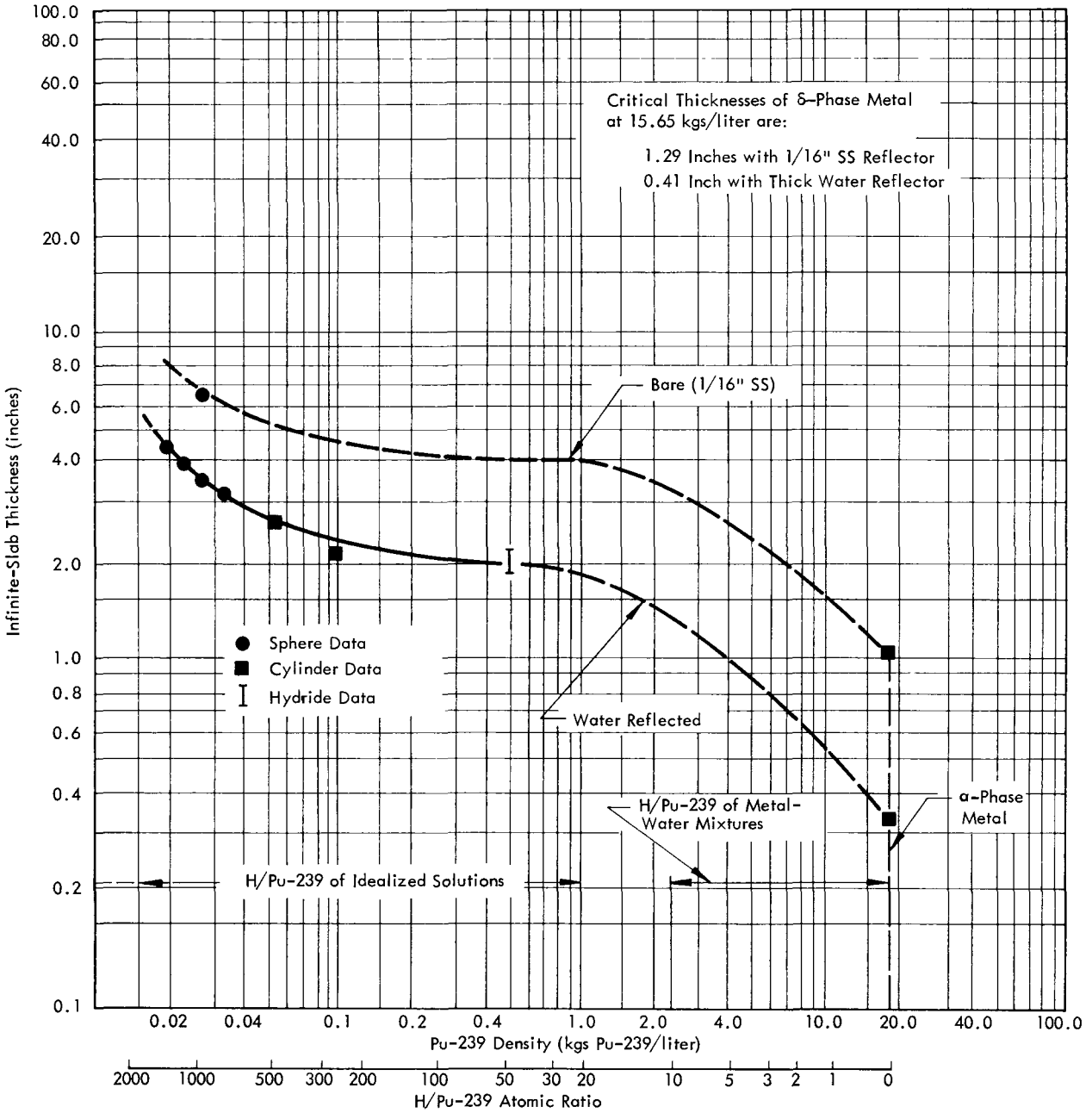


Figure J-2.8. MINIMUM INFINITE SLAB THICKNESS FOR HOMOGENEOUS Pu-239 SYSTEMS. (Estimated Critical Thicknesses of Infinite Slabs of Homogeneous Water-Moderated Pu-239 in the Absence of NO_3^- and Pu-240. Figure 8 of Paxton, et al, LAMS-2415.)

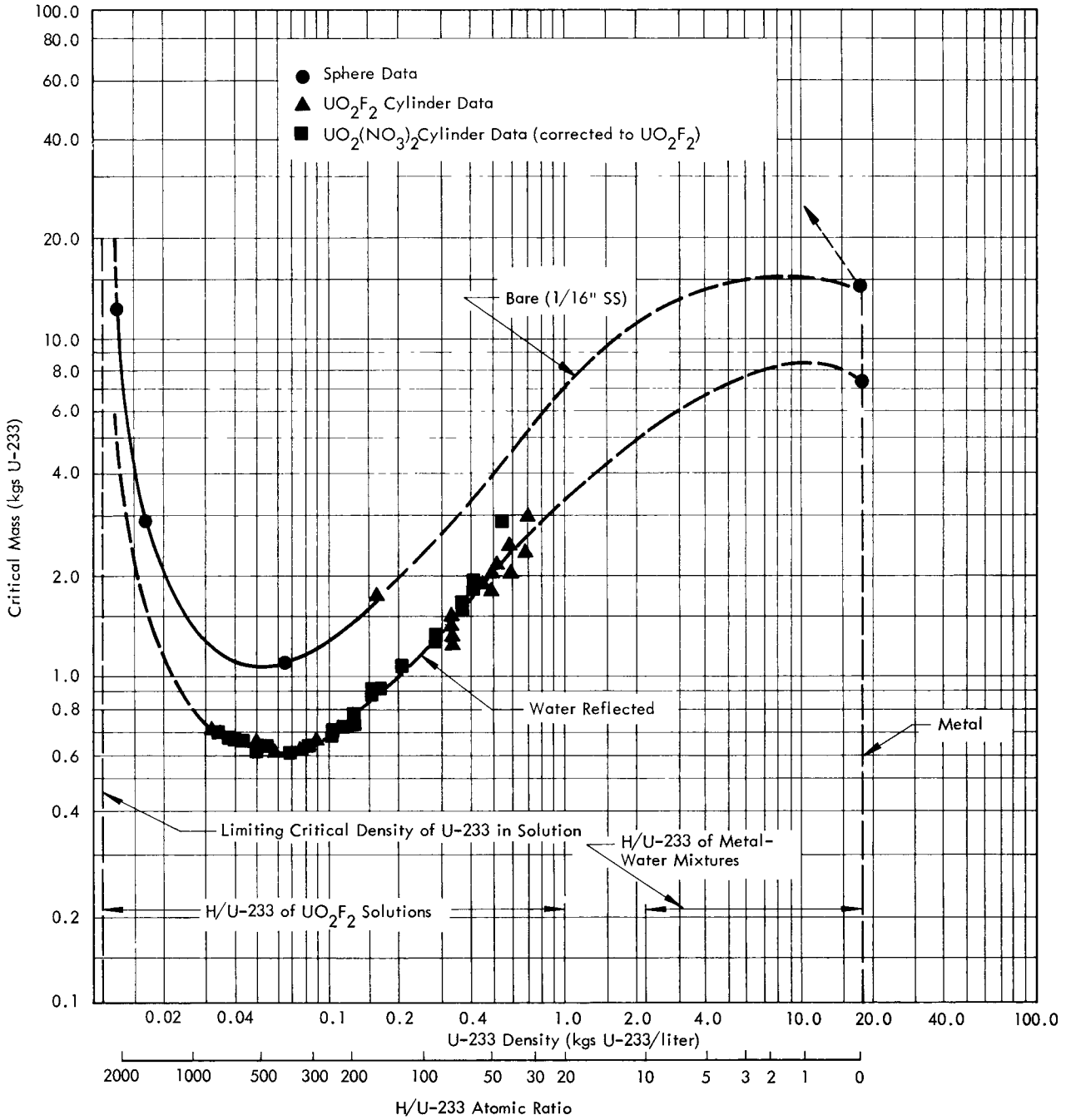


Figure J-2.9. MINIMUM MASS FOR HOMOGENEOUS U-233 SYSTEMS. (Estimated Minimum Critical Masses for Homogeneous Water-Moderated U-233 Spheres. Figure 9 of Paxton, et al, LAMS-2415.)

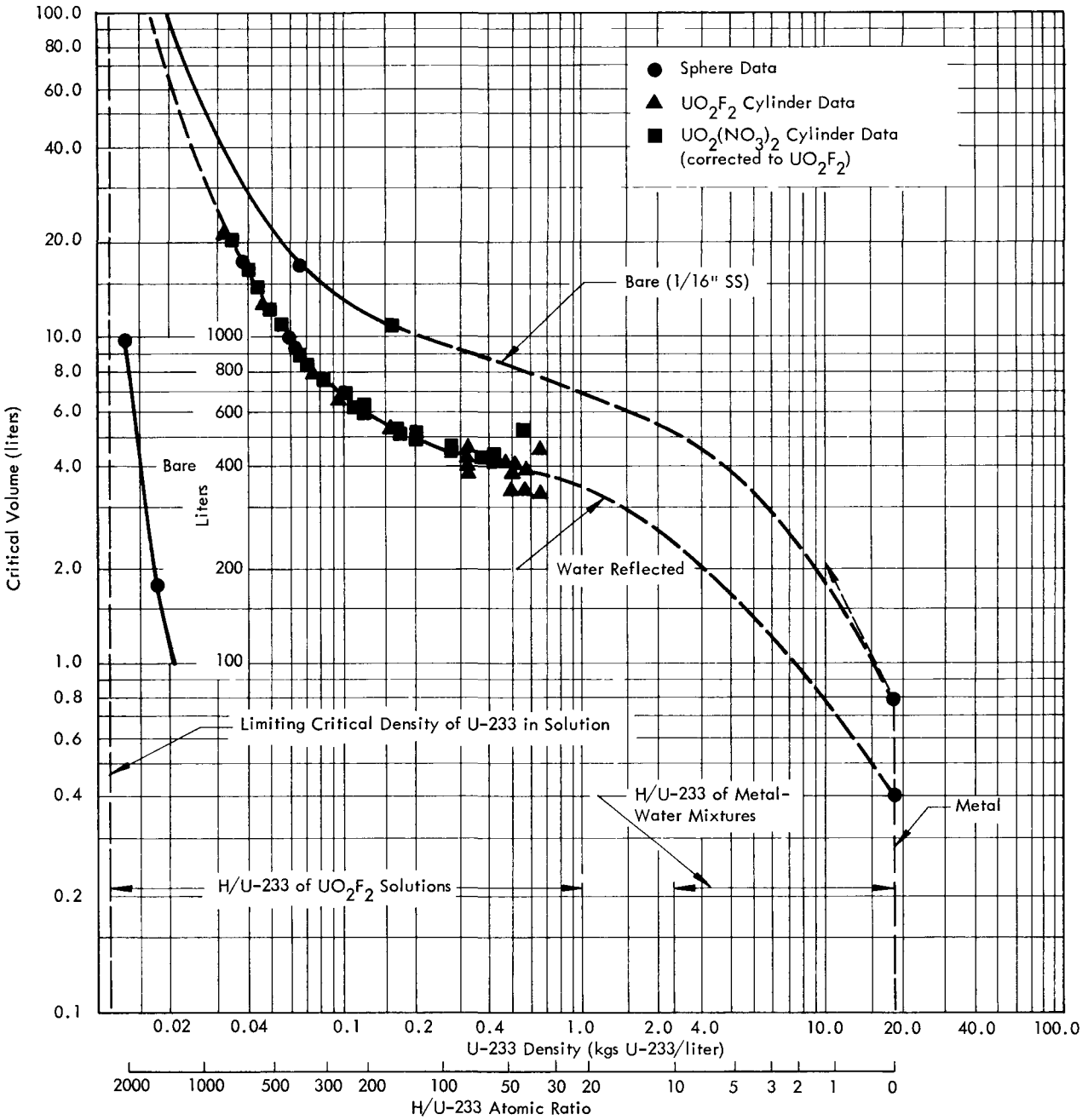


Figure J-2.10. MINIMUM VOLUME FOR HOMOGENEOUS U-233 SYSTEMS. (Estimated Minimum Critical Volume for Homogeneous Water-Moderated U-233 Spheres. Figure 10 of Paxton, et al, LAMS-2415.)

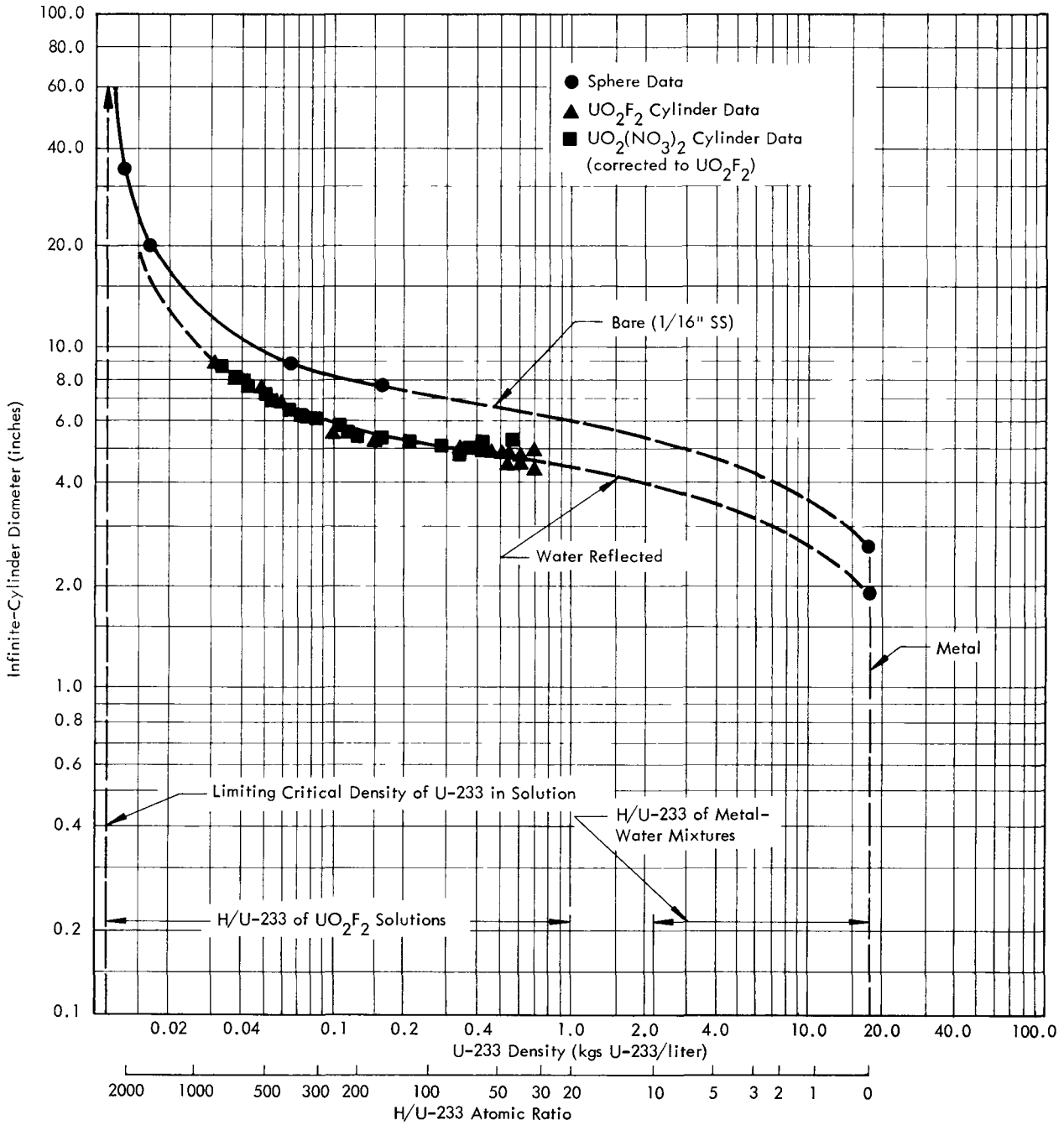


Figure J-2.11. MINIMUM INFINITE CYLINDER DIAMETERS FOR HOMOGENEOUS U-233 SYSTEMS. (Estimated Minimum Critical Diameters of Infinite Cylinders of Homogeneous Water-Moderated U-233. Figure 11 of Paxton, et al, LAMS-2415.)

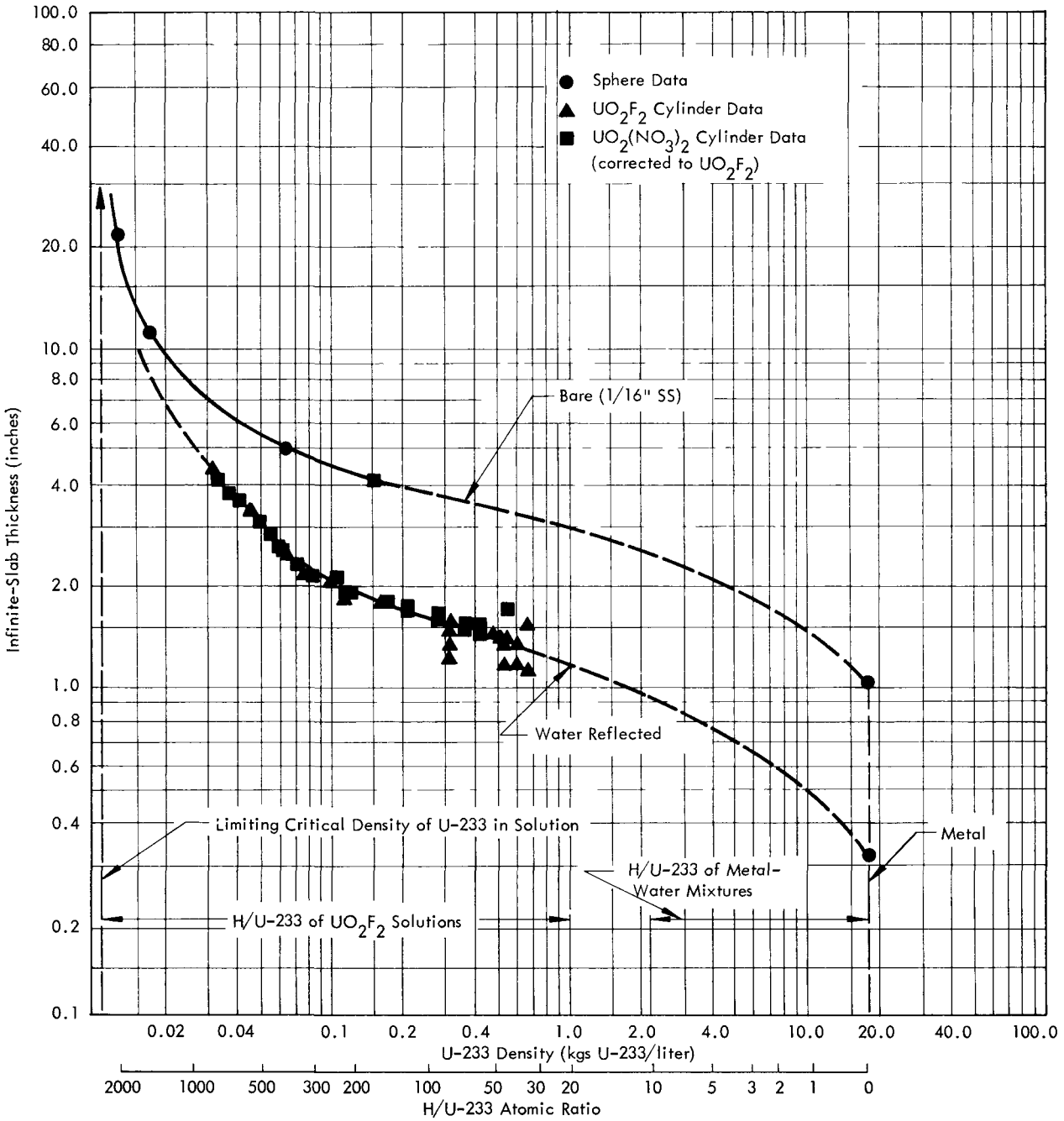


Figure J-2.12. MINIMUM INFINITE SLAB THICKNESSES FOR HOMOGENEOUS U-233 SYSTEMS. (Estimated Critical Thicknesses of Infinite Slabs of Homogeneous Water-Moderated U-233. Figure 12 of Paxton, et al, LAMS-2415.)

Table J-3.1

ESTIMATED MINIMUM CRITICAL MASSES FOR AQUEOUS URANIUM SOLUTIONS vs ISOTOPIC COMPOSITION

Tabulated values are best estimates inferred from experimental data that have been transformed to spherical geometry by equibuckling calculations. The minimum critical isotopic composition for homogeneous systems has been estimated from PCTR results at Hanford.

Reflection	Isotopic Composition	Moderation (H/U-235)	Mass (kgs U-235)	Reference
Water or Equivalent	~90	440	0.79	ORNL-56-8-201
	44.6	493	0.95	(1)
	29.8	220	1.0	KS-336
	14.7	650	1.2	KS-336
	4.9	450	1.8	K-1019
	2	500	5.4	(2)
	1.02 ± 0.02	--	∞	Hanford
Bare (SS Vessel)	~90	500	1.4	K-1019
	4.9	530	2.9	K-1019
	2	500	7.8	(2)
	1.02 ± 0.02	~620	∞	Hanford

(1) Presumably derived from AERE R/R 2051.
(2) Preliminary and unpublished data from ORNL Critical Mass Laboratory.

Table J-3.2

ESTIMATED MINIMUM CRITICAL VOLUMES FOR AQUEOUS URANIUM SOLUTIONS vs ISOTOPIC COMPOSITION

Reflection	Isotopic Composition	Moderation (H/U-235)	Minimum Volume (liters)	Reference
Water or Equivalent	~90	49.9	6.4	Figure J-2.2
	4.9	400	37.0	ORNL-2968
	2.0	~500	145.0	(1)
	1.02 ± 0.02	--	∞	Hanford
Air	~90	62.7	14.0	Figure J-2.2
	4.9	400	58.0	ORNL-2968
	2.0	~500	225.0	(1)
	1.02 ± 0.02	--	∞	Hanford

(1) Preliminary and unpublished data from ORNL Critical Mass Laboratory.

Table J-3.3

ESTIMATED MINIMUM CRITICAL CYLINDER DIAMETERS FOR AQUEOUS URANIUM SOLUTIONS vs ISOTOPIC COMPOSITION

Tabulated values are best estimates inferred from experimental data with some transformations to cylindrical geometry by equibuckling calculations.

Reflection	U-235 Isotopic Composition	Container Composition	Moderation (H/U-235)	Infinite Cylinder Diameter (inches)	Reference
Water or Equivalent	~90	Aluminum	44.3	5 5 – 5 75 (1)	ORNL-2367
	4.9	Stainless Steel	345	12	ORNL-2968
	2.0	None	400	18 2	(2)
	1.02 ± 0 02	None	--	∞	Hanford
Air	~90	Aluminum	44 3	8 5 – 8 76 (3)	ORNL-2367
	4 9	Stainless Steel	345	> 15	ORNL-2968
	2.0	None	400	21.5	(2)
	1.02 ± 0 02	None	--	∞	Hanford

(1) A 5.5-inch-diameter water-reflected aluminum cylinder containing a solution with an H/U-235 atomic ratio of 44.3 was subcritical at a solution height of 90 inches. The extrapolation of water-reflected stainless steel cylinders containing solutions with an H/U-235 atomic ratio of 44 3 indicates a stainless steel cylinder, of infinite height, to be critical at a 5.75-inch diameter Therefore, 5 5 inches and 5.75 inches are assumed to be the lower and upper limits for the critical diameter of a water-reflected, infinite-height aluminum cylinder

(2) Buckling transformation from preliminary and unpublished data from ORNL Critical Mass Laboratory

(3) The extrapolation of the multiplication curve from an 8.5-inch-diameter stainless steel cylinder containing a solution with an H/U-235 atomic ratio of 66 indicates it to be subcritical at any height. An 8.76-inch-diameter aluminum cylinder containing a solution with an H/U-235 atomic ratio of 44.3 was critical at 82.3 inches. Therefore, the bare infinite aluminum cylinder diameter is assumed to be greater than 8.5 inches and less than 8.76 inches

Table J-3.4

ESTIMATED MINIMUM CRITICAL SLAB THICKNESSES FOR AQUEOUS URANIUM SOLUTIONS vs ISOTOPIC COMPOSITION

Reference	Isotopic Composition	Moderation (H/U-235)	Infinite Slab Thickness (in)	Reference
Water or Equivalent	~90	44.7	1.76	Nu Sci and Eng, 3, 694-7 (1958)
	4.9	300	6	Figure L-2.6
	2.0	400	10	(1)
	1.02 ± 0.02	--	∞	Hanford
Air	~90	50	4.5	Figure J-2 4
	2.0	400	13.3	(1)
	1.02 ± 0.02	--	∞	Hanford

(1) Preliminary and unpublished data from ORNL Critical Mass Laboratory.

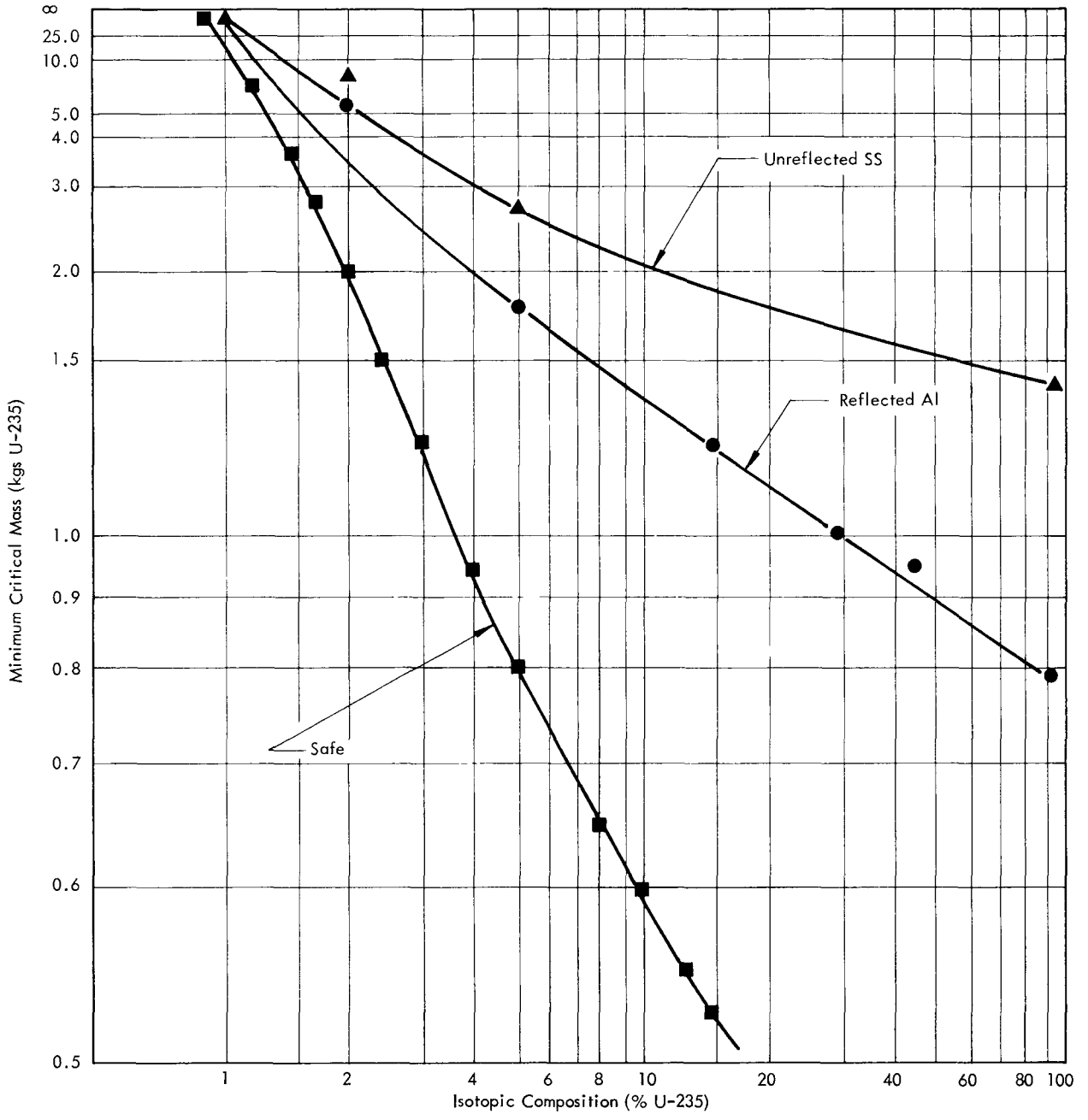


Figure J-3.1. MINIMUM CRITICAL MASS AS A FUNCTION OF THE U-235 ENRICHMENT. (Variation of Estimated Minimum Critical Mass of Aqueous Solutions (reciprocal scale) with U-235 Isotopic Composition (log scale). Critical Data have been Reduced to Equivalent Spheres by Equibuckling Transformations. The Dashed Line Connects the Safe Values Given in Section G. See Table J-3.1 for Data.)

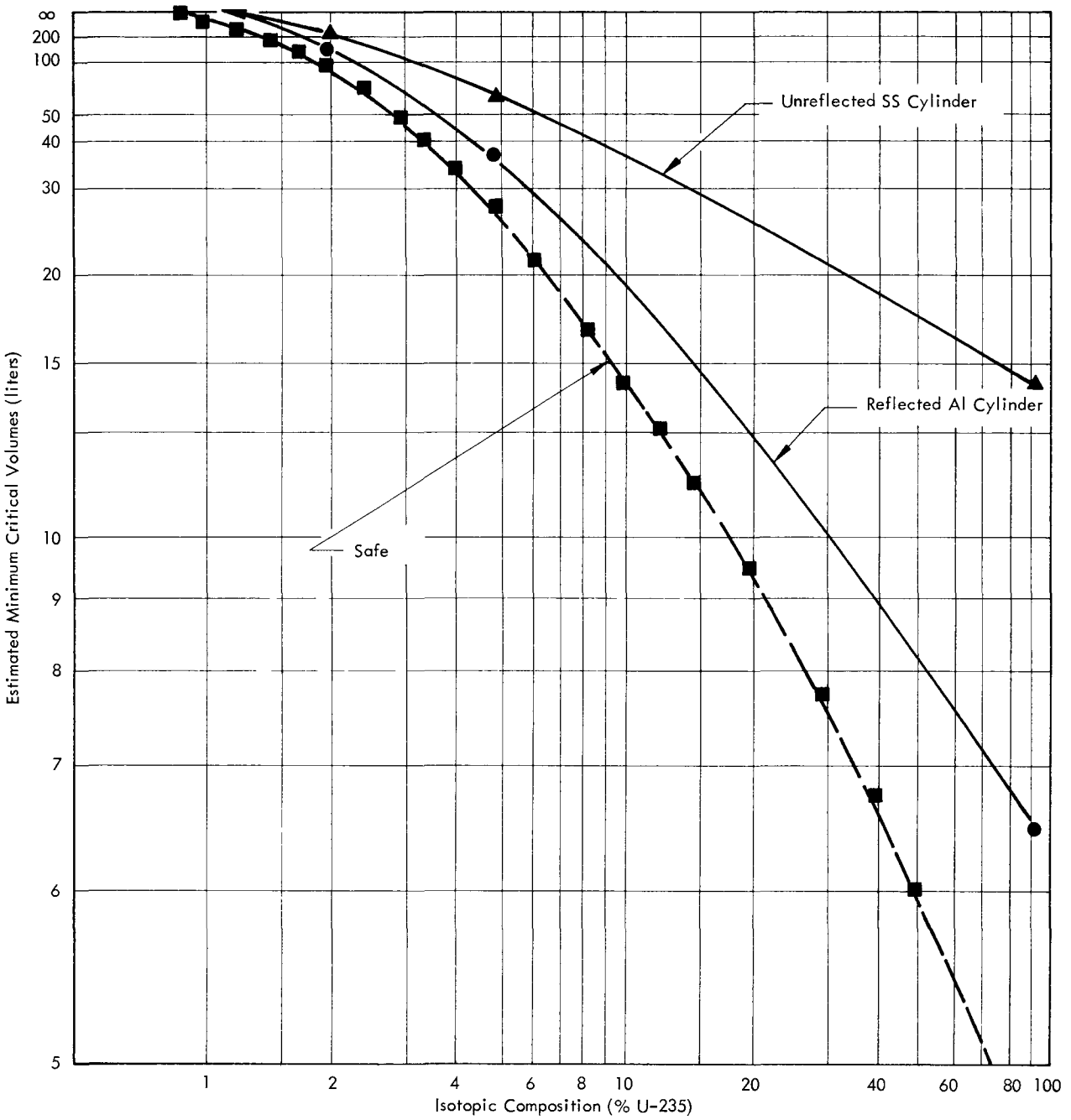


Figure J-3.2. ESTIMATED MINIMUM CRITICAL VOLUME AS A FUNCTION OF THE U-235 ENRICHMENT. (Volume is Plotted on a Reciprocal Scale. Solid and Broken Lines Merely Connect Estimated Points and have no other Significance. See Table G-3.1 for Safe Value Data; Table J-3.2 for other Data Points and References.)

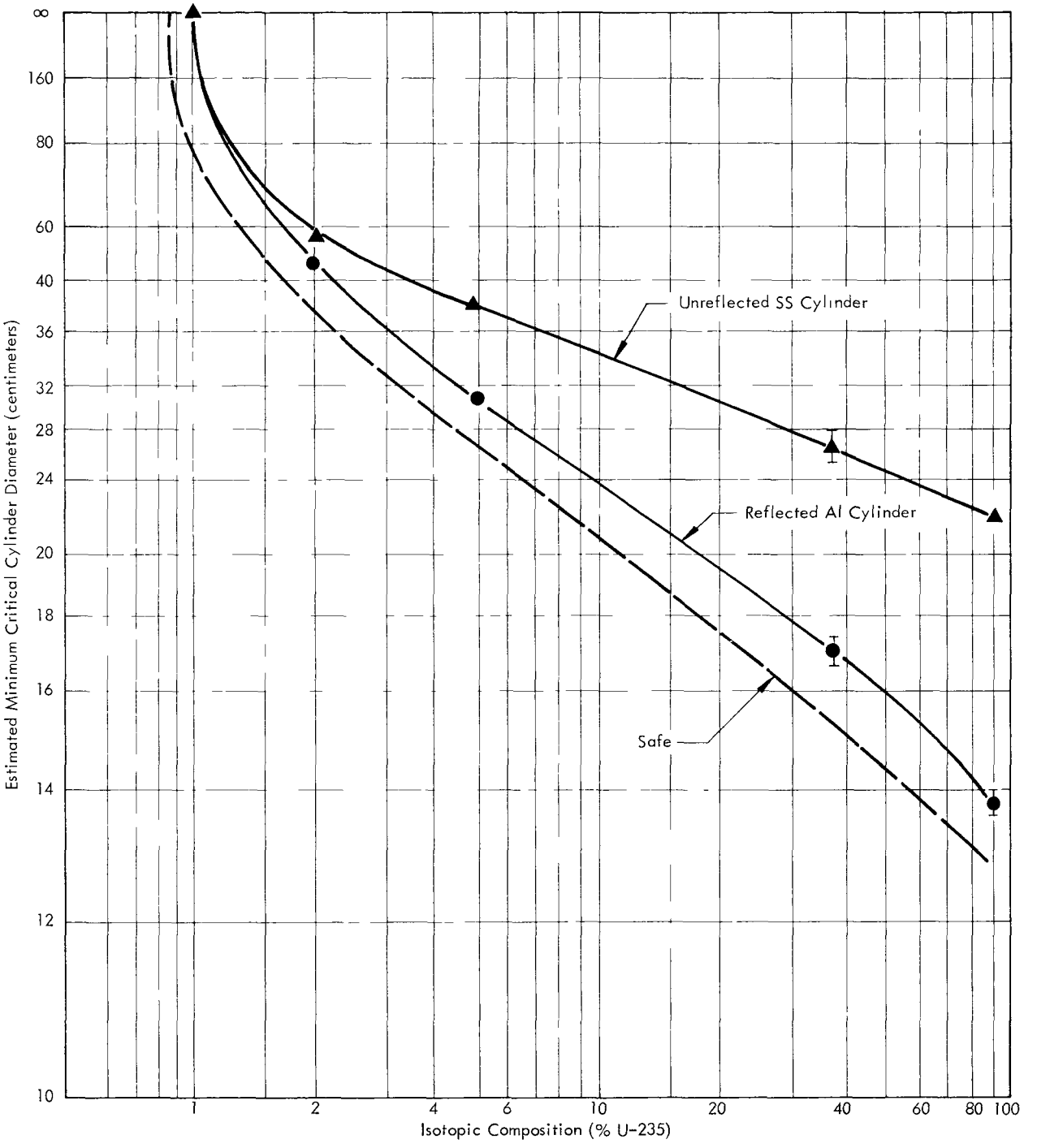


Figure J-3.3. INFINITE CYLINDER DIAMETER AS A FUNCTION OF THE U-235 ENRICHMENT. (The Estimated Minimum Critical Cylinder Diameter of Aqueous Uranium Solutions (reciprocal scale) is Plotted against the U-235 Isotopic Composition (log scale). Circles and Triangles Denote Aluminum and Stainless Steel Containers, Respectively. Limit Strikes Indicate the Extreme Range of Possible Critical Values as Inferred from Related Critical and Subcritical Experiments (see Table J-3.3), and are not Error Strikes. The Dashed Curve Connects the Safe Values of Table G-3.1. See Table J-3.3 for Critical Data References.

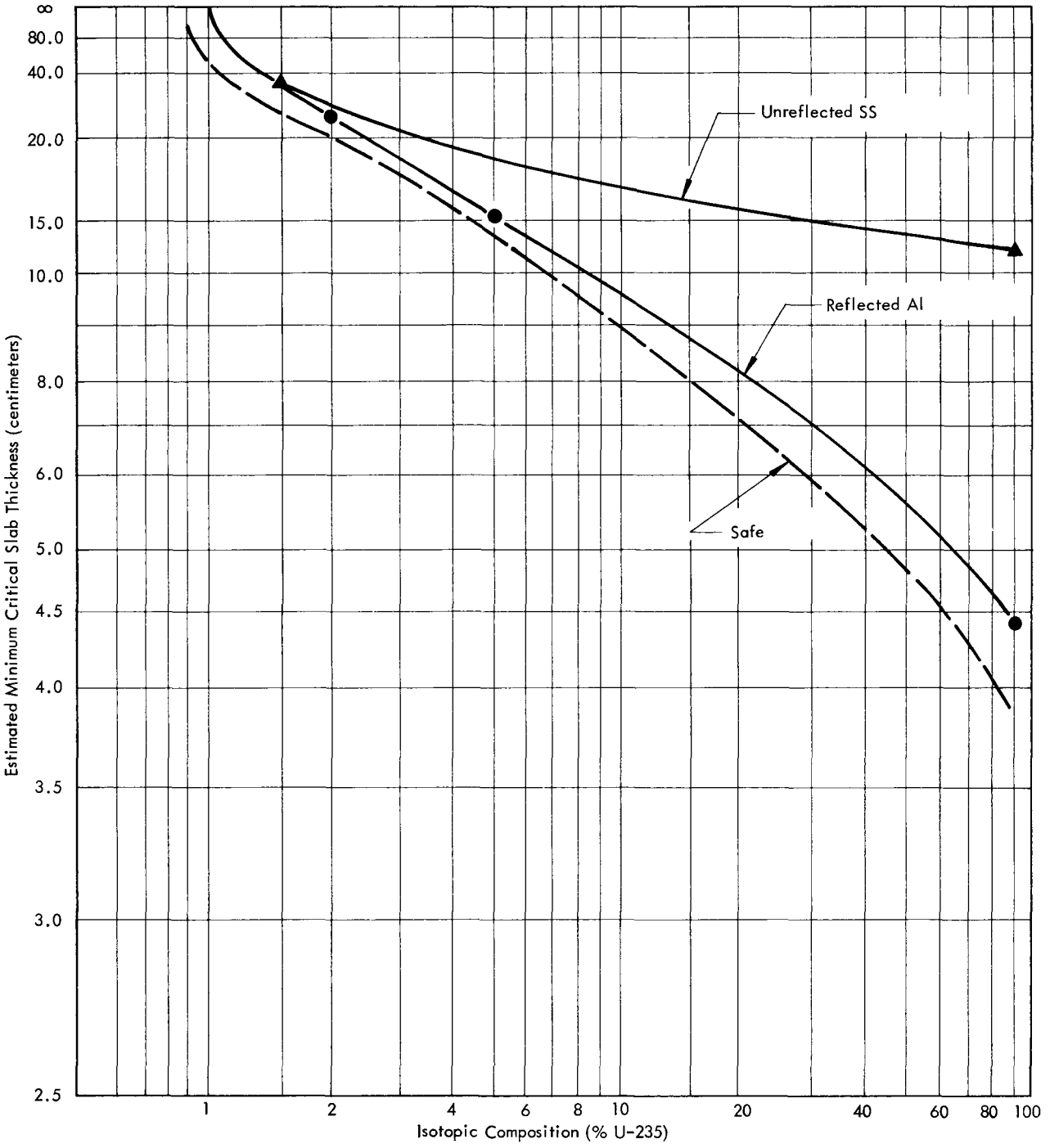


Figure J-3.4. MINIMUM CRITICAL SLAB THICKNESS AS A FUNCTION OF THE U-235 ENRICHMENT. (Estimated Minimum Critical Slab Thickness of Aqueous Uranium Solutions (reciprocal scale) against Percent U-235 Isotopic Composition (log scale). The Dashed Line Connects the Safe Values given in Table G-3.1. Triangles Denote Stainless Steel Containers; Circles Denote Aluminum Containers. See Table J-3.4 for Minimum Critical Data.)

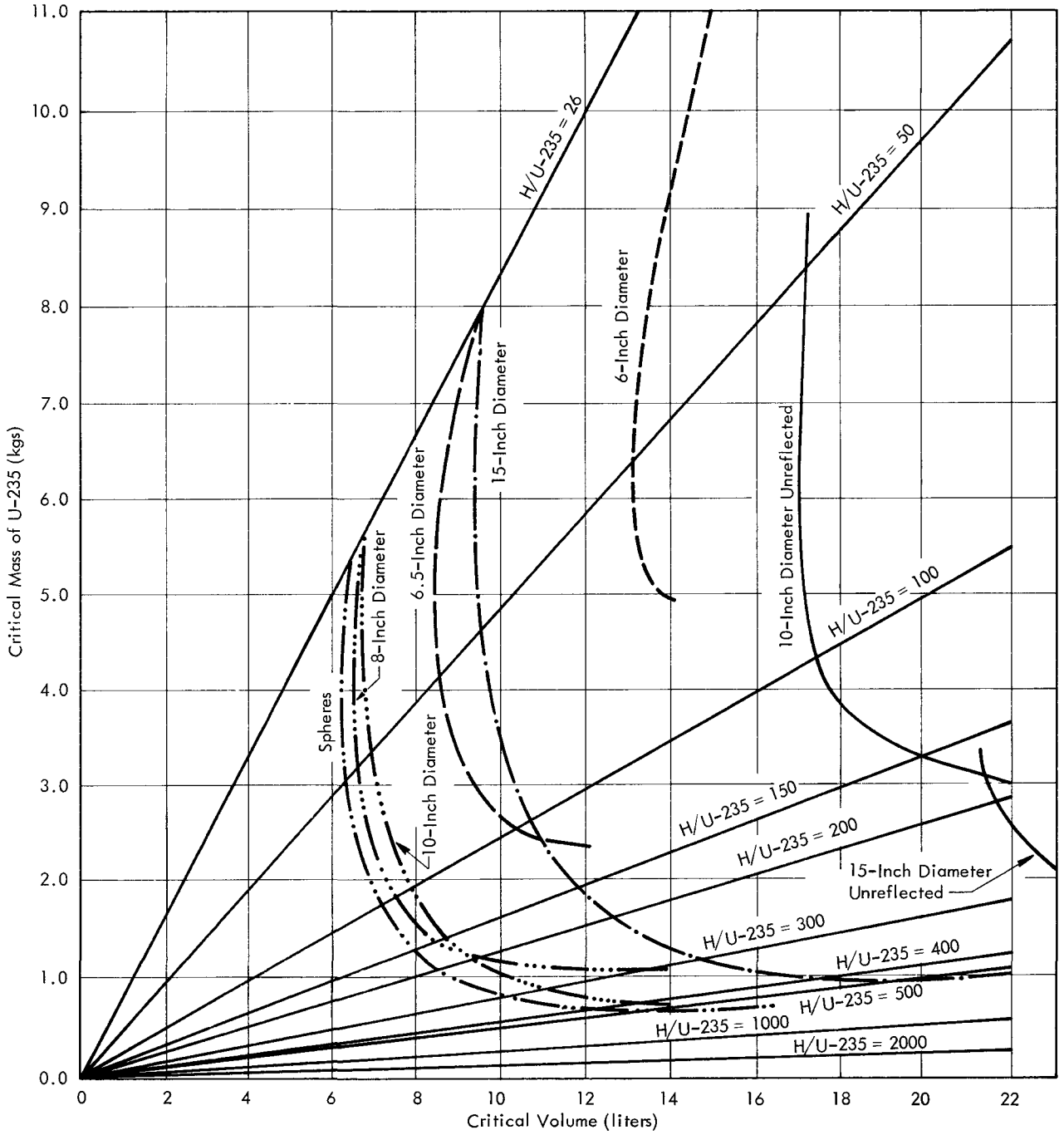


Figure K-1.1. **CRITICAL MASS AND VOLUME OF U-235 AS A FUNCTION OF THE CONCENTRATION.** (Critical Mass and Volume of U-235 as a Function of the Concentration for both Reflected and Unreflected Spherical and Cylindrical Geometries. Uranium was Enriched to 93.4% U-235. Callihan, A. D. Nucleonics, 14 (7), pp 38-41 (1956).)

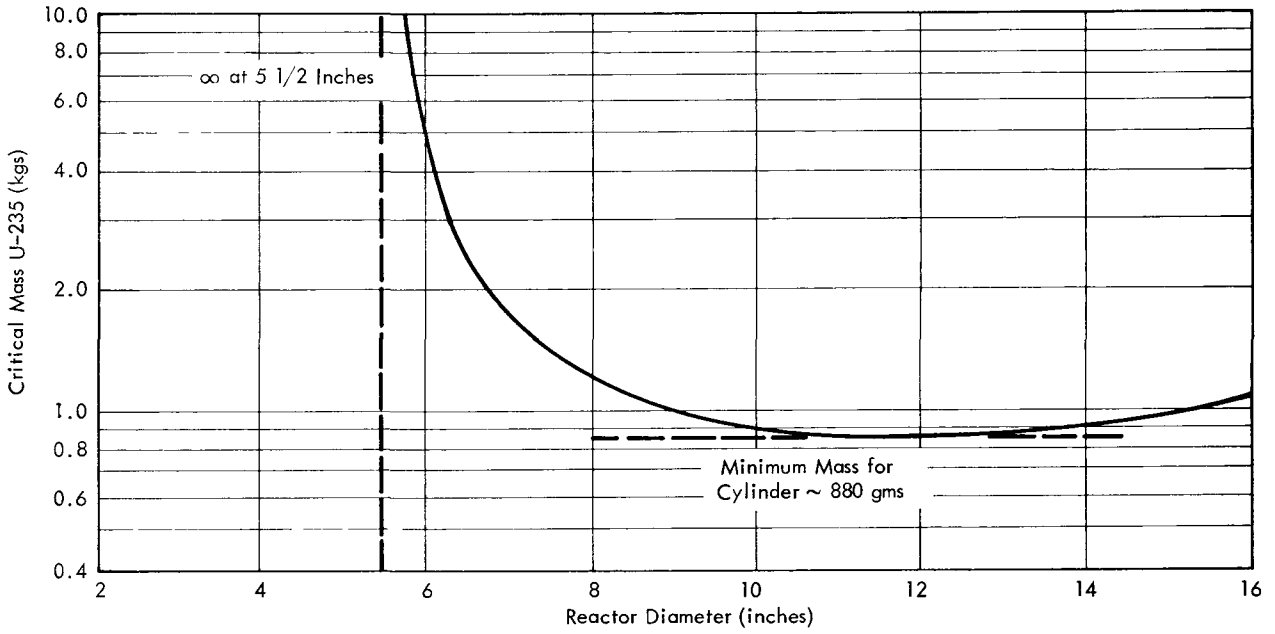
Table K-1.1

CRITICAL PARAMETERS FOR INDIVIDUAL CYLINDERS

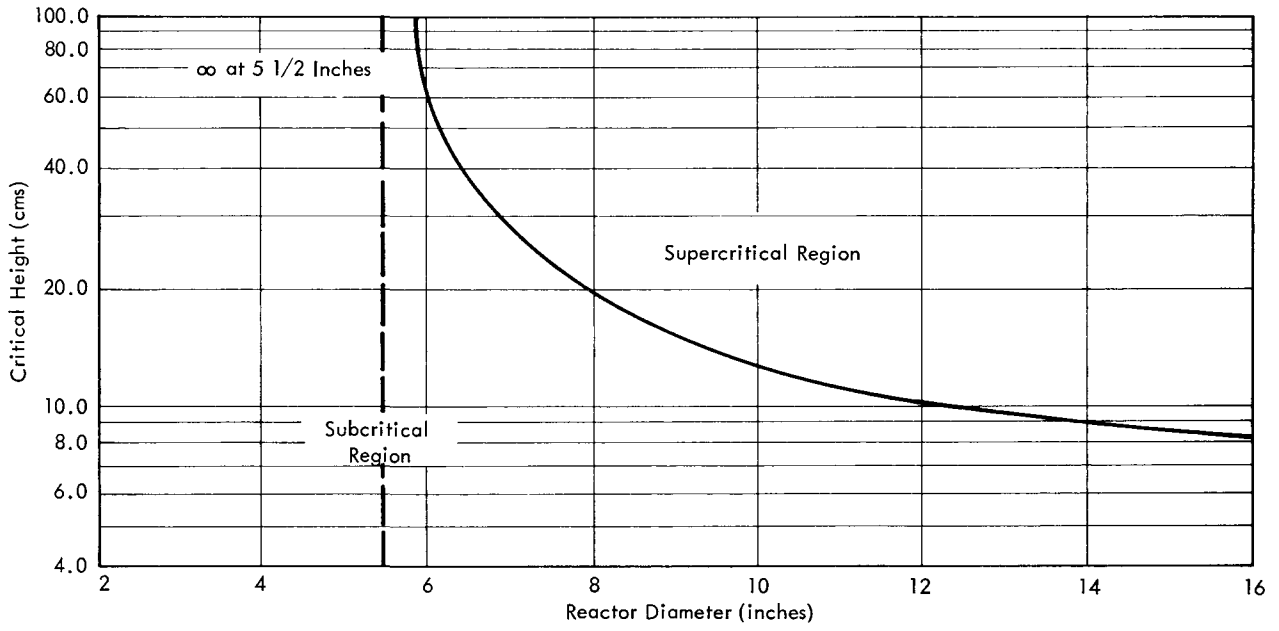
All values refer to solutions of uranyl fluoride in which the uranium was enriched to 93.4 % U-235. The reflecting material was light water of sufficient thickness to be effectively infinite.

Diameter (inches)	M_c @ H/X ≈ 50 Reflected (inches)	M_c @ H/X ≈ 50 Bare (inches)	M_c @ H/X ≈ 50 Reflected (kgs)	M_c @ H/X ≈ 50 Bare (kgs)	Minimum M_c Reflected @ H/X (kgs)	Minimum M_c Bare @ H/X (kgs)
5	∞		∞		∞	
6	47		10.8		10.8 @ 45	
7	12.79		3.19		2.10 @ 174	
8	8.19	∞	2.80	∞	1.28 @ 192	∞
9	7.09	--	2.93	--	1.09 @ 320	--
10	5.87	12.48	4.06	6.36	1.02 @ 320	2.69 @ 266
12	4.84	9.72[1]	3.53	2.67[1]	1.00 @ 499	1.78 @ 320
15	3.98	6.73	4.88	8.26	1.13 @ 755	1.61 @ 499
20	--	5.63[2]	--	6.14[2]	--	1.86 @ 755
30	1.85	5.39	11.8	33.6	--	

[1] H/X = 174
[2] H/X = 119
Source: Callihan, et al, K-343, Fox, et al, ORNL-2367.

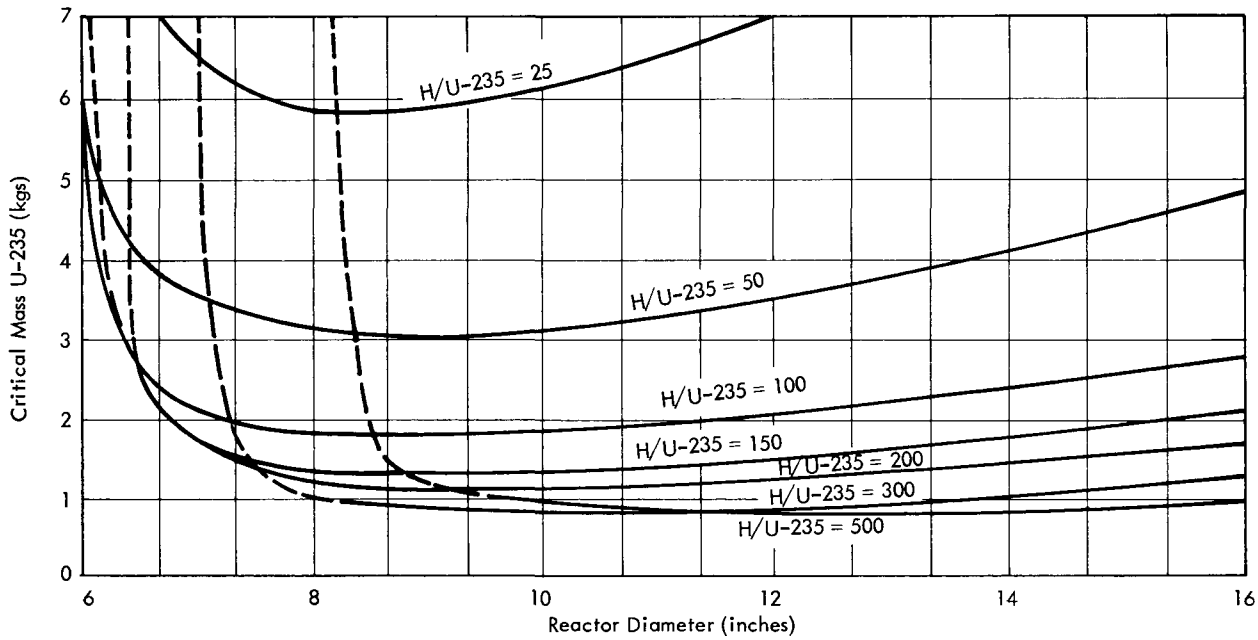


(a) Minimum Mass for Water-Reflected Aluminum Containers

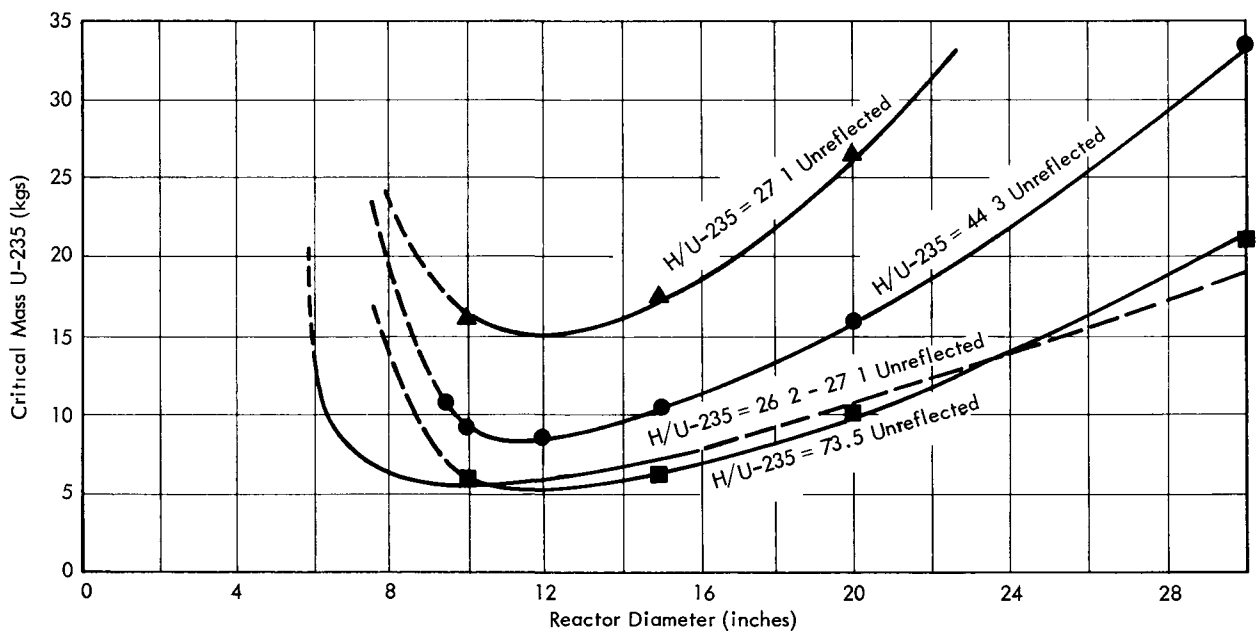


(b) Minimum Height for Water-Reflected Aluminum Containers

Figure K-1.2. MINIMUM CRITICAL MASS AND HEIGHT AS A FUNCTION OF THE DIAMETER FOR ALUMINUM REACTORS. (The Water-Reflected Cylinders Contained Uranyl Fluoride Solutions. Uranium was Enriched to 93.4% U-235. Beck, Callihan, Morfitt, and Murray, K-343.)

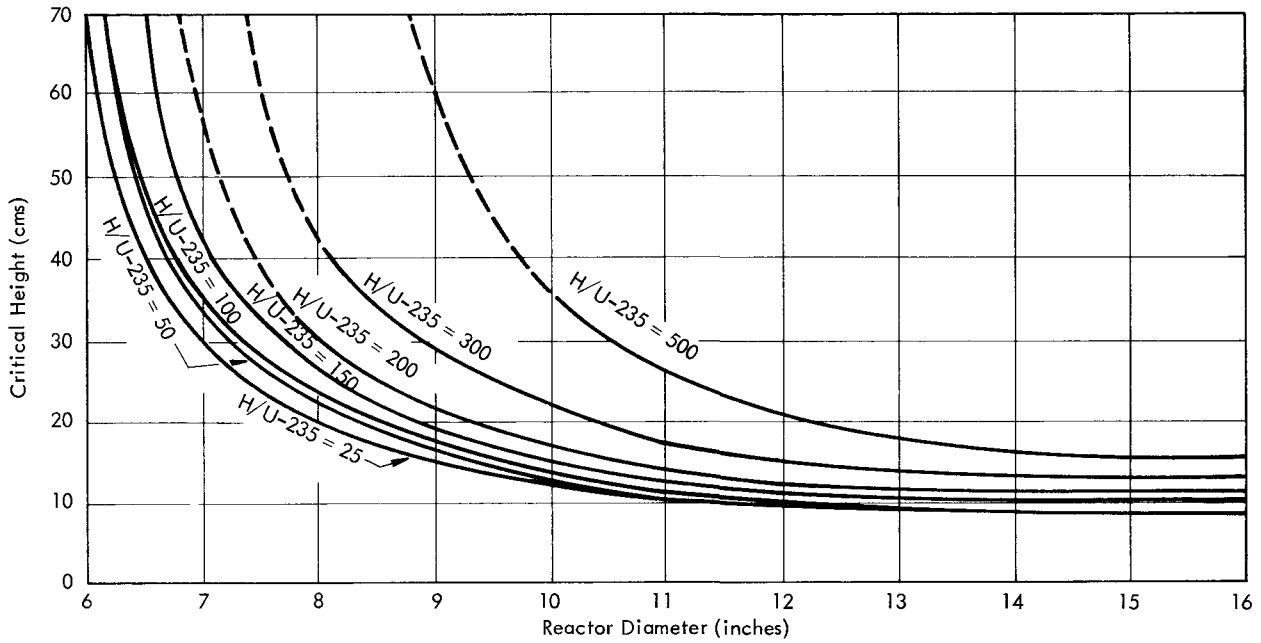


(a) Critical Mass for Water-Reflected Aluminum Containers

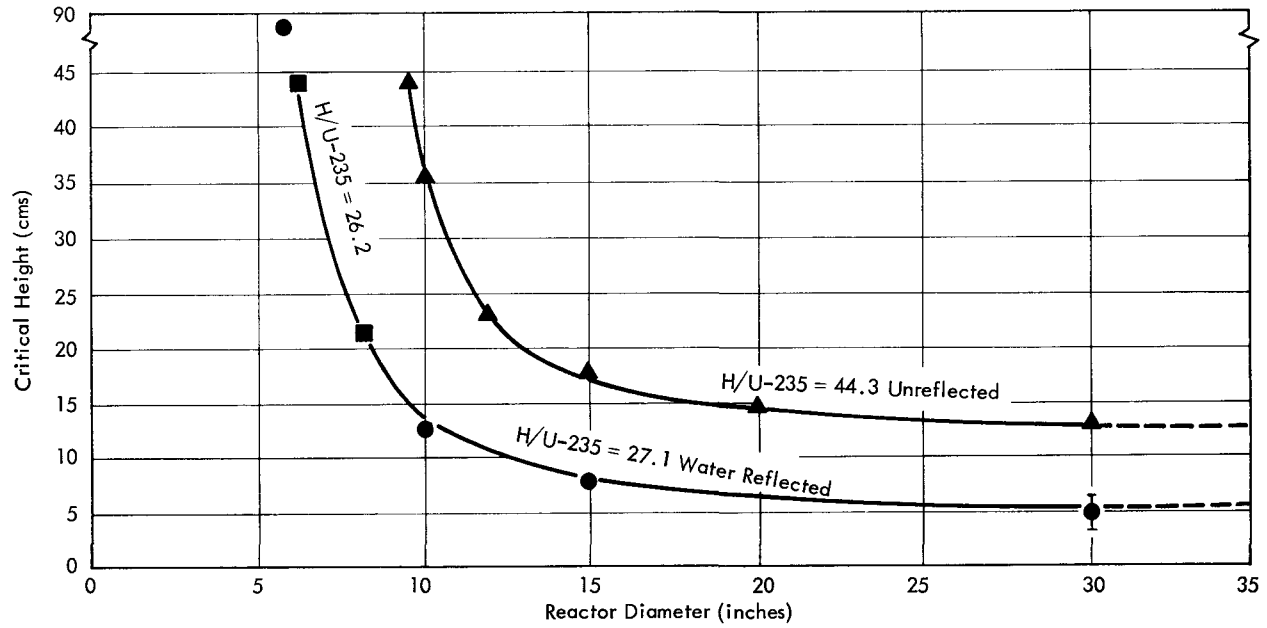


(b) Critical Mass for Unreflected and Water-Reflected Aluminum Containers

Figure K-1.3. CRITICAL MASS AS A FUNCTION OF THE DIAMETER FOR ALUMINUM REACTORS. (The Cylinders Contained Uranyl Fluoride Solutions at Various Moderations. Uranium was Enriched to 93.4% U-235. Beck et al, K-343, and Callihan, et al, ORNL-2367.)

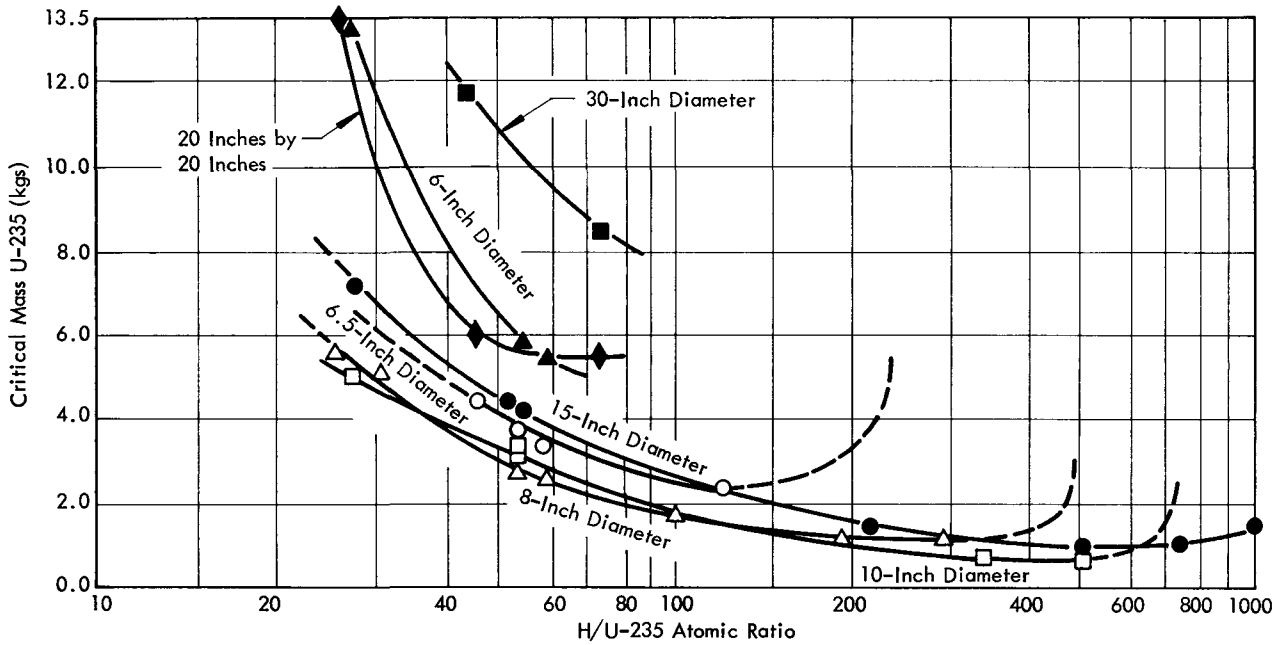


(a) Critical Height for Water-Reflected Aluminum Containers

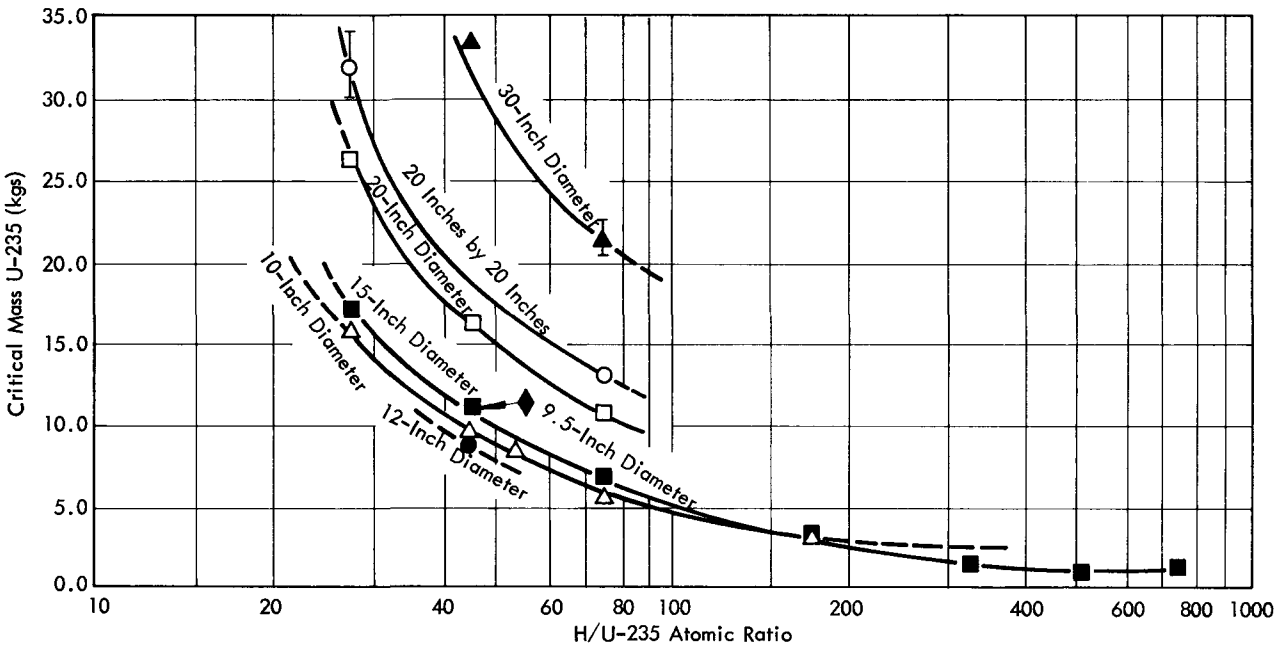


(b) Critical Height for Unreflected and Water-Reflected Aluminum Containers

Figure K-1.4. CRITICAL HEIGHT AS A FUNCTION OF THE DIAMETER FOR ALUMINUM REACTORS. (The Reactors Contained Uranyl Fluoride Solutions at Various Moderations. Uranium was Enriched to 93.4% U-235. Beck, et al, K-343, and Callihan, et al, ORNL-2367.)

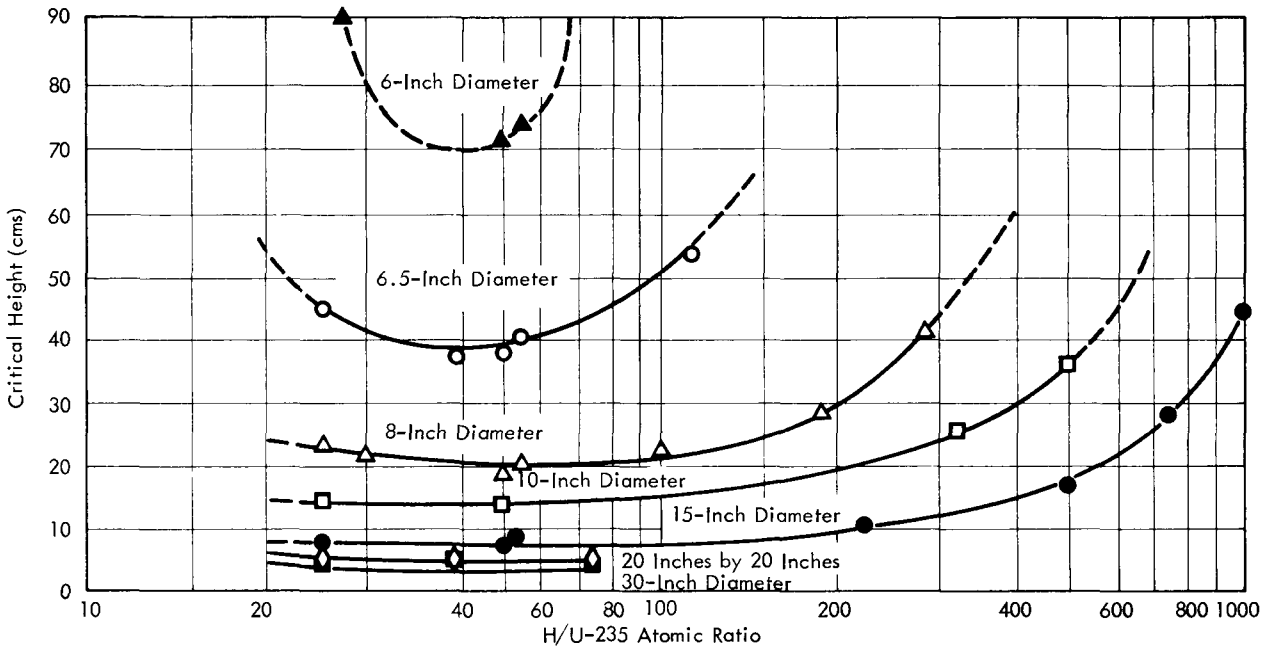


(a) Critical Mass for Water-Reflected Aluminum Containers

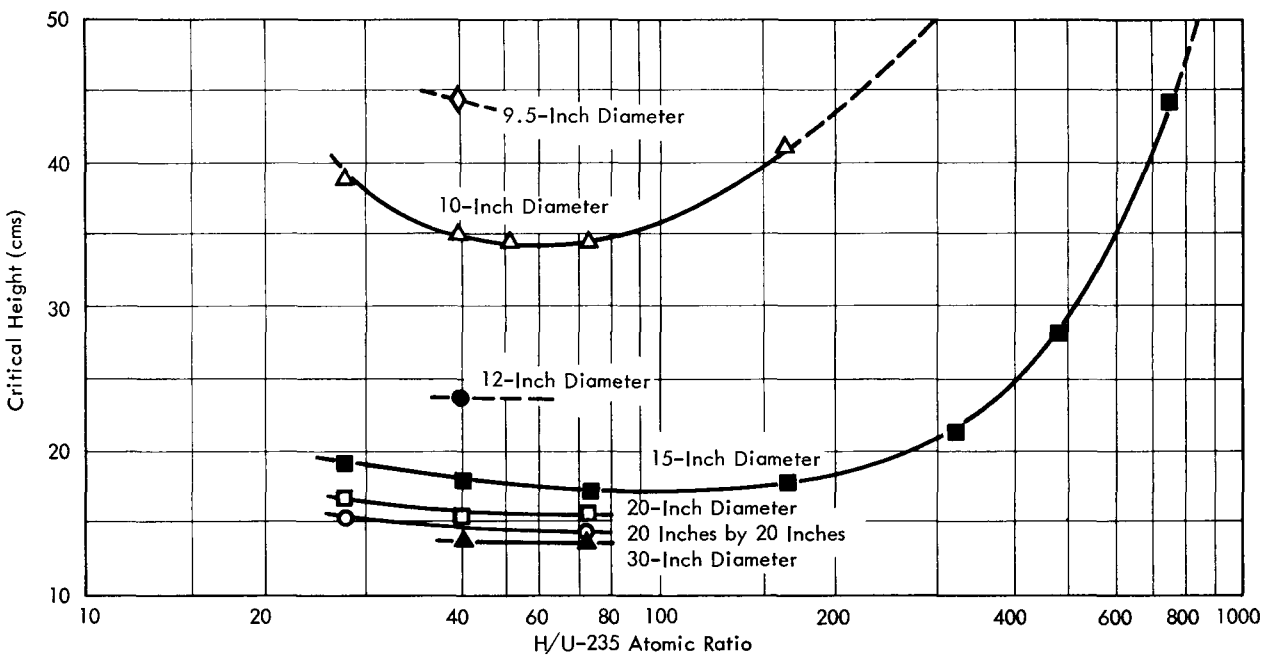


(b) Critical Mass for Unreflected Aluminum Containers

Figure K-1.5. CRITICAL MASS AS A FUNCTION OF THE MODERATION FOR ALUMINUM REACTORS. (The Various Diameter Aluminum Cylinders Contained Uranyl Fluoride Solutions. Uranium was Enriched to 93.4% U-235. Beck, et al, K-343, and Callihan, et al, ORNL-2367.)

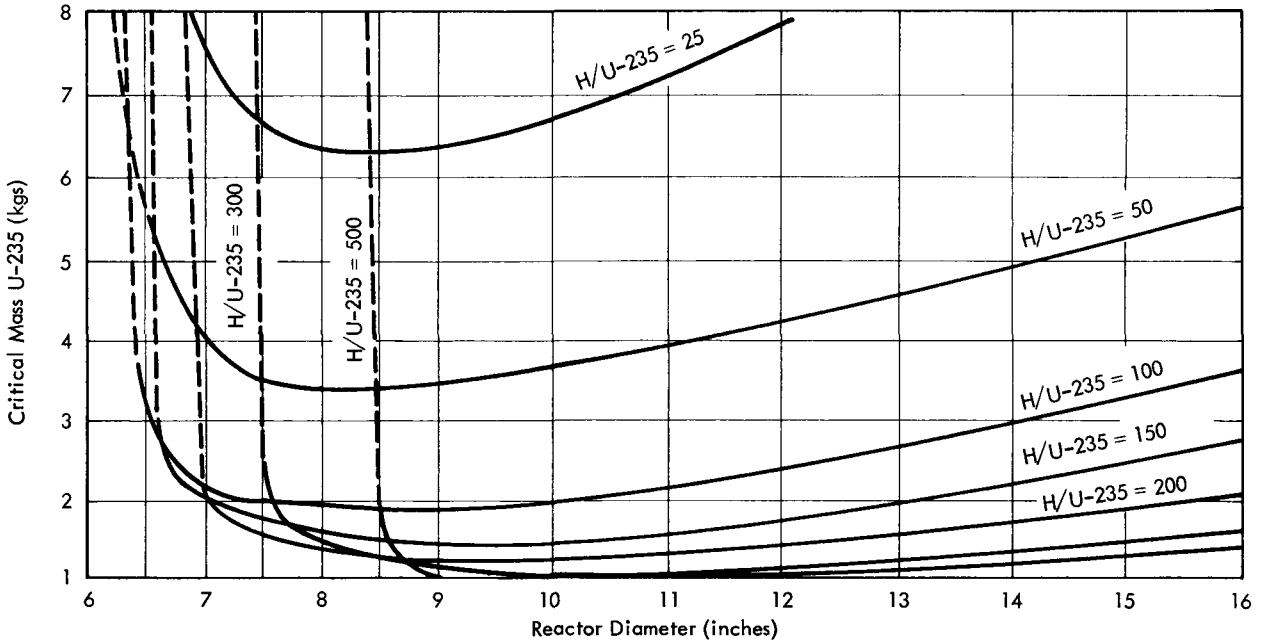


(a) Critical Height for Water-Reflected Aluminum Containers

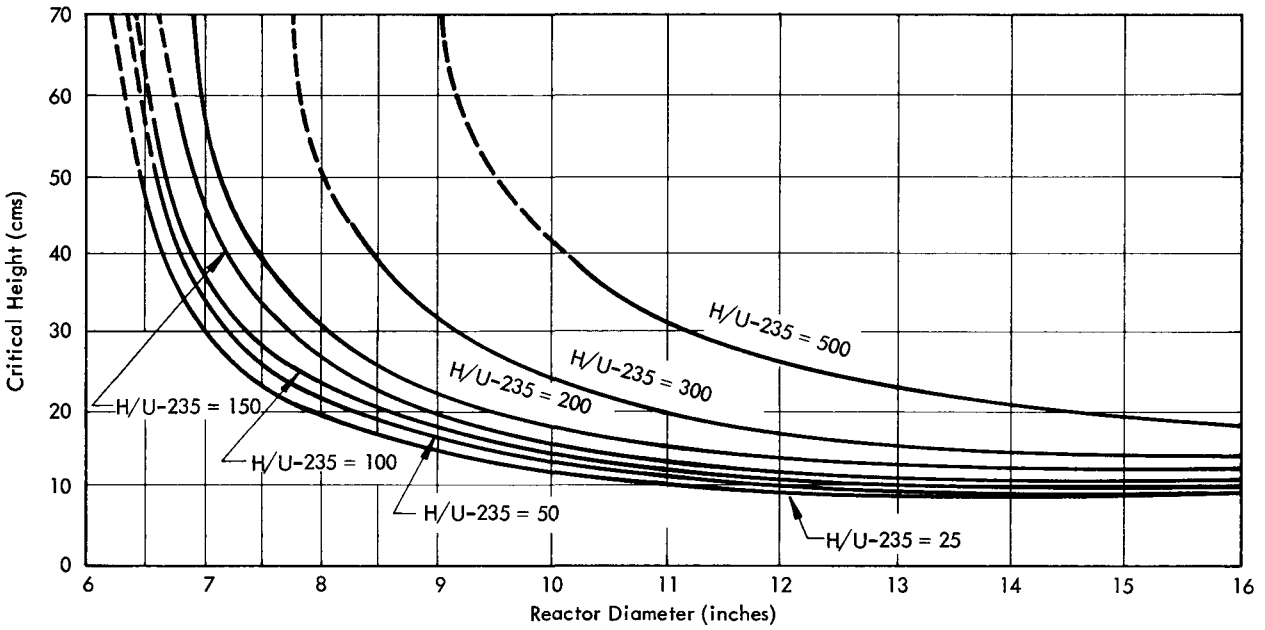


(b) Critical Height for Unreflected Aluminum Containers

Figure K-1.6. CRITICAL HEIGHT AS A FUNCTION OF THE MODERATION FOR ALUMINUM REACTORS. (The Various Diameter Aluminum Cylinders Contained Uranyl Fluoride Solutions. Uranium was Enriched to 93.4% U-235. Beck, et al, K-343, and Callihan, et al, ORNL-2367.)

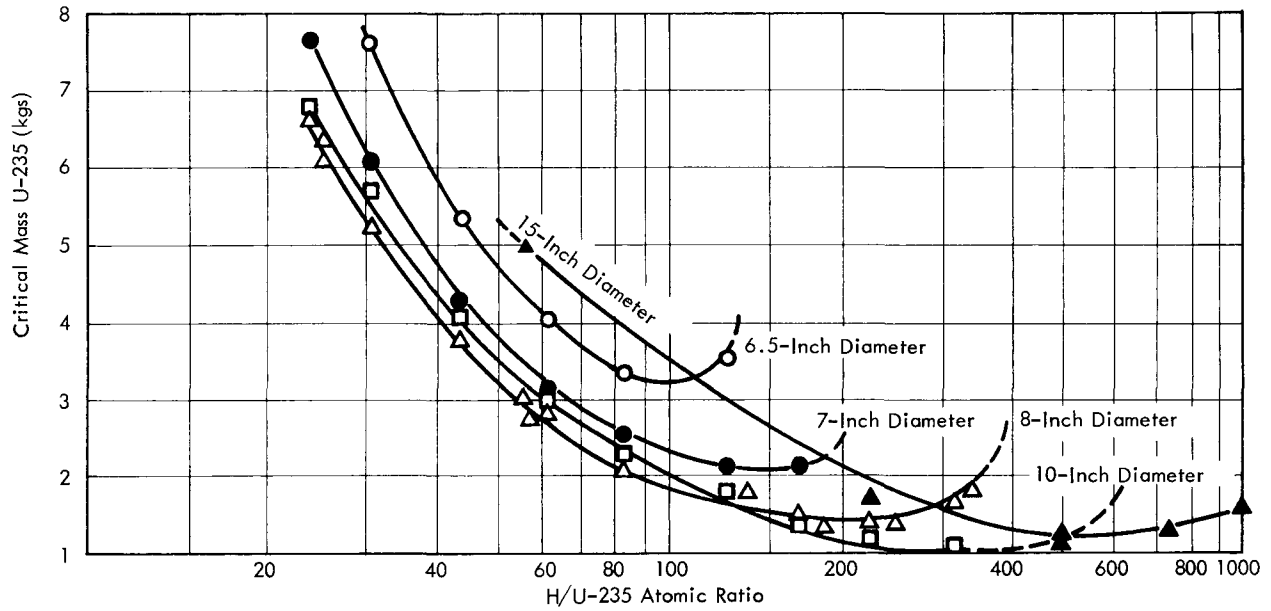


(a) Critical Mass for Water-Reflected Stainless Steel Containers

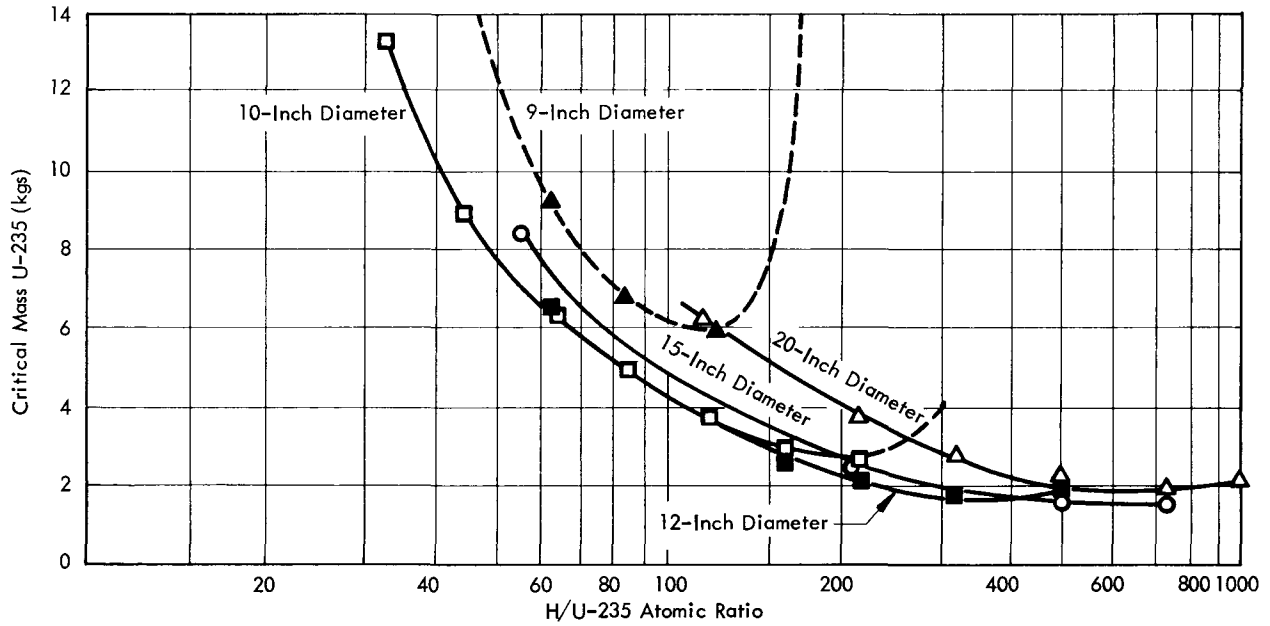


(b) Critical Height for Reflected Stainless Steel Containers

Figure K-1.7. CRITICAL MASS AND HEIGHT AS FUNCTIONS OF THE DIAMETER FOR WATER-REFLECTED STAINLESS STEEL REACTORS. (The Cylinders Contained Uranyl Fluoride Solutions at Various Moderations. Uranium was Enriched to 93.4% U-235 (Beck, et al, K-343). With an H/U-235 = 44.3, a Six-Inch-Diameter Reactor was Critical at 118.4 Centimeters -- 11.59 Kilograms of U-235 (Callihan, et al, ORNL-2367).)

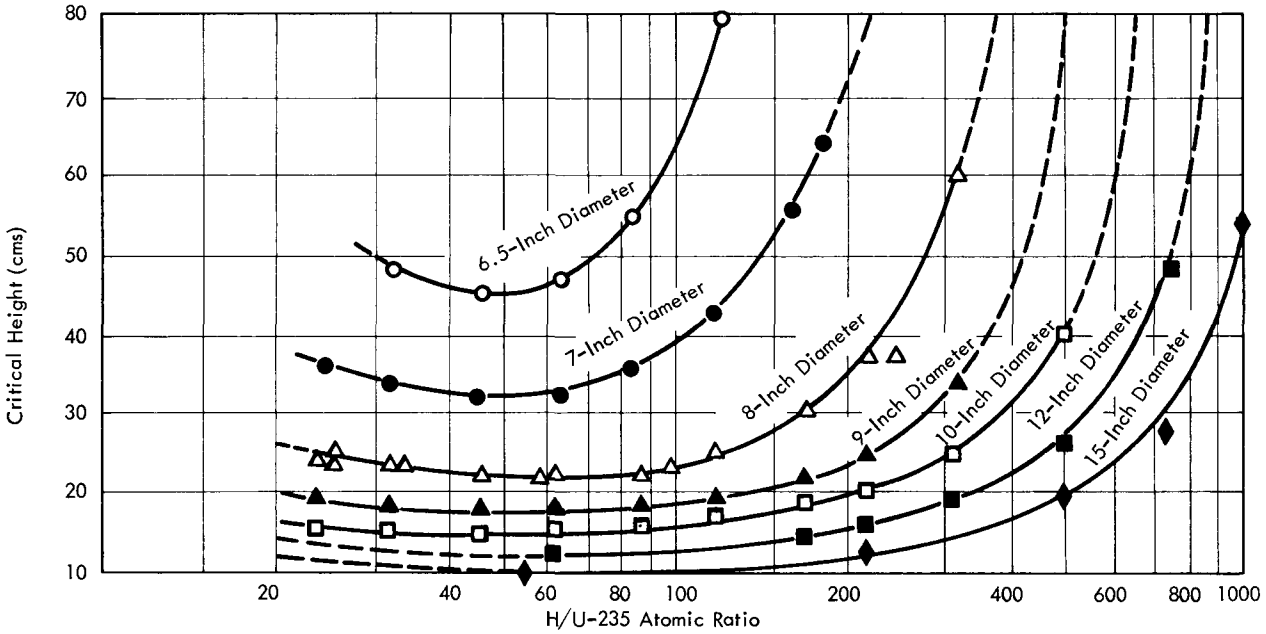


(a) Critical Mass for Water-Reflected Stainless Steel Containers

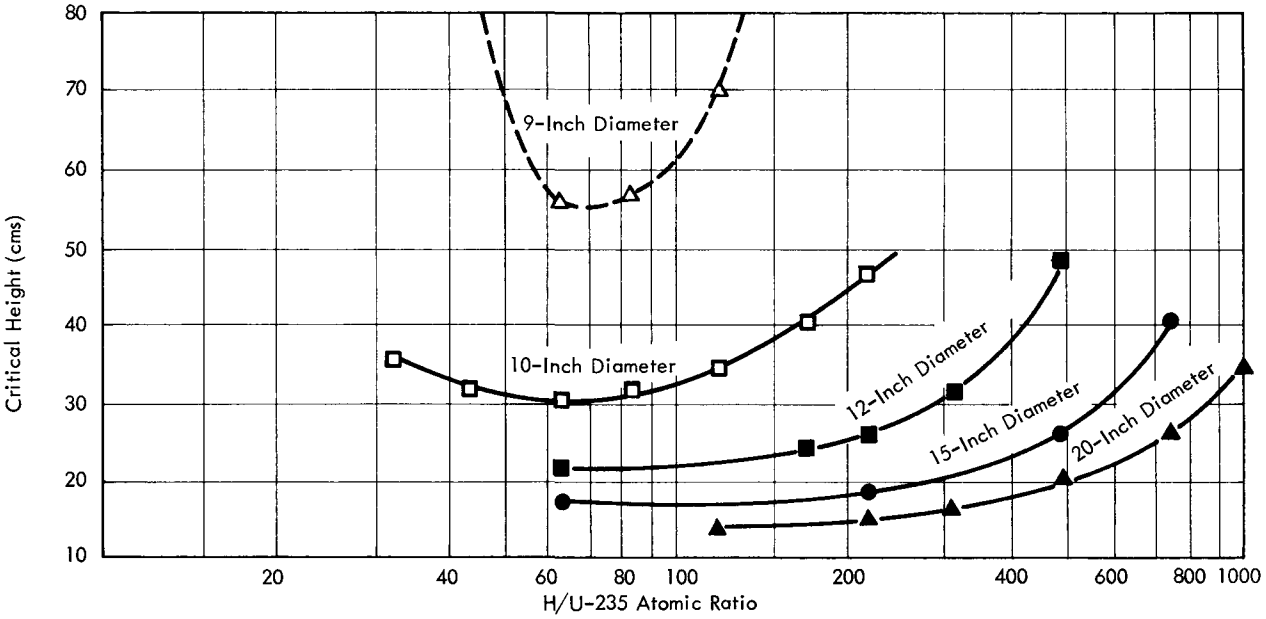


(b) Critical Mass for Unreflected Stainless Steel Containers

Figure K-1.8. CRITICAL MASS AS A FUNCTION OF THE MODERATION FOR STAINLESS STEEL REACTORS. (The Various Diameter Cylinders Contained Uranyl Fluoride Solutions Enriched to 93.4% U-235. Beck, et al, K-343.)



(a) Critical Height for Water-Reflected Stainless Steel Cylinders



(b) Critical Height for Unreflected Stainless Steel Cylinders

Figure K-1.9. CRITICAL HEIGHT AS A FUNCTION OF THE MODERATION FOR STAINLESS STEEL REACTORS. (The Various Diameter Cylinders Contained Uranyl Fluoride Solutions Enriched to 93.4% U-235. Beck, et al, K-343.)

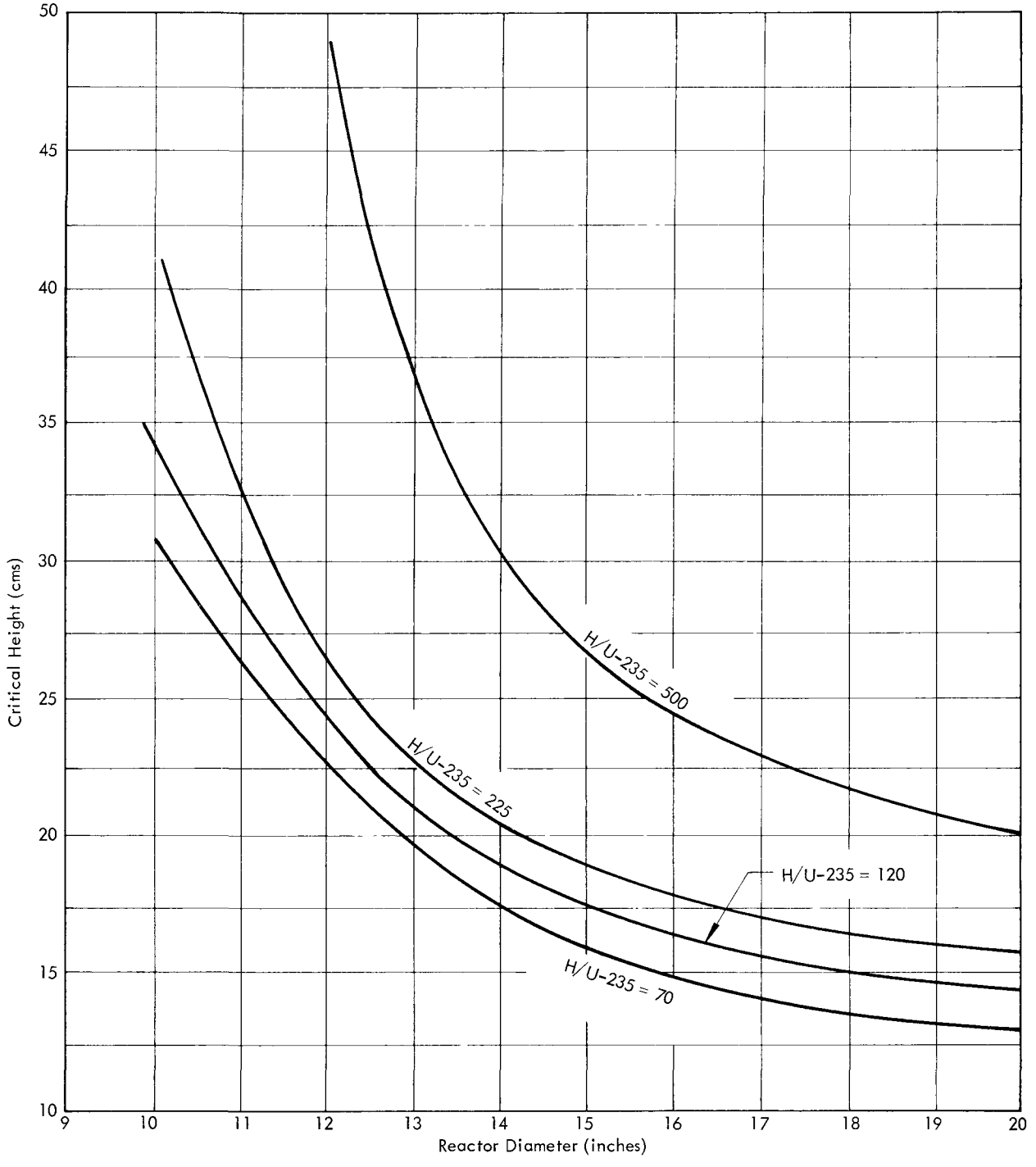
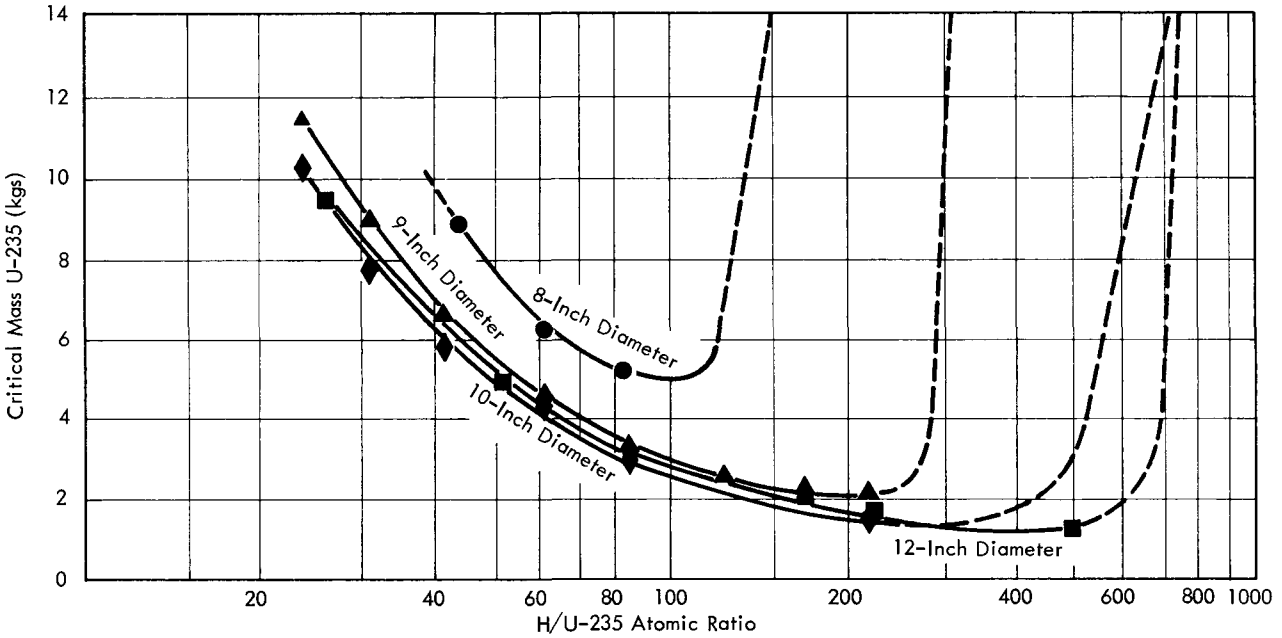
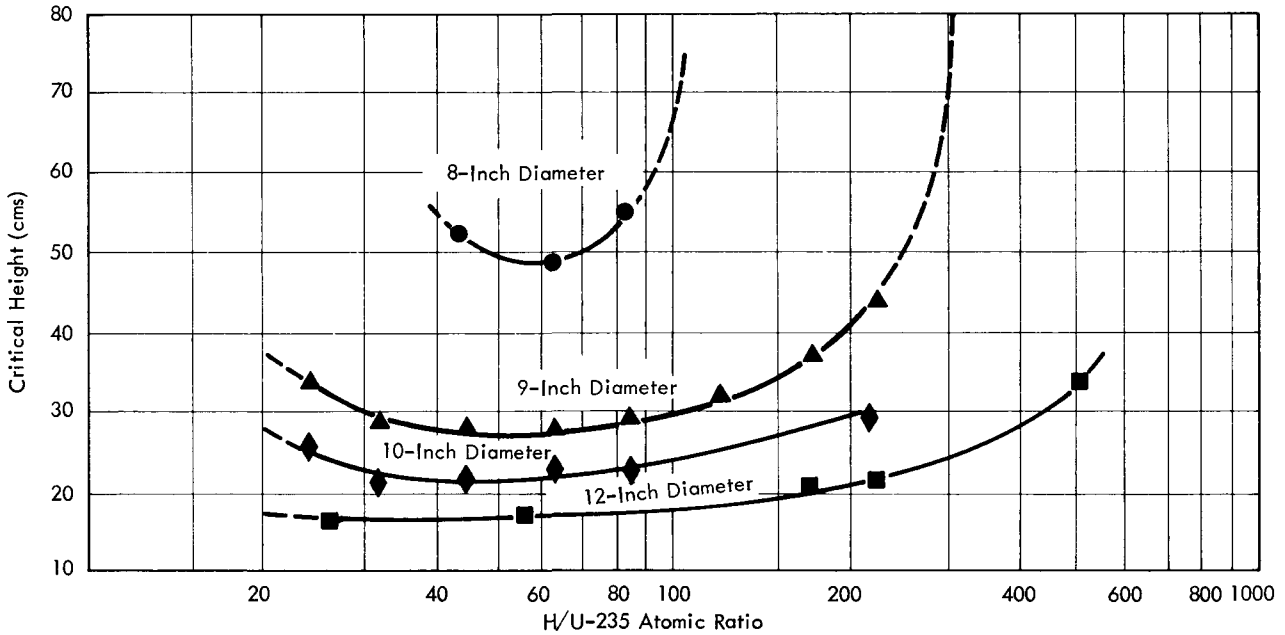


Figure K-1.10. CRITICAL HEIGHT AS A FUNCTION OF THE DIAMETER FOR UNREFLECTED STAINLESS STEEL REACTORS. (The Various Diameter Cylinders Contained Uranyl Fluoride Solutions at Various Moderations. Uranium was Enriched to 93.4% U-235. Beck, et al, K-343.)

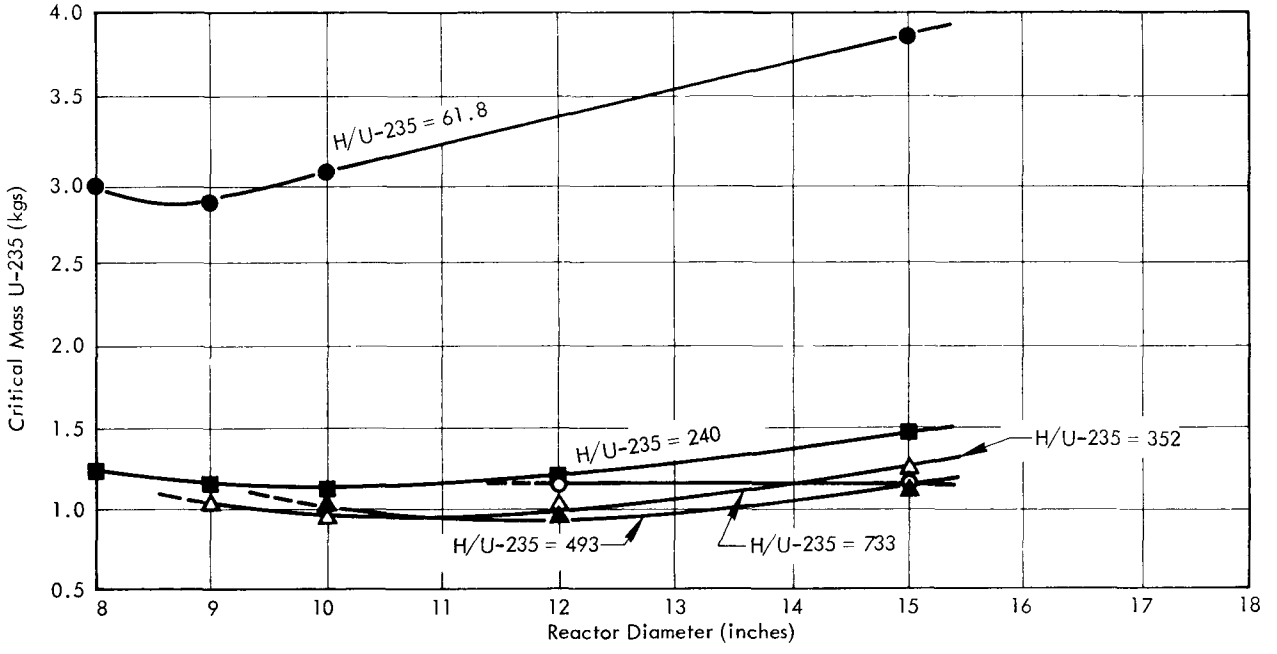


(a) Critical Mass for Water-Reflected, Cadmium-Shielded, Stainless Steel Containers

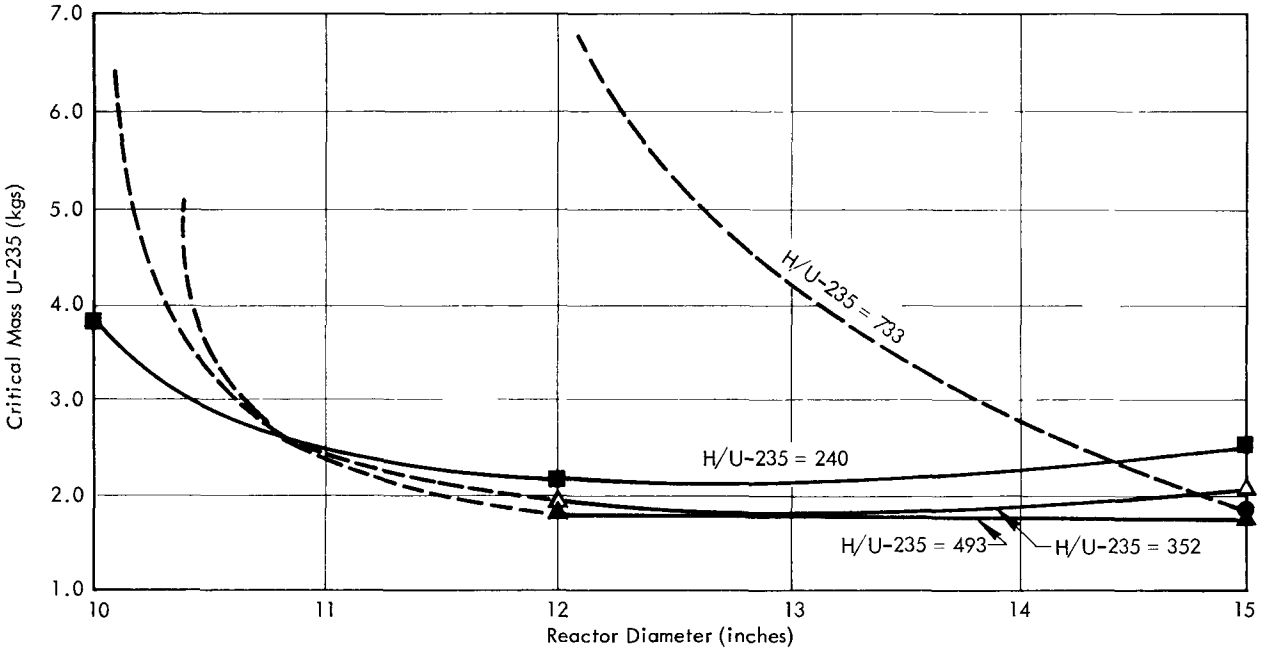


(b) Critical Height for Water-Reflected, Cadmium-Shielded, Stainless Steel Containers

Figure K-1.11. CRITICAL MASS AND HEIGHT AS FUNCTIONS OF THE MODERATION FOR WATER-REFLECTED, CADMIUM-SHIELDED, STAINLESS STEEL REACTORS. (The Various Cylinders Contained Uranyl Fluoride Solutions at Various Moderations. Uranium was Enriched to 93.4% U-235. Beck, et al, K-343.)

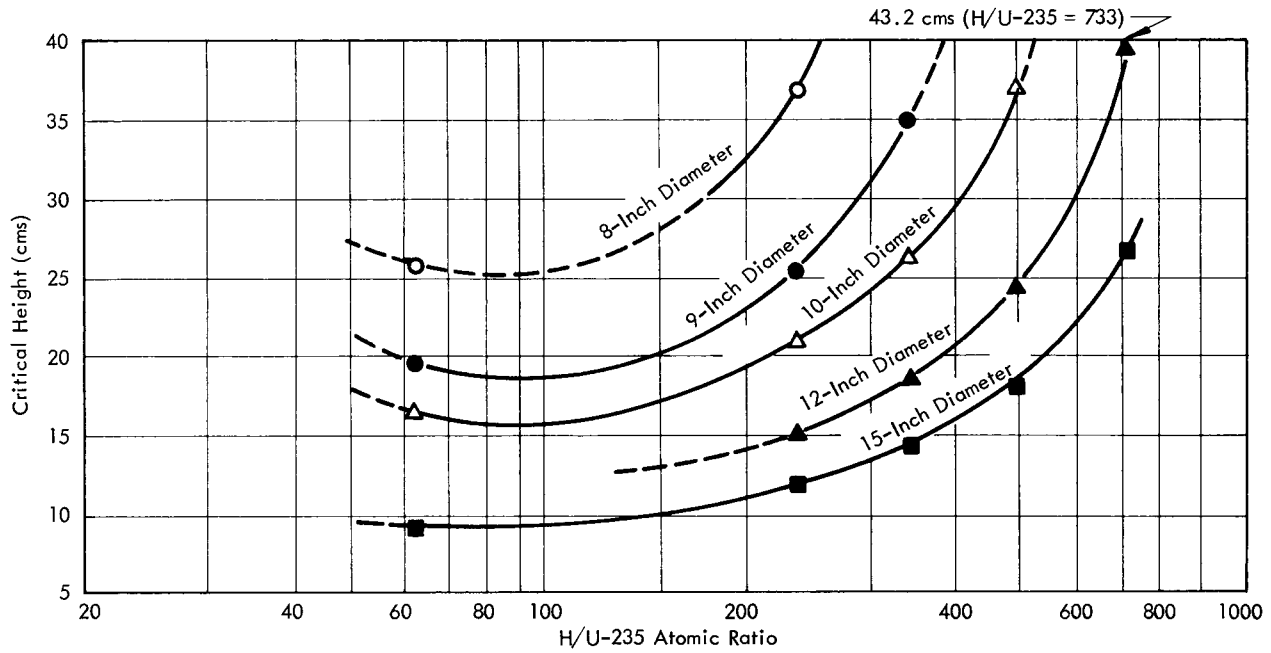


(a) Water-Reflected Aluminum Containers

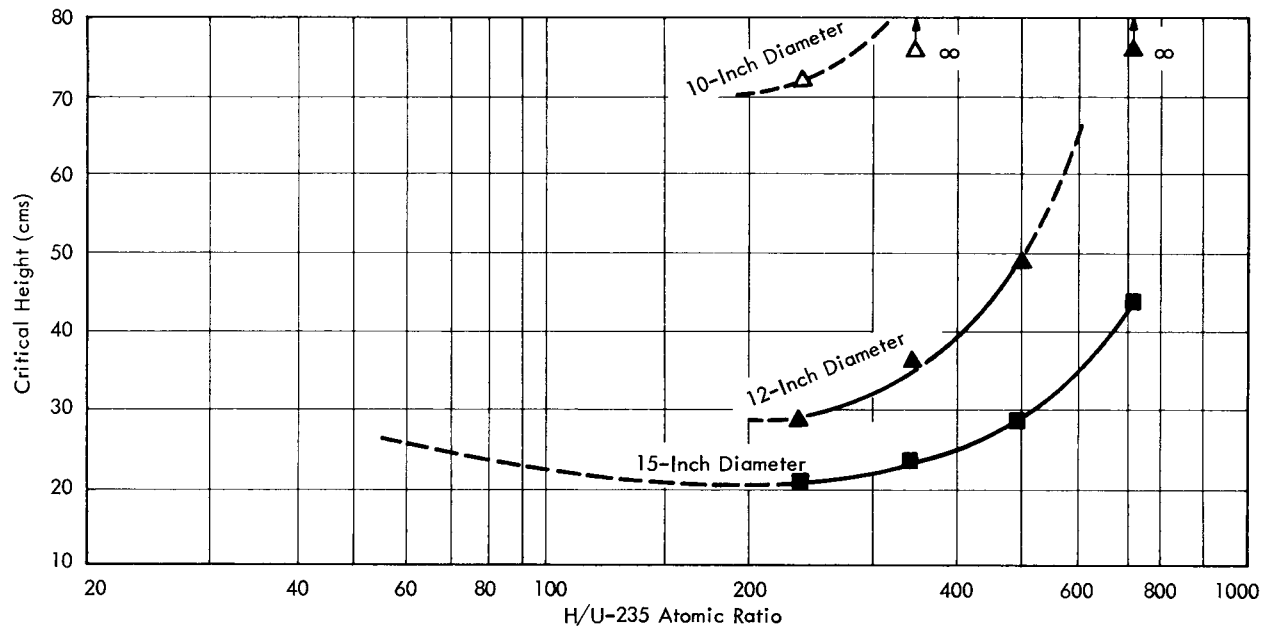


(b) Unreflected Aluminum Containers

Figure K-2.1. CRITICAL MASS OF URANYL NITRATE SOLUTION AS A FUNCTION OF THE DIAMETER OF ALUMINUM REACTORS. (The Wall Thickness of the Aluminum Cylinders was 1/16 Inch. The N/U-235 Atomic Ratio was 2.86. The Uranium was Enriched to 93.3% U-235. Figures 7 and 9 of Callihan, et al, K-643.)



(a) Water-Reflected Aluminum Containers



(b) Unreflected Aluminum Containers

Figure K-2.2. CRITICAL HEIGHT OF URANYL NITRATE SOLUTION AS A FUNCTION OF THE MODERATION IN ALUMINUM REACTORS. (The Wall Thickness of the Aluminum Cylinders was 1/16 Inch. The N/U-235 Atomic Ratio was 2.86. The Uranium was Enriched to 93.3% U-235. Figures 1 and 3 of Callihan, et al, K-643.)

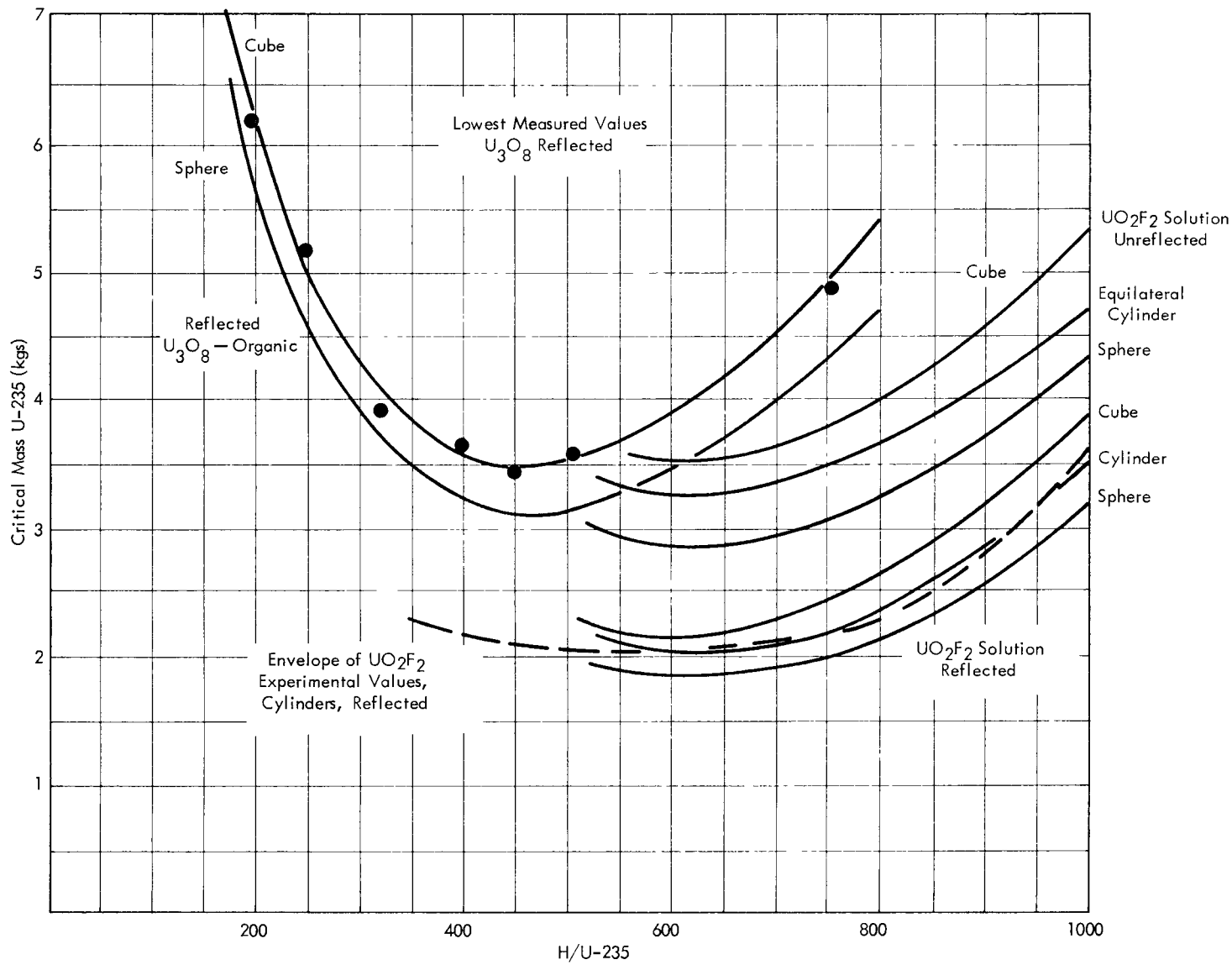


Figure L-1.1. CALCULATED CURVES OF CRITICAL MASS AS A FUNCTION OF THE H/U-235 ATOMIC RATIO FOR 4.9% ISOTOPIC ENRICHMENT. (Closed Circles Denote Lowest Measured Values of U_3O_8-Organic. All Values are Based on Measurements with Aluminum Vessels. Data Obtained with Reflected Cylinders of UO_2F_2 were Transformed to other Geometries. "Organic" Refers to Glyceryl Tristerate Mixed Homogeneously with the Oxide. Cronin, Critical Mass Studies, Part X, Uranium of Intermediate Enrichment, ORNL-2968, September 20, 1960.)

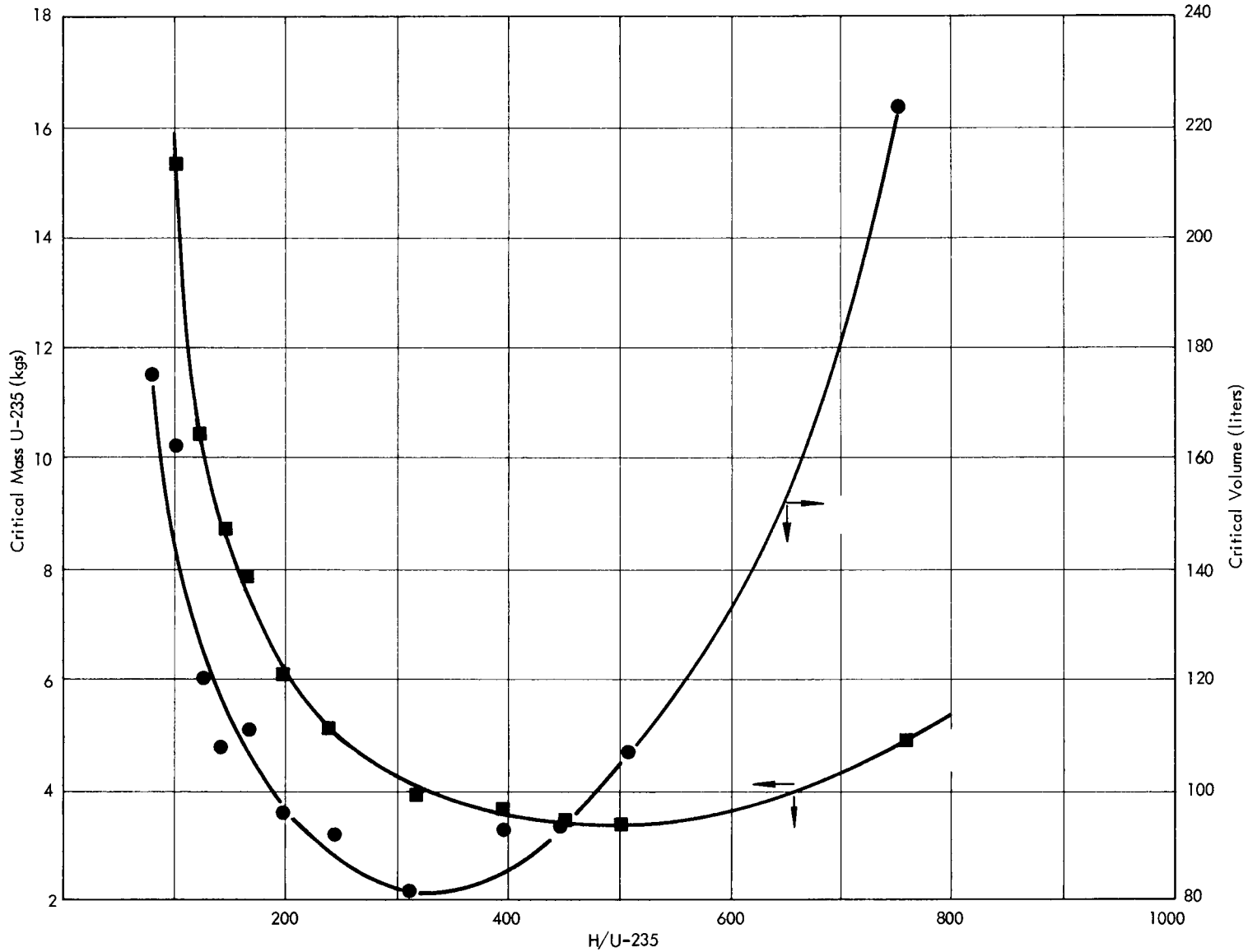


Figure L-1.2. MINIMUM MEASURED REFLECTED CRITICAL MASSES AND VOLUMES AT EACH MODERATION OF U_3O_8-ORGANIC MIXTURE FOR 4.9% U-235 ISOTOPIC ENRICHMENT. (Reactors were Approximately Cubical in Shape, and Weighing Factors were Applied to Distribute the Effects of Surface Irregularities over the Array. "Organic" Refers to Glyceryl Tristerate. Cronin, Critical Mass Studies, Part X, Uranium of Intermediate Enrichment, ORNL-2968, September 20, 1960.)

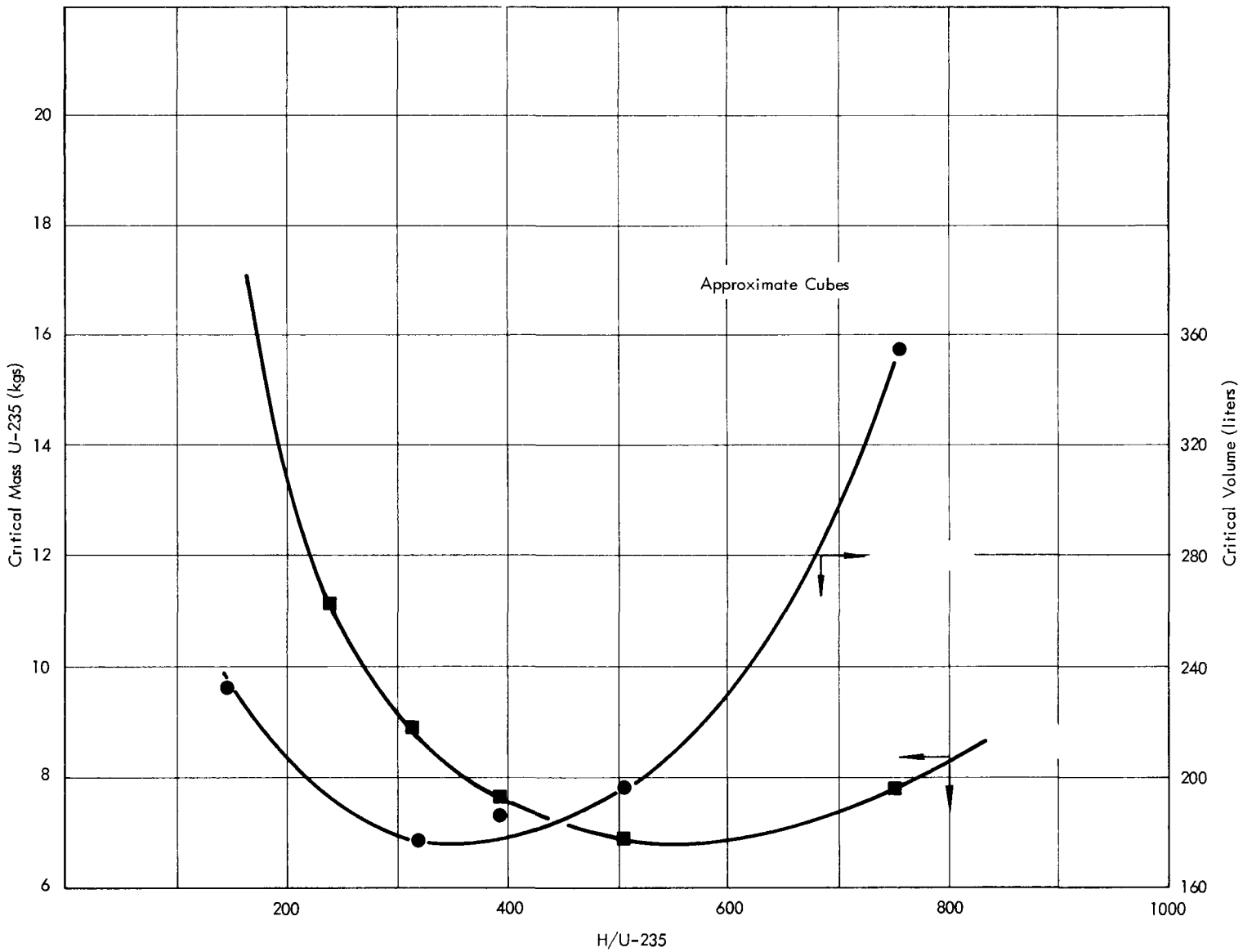


Figure L-1.3. MINIMUM MEASURED BARE CRITICAL MASSES AND VOLUMES AT EACH MODERATION OF U_3O_8-ORGANIC MIXTURE FOR 4.9% U-235 ISOTOPIC ENRICHMENT. (Reactors were Approximately Cubical in Shape, and Weighing Factors were Applied to Distribute the Effects of Surface Irregularities over the Array. "Organic" Refers to Glyceryl Tristerate. Cronin, Critical Mass Studies, Part X, Uranium of Intermediate Enrichment, ORNL-2968, September 20, 1960.)

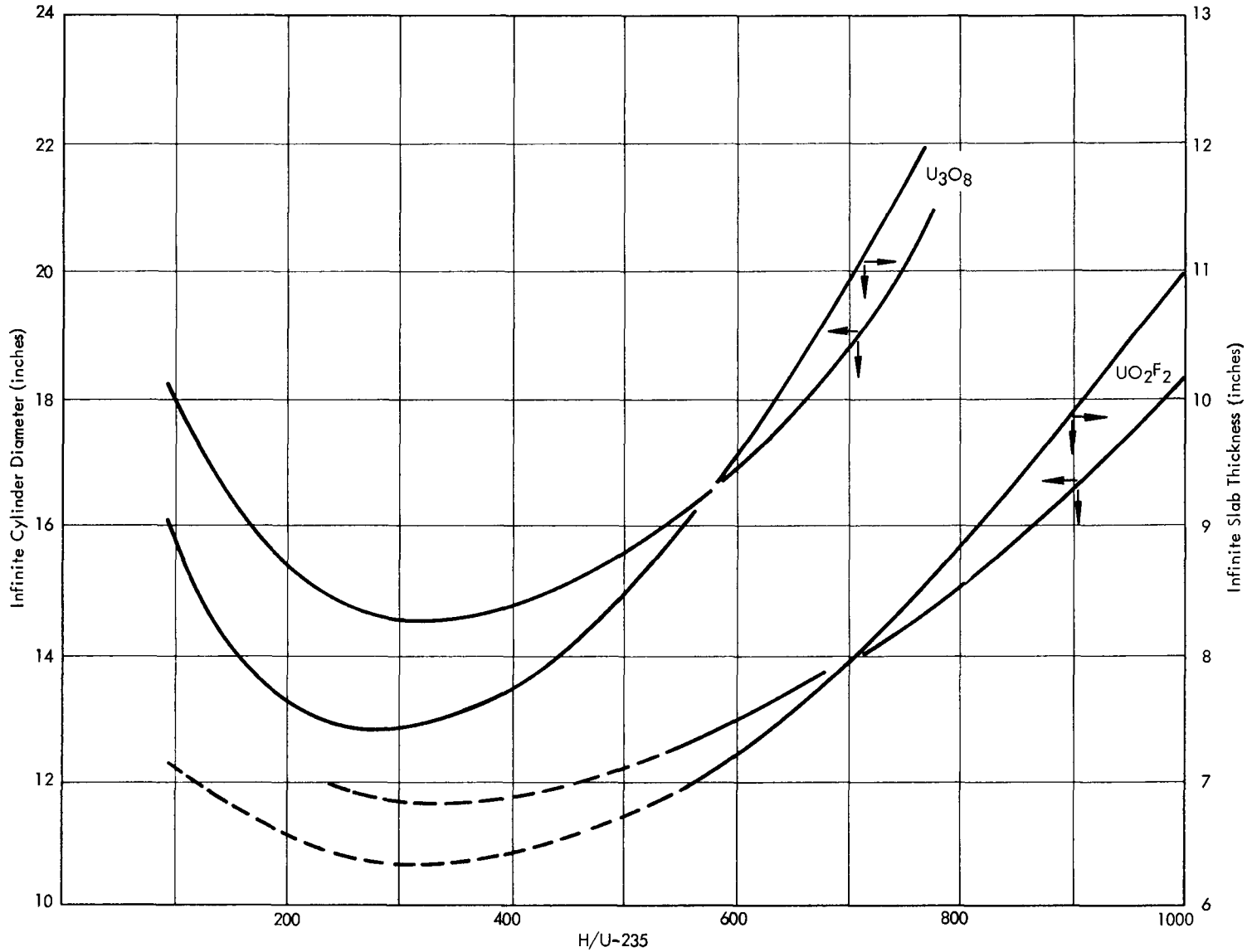


Figure L-1.4. INFINITE CYLINDER DIAMETER AND INFINITE SLAB THICKNESS FOR REFLECTED U_3O_8-ORGANIC AND URANYL FLUORIDE SOLUTION AT 4.9% ISOTOPIC ENRICHMENT. (Values were Calculated by Buckling Transformations Using Empirically Determined Extrapolation Lengths. Containers were Aluminum. Cronin, Critical Mass Studies, Part X, Uranium of Intermediate Enrichment, ORNL-2968, September 20, 1960.)

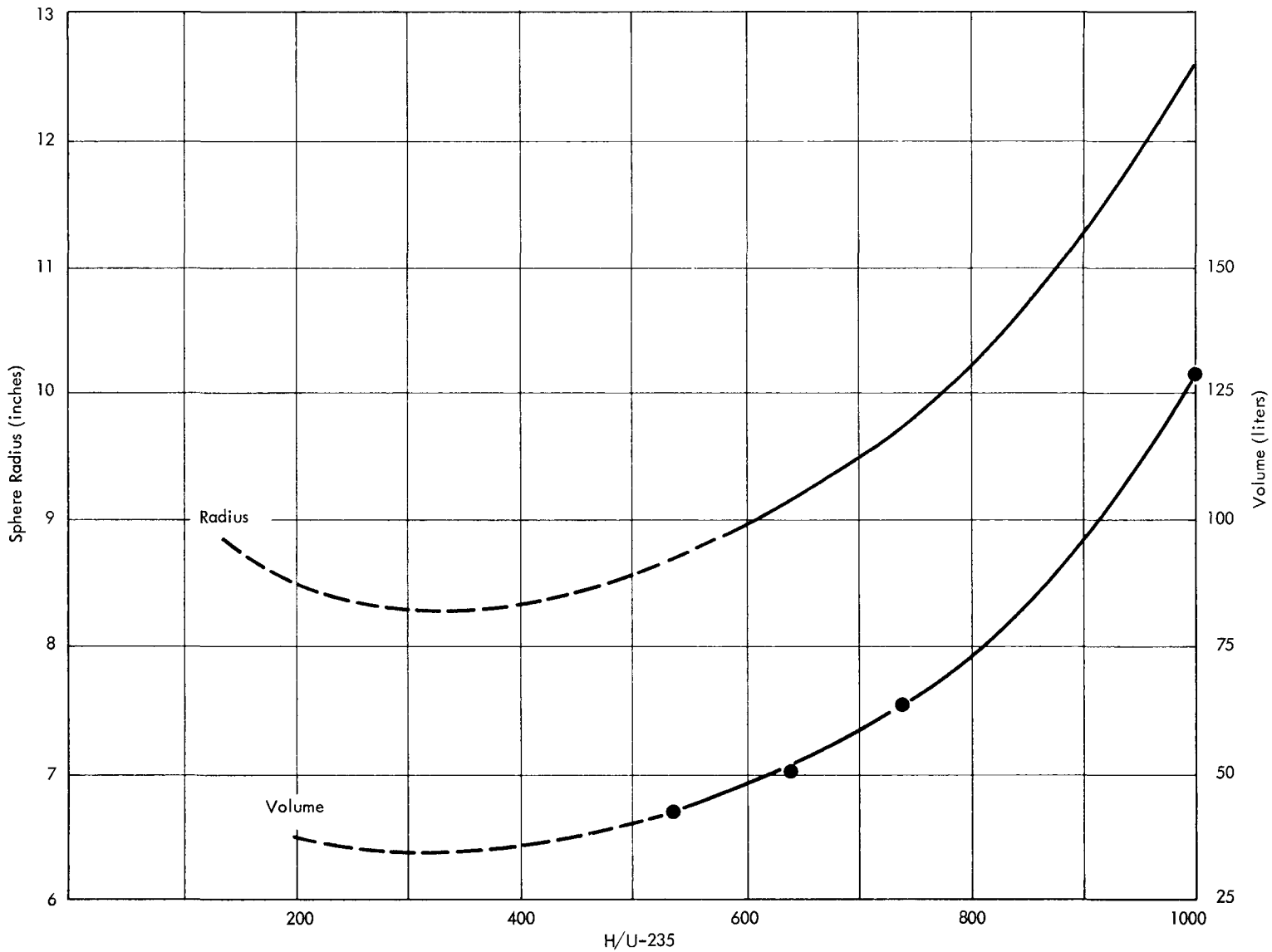
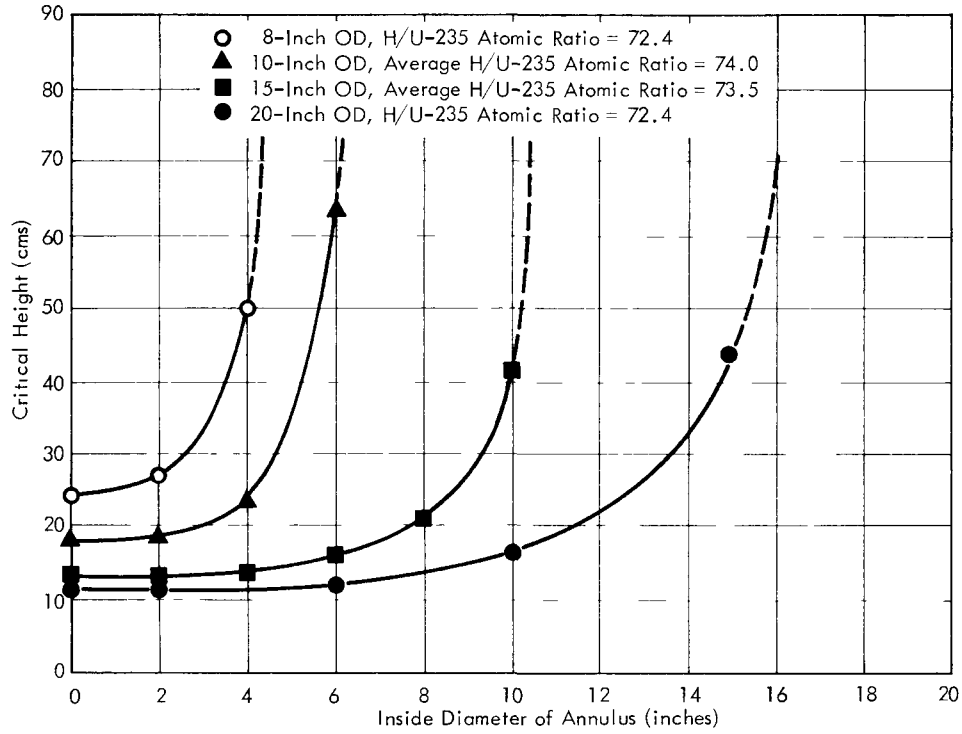
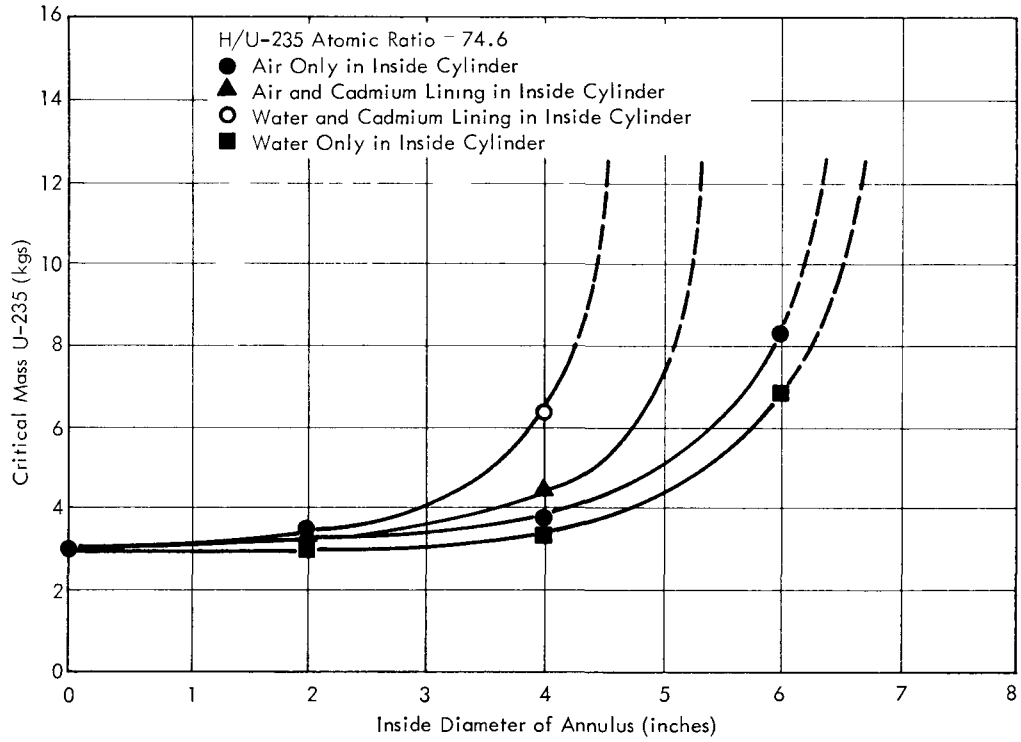


Figure L-1.5. CRITICAL SPHERE RADIUS AND VOLUME FOR REFLECTED URANYLFLUORIDE SOLUTIONS AT 4.9% ISOTOPIC ENRICHMENT. (Values were Calculated by Buckling Transformations Using Empirically Determined Extrapolation Lengths. Containers were Aluminum. Cronin, Critical Mass Studies, Part X, Uranium of Intermediate Enrichment, ORNL-2968, September 20, 1960.)

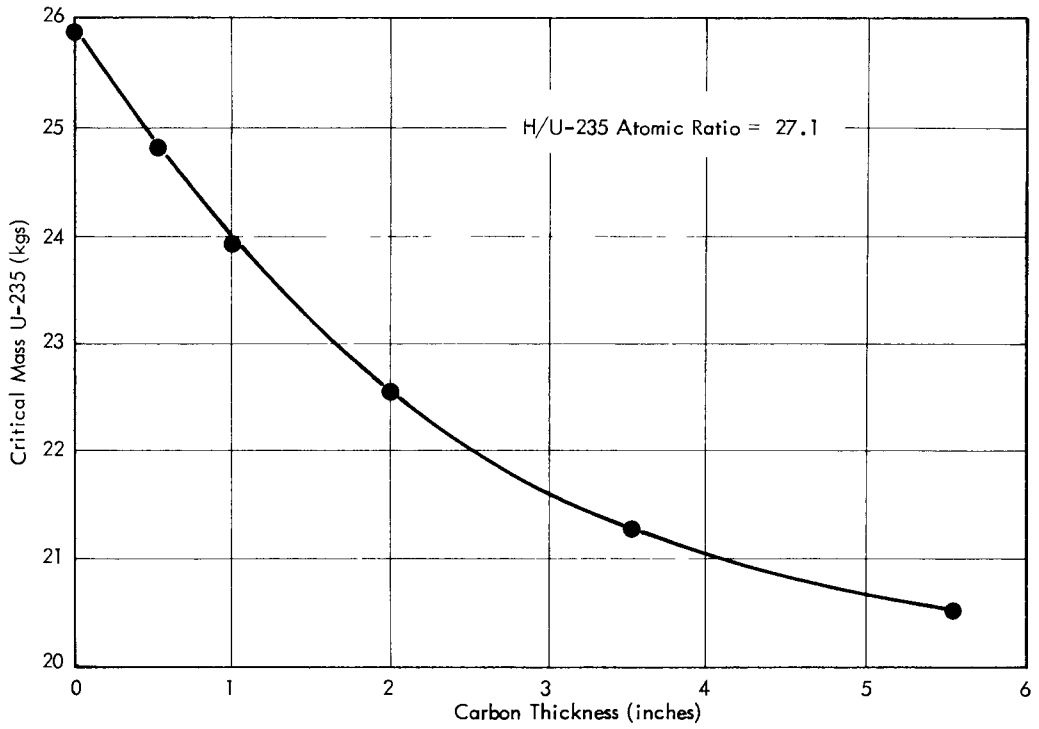


(a) Inside Cylinder Filled with Water

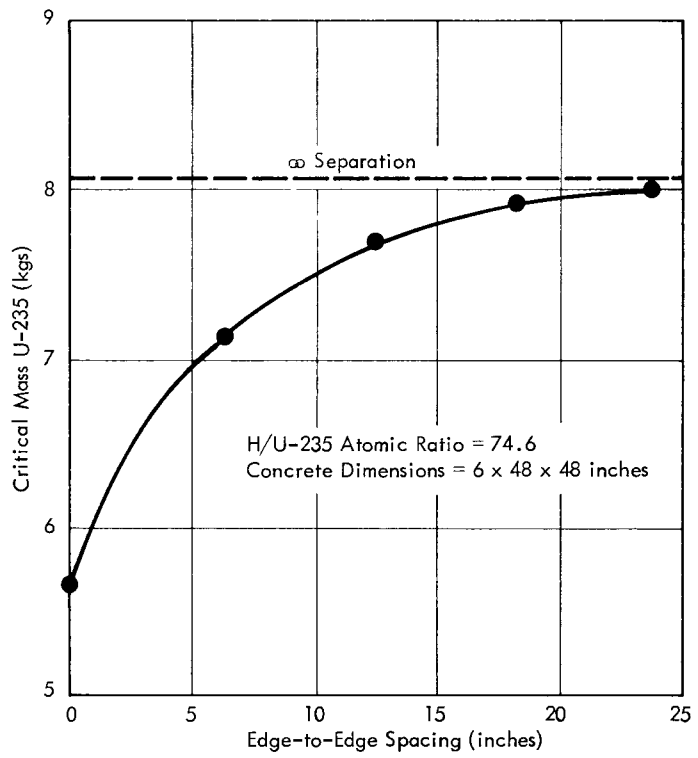


(b) Inside Cylinder Filled with Air, or Water, with or without Cadmium Lining

Figure M-1.1. CRITICAL MASS AS A FUNCTION OF THE INSIDE DIAMETER OF A WATER-REFLECTED 10-INCH OD ANNULUS CONTAINING AN ENRICHED (~90% U-235) URANYL FLUORIDE SOLUTION. (Figures 17 and 18 of Fox, Gilley, and Callihan, ORNL-2367.)

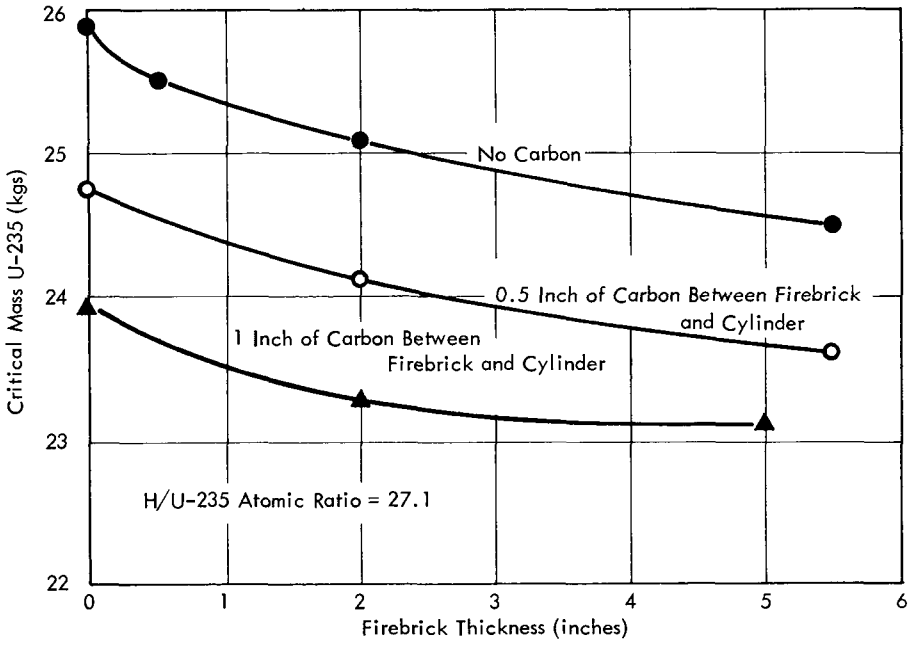


(a) Single Carbon Reflector

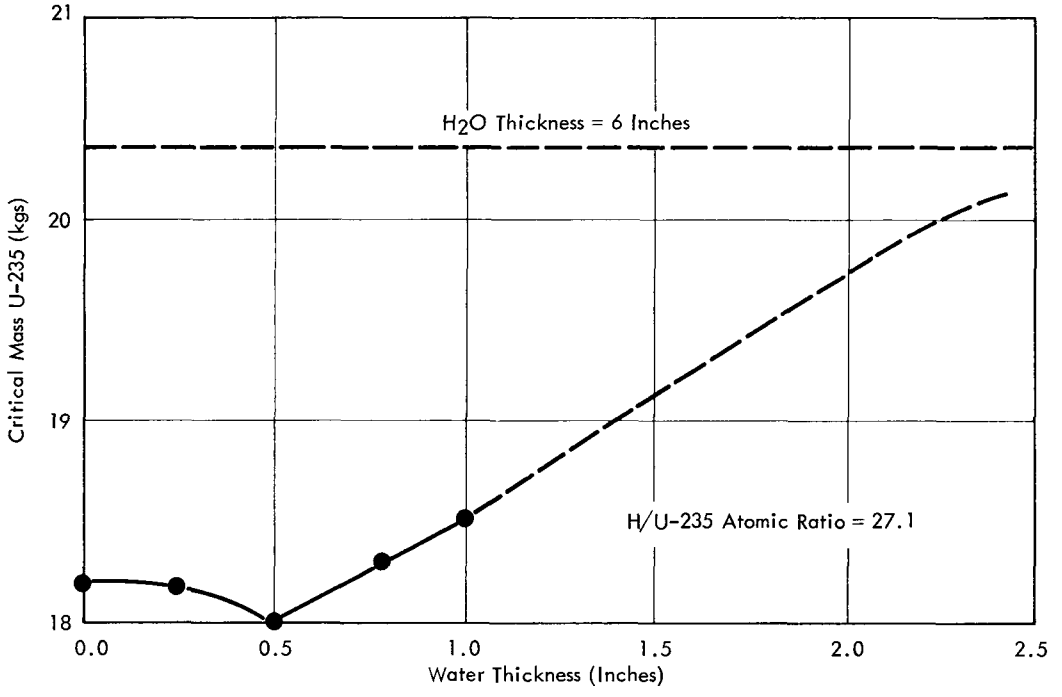


(b) Air Separation between Reactor and Concrete Wall

Figure N-1.1. **CRITICAL MASS AS A FUNCTION OF VARIOUS REFLECTORS.** (Curve (a) Refers to a Carbon Reflector on the Bottom of a 20-Inch Aluminum Cylinder Containing Enriched Uranium Solution. Curve (b) Relates the Critical Mass to the Edge-to-Edge Separation of a 9-Inch-Diameter Stainless Steel Cylinder Containing Enriched Uranium Solution and a 6-Inch-Thick Concrete Wall. Figures 20 and 22 of Gilley, Fox, and Callihan, ORNL-2367.)



(a) Carbon and Firebrick Reflector



(b) Water between Cylinder and 5.5-Inch Carbon Reflector

Figure N-1.2. **CRITICAL MASS AS A FUNCTION OF VARIOUS REFLECTORS.** (Curve (a) Refers to Various Combinations and Thicknesses of Carbon and Firebrick as a Reflector on the Bottom of a 20-Inch-Diameter Aluminum Cylinder Containing an Enriched Uranium Solution. Curve (b) Relates the Critical Mass to the Thickness of Water between the Bottom of a 20-Inch-Diameter Cylinder Containing an Enriched Uranium Solution and a 5.5-Inch-Thick Carbon Reflector. Figures 21 and 23 of Gilley, Fox, and Callihan, ORNL-2367.)

Table O-1.1

MINIMUM CRITICAL PARAMETERS FOR INDIVIDUAL METAL PIECES

All values refer to pure fissionable materials having a thick reflector of water or its nuclear equivalent only. In general, they are extensions of experimental data to conditions of greatest reactivity for the conditions concerned; eg, spherical geometry is implied for mass and volume data. Values pertain only to single masses without re-entrant sections or marked concavities. Bundles of rods and accumulations of pellets are specifically excluded.

Basic Nuclear Parameter	Minimum Critical Value		
	U-235	U-233	Pu-239
Mass (kgs)	22 8	8 0	5 6
Cylinder Diameter (inches)	2 9	--	--
Slab Thickness (inches)	0.6	--	--
Volume (l)	1.23	--	--

Source: Callihan, A. D., "Values of Nuclear Variables", Memorandum, June 25, 1958. Mihalczo and Lynn, Neutron Multiplication Experiments with Enriched Uranium Metal in Slab Geometry, CF-61-4-33, April 10, 1961.

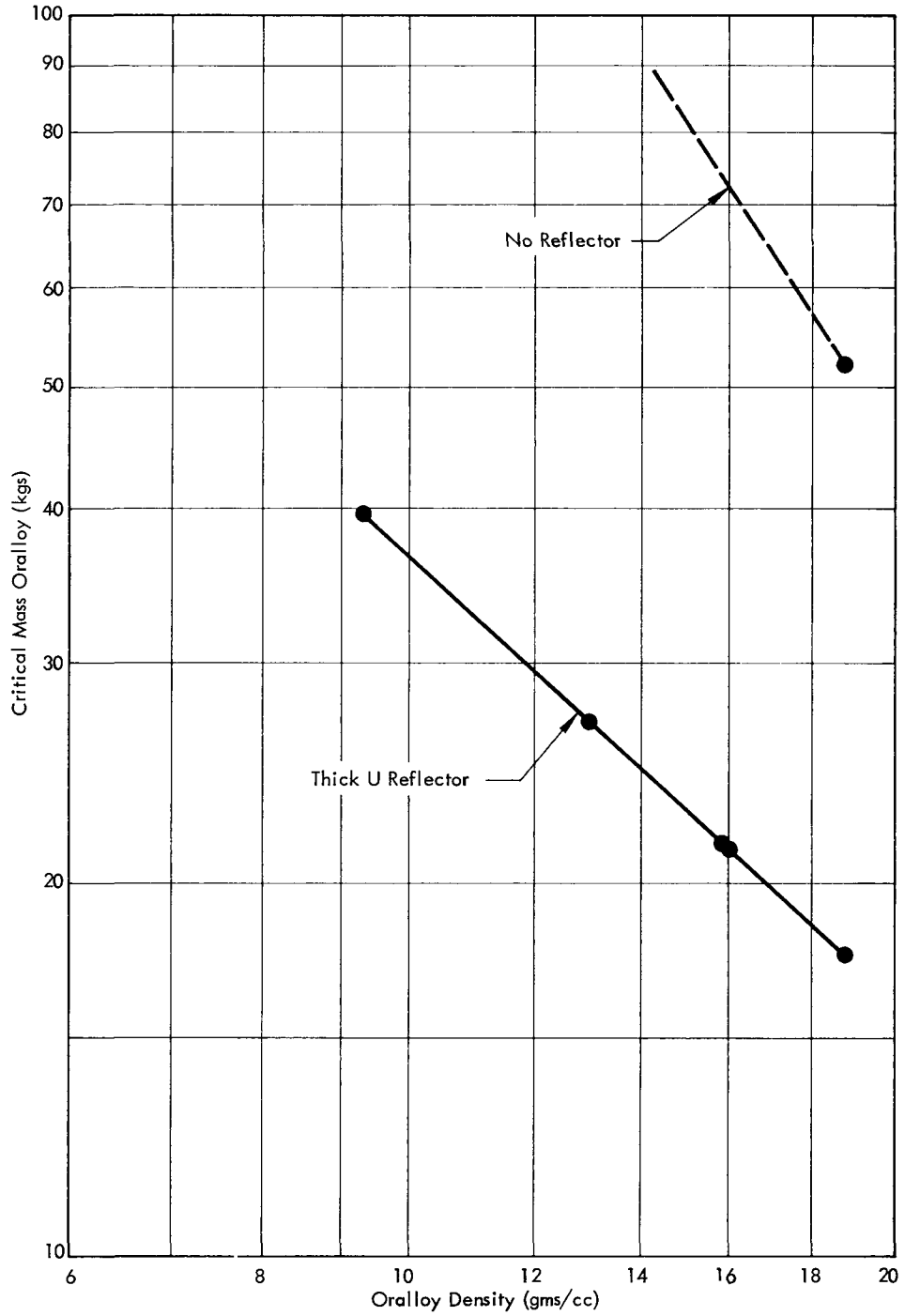


Figure O-2.1. CRITICAL MASS OF URANIUM METAL SPHERES AS A FUNCTION OF THE URANIUM METAL DENSITY FOR A THICK REFLECTOR OF URANIUM OF NORMAL ISOTOPIC ENRICHMENT AND DENSITY. (The Core of Uranium was Enriched to 93.5% U-235. The Broken Line Represents the Computed Relation for the Core Material without Reflector. Figure 5 of Mallary, Paxton, and White, LA-1958.)

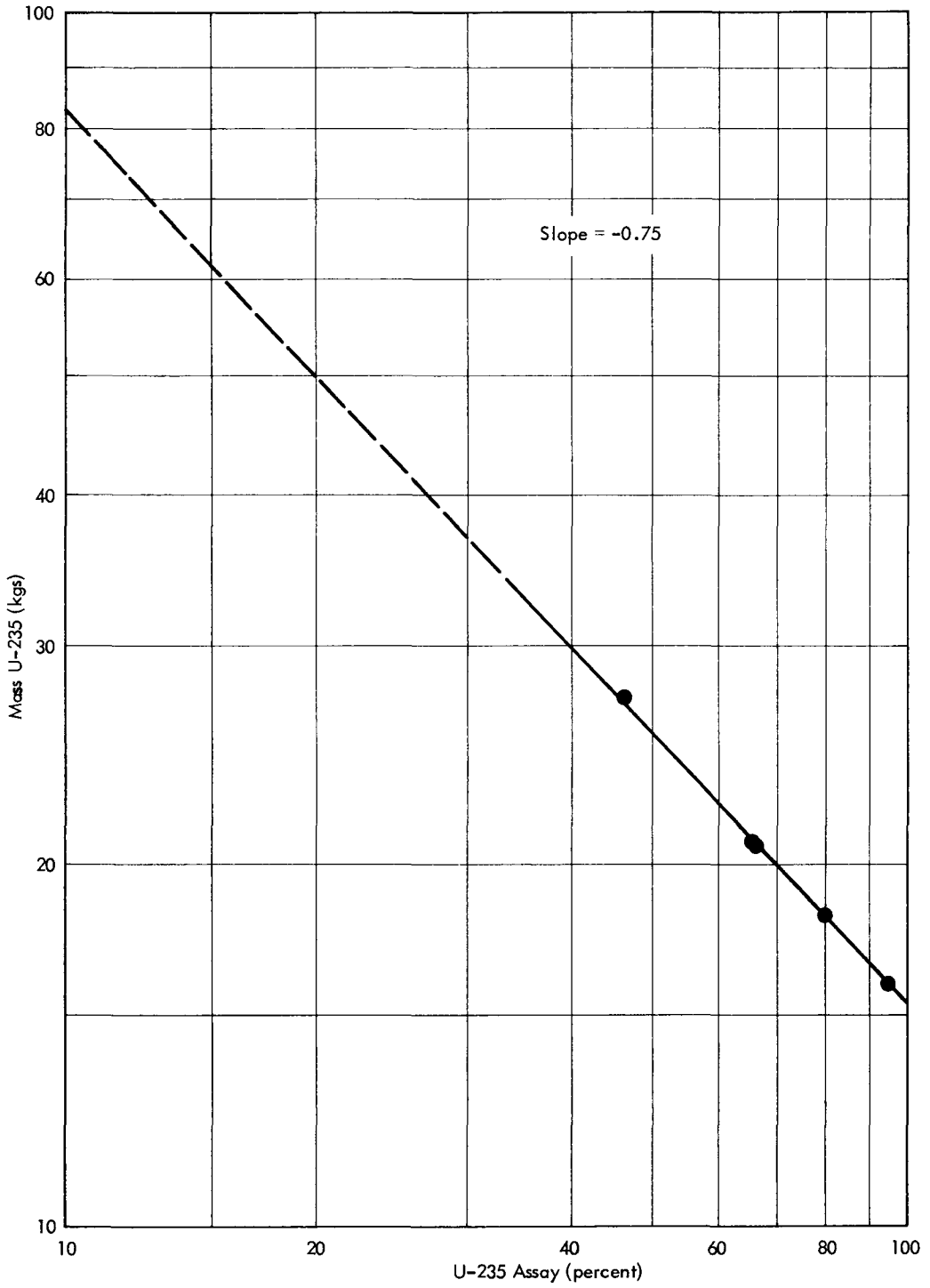


Figure O-3.1. CRITICAL MASS OF URANIUM METAL SPHERES AS A FUNCTION OF THE U-235 ISOTOPIC ENRICHMENT FOR AN EFFECTIVELY INFINITE REFLECTOR OF URANIUM OF NORMAL ISOTOPIC ENRICHMENT. (No Corrections have been Attempted for Slight Variation in the Density of the Core and in the Thickness of the Reflector. Figure 5 of Gwin and Mee, Y-1248.)

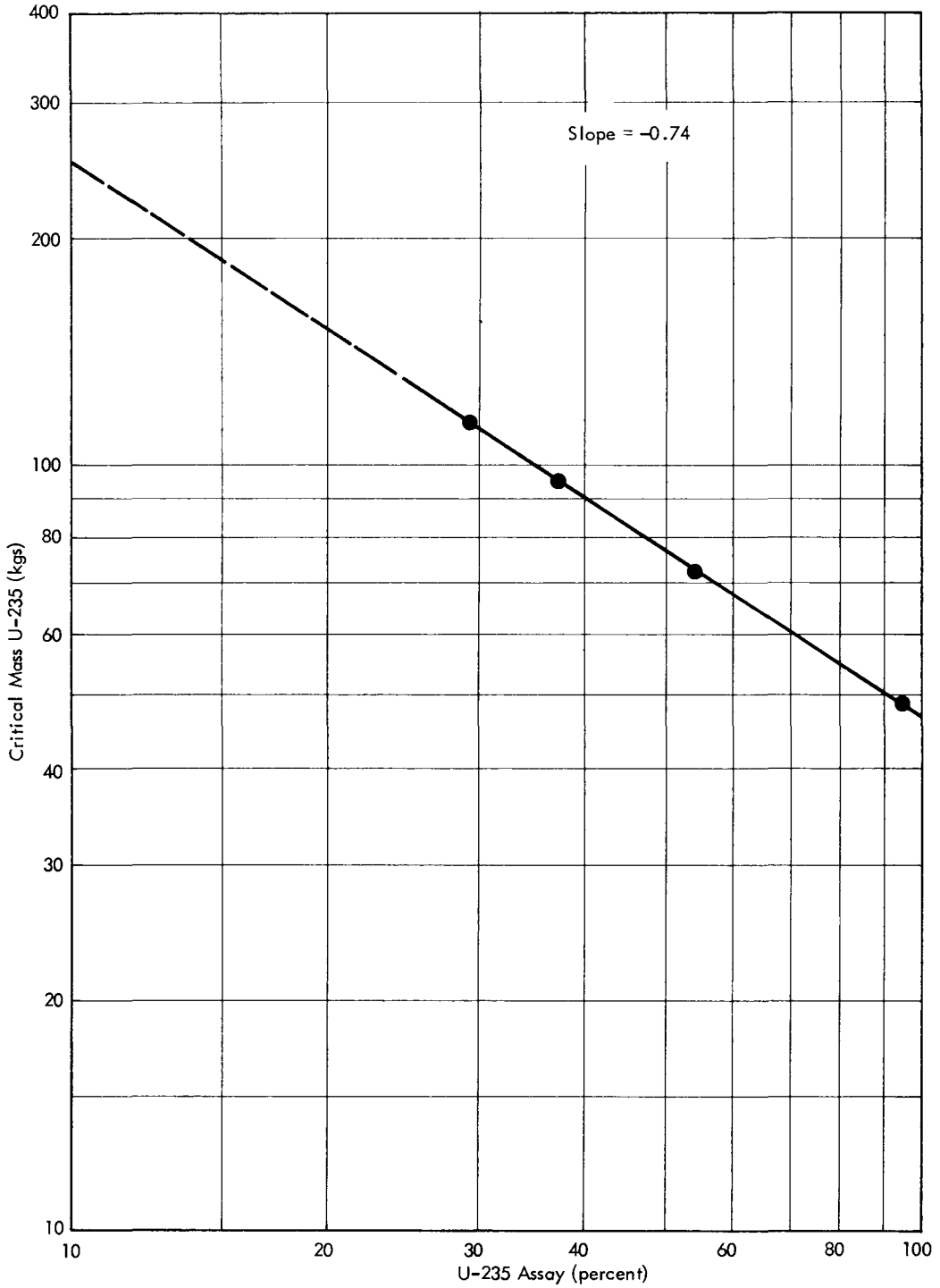


Figure O-3.2. CRITICAL MASS OF UNREFLECTED URANIUM METAL SPHERES AS A FUNCTION OF THE U-235 ISOTOPIC ENRICHMENT. (The Cylindrical Data were Converted to Spherical Geometry by Elementary Pile Theory, Making the Assumption that the Extrapolation Length Found for Uranium (2.745 cms) will Give Good Results for Lower Enrichment Material. Figure 6 of Gwin and Mee, Y-1248.)

Table P-1.1

CRITICAL ASSEMBLIES OF URANIUM METAL AT ≈90% U-235 ISOTOPIC ENRICHMENT

Experimental cylinder heights were determined using the h/d ratio and the cylinder diameter given by Paxton (W-2-342, Table 1). Isotopic concentration was between 93.7 and 94% U-235.

Reflector	Diameter (cms)	Height (cms)	Mass (kgs U)	Maximum Multiplication
None	12.07	> 46	> 100	13.3
	13.97	24.59	70.6	96
	16.18	15.42	58.8	85
	17.78	12.85	59.2	76
	19.05	11.62	61.9	54
Water	10.11	19.21	28.5	200
	12.06	11.82	25.3	101
	13.97	9.22	26.0	200
	16.19	7.45	27.6	150
	17.78	6.49	29.5	108
	19.05	5.72	30.9	53
Graphite	8.26	24.37	24.0	17
	10.11	13.14	19.5	109
	12.065	9.83	18.7	82
	13.97	6.92	19.7	78
	16.19	5.59	21.3	107
	19.05	4.48	24.1	105

Source: Gwin and Mee, Y-1248.

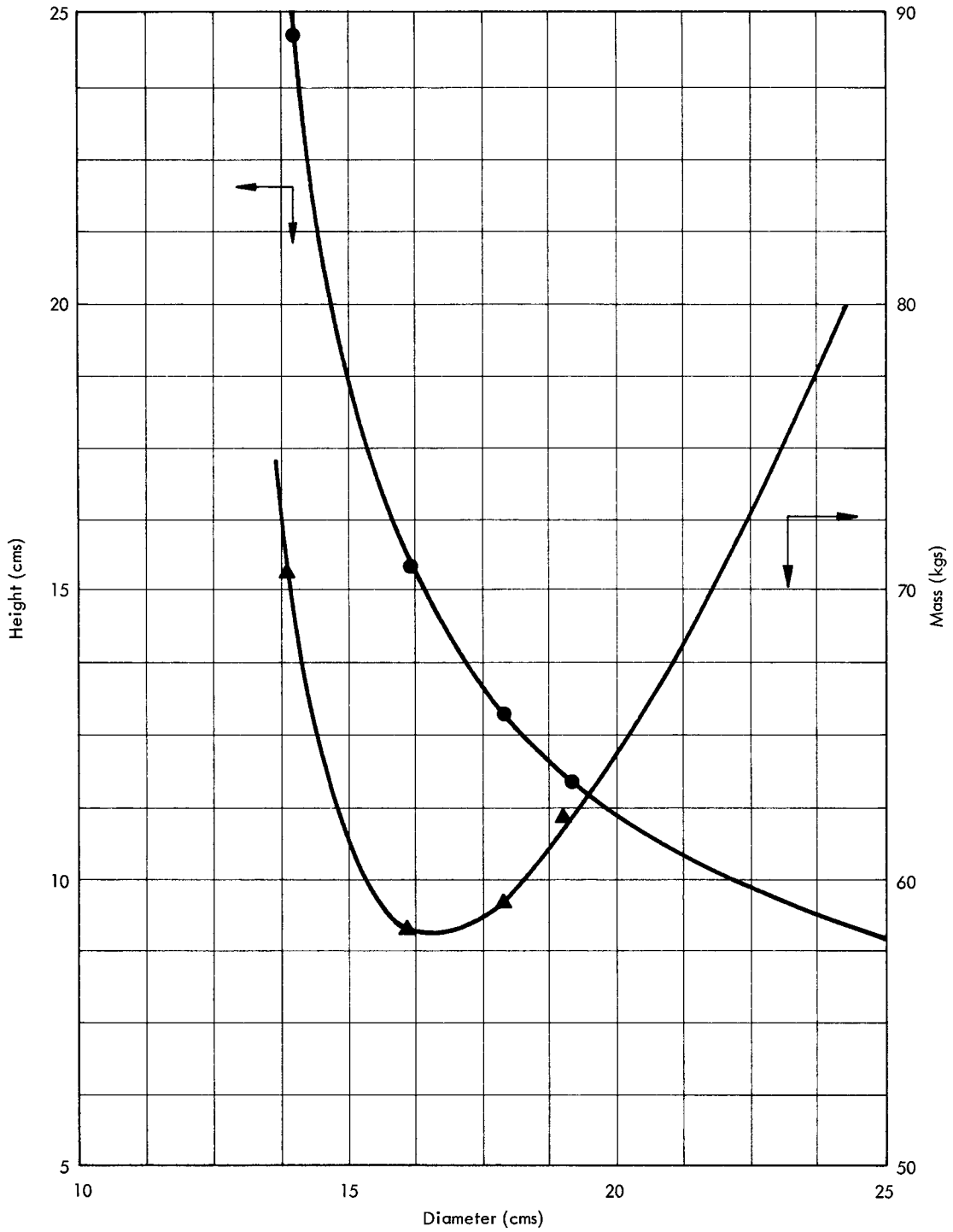


Figure P-1.1. CRITICAL MASS AND HEIGHT OF AN UNREFLECTED URANIUM METAL CYLINDER AS A FUNCTION OF THE CYLINDER DIAMETER. (The Uranium was Enriched to ~90% U-235. Curves were Drawn through the Experimental Points Using the Empirical Values of 2.745 cms for Extrapolation Length and 0.07201 cm^{-2} for the Effective Buckling. Figure 1 of Gwin and Mee, Y-1248.)

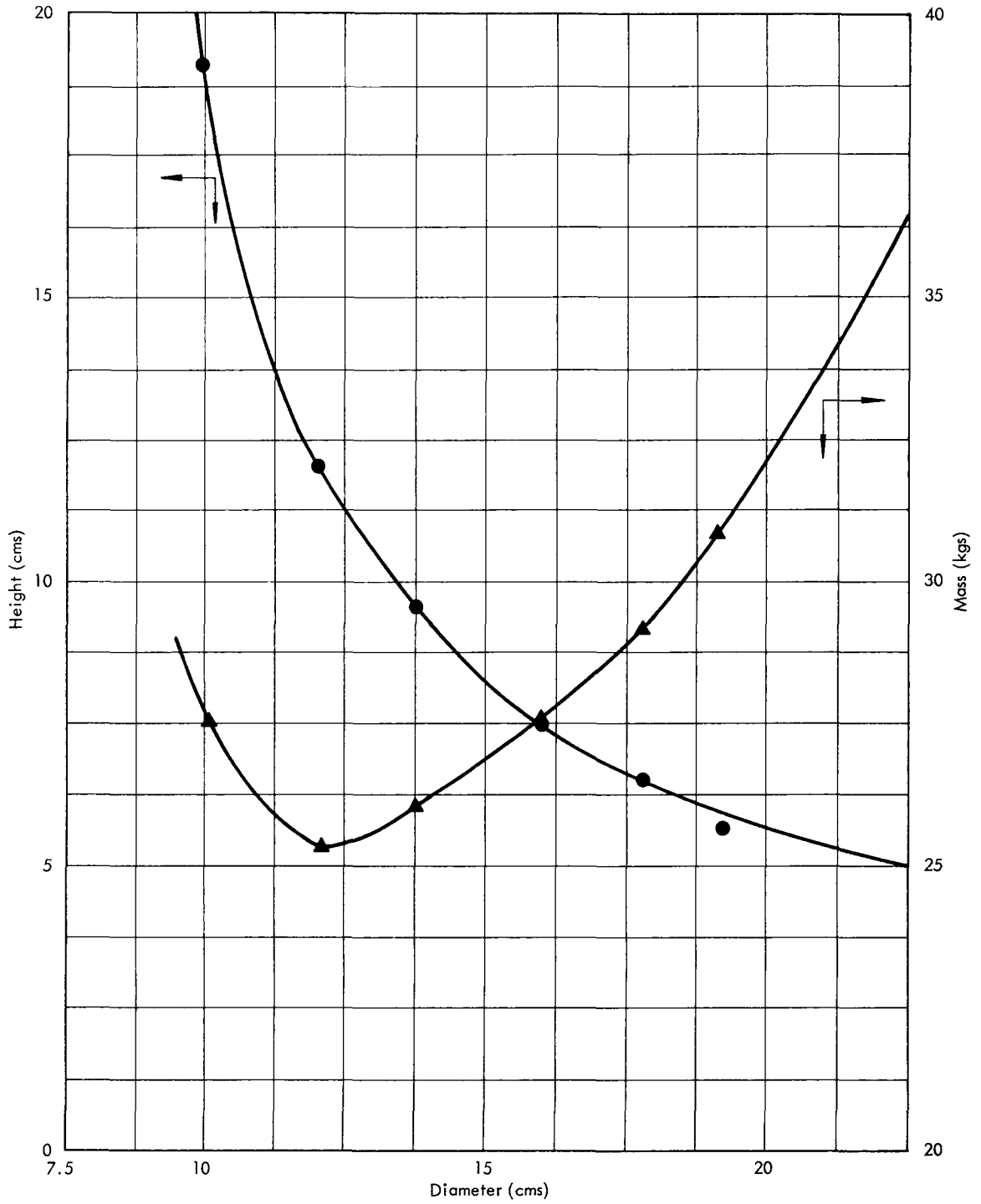


Figure P-1.2. CRITICAL MASS AND HEIGHT OF WATER-REFLECTED URANIUM METAL CYLINDERS AS FUNCTIONS OF THE CYLINDER DIAMETER. (The Uranium was Enriched to ~90% U-235. Reflector Thickness was Effectively Infinite. Curves were Drawn through the Experimental Points Using the Empirical Relationship: $(d - 7.34)(h - 1.84) = 48\ cm^2$, where d and h are the Cylinder Diameter and Height. Figure 2 of Gwin and Mee, Y-1248.)

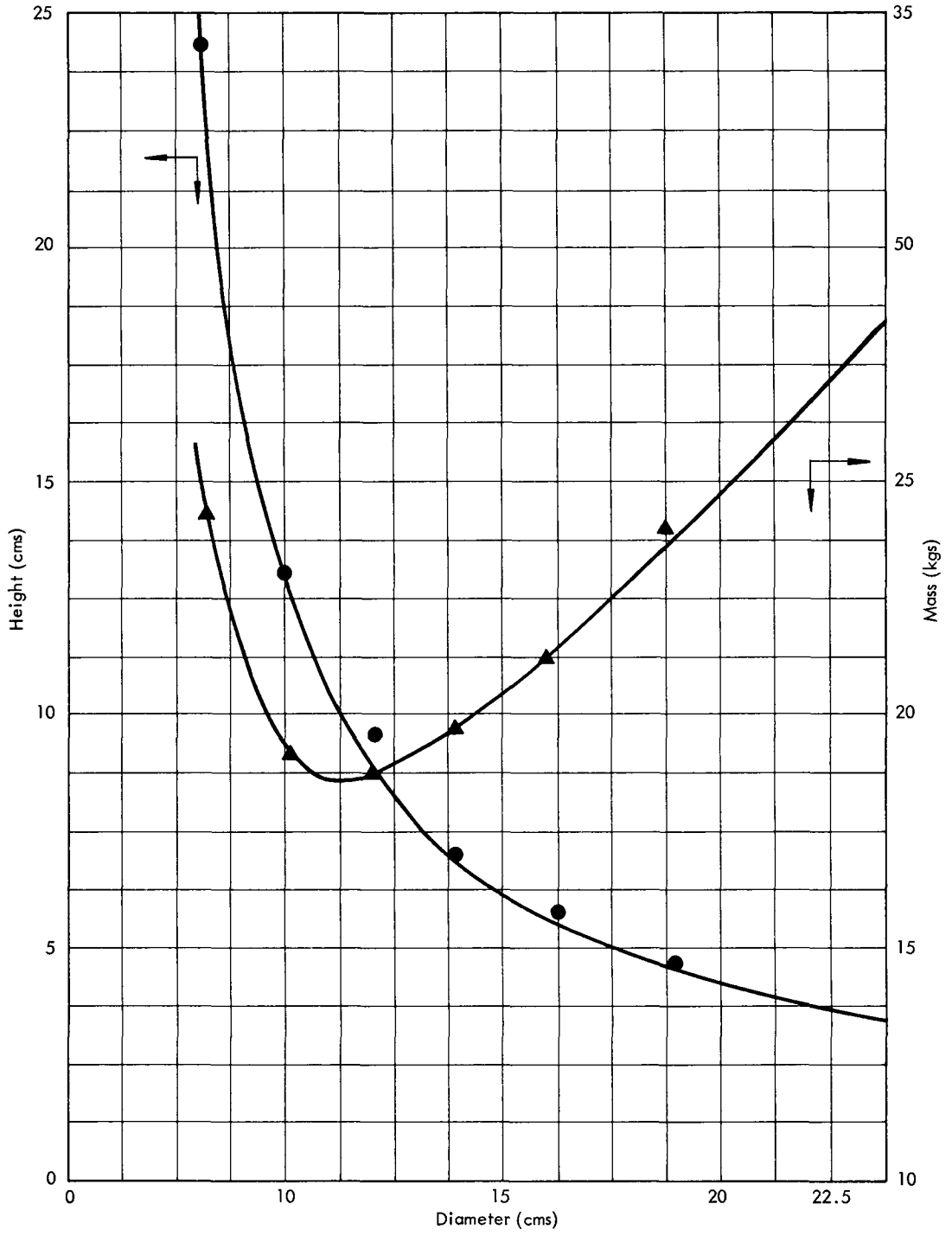


Figure P-1.3. CRITICAL MASS AND HEIGHT OF GRAPHITE-REFLECTED URANIUM CYLINDERS. (Reflector Thickness was Effectively Infinite. The Uranium was Enriched to ~90% U-235. Curves were Drawn through the Experimental Points Using the Empirical Relationship: $(d-6.21)(h-0.83) = 48\ cm^2$, where d and h are the Cylinder Diameter and Height. Figure 3 of Gwin and Mee, Y-1248.)

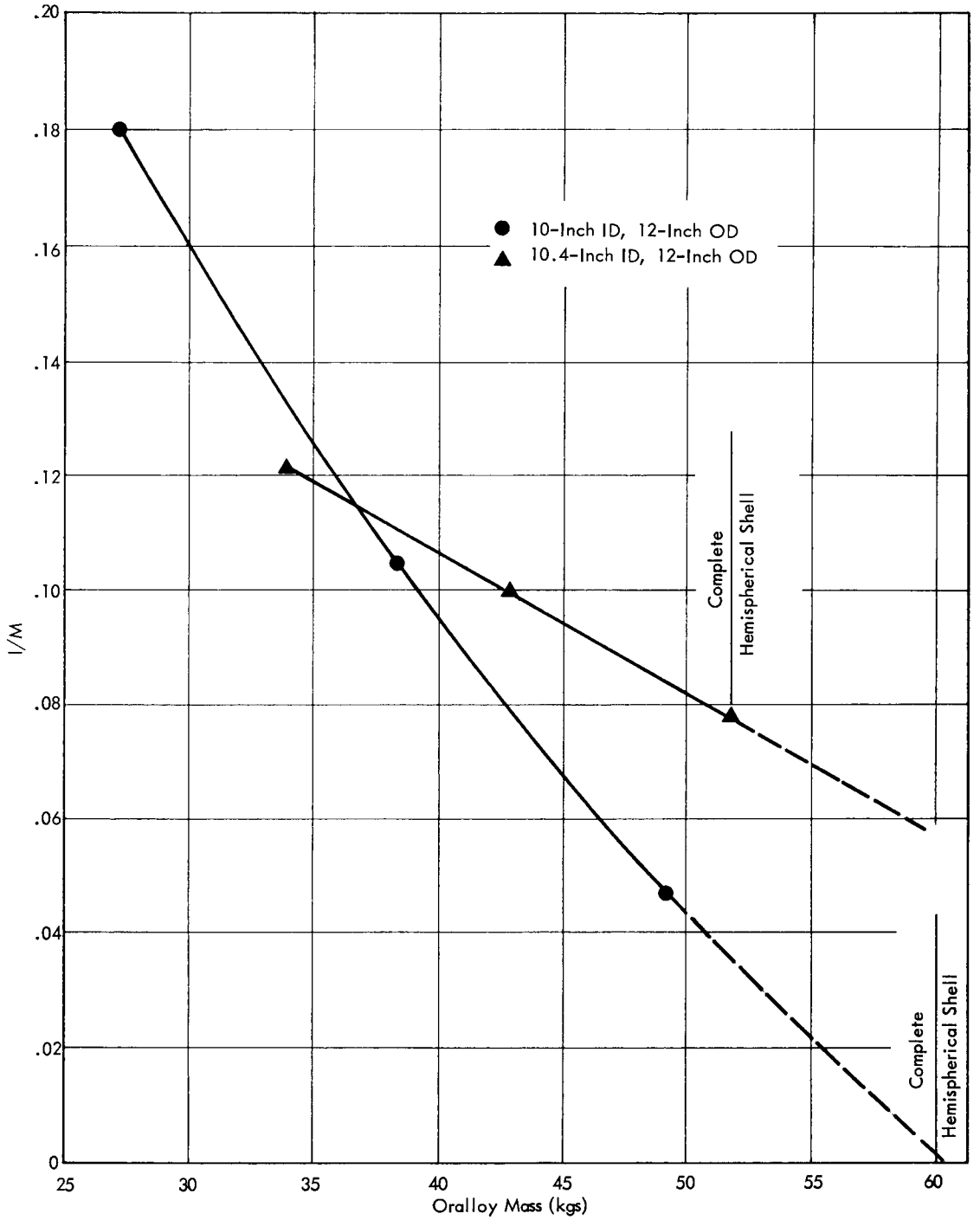


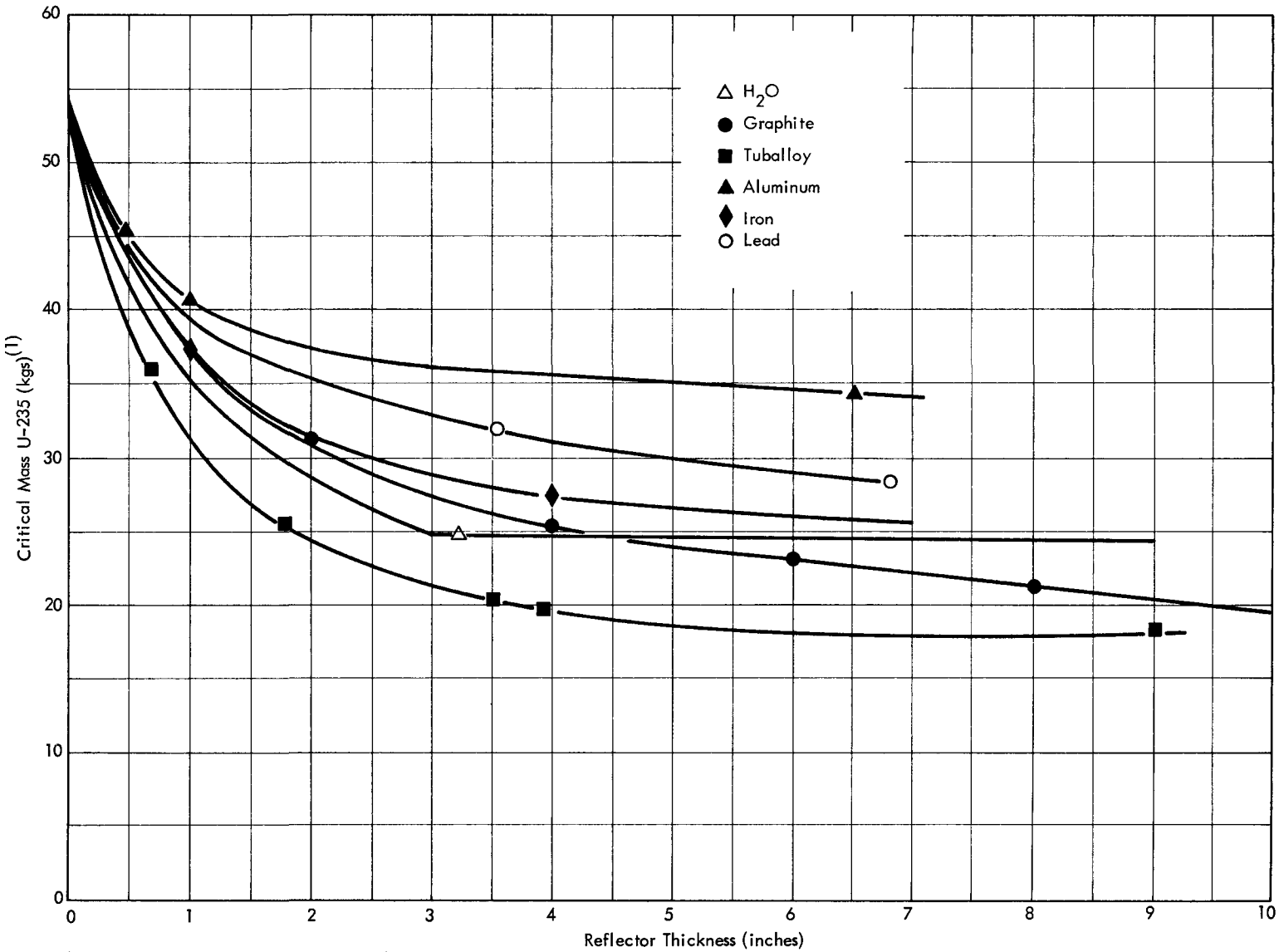
Figure Q-1.1. RECIPROCAL MULTIPLICATION AS A FUNCTION OF THE ORALLOY MASS OF TWO LARGE HEMISPHERICAL SHELLS IN INFINITE WATER TAMPING. (The 10-Inch-ID, 1-Inch-Wall Thickness Hemispherical Shell would be just Critical. Figure 5.2 of Hart, LA-1623.)

Table Q-2.1

CRITICAL MASSES OF $12\frac{1}{4}$-INCH-OD BY 6-INCH-ID ANNULI OF Oy (~ 93%) METAL

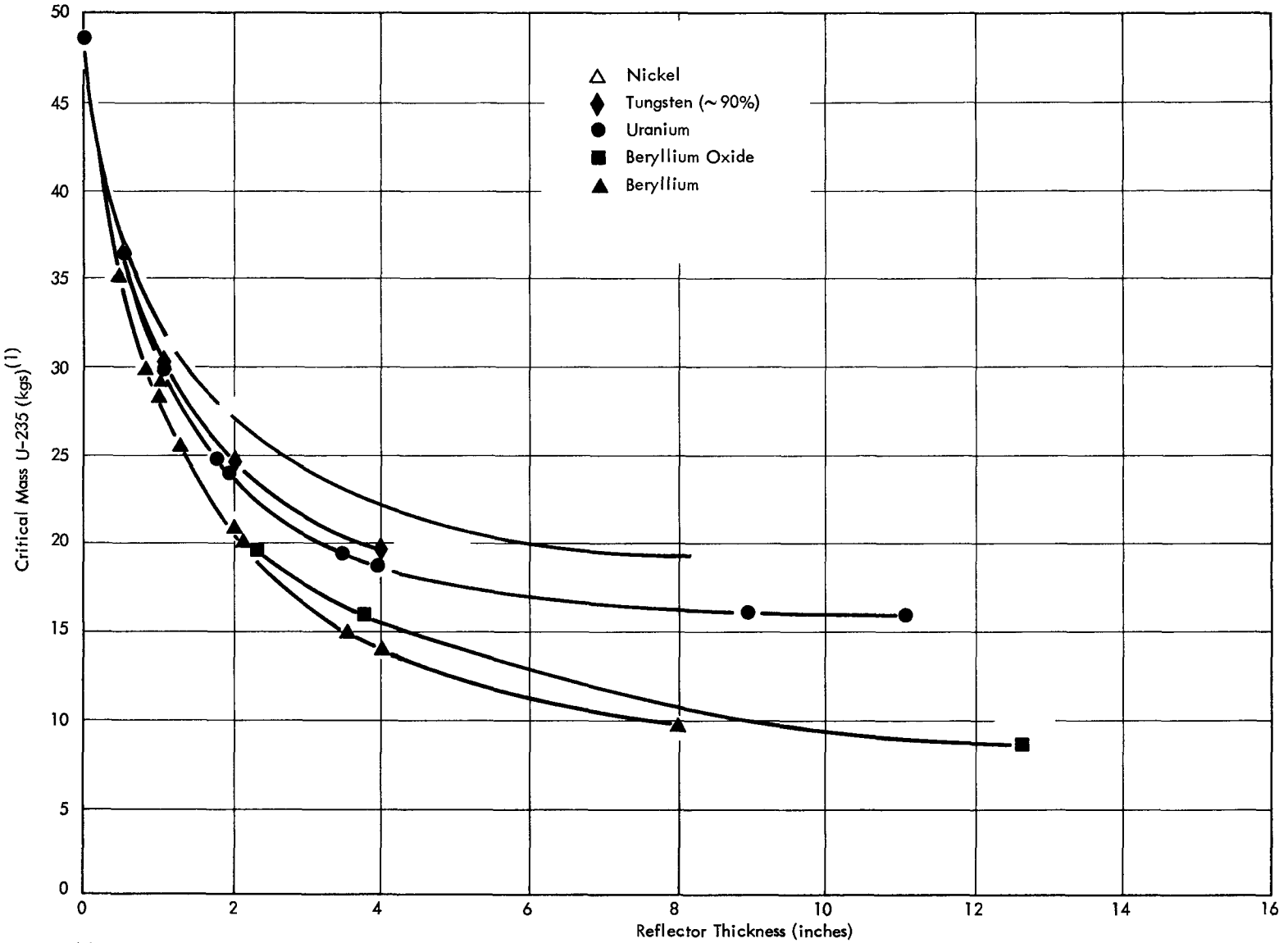
Reflector (material, thickness)	Critical Mass (kgs Oy)	Critical Height (inches Oy)
One-Inch Normal U, Complete (some excess)	82.7 ± 0.3	3.01
Three-Inch Normal U, Complete	55.9 ± 0.3	2.03
Three-Inch Polyethylene, Complete	60.6 ± 0.3	2.20
Two-Inch CS-312 Graphite (inner cylinder completely filled)	78.5 ± 0.3	2.86
Two-Inch Graphite Crucible, Same as Last Except Without Top Reflector (wall extends five inches above base of Oy)	97 ± 2	3.54
One-Inch Normal U In Two Inches of Polyethylene, Complete	54.5 ± 0.3	1.98
One-Inch Normal U In Two Inches of Polyethylene (no reflector in inner six-inch cylinder)	60.8 ± 0.3	2.21

Source: Paxton, H. C., Critical Data for Nuclear Safety Guidance, LAMS-2415, May 16, 1960.



(1) Content of oralloy at ρ = 18.8 gms/cc

Figure R-1.1. CRITICAL MASS OF SPHERICAL U-235 METAL AS A FUNCTION OF THE REFLECTOR THICKNESS. (See Figure R-1.2 for Additional Reflector Materials. The Isotopic Composition of the Uranium Metal was 93.5% by Weight and its Density was 18.8 gms/cc. Figure 4 of Gwin and Mee, Y-1248.)



(1) Content of oralloy at ρ = 18.8 gms/cc

Figure R-1.2. CRITICAL MASS OF SPHERICAL U-235 METAL AS A FUNCTION OF THE REFLECTOR THICKNESS. (See Figure R-1.1 for Additional Reflector Materials. The Isotopic Composition of the Uranium Metal was 93.5% by Weight and its Density was 18.8 gms/cc. Figure 6 of Paxton, N-2-850.)

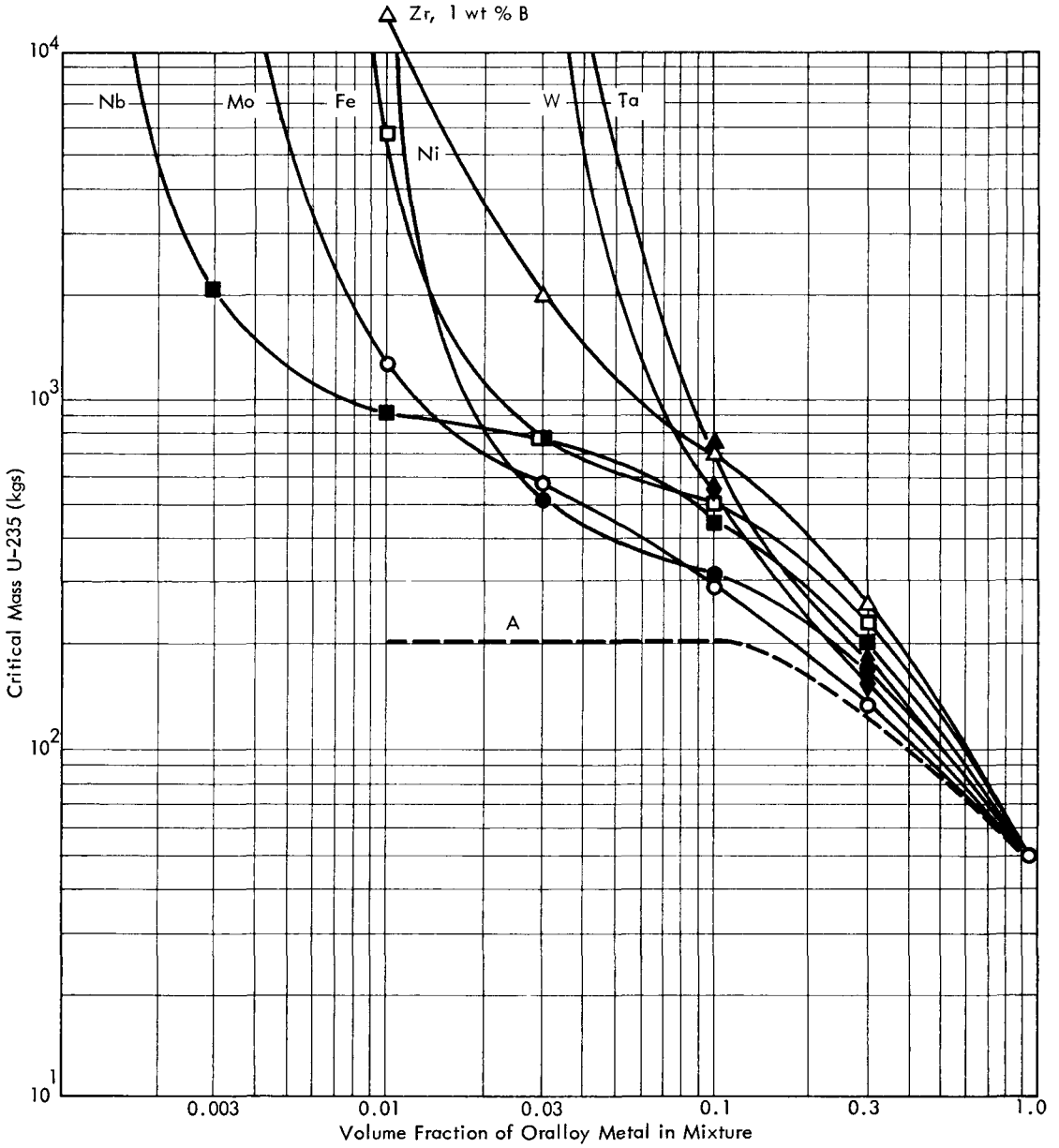


Figure S-1.1. CALCULATED CRITICAL MASSES OF BARE SPHERES AS FUNCTIONS OF THE VOLUME FRACTION OF NONHYDROGENOUS DILUTED ORALLOY (~90% U-235) WITH NONFISSIONABLE METALS. (Paxton, LADC-2528. See Figure R-1.4 for Additional Diluting Materials.)

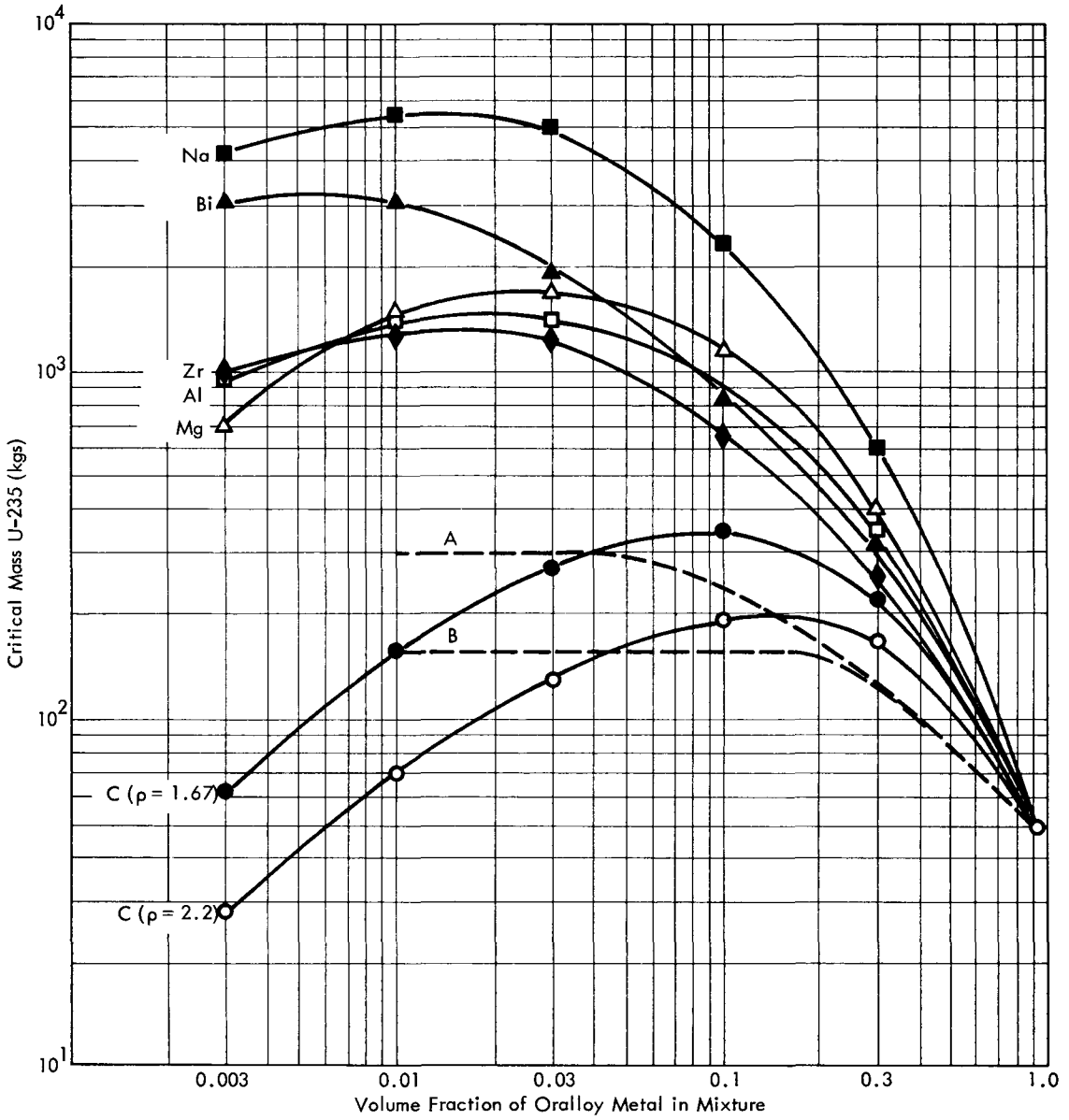
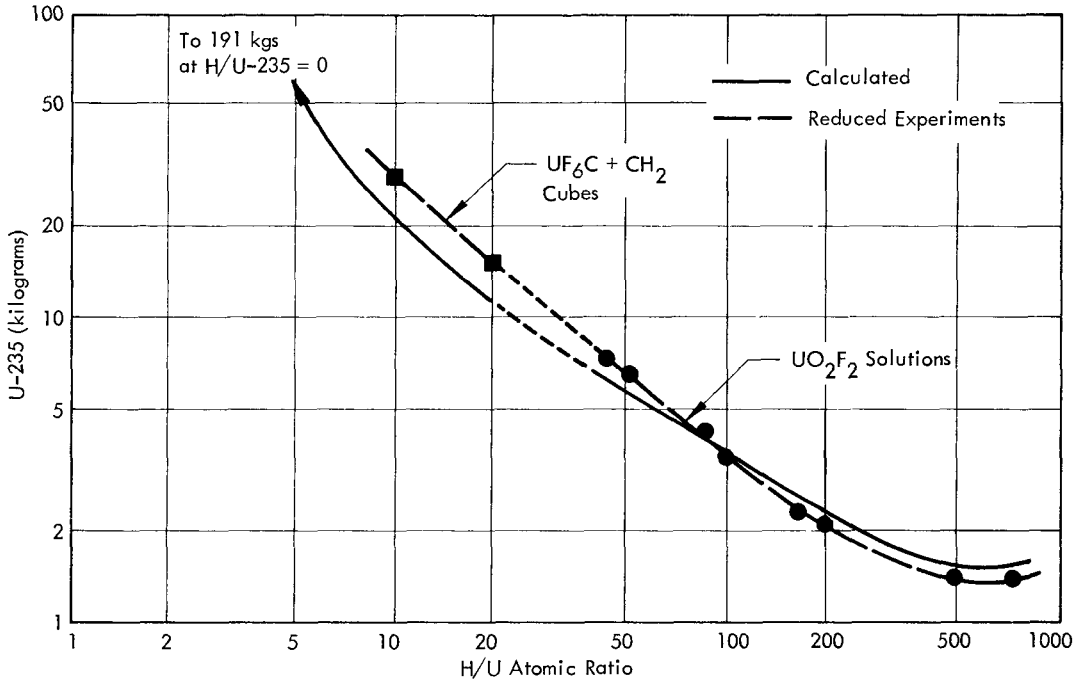
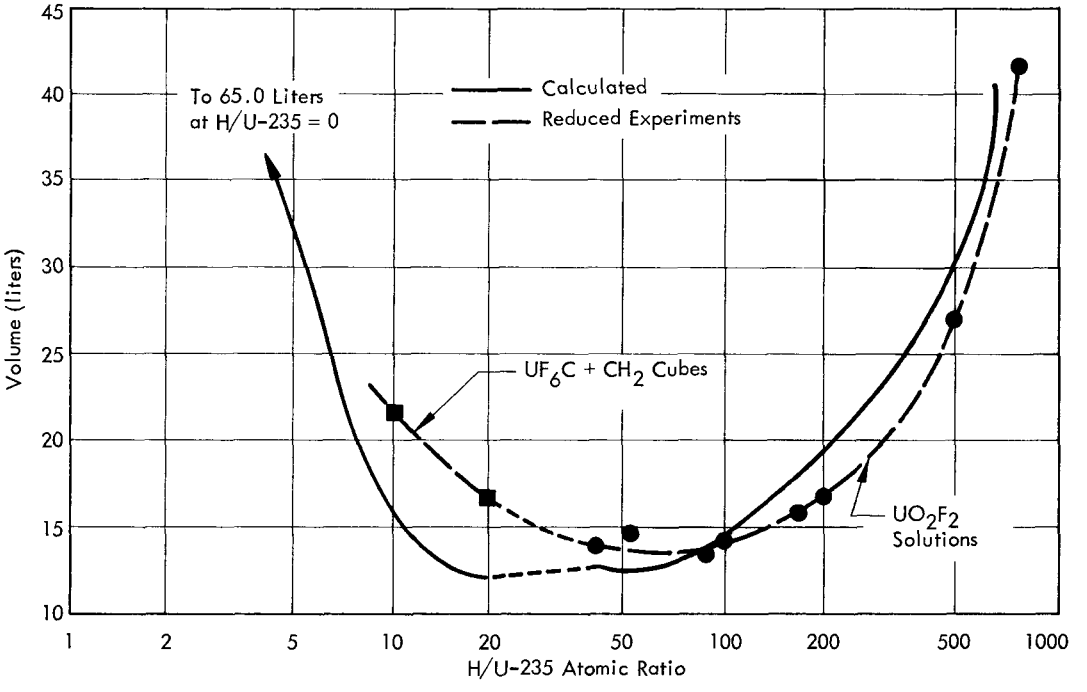


Figure S-1.2. CALCULATED CRITICAL MASSES OF BARE SPHERES AS FUNCTIONS OF THE VOLUME FRACTION OF NONHYDROGENOUS DILUTED ORALLOY (~90% U-235) WITH NONFISSIONABLE METALS. (Paxton, LADC-2528. See Figure R-1.3 for Additional Diluting Materials.)

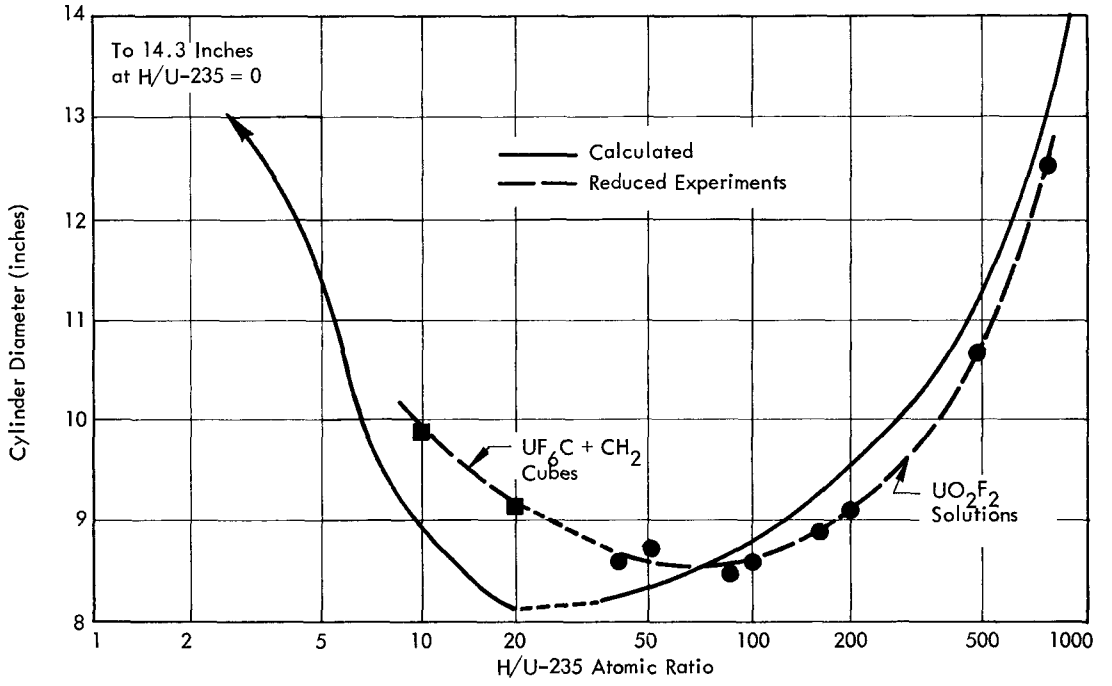


(a) Critical Mass as a Function of the H/U-235 Atomic Ratio

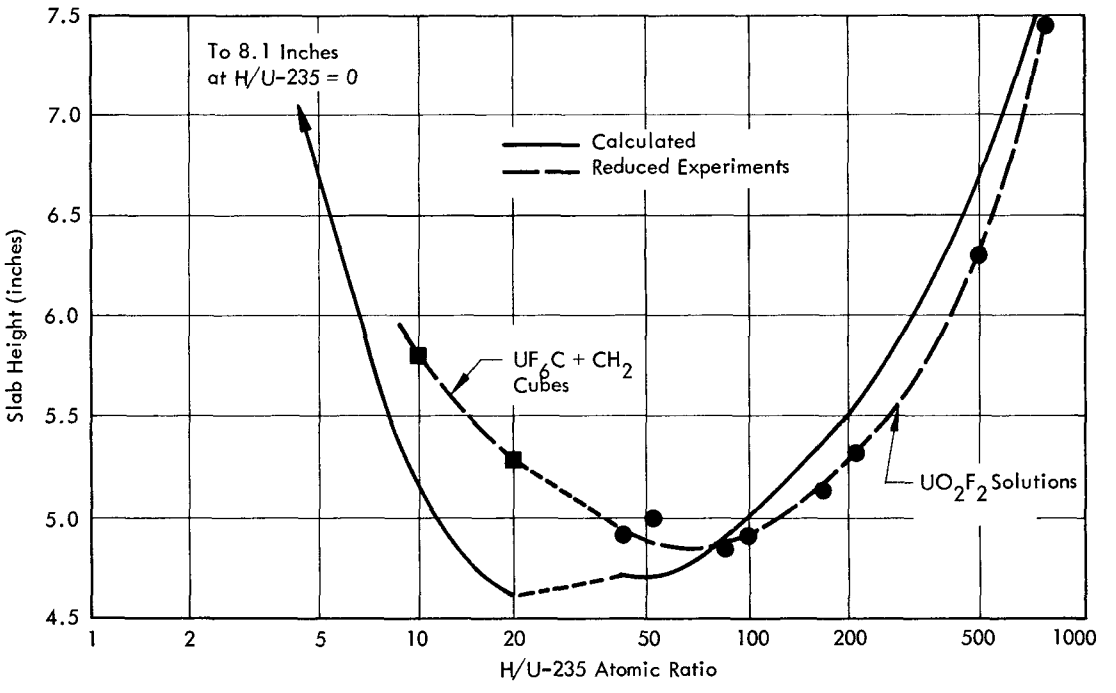


(b) Critical Volume as a Function of the H/U-235 Atomic Ratio

Figure S-2.1. **CRITICAL PARAMETERS FOR BARE SPHERES.** (The Experimental Points have been Reduced to Values for Spheres by Elementary Pile Theory. The Experimental Data are from Beck, Callihan, and Murray, Critical Mass Studies, Part I, A-4716, and Beck, Callihan, Morfitt, and Murray, Critical Mass Studies, Part III, K-343. Knight, J. R., Criticality Calculations for Hydrogeneous Systems, K-1260.)



(a) Critical Diameter of an Infinite Cylinder as a Function of the H/U-235 Atomic Ratio



(b) Critical Height of an Infinite Slab as a Function of the H/U-235 Atomic Ratio

Figure S-2.2. CRITICAL DIMENSIONS FOR INFINITE SLABS AND CYLINDERS. (The Experimental Points have been Reduced to the Appropriate Geometries by Elementary Pile Theory. The Experimental Data are from Beck, Callihan, and Murray, Critical Mass Studies, Part I, A-4716, and Beck, Callihan, Morfitt, and Murray, Critical Mass Studies, Part III, K-343. Knight, J. R., Criticality Calculations for Hydrogeneous Systems, K-1260.)

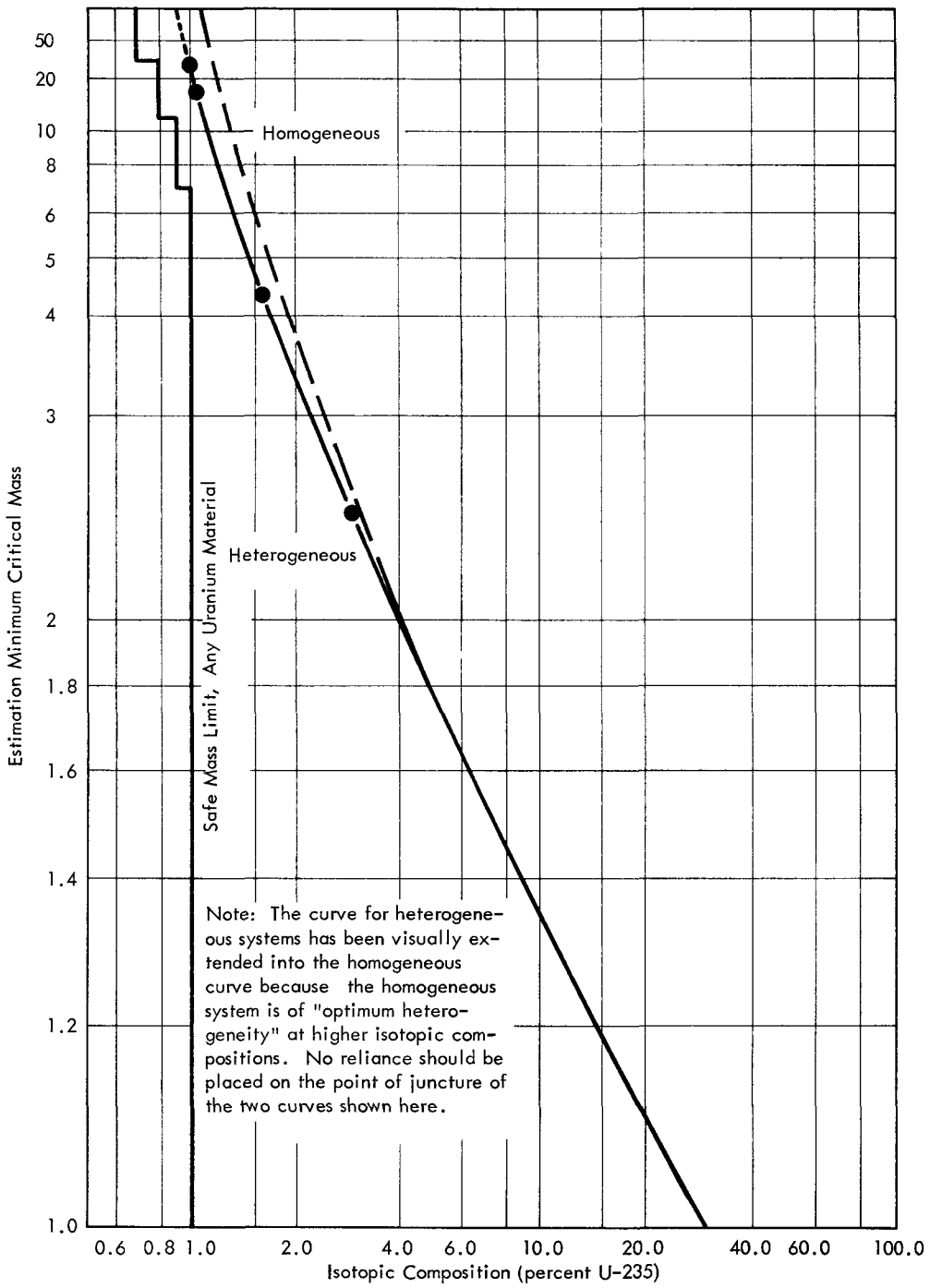


Figure T-1.1. VARIATION OF ESTIMATED MINIMUM CRITICAL MASS FOR HETEROGENEOUS SYSTEMS OF URANIUM METAL IN LIGHT WATER WITH U-235 ISOTOPIC COMPOSITION. (Reciprocal Critical Mass is Plotted as a Function of the Log Isotopic Composition. See Table T-1.1 for Data and Method of Derivation; Table J-3.1 for Homogeneous Data; Table I-3.1 for Safe Limits.)

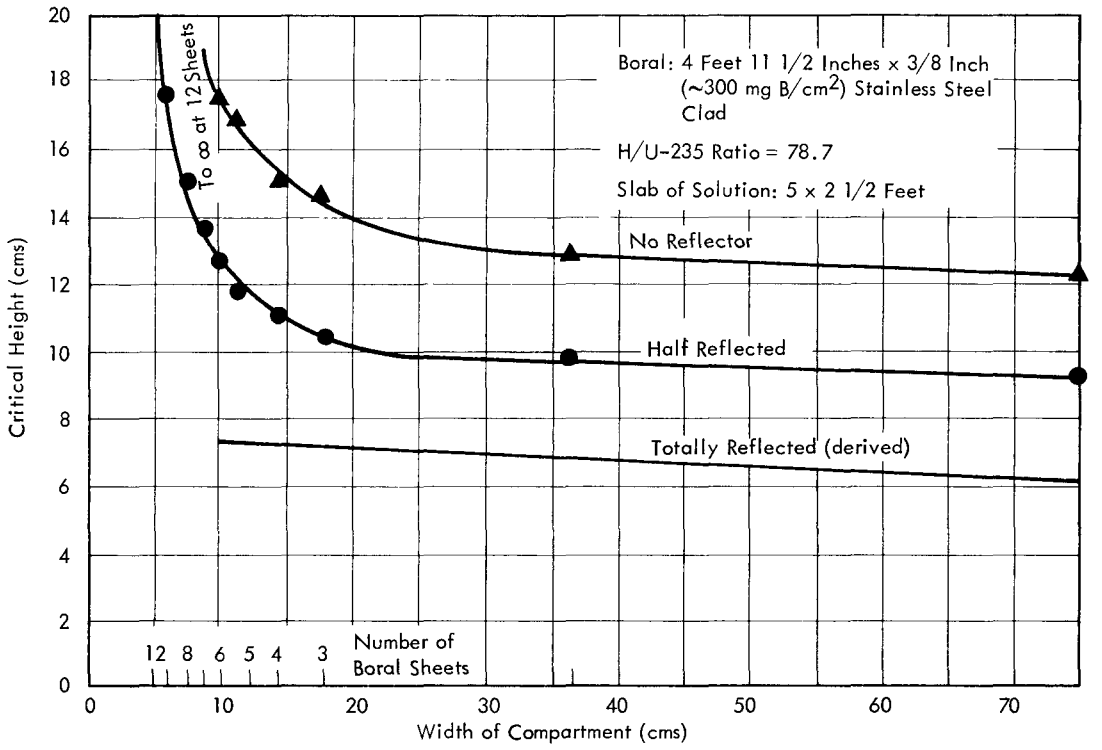
Table T-1.1

MINIMUM MASS FOR LATTICED URANIUM METAL IN LIGHT WATER

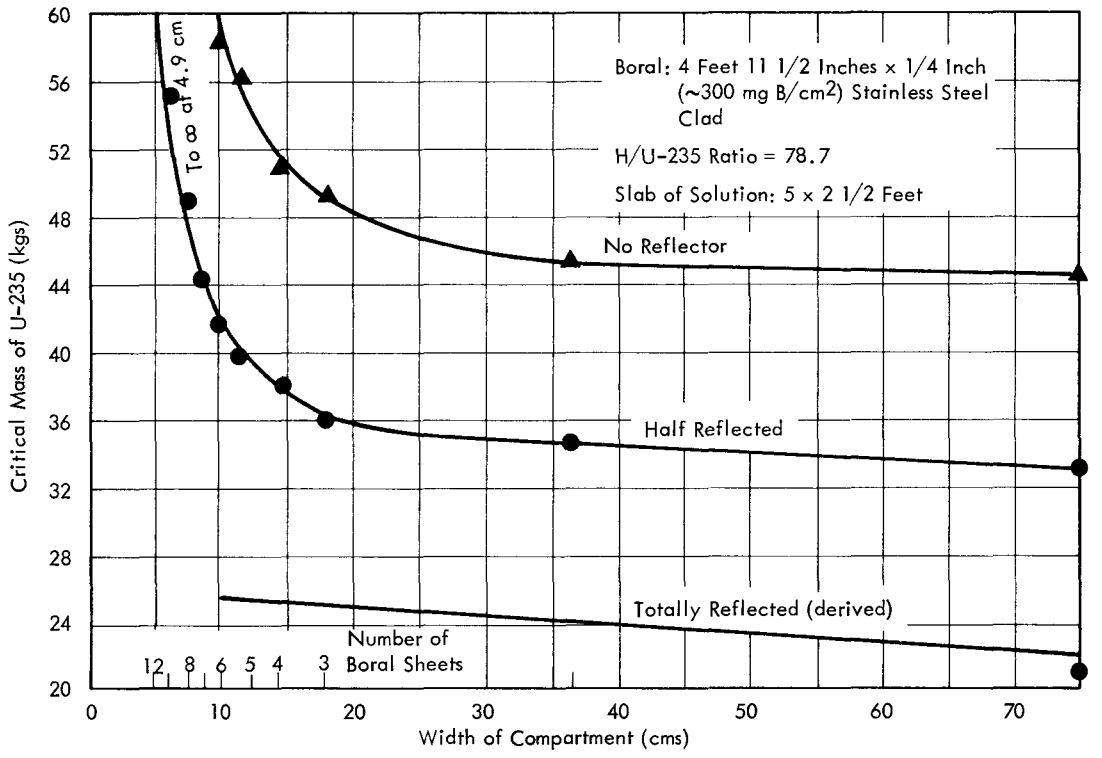
In general, the listed values represent estimates of the minimum mass as calculated from experimental determinations of minimum volume measured under optimum conditions of size and spacing of solid, cylindrical, uranium metal rods. These data are plotted as solid circles in Figure T-1.1.

Isotopic Composition (% U-235)	Mass of Uranium (lbs)	Mass of U-235 (kgs)	Reference
3	175	2.39	HW-51983
1.6	600	4.36	HW-47012
1.027	3350	15.6	HW-43579
1.007	5000	22.2	HW-40930

Source: Attachment 8, Letter to Subcommittee, ORO Criticality Working Committee from H. C. Zeitz, NLO, dated October 31, 1958.



(a) Critical Height as a Function of the Compartment Width



(b) Critical Mass as a Function of the Compartment Width

Figure U-2.1. **EFFECT OF BORON POISONING ON CRITICAL HEIGHT OF A SLAB OF URANIUM SOLUTION.** (Half-Reflected Points were Taken with the Level of the Reflector Water at the Height of the Center of Mass of the Fuel Solution. Uranyl Fluoride Enriched to ~90% U-235 was Used. Gilley Cronin, and Harness, Boron Poison-in Critical Slabs, ORNL-1715.)

Table U-2.1

SUMMARY OF TESTS USING PYREX GLASS AS A FIXED NUCLEAR POISON

Critical heights and masses are given for uranyl nitrate solution in a 20-inch stainless steel cylinder containing various arrays of Pyrex glass pipes as poison rods. The glass contained ~4% B by weight. The pipes were 36 inches in length and were mounted in a hexagonal lattice having the glass-to-solution volume ratio (Vg/Vs) shown. Pipes were confined to a 17.5-inch OD array. The isotopic enrichment of the uranium was 87% U-235. These data are plotted, in part, in Figure U-2.3.

						Bare		Reflected	
H/U-235	Pipe ID (inches)	Center-to-Center Spacing (inches)	Number of Pipes	Vg/Vs	Solution Vol %	H_c (inches)	M_c U-235 (kgs)	H_c (inches)	M_c U-235 (kgs)
81.4	0	0	0	0.0000	1.000	5.97	8.9	4.8	7.16
85	2.0	3	19	0.0850	0.922	16.77	23.06	9.75	13.41
85	2.0	3	23	0.1042	0.906	24.31	32.85	11.5	15.54
85	1.5	2.75	31	0.1091	0.902	26 57	35.75	12.66	17.03
85	3.0	3.78	16	0.1268	0.887	23.43	31.0	12.5	16.54
85	2.0	2.75	28	0.1298	0.885	40.42(1)	54.10(1)	13.6	17.95
85	2.0	2.675	34	0.1621	0.861	41.68(1)	54.70(1)	30.11	38.67
85	1.5	2.125	53	0.2015	0.832	--	--	41.1(2)	52.28(1)
85	1.5(3)	Random	1964	0.1255	0.888	--	--	37.48(2)	49.89(1)
85	2.0(4)	Random	493	0.1540	0.866	40.54(1)	53.27(1)	19.58	25.29
141	0	0	0	0.0000	1.000	6.15	5.36	5.19	7.16
141	2.0	3.0	19	0.0850	0.922	35.50	28.51	11.3	9.08
276	0	0	0	0.0000	1.000	6.6	2.92	5.71	2.52
300	2.0	3.0	19	0.0850	0.922	--	--	37.9(2)	15.51(1)

(1) Includes mass above pipes.
(2) Height of glass = 36 inches.
(3) Raschig rings 1.5-inch OD by 1.5 inches high.
(4) Raschig rings 2.0-inch OD by 2.0 inches high.

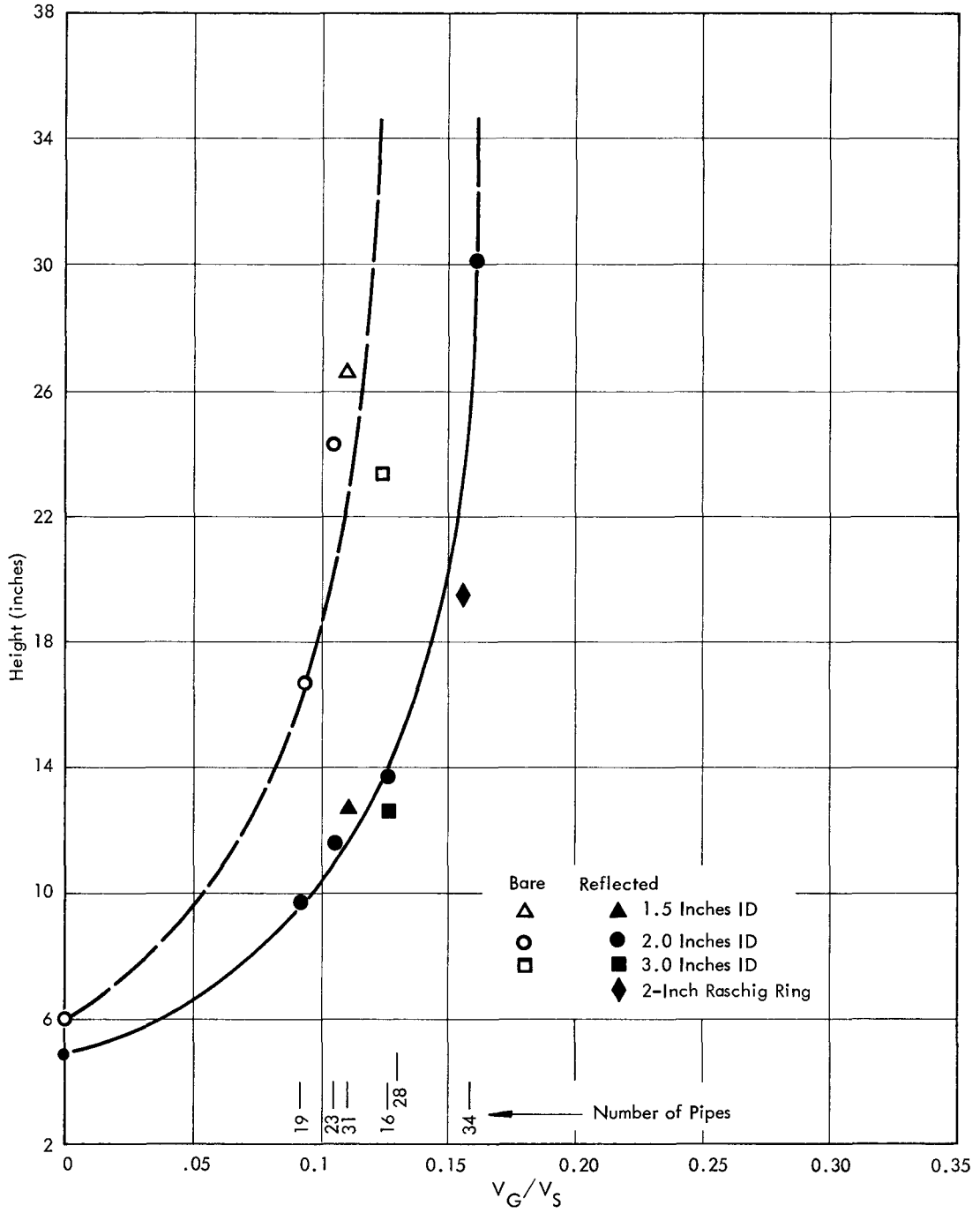


Figure U-2.2. CRITICAL HEIGHT OF URANYL NITRATE SOLUTION IN A 20-INCH-ID SS CYLINDER FILLED WITH PYREX GLASS PIPE AS A FUNCTION OF THE GLASS-TO-SOLUTION VOLUME RATIO. (The Uranium was Enriched to 87% U-235 and the H/U-235 Atomic Ratio was ~85.)

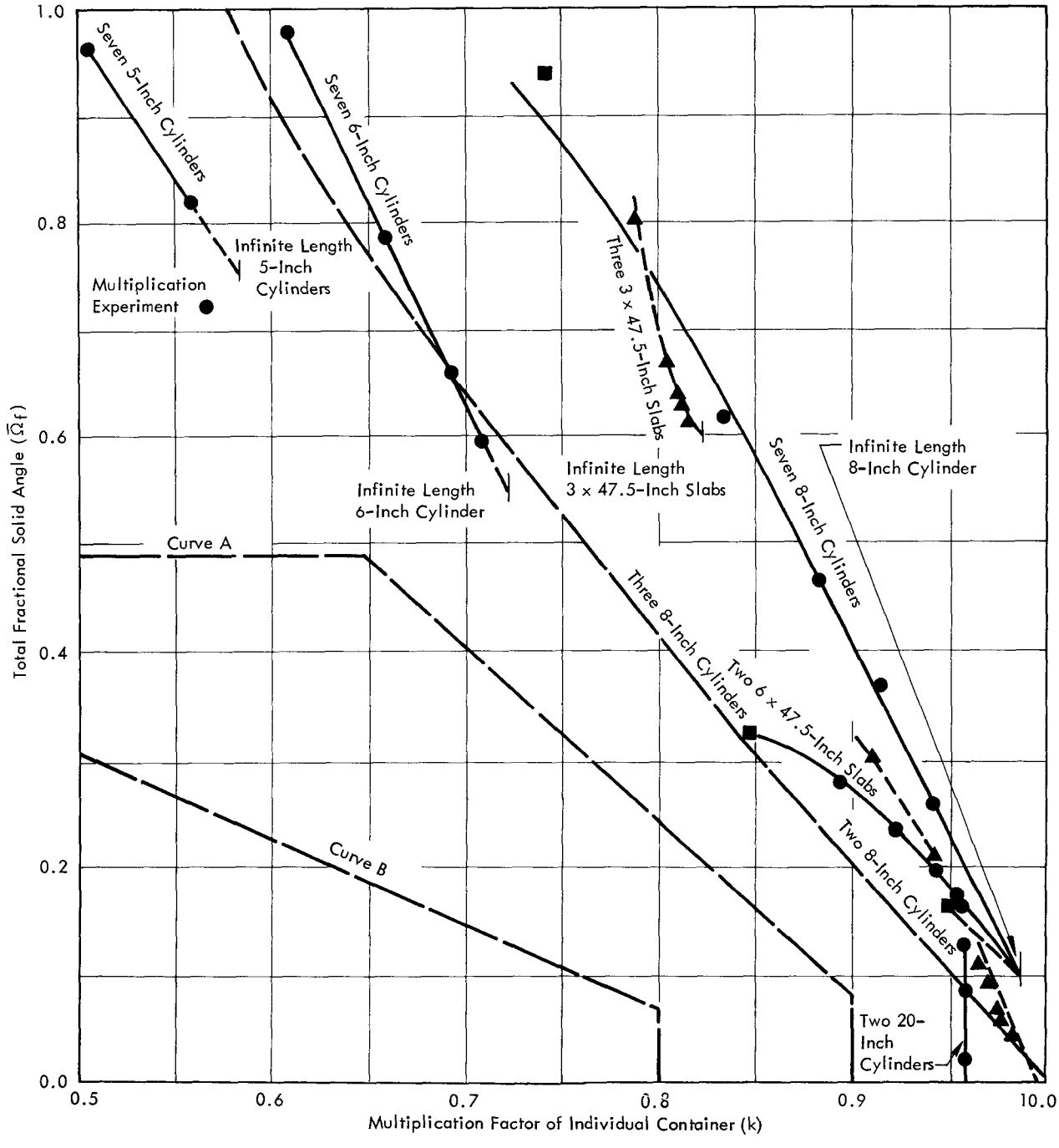
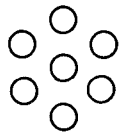
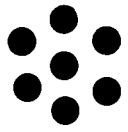
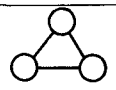
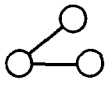


Figure V-1.1. **TOTAL FRACTIONAL SOLID ANGLE OF CRITICAL ARRAYS AS A FUNCTION OF THE EFFECTIVE MULTIPLICATION CONSTANT.** (Total Fractional Solid Angle of Critical Arrays of Similar, Unreflected Cylinders and Slabs as a Function of the Effective Multiplication Constant of an Individual Container of the Array. Solid Circles Denote Cylinders in Contact. The 5, 6, and 8-Inch-ID Cylinder Data is that of Table V-1.1. The H/U-235 Atomic Ratio was ~169 for the 20-Inch-ID Cylinders, and ~330 for the Slabs. Uranyl Fluoride Solution at ~90% U-235 Isotopic Concentration was Used; Containers were Aluminum. A Variable Extrapolation Length was Used for the Slabs. Curve A is the ORGDP Safe Limit for Unreflected Containers (as Special Cases only); Curve B is Safe for any Container. Figure 1 of Newlon, Interaction Problems, pp 1 - 2, K-1380.)

Table V-1.1

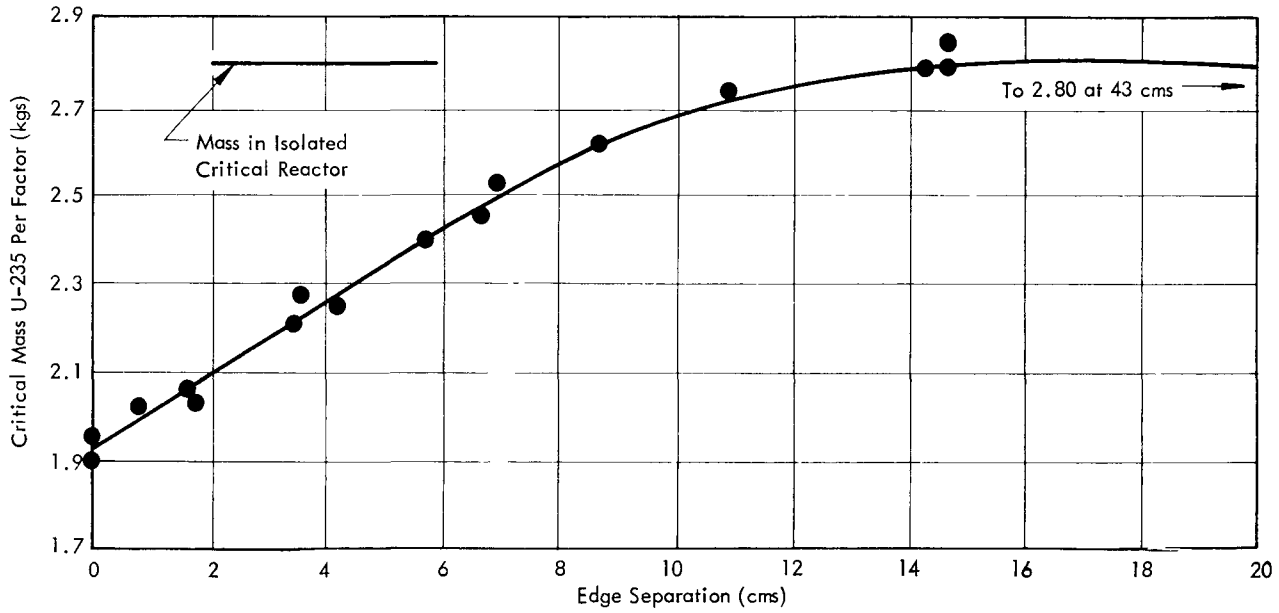
CRITICAL HEIGHT IN INCHES OF INTERACTING CYLINDERS CONTAINING U-235 SOLUTION

(Uranyl fluoride solution at ~90% U-235 isotopic composition was contained within aluminum cylinders of about 1/16-inch thickness The H/U-235 atom ratio was about 44)

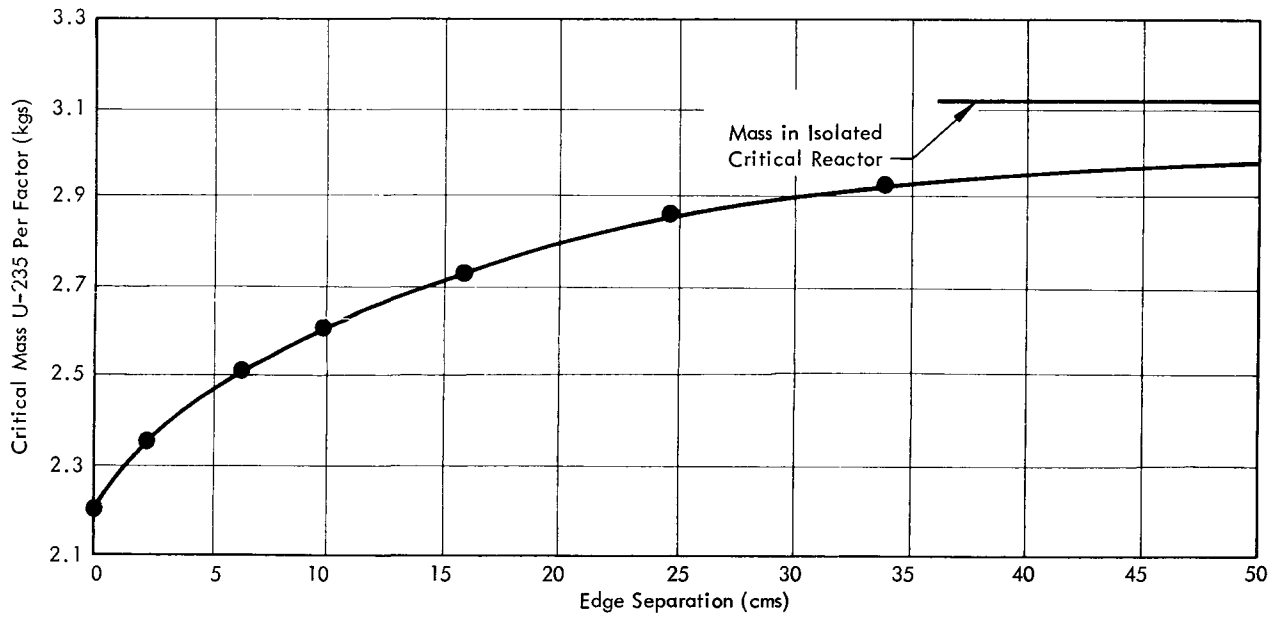
CONFIGURATION			Edge-to-Edge Separation (inches)	WATER REFLECTED-TO-SOLUTION HEIGHT Inside Diameter of Cylinder (inches)			NO REFLECTOR Inside Diameter of Cylinder (inches)		
				5(1)	6	8	5(1)	6	8
SINGLE CYLINDER			–	∞	28 8(2)	8 97(3)	∞	∞	∞
			1/8	–	5 02(4)	4 70	–	8 85	7 20
			1/4	5 71	–	–	11 22	–	–
			1	6 19	5 42	5 03	26 12	13 00	8 51
			2	8 38	6 89	5 89	35 08(5)	20 30	10 14
			3	–	9 20	6 95	–	33 6(4)	11 73
			4	25 47	12 15	7 78	–	53 (6)	13 20
			4 5	(7)	–	–	–	–	–
			6	–	18 80	8 73	–	∞	16 50
			9	–	25 90	8 95	–	–	~22
			12	–	28 40	–	–	–	>29(6)
			15	–	28 93	–	–	–	–
			24 5	–	28 78	–	–	∞	–
SINGLE CYLINDER, Cd WRAPPED			–	∞	∞	23 80	∞	∞	–
CADMIUM  WRAPPED			1/8	–	8 06	6 22	–	10 25	7 71
			1/4	–	–	–	–	–	–
			1	–	17 44	8 21	–	15 10	9 03
			2	–	∞ (6)	11 17	–	24 64	10 48
			3	–	∞ (6)	14 32	–	>50 (5)	11 98
			4	–	∞ (6)	17 12	–	~58 (5)	13 57
			6	–	–	~22(5)	–	–	16 93
			9	–	–	>20(8)	–	–	~26(5)
			1/8	–	6 99	5 73	–	>70(5)	10 66
			1/4	–	–	–	–	–	–
			1	–	(9)	6 11	–	(9)	13 80
			2	–	–	6 96	–	∞	17 80
			3	–	12 25	7 79	–	–	22 02
			4	–	–	8 37	–	–	27 07
			5	–	–	–	–	–	–
			6	–	–	8 90	–	–	~42
			9	–	–	–	–	–	>60
	Angle (degrees)	45	1/8	–	–	–	–	–	–
			3	–	9 21(10)	6 63	–	–	16 36
		60	1/8	–	6 99	5 73	–	–	10 66
			3	–	12 25	7 79	–	–	22 02
		90	1/8	–	7 76	6 13	–	–	14 22
			3	–	14 07	8 01	–	–	28 10
		120	1/8	–	8 03	6 23	–	–	16 73
			3	–	14 16	8 03	–	–	34 41
		180	1/8	–	8 13	6 28	–	–	18 02
			3	–	14 22	8 22	–	–	~51
	Number of Cylinders in Line	2	1/8	–	9 67	6 85	–	–	26 87
			1/5	14 3	–	–	–	–	–
			3	–	16 26	8 33	–	–	–
			6	–	24 88	–	–	–	–
			9	–	28 24	–	–	–	–
		3	1/8	–	8 13	6 28	–	∞	18 02
			3	–	14 22	8 22	–	–	~51
			6	–	23 33	–	–	–	–
			9	–	27 81	–	–	–	–
			12	–	28 84	–	–	–	–
		4	1/8	–	7 76	6 15	–	∞	16 52
			3	–	13 65	7 99	–	–	37 5
			6	–	23 00	–	–	–	–
		5	1/8	–	–	6 08	–	–	15 81
			3	–	13 38	7 95	–	–	~31
			9	–	27 41	–	–	–	(11)
		6	1/8	–	7 41	–	–	∞	–
			2	16 54	–	–	–	–	–
			3	–	13 19	–	–	–	–
			6	–	22 60	–	–	–	–
		7	1/4	9 26	–	–	–	–	–
			1	11 01	–	–	–	–	–
			2	16 12	–	–	–	–	–
			3	35 98(12)	–	–	–	–	–

(1) Callihan, Cronin, Fox, Macklin, and Morfitt, K-406, Blizard, ORNL-2389. H/U-235 atomic ratio about 50.
(2) 28.97 inches when experiment repeated.
(3) 9.02 inches when experiment repeated.
(4) Infinite if two outer cylinders on opposite sides are removed.
(5) Extrapolated.
(6) Very poor data. Long extrapolation.
(7) Infinitely high cylinders require about 4.6 inches.
(8) Indefinite.
(9) Infinite if cadmium wrapped.
(10) About 390.
(11) Infinite at 15 inches.
(12) Infinite line at infinite height at 3.5 inches.

Source Fox, Gilley, and Callihan, ORNL-2367.

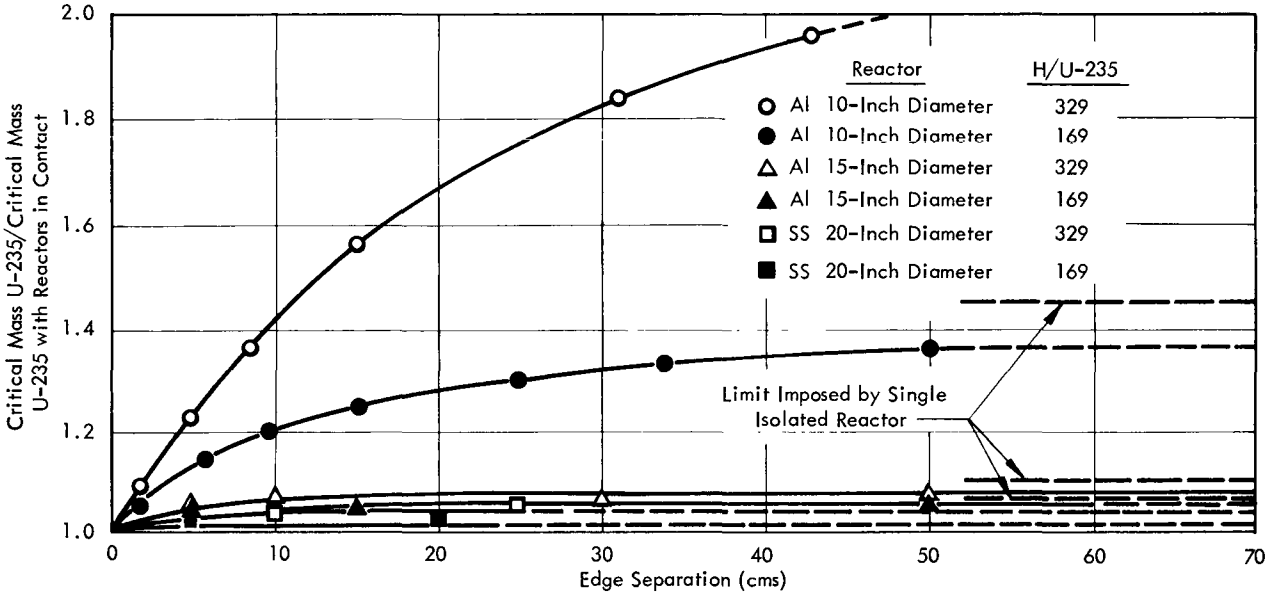


(a) Water-Reflected Eight-Inch-Diameter Cylinders (H/U-235 Atomic Ratio = 52.9)

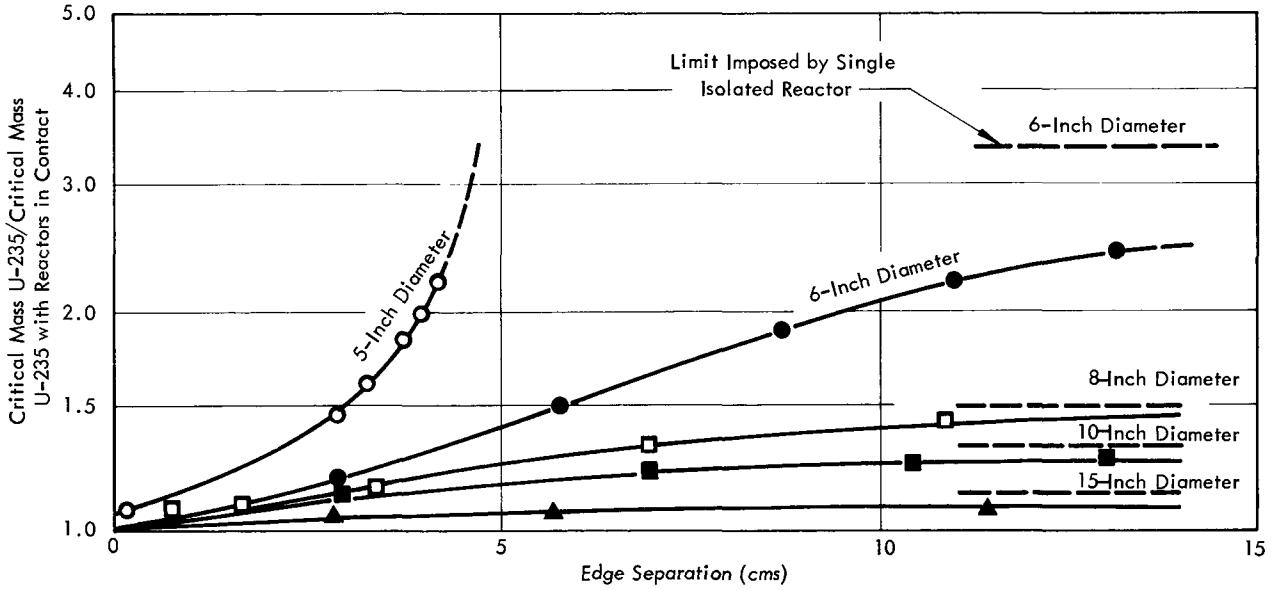


(b) Unreflected Ten-Inch-Diameter Cylinders (H/U-235 Atomic Ratio = 169)

Figure V-2.1. CRITICAL MASS AS A FUNCTION OF REACTOR SEPARATION. (The Critical Mass of Two Right Cylindrical Aluminum Reactors Containing Uranyl Fluoride Solution Enriched to 93.4% U-235 is Plotted against the Edge-to-Edge Separation. Figures 9 and 11 of Callihan, et al, K-406.)

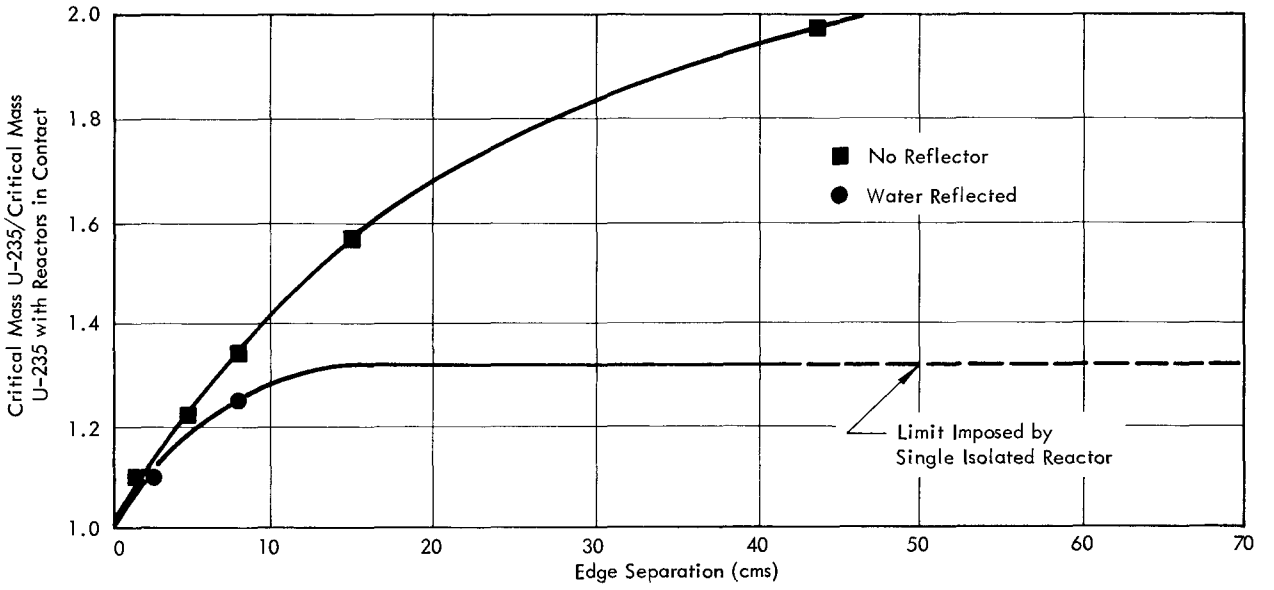


(a) Unreflected Cylinders with Varying Moderation

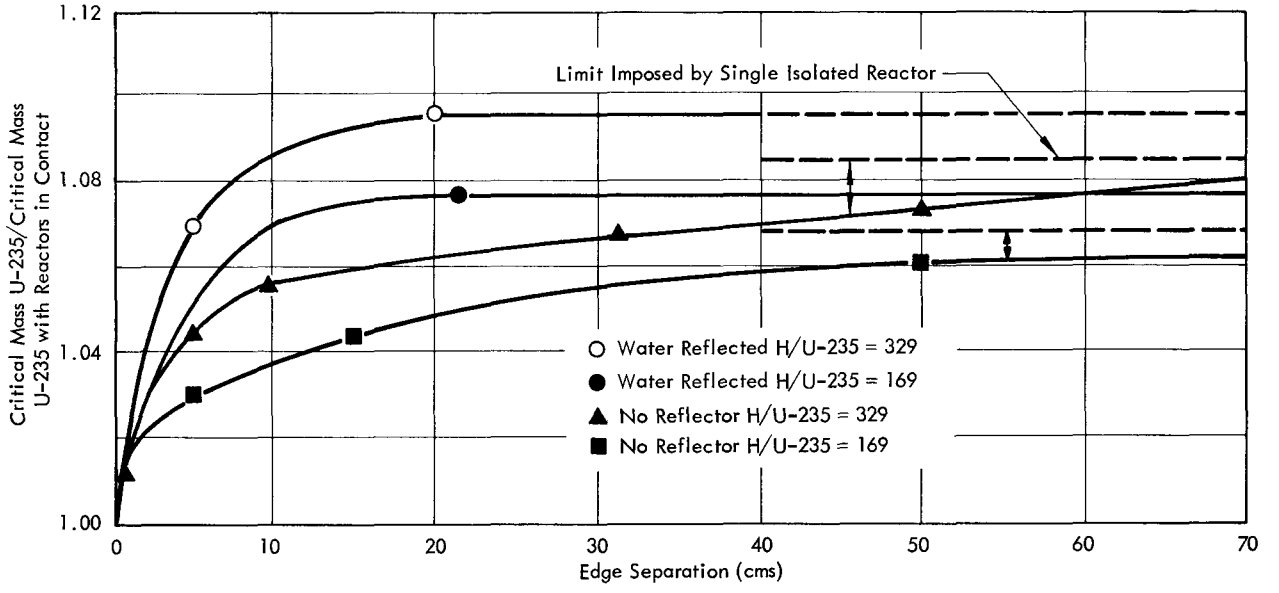


(b) Reflected Aluminum Cylinders (H/U-235 Atomic Ratio = 52.9)

Figure V-2.2. CRITICAL MASS RATIO AS A FUNCTION OF THE REACTOR SEPARATION. (The Critical Mass Ratio, Normalized at Contact, of Two Right Cylindrical Reactors Containing Uranyl Fluoride Solution Enriched to 93.4% U-235 is Plotted against the Edge-to-Edge Separation. Figures 10 and 12 of Callihan, et al, K-406.)



(a) Ten-Inch-Diameter Cylinders (H/U-235 Atomic Ratio = 329)



(b) Fifteen-Inch-Diameter Cylinders

Figure V-2.3. CRITICAL MASS RATIO AS A FUNCTION OF THE REACTOR SEPARATION. (Each Curve Represents the Interaction of Two Aluminum Cylinders Containing Uranyl Fluoride Solution Enriched to 93.4% U-235. The Critical Mass Ratio is Normalized at Contact. Figures 13 and 14 of Callihan, et al, K-406.)

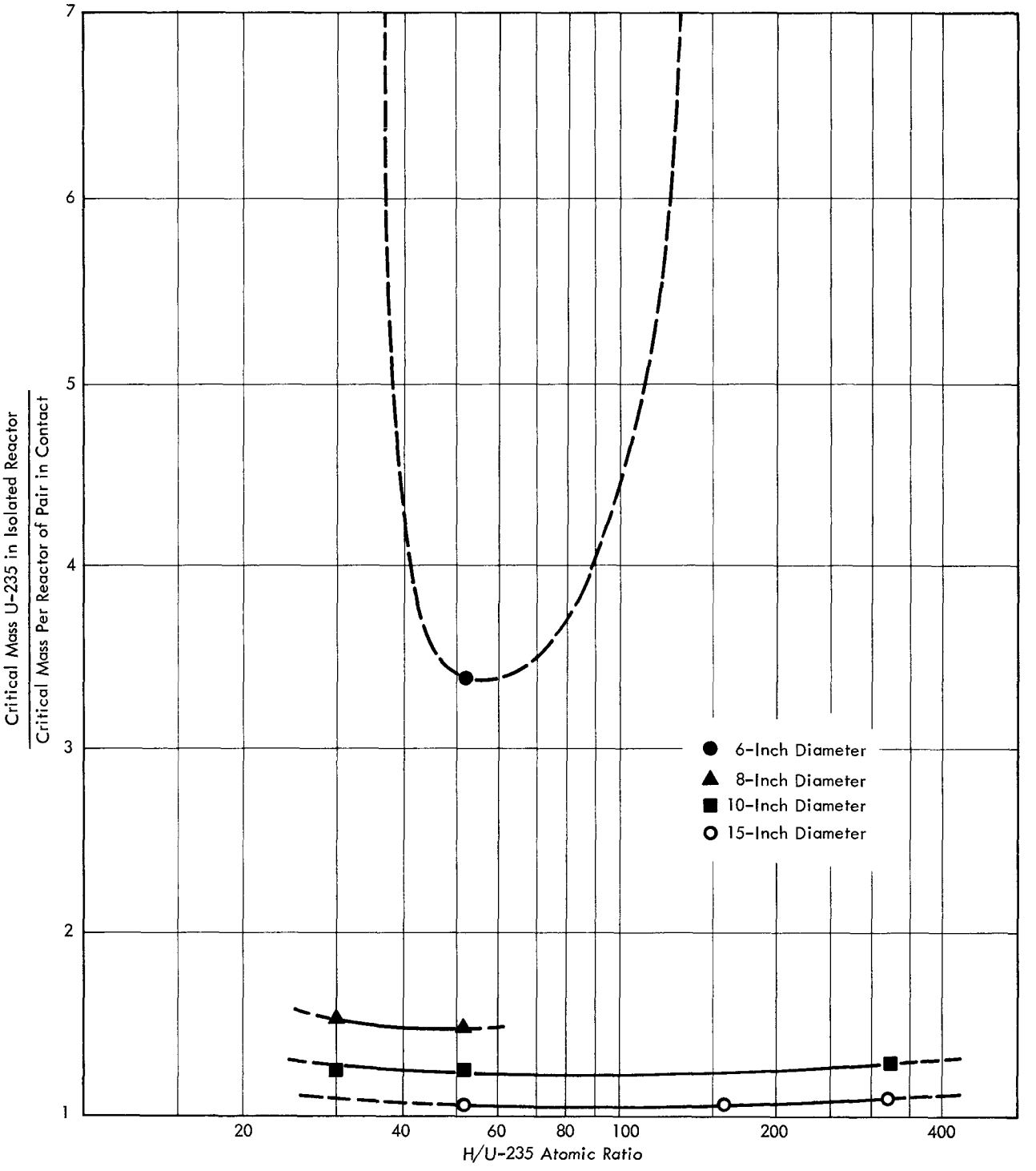


Figure V-2.4. CRITICAL MASS RATIO AS A FUNCTION OF THE FUEL MODERATION. (The Apparent Interaction of Two Right Cylindrical, Water-Enclosed, Aluminum Reactors is Plotted against the H/U-235 Atomic Ratio. The Uranyl Fluoride Solution is Enriched to 93.4% U-235. Figure 15 of Callihan, et al, K-406.)

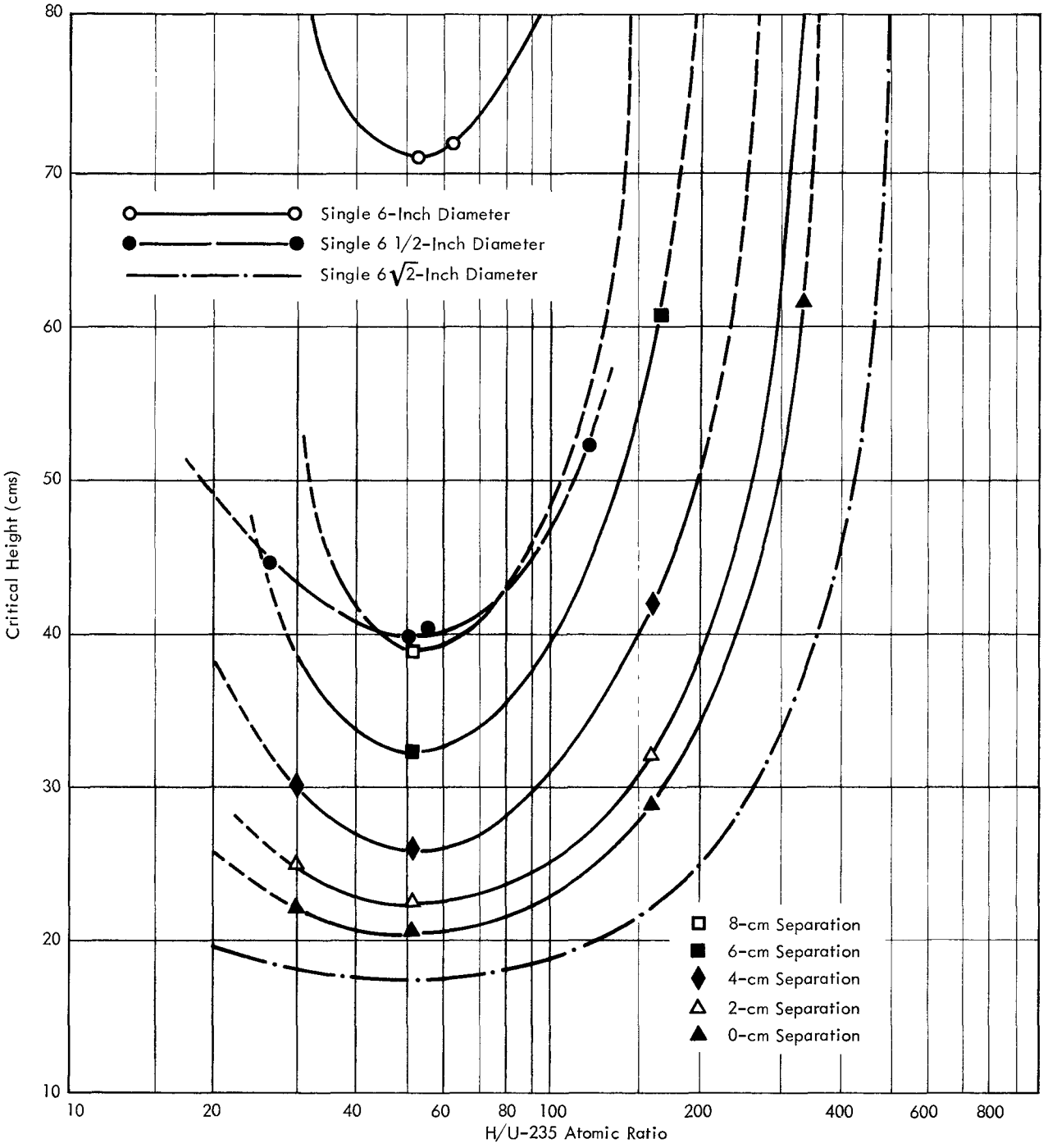
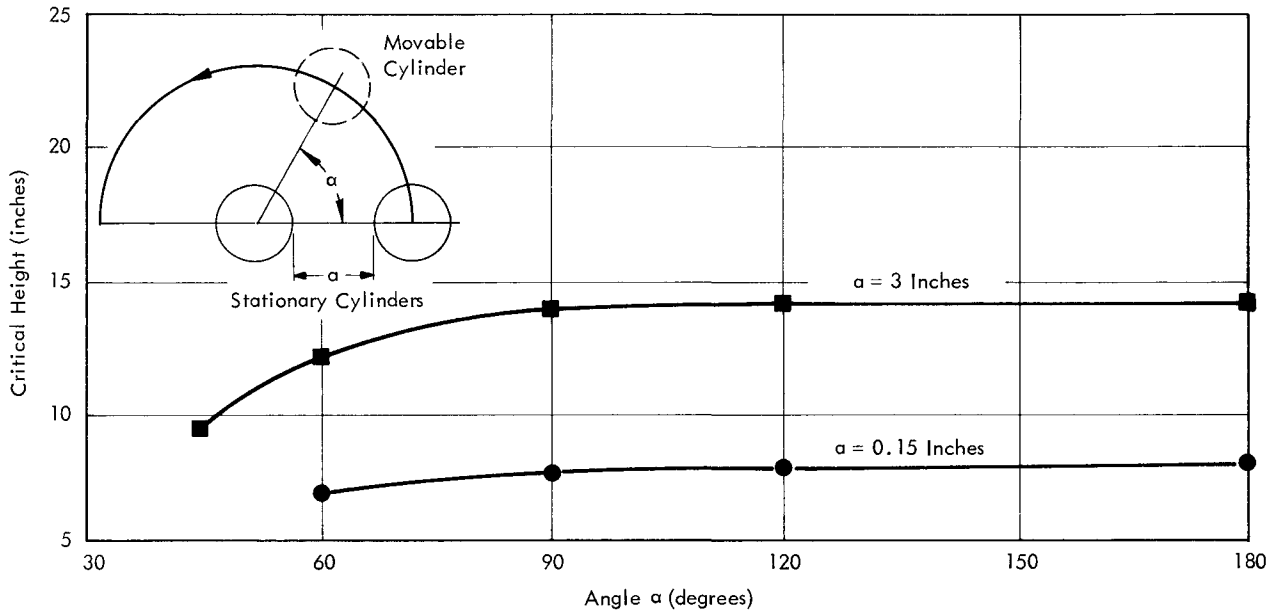
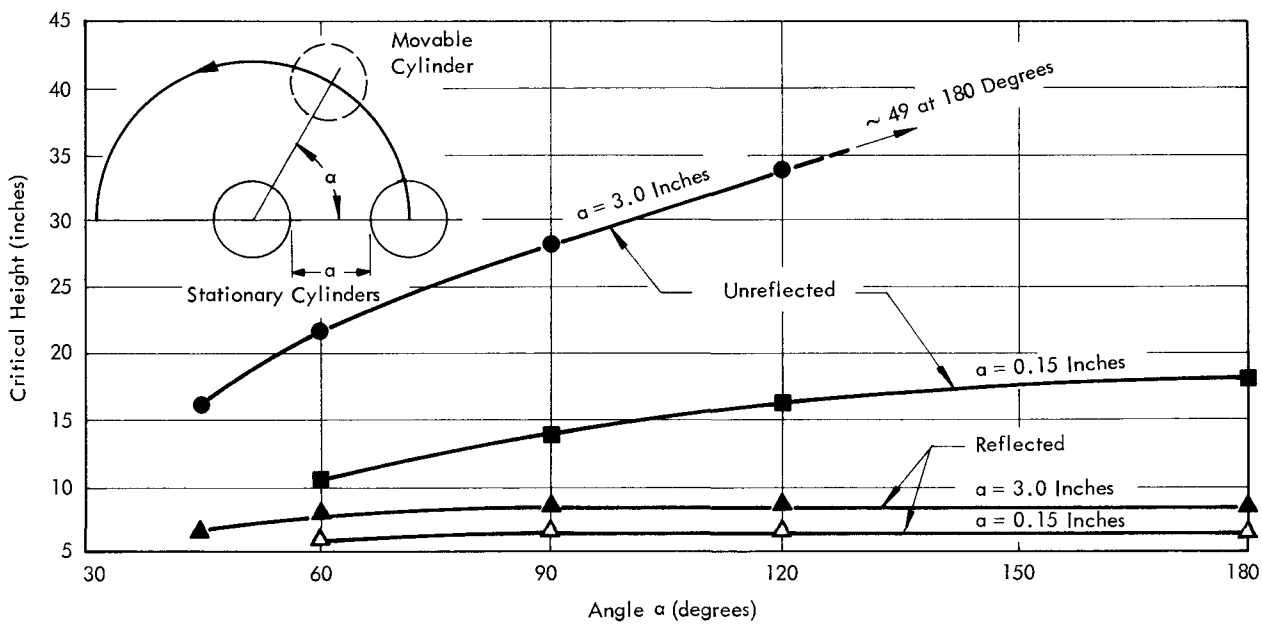


Figure V-2.5. CRITICAL HEIGHT AS A FUNCTION OF THE FUEL MODERATION. (The Critical Height of Two Right Cylindrical Reactors Containing Uranyl Fluoride Solution Enriched to 93.4% U-235 is Plotted against the H/U-235 Atomic Ratio. The Six-Inch-Diameter Aluminum Cylinders are Water Enclosed. Curves for Single 6, 6½, and 6 $\sqrt{2}$-Inch Reactors have been Included for Comparison with Various Separations of the Interacting Six-Inch Cylinders. Figure 16 of Callihan, et al, K-406.)

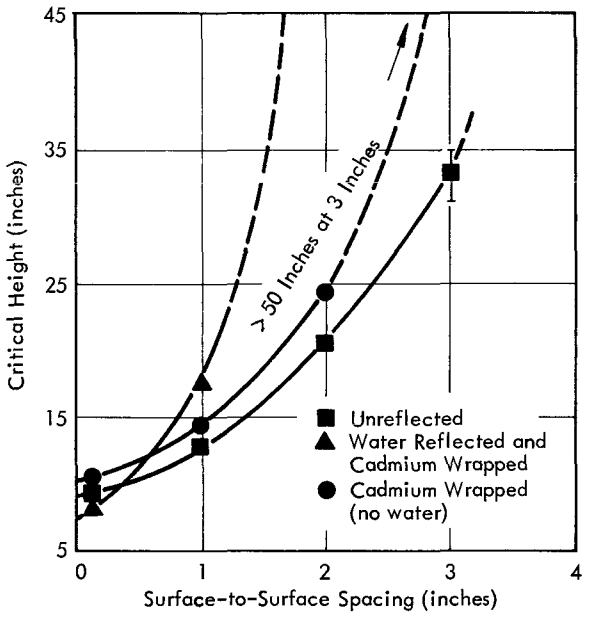


(a) Water-Reflected Six-Inch-Diameter Cylinders

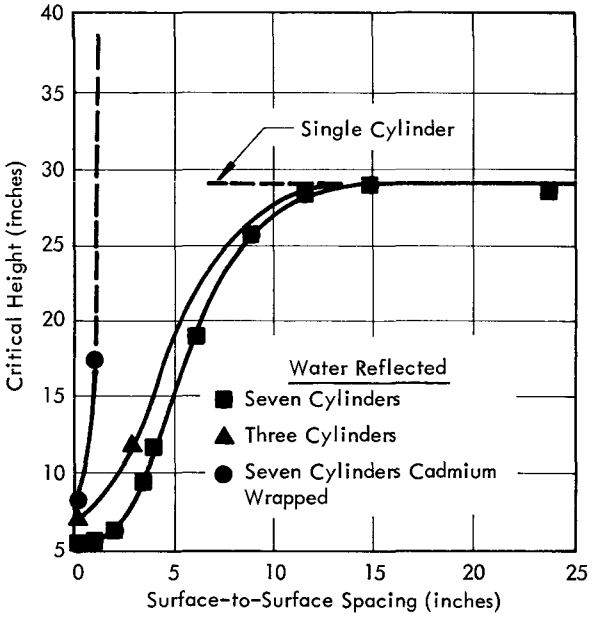


(b) Unreflected and Water-Reflected Eight-Inch-Diameter Cylinders

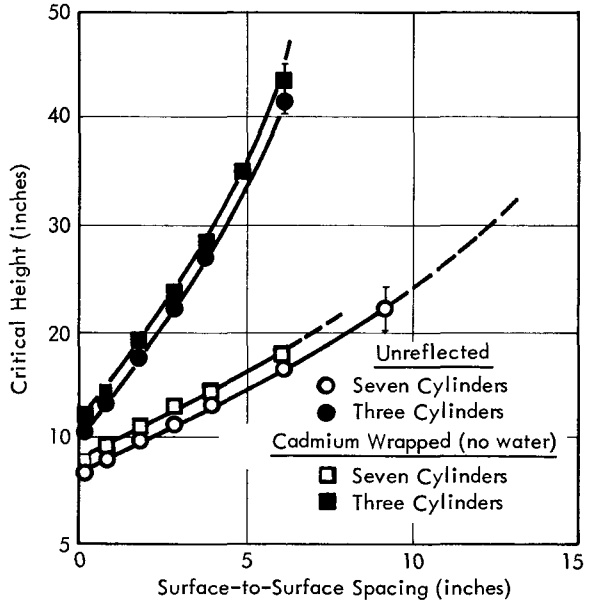
Figure V-3.1. CRITICAL HEIGHT AS A FUNCTION OF THE VERTEX ANGLE OF AN ISOSCELES TRIANGLE. (The Critical Height of Three Aluminum Cylinders Containing an Enriched (93.2%) U-235 Uranyl Fluoride Solution (H/U-235 atomic ratio = 44.3) is Plotted as a Function of the Vertex Angle of an Isosceles Triangle Describing the Relative Locations of the Cylinders. Figures 8 and 9 of Gilley, Fox, and Callihan, ORNL-2367.)



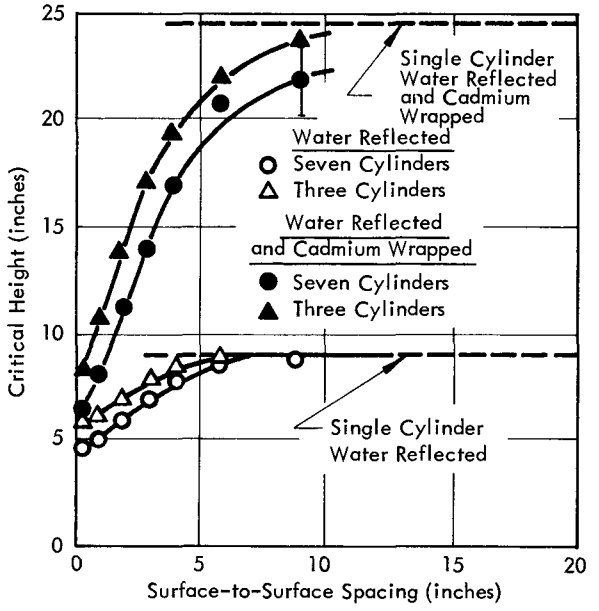
(a) Unreflected and Water-Reflected Six-Inch-Diameter Cylinder in Hexagonal Arrays



(b) Water-Reflected Six-Inch-Diameter Cylinder in Hexagonal and Triangular (equilateral) Arrays

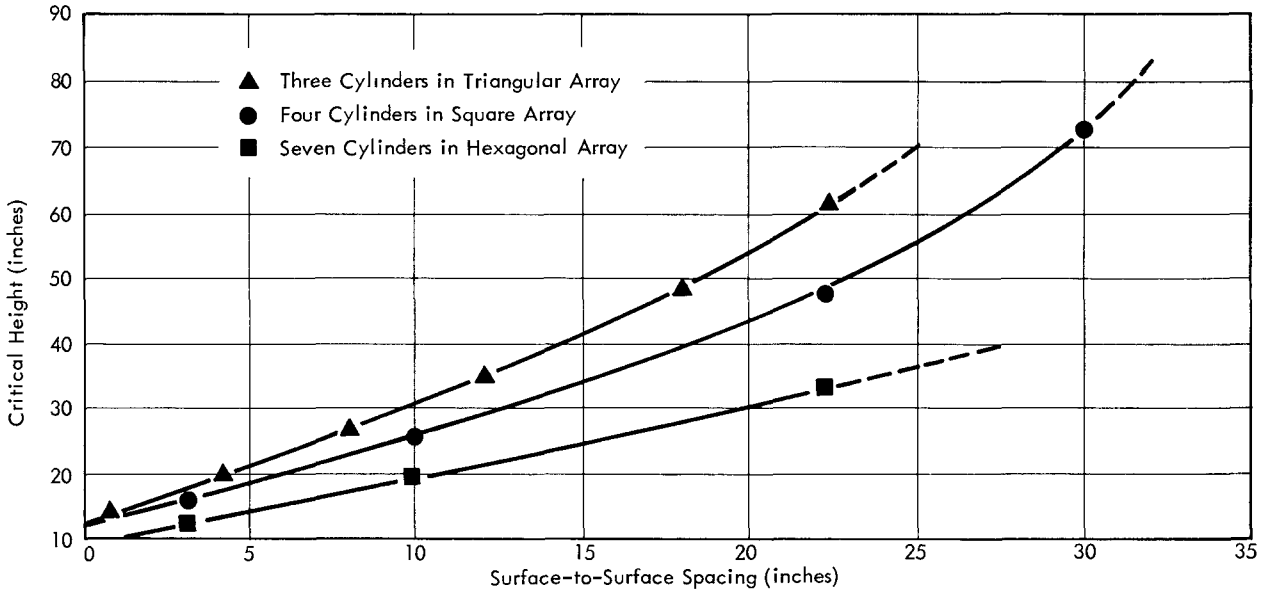


(c) Unreflected Eight-Inch-Diameter Cylinder in Hexagonal and Triangular (equilateral) Arrays

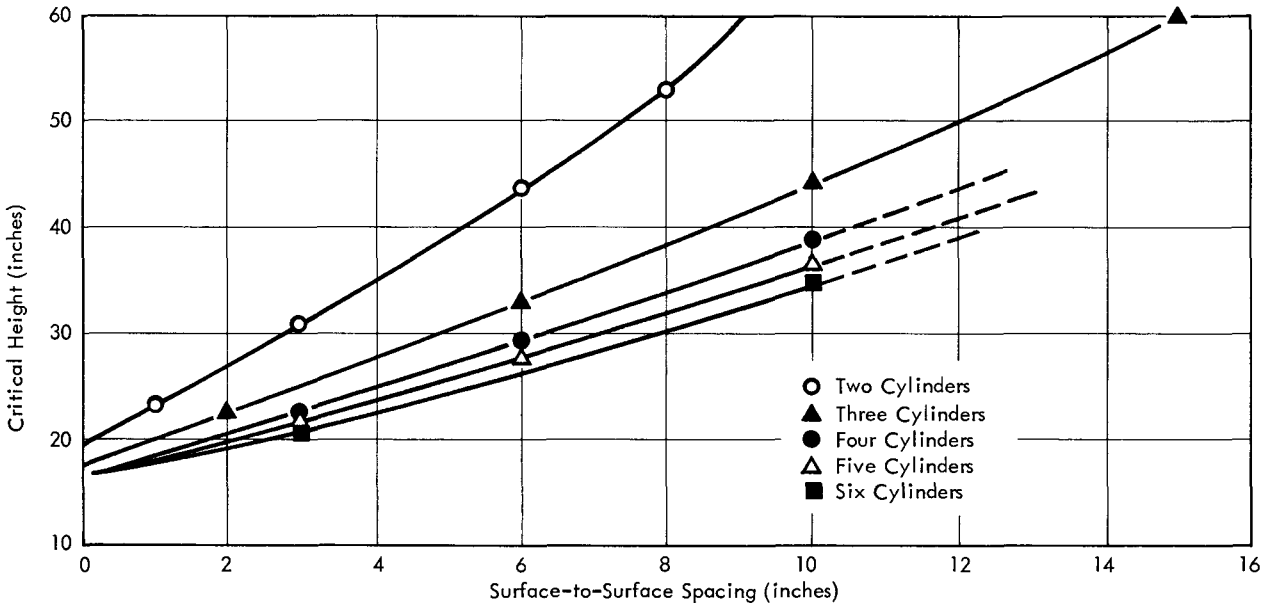


(d) Water-Reflected Eight-Inch-Diameter Cylinder in Hexagonal and Triangular (equilateral) Arrays

Figure V-3.2. CRITICAL HEIGHT AS A FUNCTION OF THE SURFACE-TO-SURFACE SPACING. (The Critical Height of Aluminum Cylinders Containing an Enriched (93.2%) U-235 Uranyl Fluoride Solution (H/U-235 atomic ratio = 44.3) is Plotted as a Function of the Surface-to-Surface Spacing of the Cylinders. The Cylinders were with and without Cadmium Wrapping. Figures 2 - 5 of Gilley, Fox, and Callihan, ORNL-2367.)



(a) Varying Arrays



(b) Straight-Line Arrays

Figure V-3.3. CRITICAL HEIGHT AS A FUNCTION OF THE SURFACE-TO-SURFACE SEPARATION FOR 9.5-INCH-DIAMETER CYLINDERS. (Critical Solution Height as a Function of Surface-to-Surface Spacing of Unreflected Arrays of 9.5-Inch-Diameter Aluminum Cylinders Containing Aqueous Solutions of 93.2% U-235 Enriched Uranyl Fluoride (H/U-235 atomic ratio = 297). Figures 3.7.2 and 3.7.3, Fox and Gilley, ORNL-2842.)

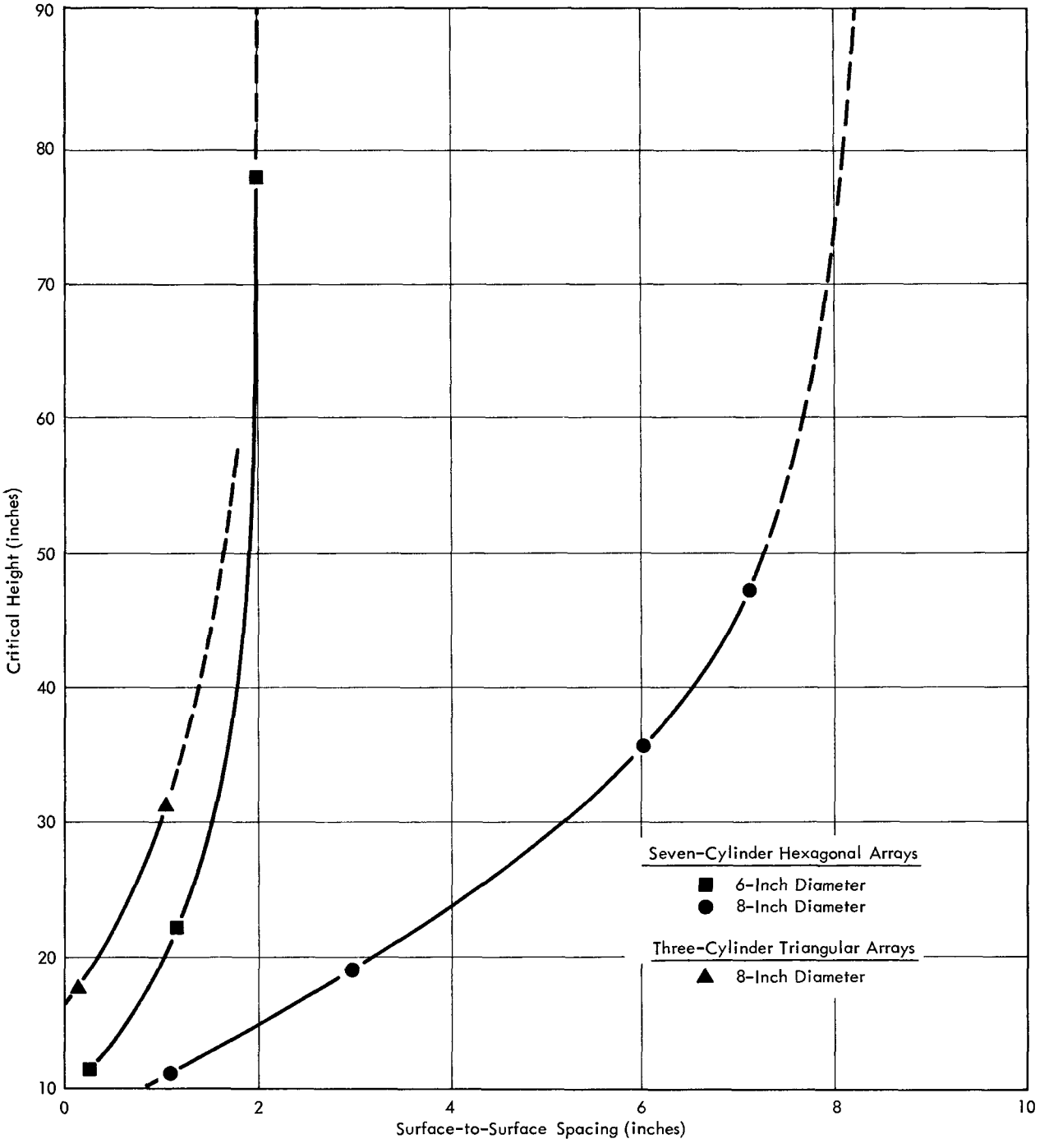


Figure V-3.4. CRITICAL HEIGHT AS A FUNCTION OF THE SEPARATION FOR UNREFLECTED SIX AND EIGHT-INCH-DIAMETER CYLINDERS. (Critical Height as a Function of Edge-to-Edge Spacing of Unreflected Arrays of 6 and 8-Inch-Diameter Cylinders Containing Aqueous Solutions of 93.2% U-235 Enriched Uranyl Fluoride (H/U-235 atomic ratio = 309). Figure 3.7.1 of Fox and Gilley, ORNL-2842.)

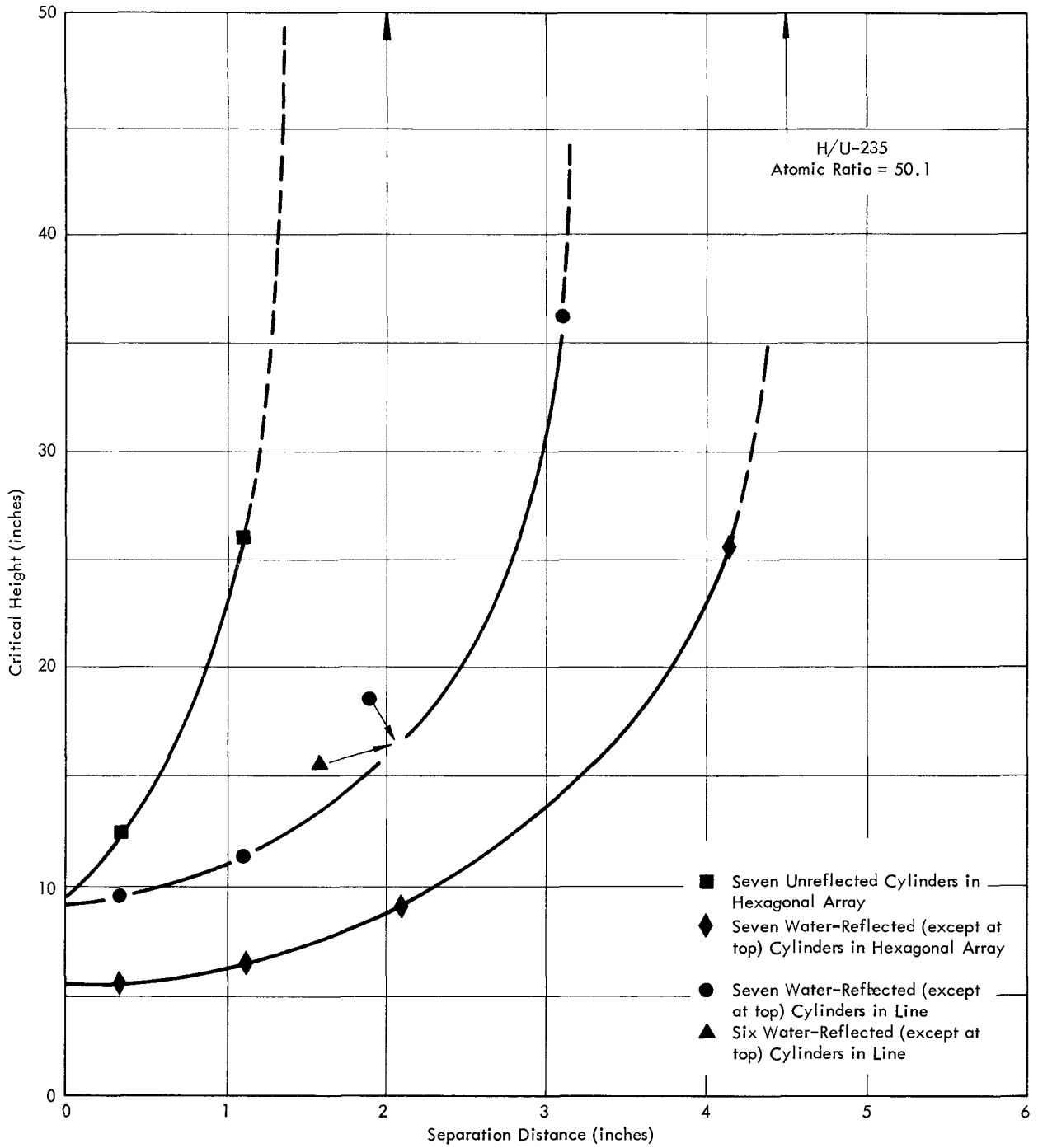
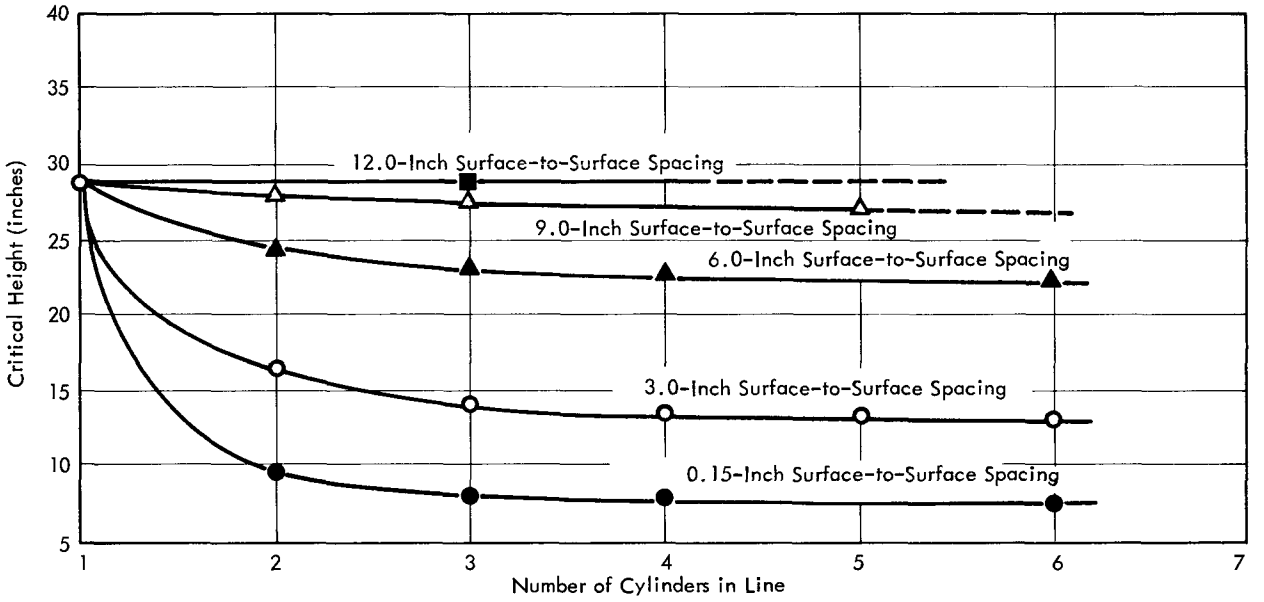
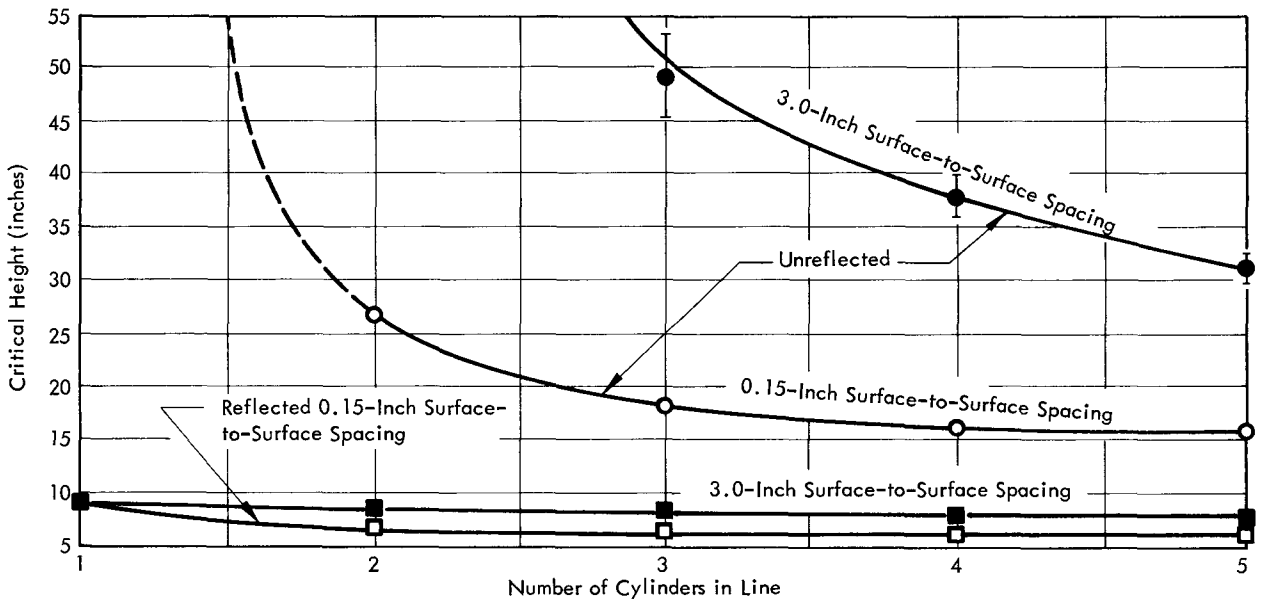


Figure V-3.5. CRITICAL HEIGHT AS A FUNCTION OF THE SEPARATION FOR FIVE-INCH-DIAMETER CYLINDERS. (Critical Height of Arrays of 5-Inch-Diameter Aluminum Cylinders Containing Aqueous Solutions of 93.2% U-235 Enriched Uranium Fluoride (H/U-235 atomic ratio = 50.1). Figure 4.1.15 of Fox and Gilley, ORNL-2389.)

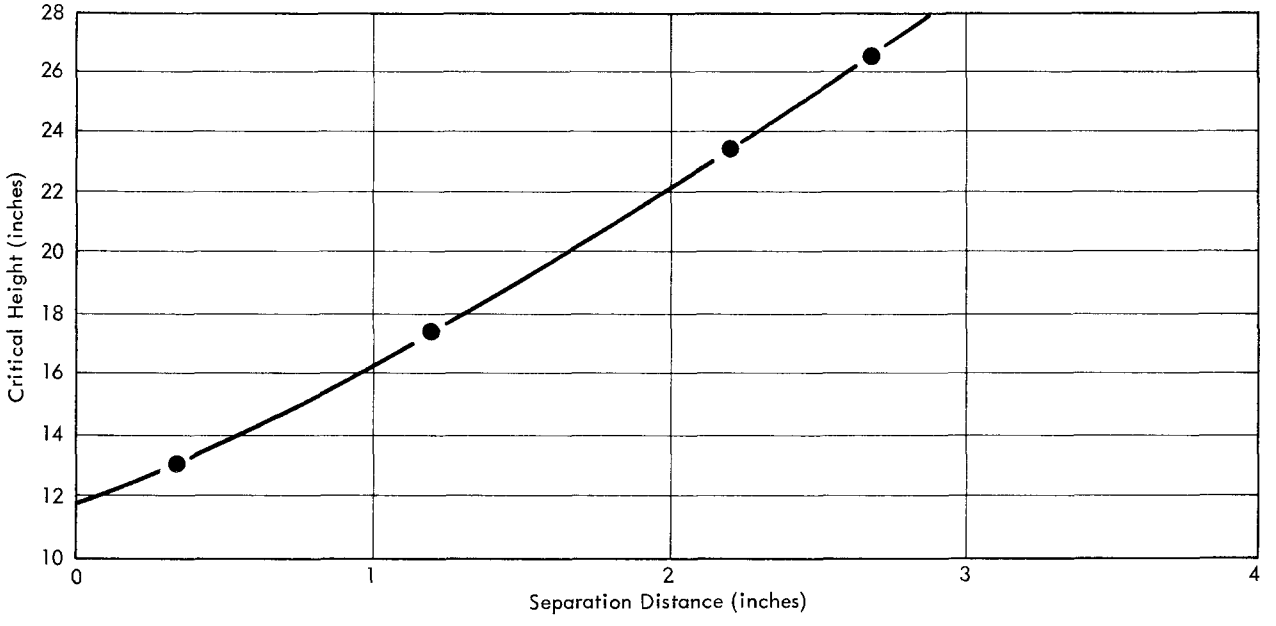


(a) Water-Reflected Six-Inch-Diameter Cylinders

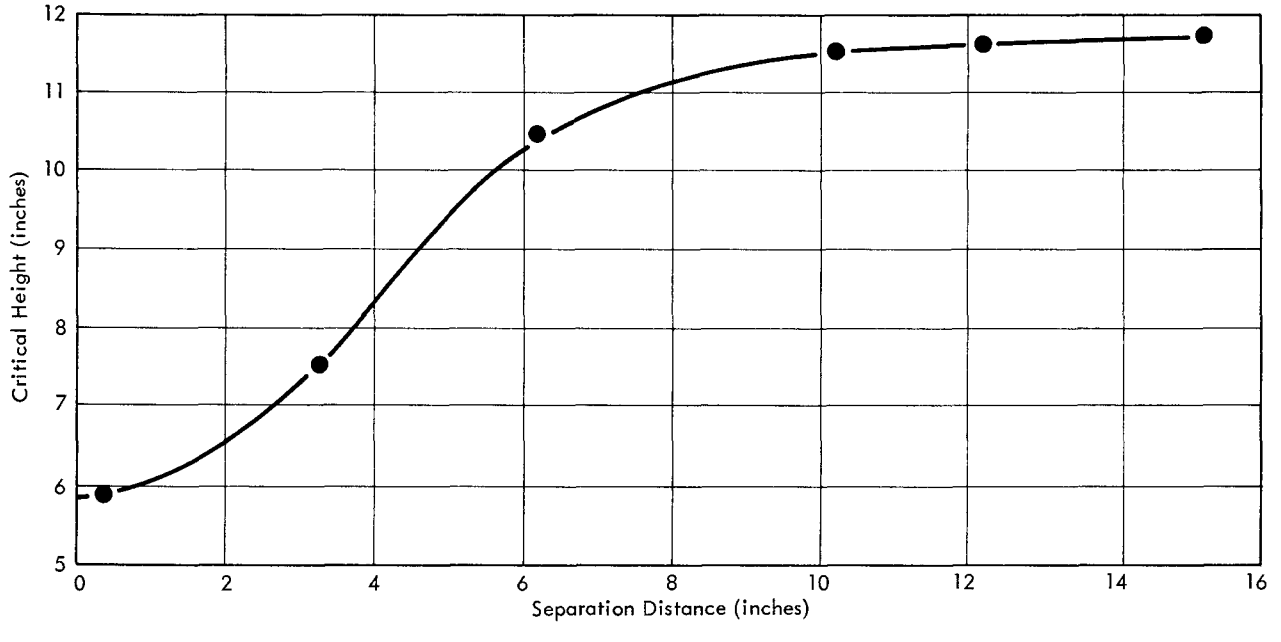


(b) Unreflected and Water-Reflected Eight-Inch-Diameter Cylinders

Figure V-3.6. CRITICAL HEIGHT AS A FUNCTION OF THE NUMBER OF CYLINDERS IN LINE. (The Critical Height of Aluminum Cylinders Containing an Enriched (93.2%) U-235 Uranyl Fluoride Solution (H/U-235 atomic ratio = 44.3) is plotted as a Function of the Number of Cylinders in a Straight-Line Array at Various Surface-to-Surface Spacings. Figures 6 and 7 of Gilley, Fox, and Callihan, ORNL-2367.)

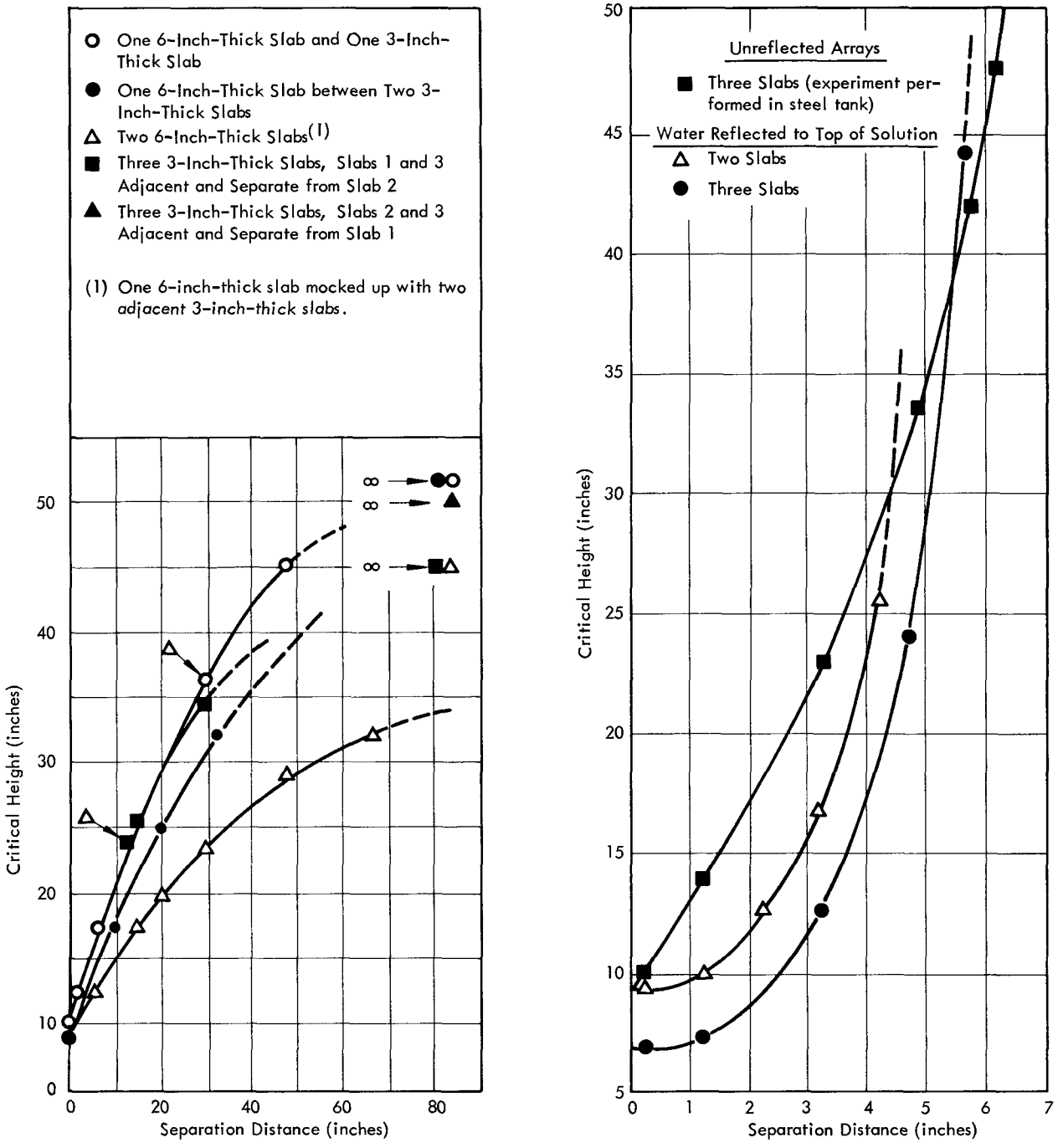


(a) Unreflected



(b) Reflected

Figure V-4.1. CRITICAL HEIGHT OF TWO PARALLEL THREE-INCH-THICK SLABS AS A FUNCTION OF THE SEPARATION DISTANCE. (Curve (a) Represents the Critical Height of Two Parallel Unreflected Slabs as against the Surface-to-Surface Separation. Curve (b) Represents the Critical Height of Two Parallel Reflected Slabs as against the Separation Distance. In Each Experiment the H/U-235 Ratio was Equal to 50:1, and the Uranium was Enriched to 93.2% U-235. Blizard, E. P., et al, Applied Nuclear Physics Division Annual Progress Report Ending 9-1-57, October 18, 1957, ORNL-2389.)



(a) Unreflected

(b) Reflected

Figure V-4.2. CRITICAL HEIGHTS OF ARRAYS OF INTERACTING PARALLEL SLABS AS A FUNCTION OF THE CRITICAL HEIGHT. (Curve (a) Represents Various Configurations and Separations of Parallel Unreflected Aluminum Slabs 3 and 6 Inches in Thickness. Curve (b) Represents Reflected and Unreflected Separations of 3-Inch-Thick Parallel Aluminum Slabs against Separation Distance. In each Experiment the H/U-235 Ratio was Equal to 337 and the Uranium was Enriched to 93.2% U-235. Blizard, E. P., Applied Nuclear Physics Division Annual Progress Report Ending 9-1-57, October 18, 1957, ORNL-2389.)

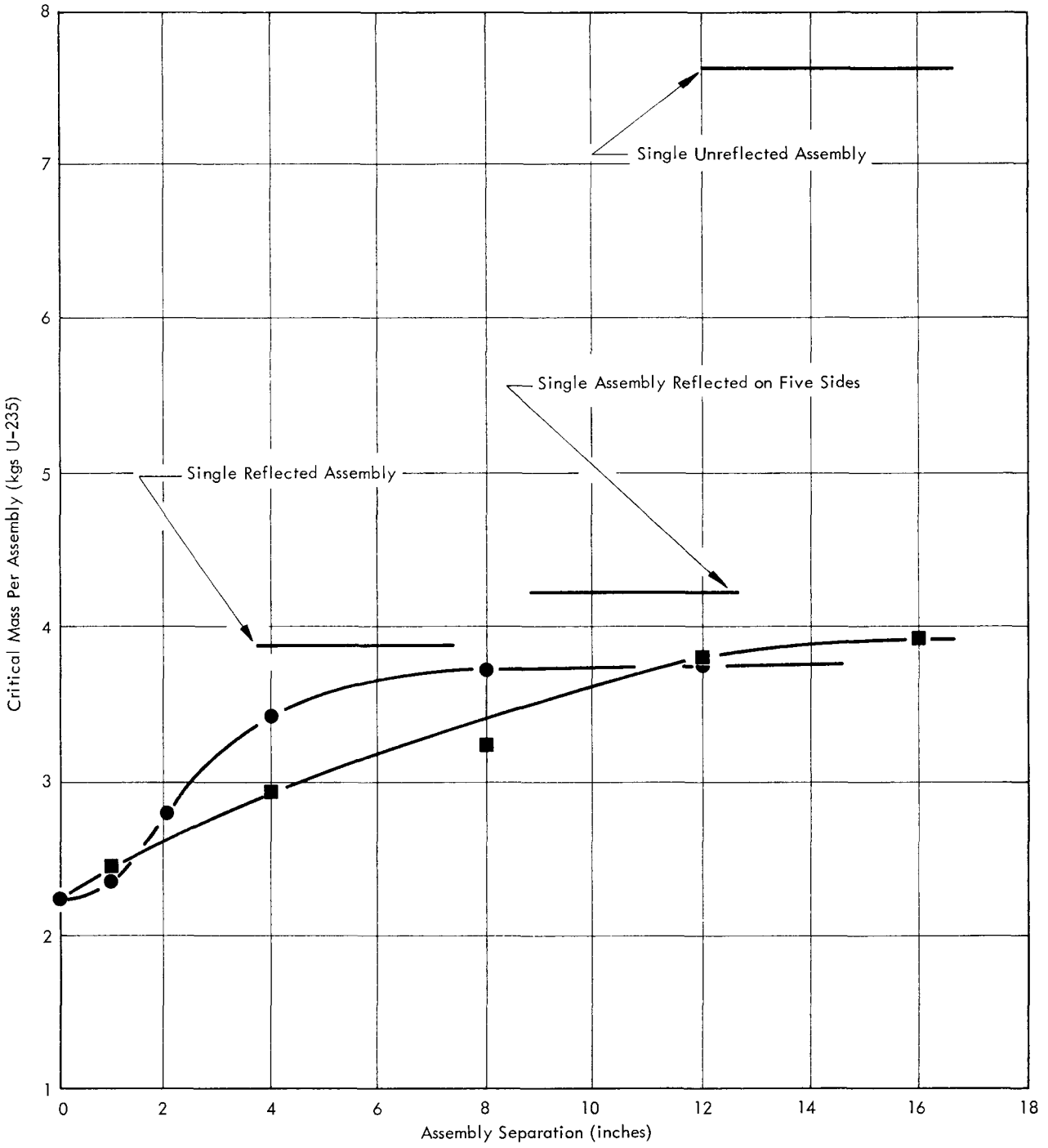


Figure V-5.1. CRITICAL MASS OF U-235 AS A FUNCTION OF THE ASSEMBLY SEPARATION. (Two Cubical Assemblies of Uranium Oxide Enriched to 5% U-235 Mixed with Glyceryl Tristerate to Provide a H/U-235 Ratio of 395 were Ring Tamped (completely surrounded by, but not separated by, water). The Circles Represent Experimental Data for the Separations between Assemblies Filled with Water, and the Squares Represent the Separation Filled with air. Callihan, et al, Ring Tamping, Y-B23-22, November 5, 1952.)

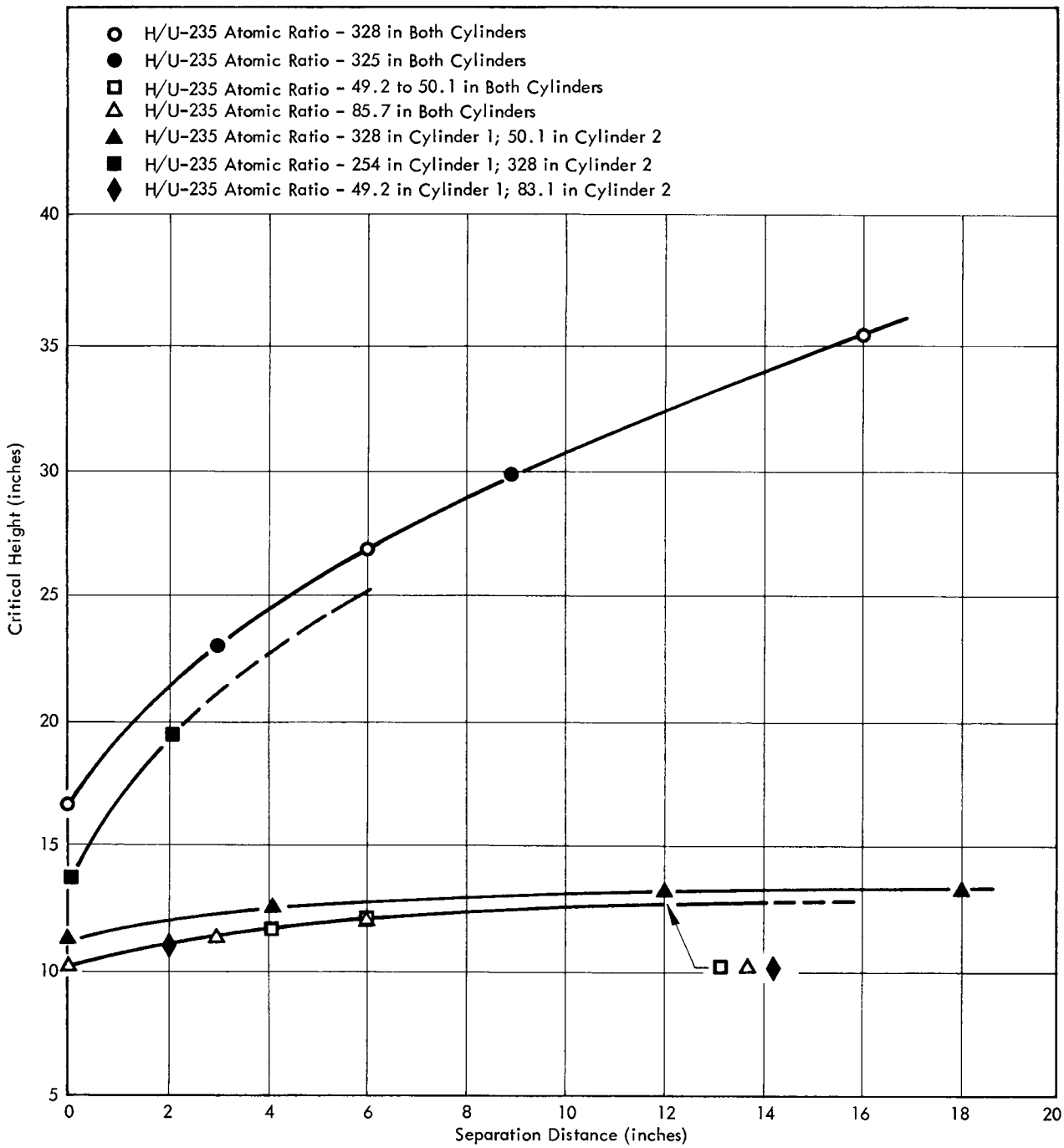


Figure V-5.2. INTERACTION BETWEEN CYLINDERS OF DIFFERENT SOLUTION MODERATION. (Critical Height of the Unreflected Interacting 10-Inch-Diameter Cylinder is Plotted against the Separation Distance. The Solution was UO_2F_2 Enriched to 93.2% U-235, and the Cylinders were Aluminum. Blizard, E. P., et al, Applied Nuclear Physics Division Annual Progress Report Ending 9-1-57, October 18, 1957, ORNL-2389.)

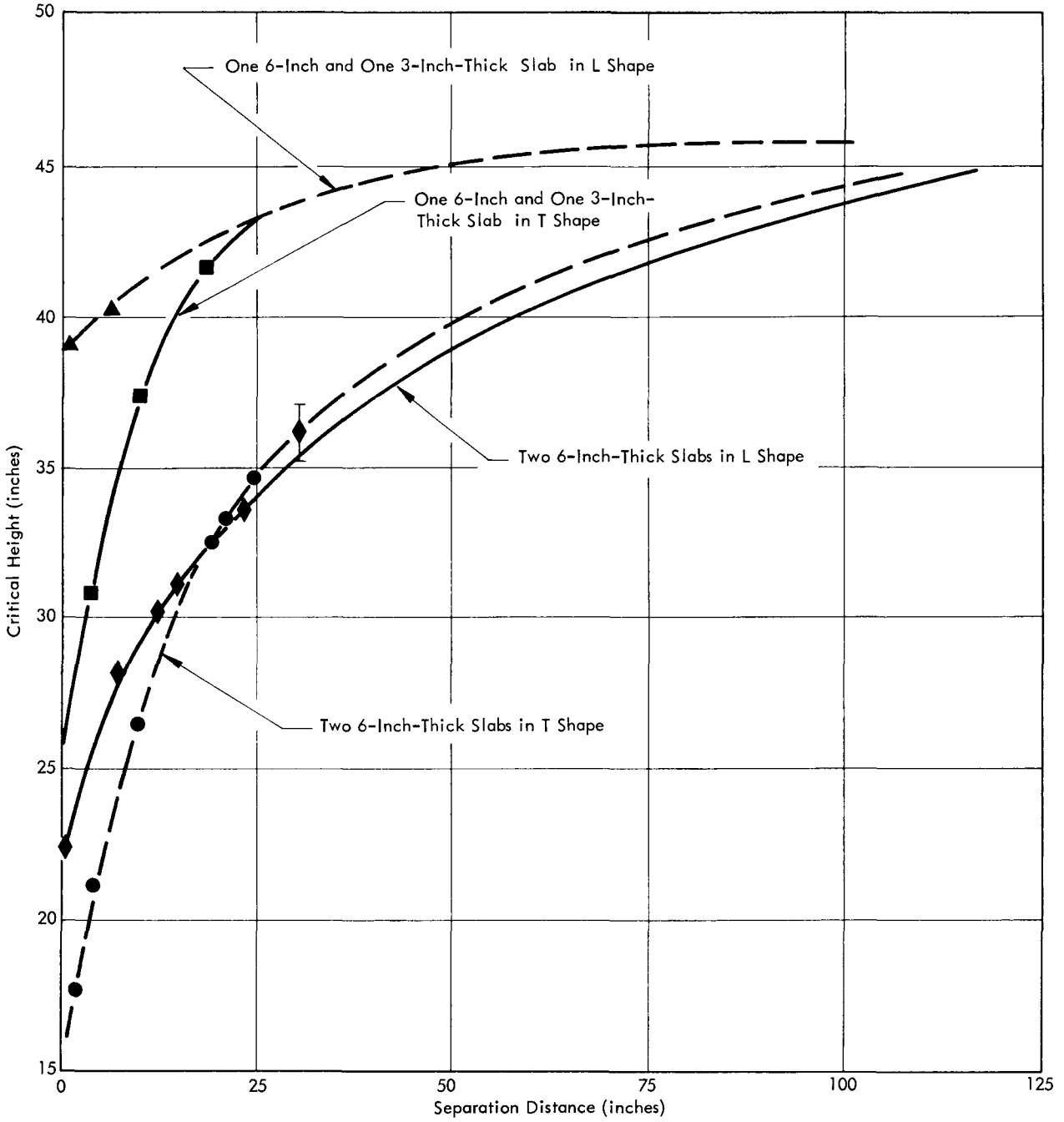
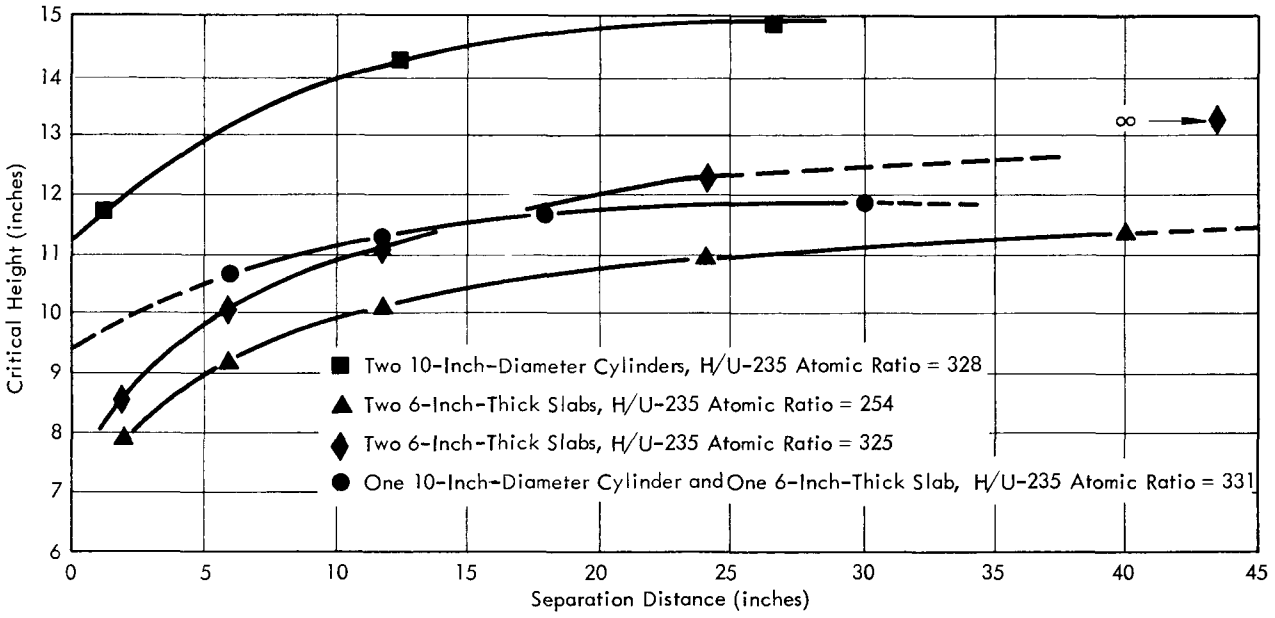
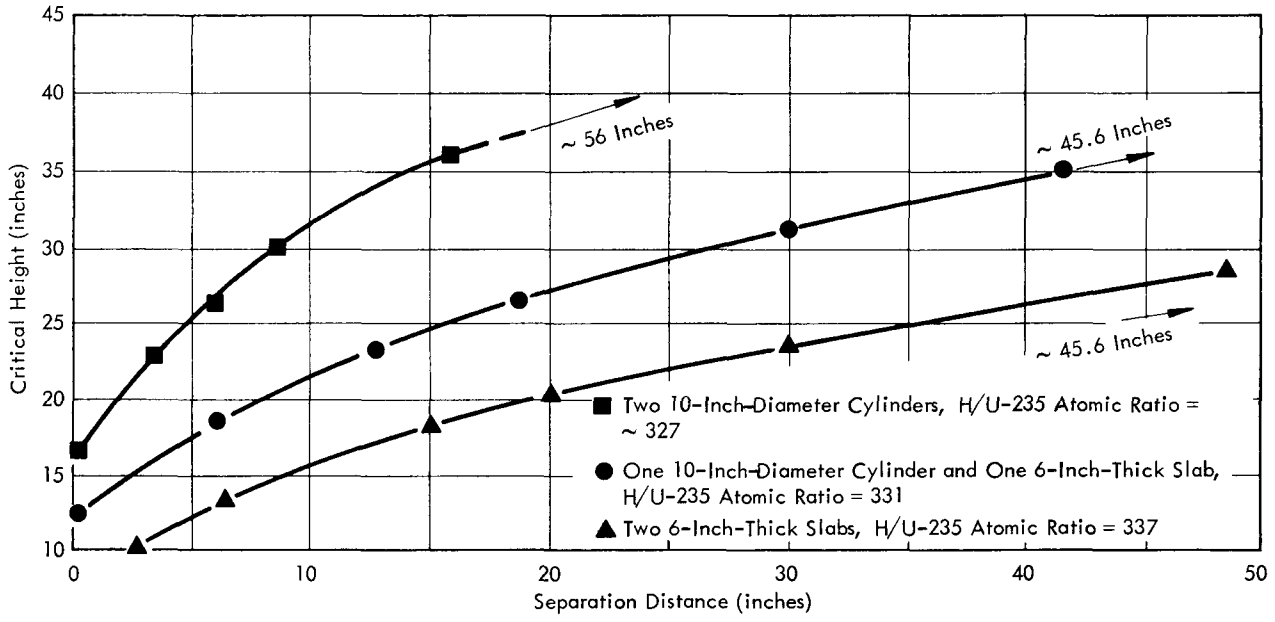


Figure V-5.4. INTERACTION BETWEEN SLABS IN THE T AND L GEOMETRIES. (The Common Critical Height of Nonparallel Interacting Slabs Containing UO_2F_2 Solution at 93.2% Isotopic Enrichment is Given as a Function of the Seperation. The H/U-235 Ratio was Equal to 325, and the Containers were Aluminum and Unreflected. The Separation Represents the Distance between the Interacting Faces of the Particular Existing Conditions. Blizard, E. P., et al, Applied Nuclear Physics Division Annual Progress Report Ending 9-1-57, October 18, 1957, ORNL-2389.)

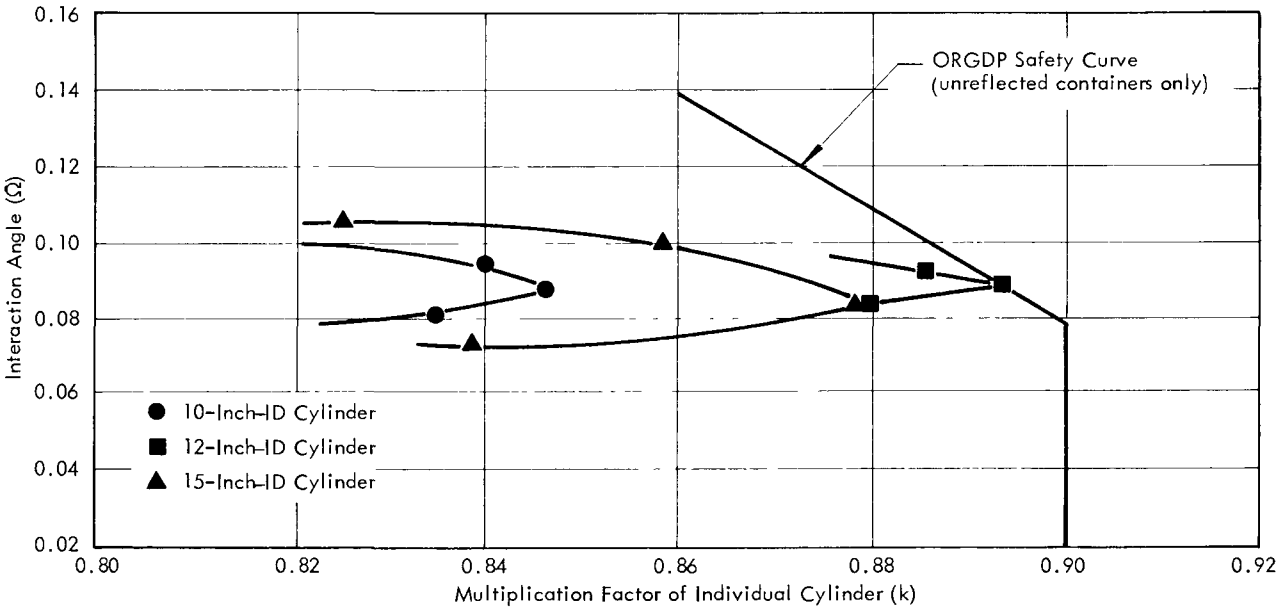


(a) Reflected

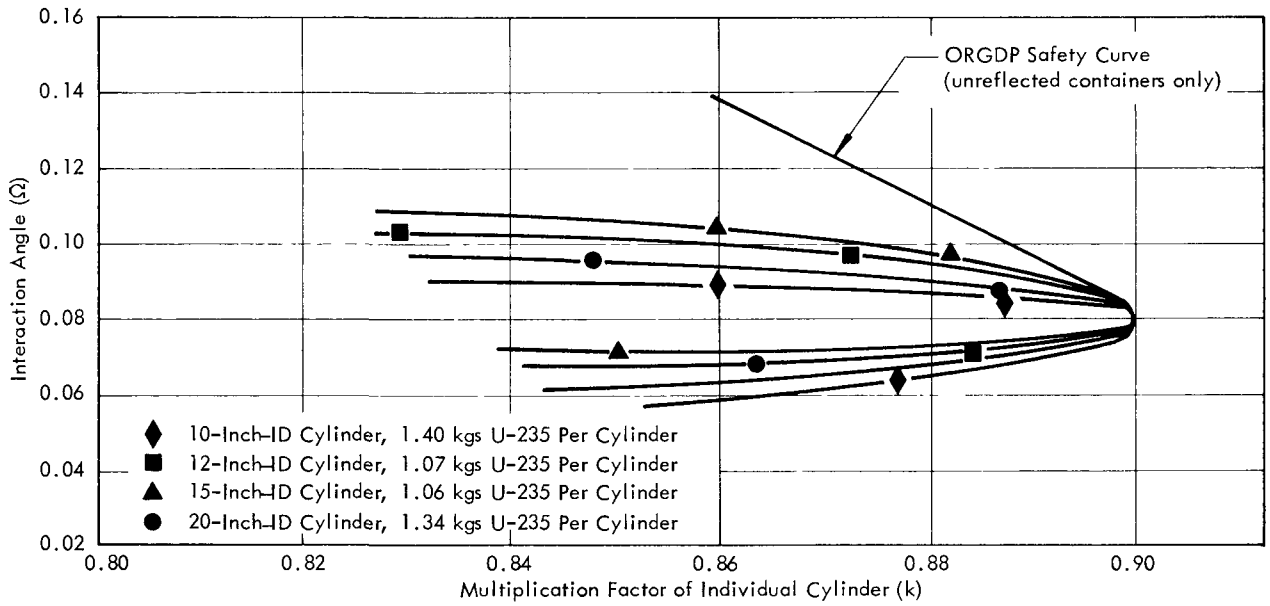


(b) Unreflected

Figure V-5.5. INTERACTION BETWEEN CONTAINERS OF DIFFERENT GEOMETRY. (Critical Height of Dissimilar Interacting Containers is Plotted against the Separation Distance. Curve (a) Represents the Critical Height of Water-Reflected (except distance-separating containers) Dissimilar Interacting Containers as against the Separation Distance. Curve (b) Represents the Unreflected Critical Height of Dissimilar Interacting Cylinders against the Separation Distance. The Experiments were Performed Using UO_2F_2 Solution Enriched to 93.2% U-235. The Vessels were Aluminum. One 6-Inch-Thick Slab was Mocked up with Two Adjacent 3-Inch-Thick Slabs. The H/U-235 Ratio Range was from 254 to 337 in the Experiments. Blizard, E. P., et al, Applied Nuclear Physics Division Annual Progress Report Ending 9-1-57, ORNL-2389.)



(a) Interaction of Cylinders with Optimum Mass



(b) Interaction of Cylinders with Constant Mass

Figure V-6.1. VARIATION OF INTERACTION ANGLE, Ω, AS A FUNCTION OF THE MULTIPLICATION FACTOR, k, OF AN INDIVIDUAL CYLINDER. (The Values of k for a Given Cylindrical Container having a Specified Mass of U-235 were Determined by the Two-Group Theory as a Function of the Solution Height. The Various Actual Interaction Angles between this Container and an Identical One Spaced at a Given Distance were then Determined. Uranium was Enriched to 93.2% U-235. Henry, H. F., et al, K-1335, June 4, 1957.)

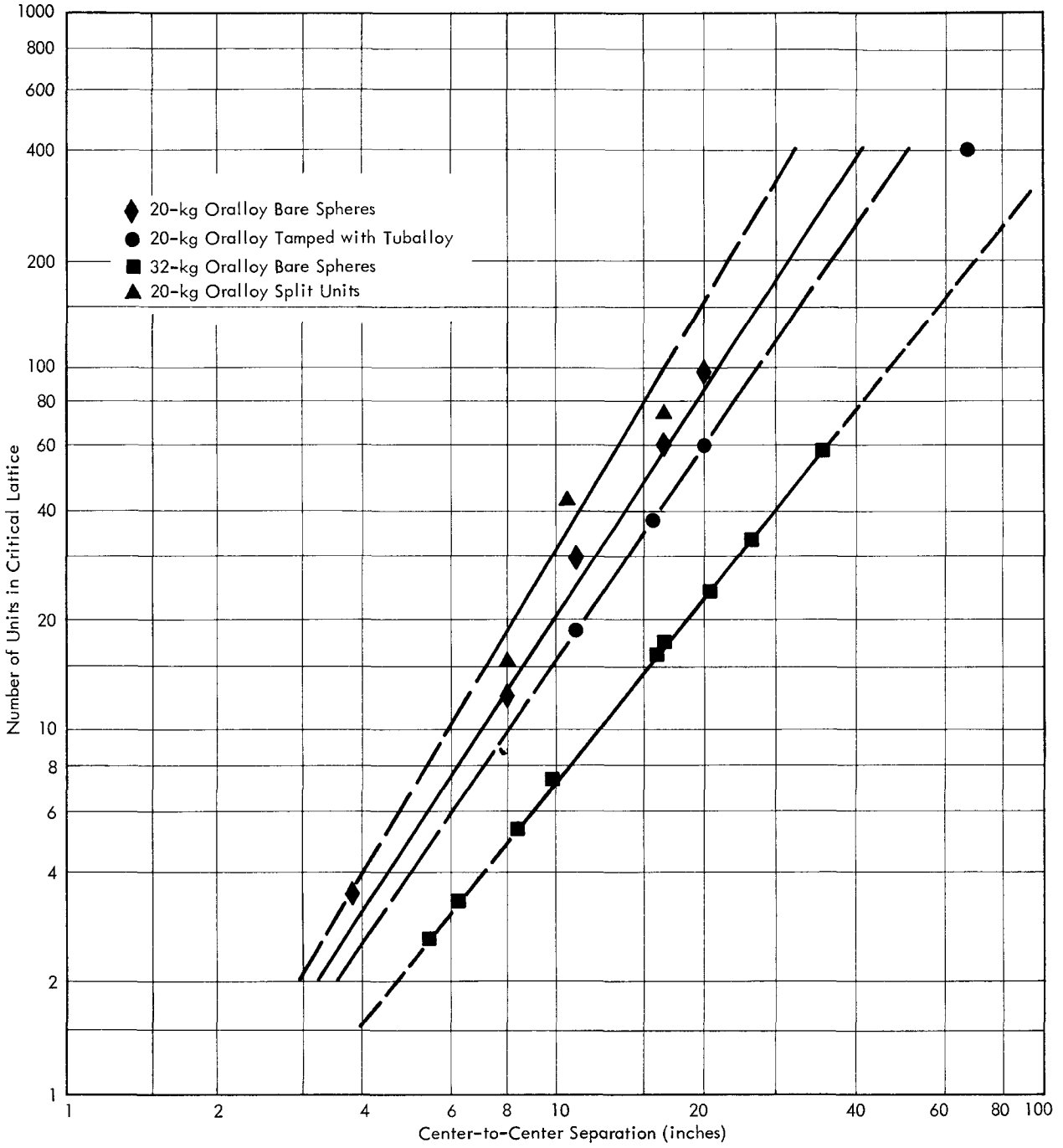


Figure W-1.1. CRITICAL NUMBER OF UNITS IN AN ARRAY AS A FUNCTION OF THE CENTER-TO-CENTER SPACING. (Arrays were nearly Cubical in Shape and were Contained within a Closely Fitting One-Foot Concrete Vault. The Self Multiplication of the Bare 20-Kilogram U-Equivalent Sphere was 3. Paxton, LA-1958-Del and LA-1875-Del.)

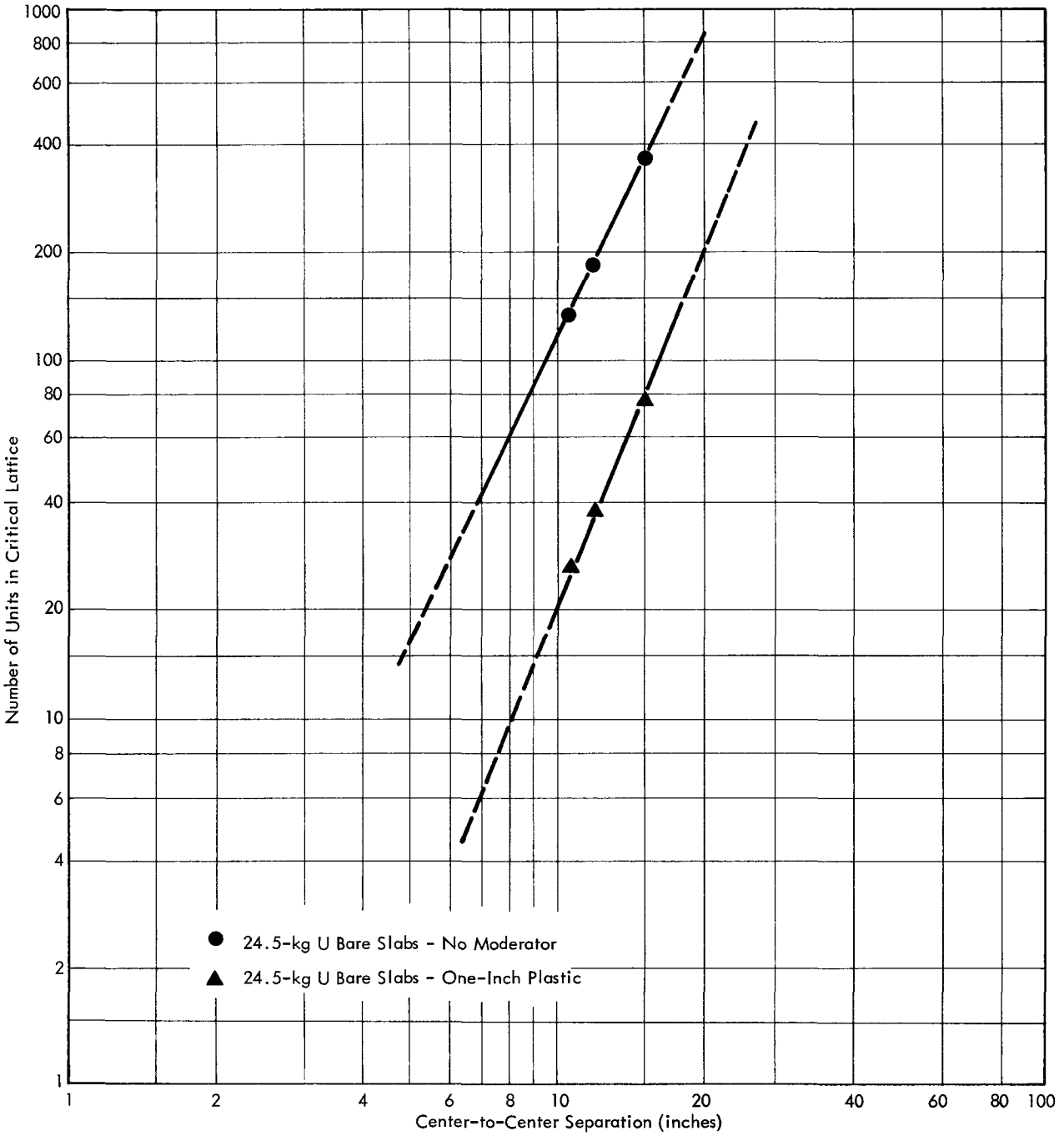


Figure W-1.2. NUMBER OF URANIUM METAL SLABS IN A CRITICAL LATTICE AS A FUNCTION OF THE CENTER-TO-CENTER SPACING OF UNITS. (Arrays were nearly Cubical in Shape, and were Reflected with One Inch of Plexiglas. Slabs were ~10 Inches by Eight Inches by One Inch, Averaged 24.5 Kilograms of Uranium, and Exhibited a Self Multiplication of 1.5 with Internal Source. Triangular Points Denote Arrays in which Moderating One-Inch Plexiglas Sheets were Inserted Midway between Adjacent Slabs. Mihalczo and Lynn, CF-59-7-87.)

Table W-1.1

ESTIMATED NUMBER OF FISSILE UNITS REQUIRED FOR CRITICAL LATTICES IN ONE-INCH-THICK REFLECTOR VAULT

Arrays were nearly cubical in shape. Fissile units were ~10-inch by 8-inch by 1-inch metal slabs enriched to 93.4% U-235 with an average mass of 24.5 kgs U (Mihalczo and Lynn, CF-59-7-87).

Center-to-Center Separation of Fissile Units (inches)	Number of Fissile Units			
	Unmoderated Lattice	Plexiglas[1] Between Fissile Units	Plexiglas[1] and Styrofoam[2] Between Fissile Units	Plexiglas[1] and Foamglas[2][3] Between Fissile Units
15	350 ± 30	75^{+5}_{-2}		
12	185 ± 10	36^{+5}_{-2}	36^{+5}_{-2}	185 ± 30
11	145 ± 5[3]	$27^{+0.5}_{-0}$[4]		

[1] One-inch thick.
[2] 70 vol % of unit cell.
[3] Containing 2% boron.
[4] Extrapolations of inverse multiplication curves.

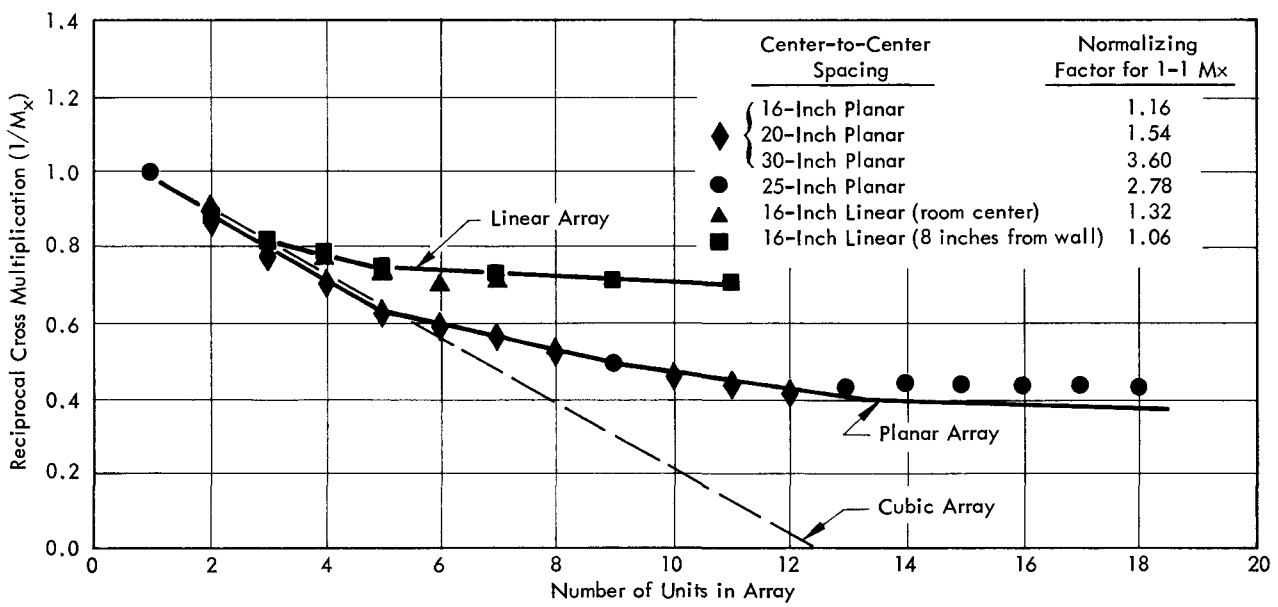


Figure W-1.3. RECIPROCAL CROSS MULTIPLICATION AS A FUNCTION OF THE NUMBER OF UNITS IN THE ARRAY. (Cross Multiplication Data for Linear and Two-Dimensional Arrays of ~32-Kilogram Oralloy Spheres are Plotted as a Function of the Number of Units in the Array. The Arrays were Centered Eight Inches above the Concrete Floor in a Room with Concrete Walls. Paxton, H. C., "Standards for Fissionable Materials Outside reactors, Standard Work in the American Nuclear Society", A Special Session of Invited Papers, pp 55 - 63, June 1959.)

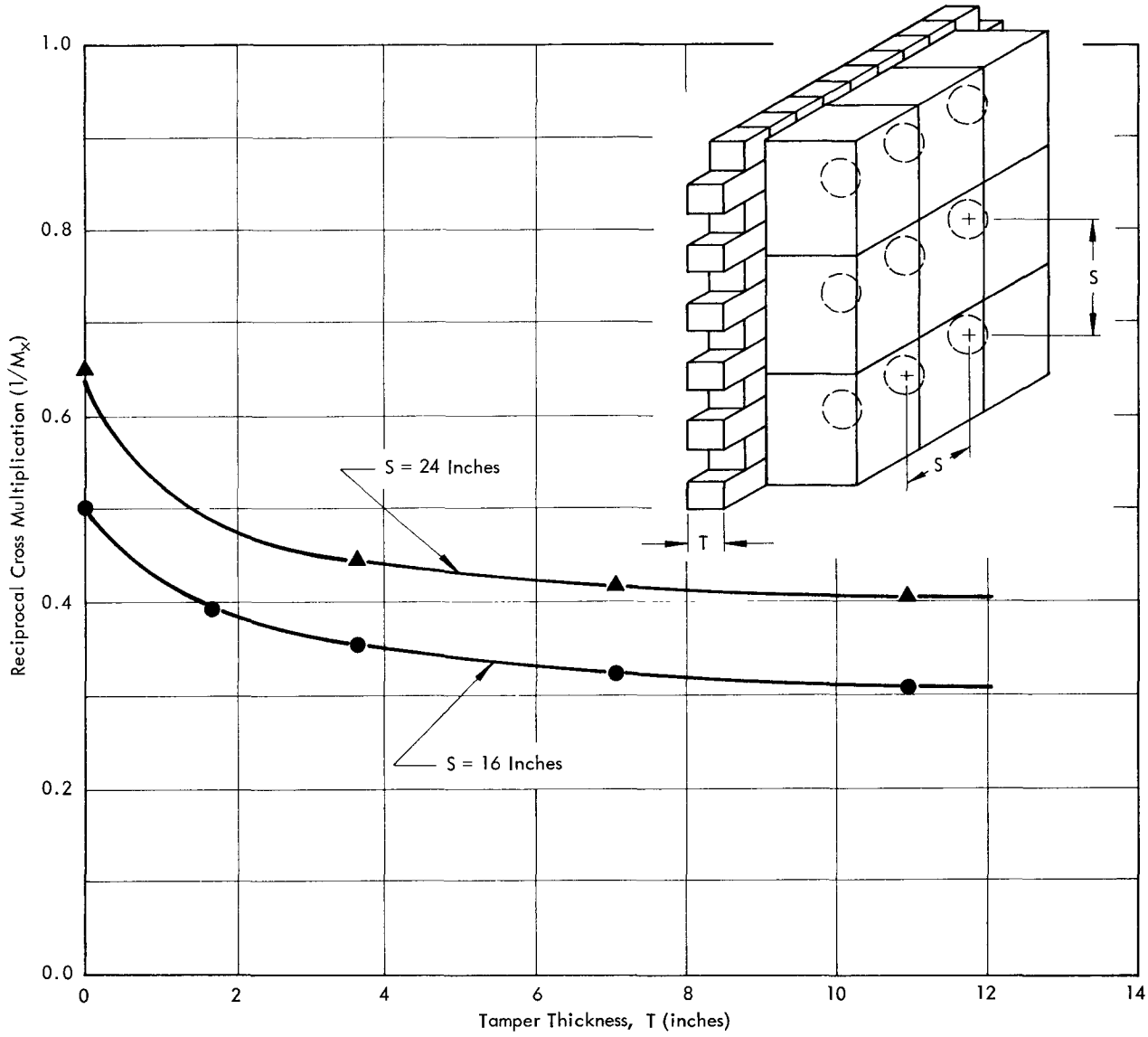


Figure W-2.1. **PLANE ARRAY REFLECTED BY A CONCRETE WALL.** (The Multiplication Data of a Three-Inch by Three-Inch Vertical Plane Array of 32-Kilogram Oralloy Metal Units are Plotted as a Function of the Thickness of a Concrete Wall Located 8½ Inches from the Array. S is the Center-to-Center Separation between the Metal Units. Schuske, C. L., Arthur, M. G., and Smith, D. F., CD56-869, July 1956.)

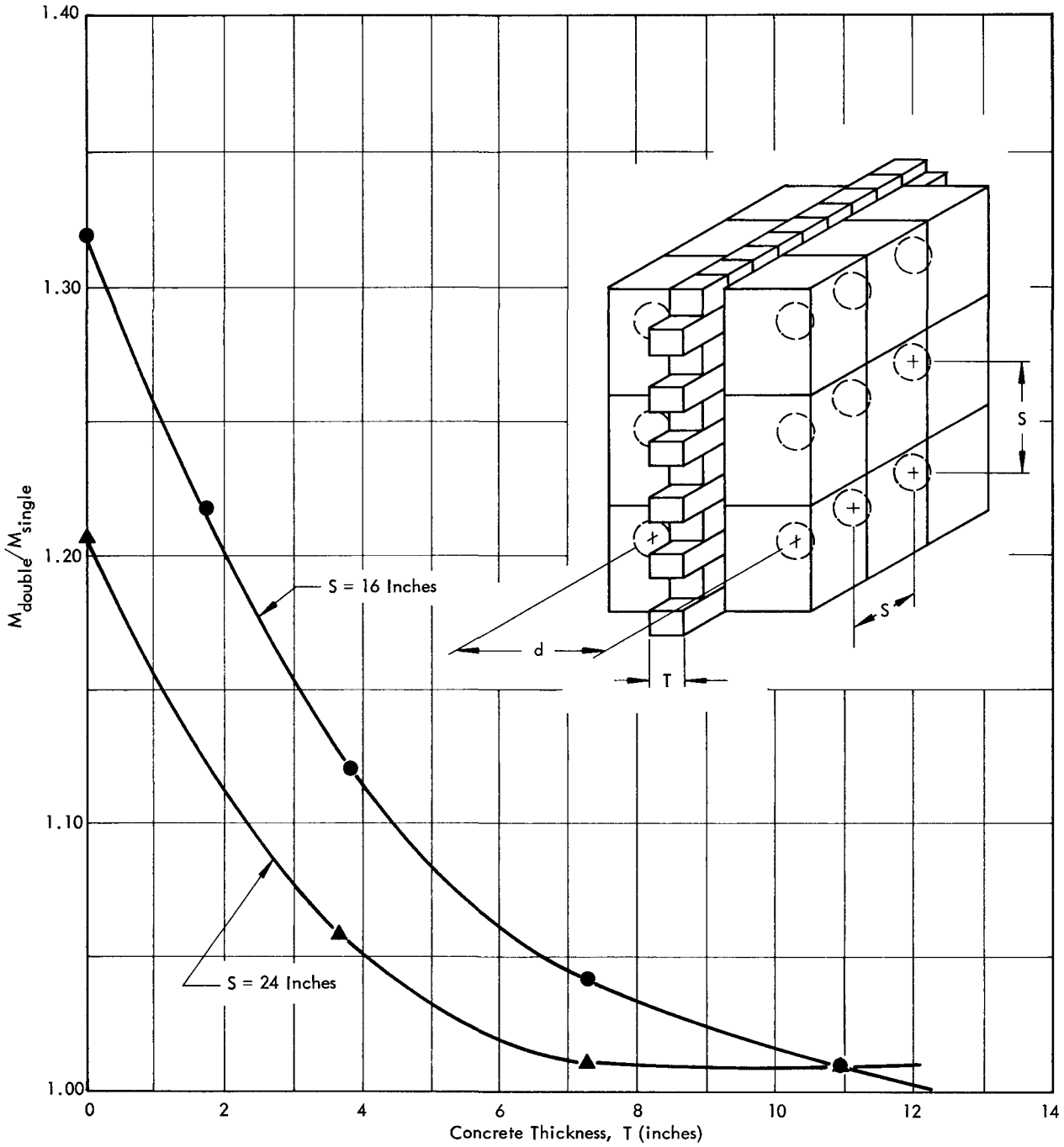


Figure W-2.2. PLANE ARRAYS SEPARATED BY A CONCRETE WALL. (The Degree to which a Concrete Wall of Various Thicknesses Isolates Two Vertical Plane Arrays of 32-Kilogram Oralloy Metal Units, 8½ Inches from Each Side of the Wall, is Shown. The Ordinate is the Ratio of Multiplication of the Two Arrays, with Wall between, to that of a Single Array. The Abscissa is the Thickness of the Concrete Wall in Inches. S is the Center-to-Center Separation between the Metal Units. The Distance, d, (center-to-center separation) between Arrays is 17 + T Inches Schuske, C. L., Arthur, M. G., and Smith, D. F., CD56-869, July 1956.)

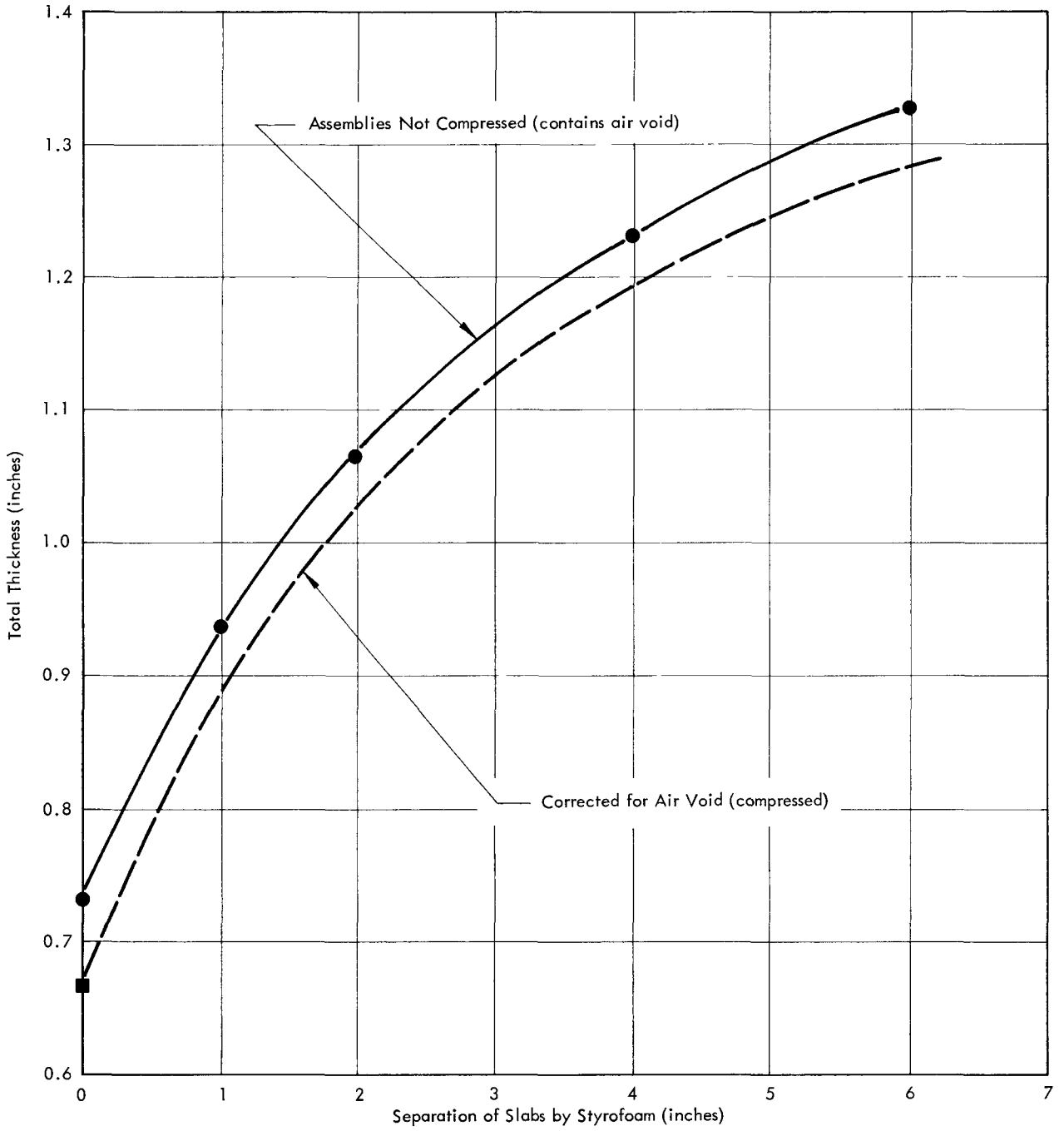
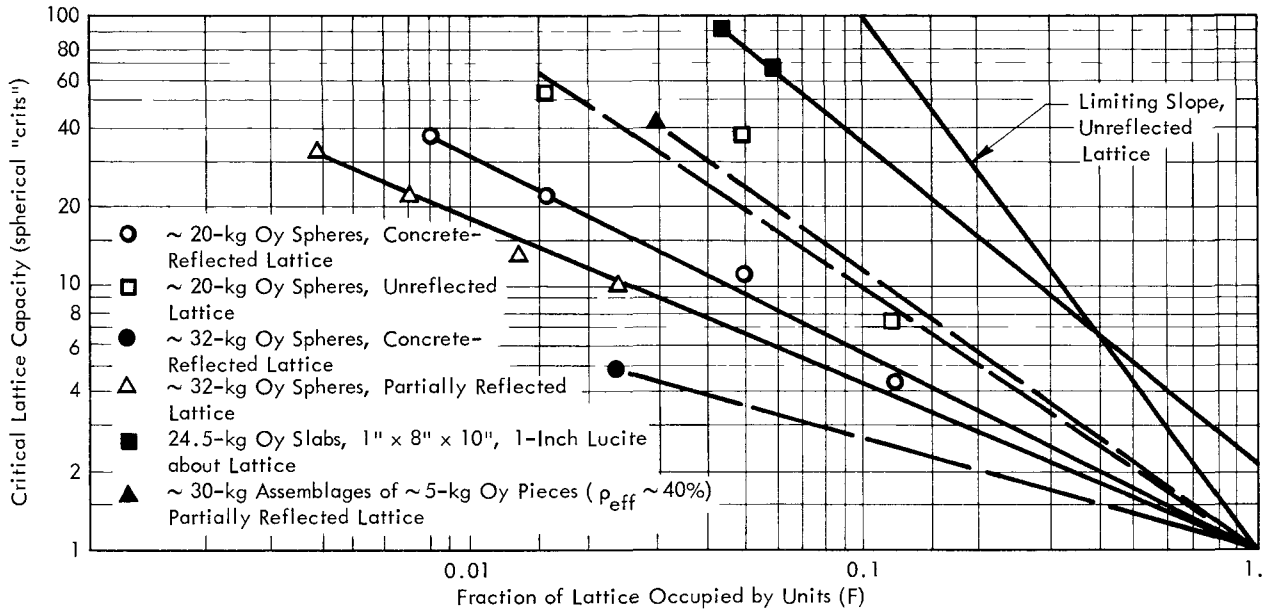
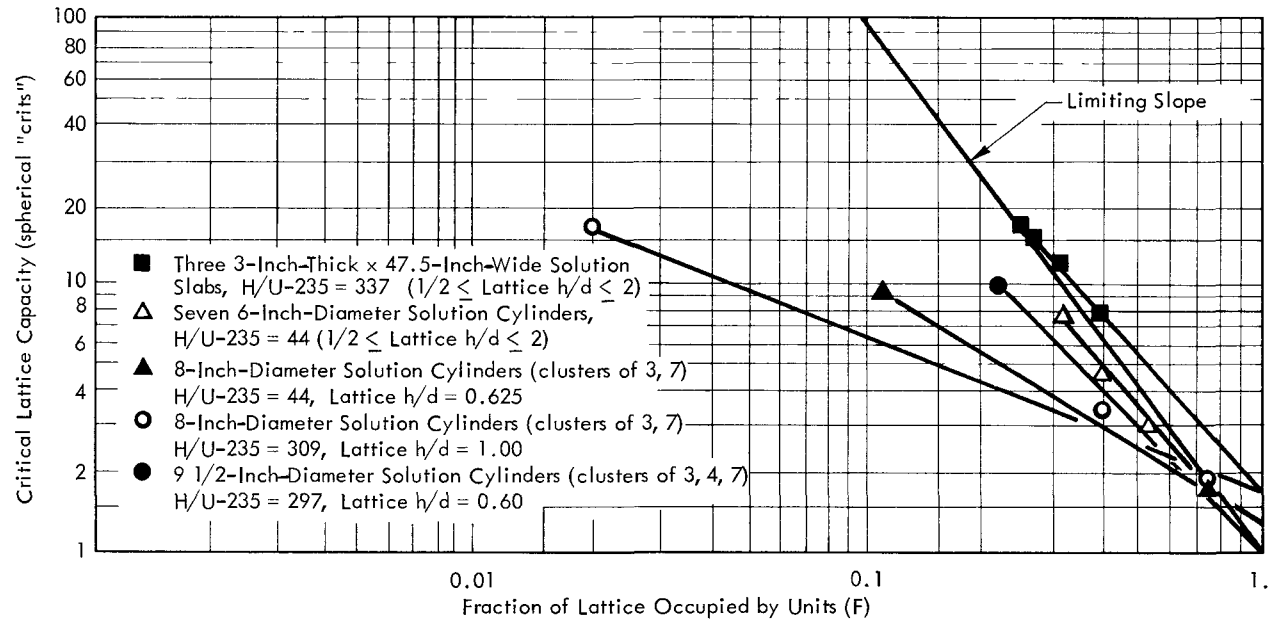


Figure W-2.3. **TOTAL THICKNESS AS A FUNCTION OF THE SEPARATION OF SLABS BY STYROFOAM.** (Two 12.5-Inch-Diameter Plutonium (~15.8 gms/cc) Slabs of Equal Thickness Interacting through Styrofoam. Reflection by Four Inches of Plexiglas on Top and Bottom; Three Inches of Plexiglas on Sides. Styrofoam Density ~0.026 gms/cc. Schuske, C. L., et al, Interaction of Two Metal Slabs of Plutonium in Plexiglas, RFP 174, December 28, 1959.)



(a) Cubic Lattices of Highly Enriched Uranium Metal



(b) Approximately Unreflected Cubic Arrays of U-235 Solutions

Figure X-1.1. CRITICAL LATTICE CAPACITY (Spherical "Crits") AS A FUNCTION OF THE FRACTION OF THE LATTICE OCCUPIED BY UNITS (F). (Critical Data for Cubic Lattices of Oralloy Metal Units and UO_2F_2 (93.2% U-235 enriched) Solution Slabs and Cylinders are Summarized. The Ordinate is the Critical Capacity of the Array in Terms of the Number of Bare, Spherical Critical Masses of the Material. The Abscissa is the Volume Fraction (F) of the Lattice that is Occupied by the Units. Consistent Densities of the Units are Used for Determining Coordinates. Paxton, H. C., "Standards for Fissionable Material Outside Reactors, Standard Work in the American Nuclear Society", A Special Session of Invited Papers, pp 55-63, June 1959; Fox, J. K., Gilley, L. W., and Callihan, A. D., Critical Mass Studies, Part IX, Aqueous U-235 Solution, ORNL-2367, February 1958.)

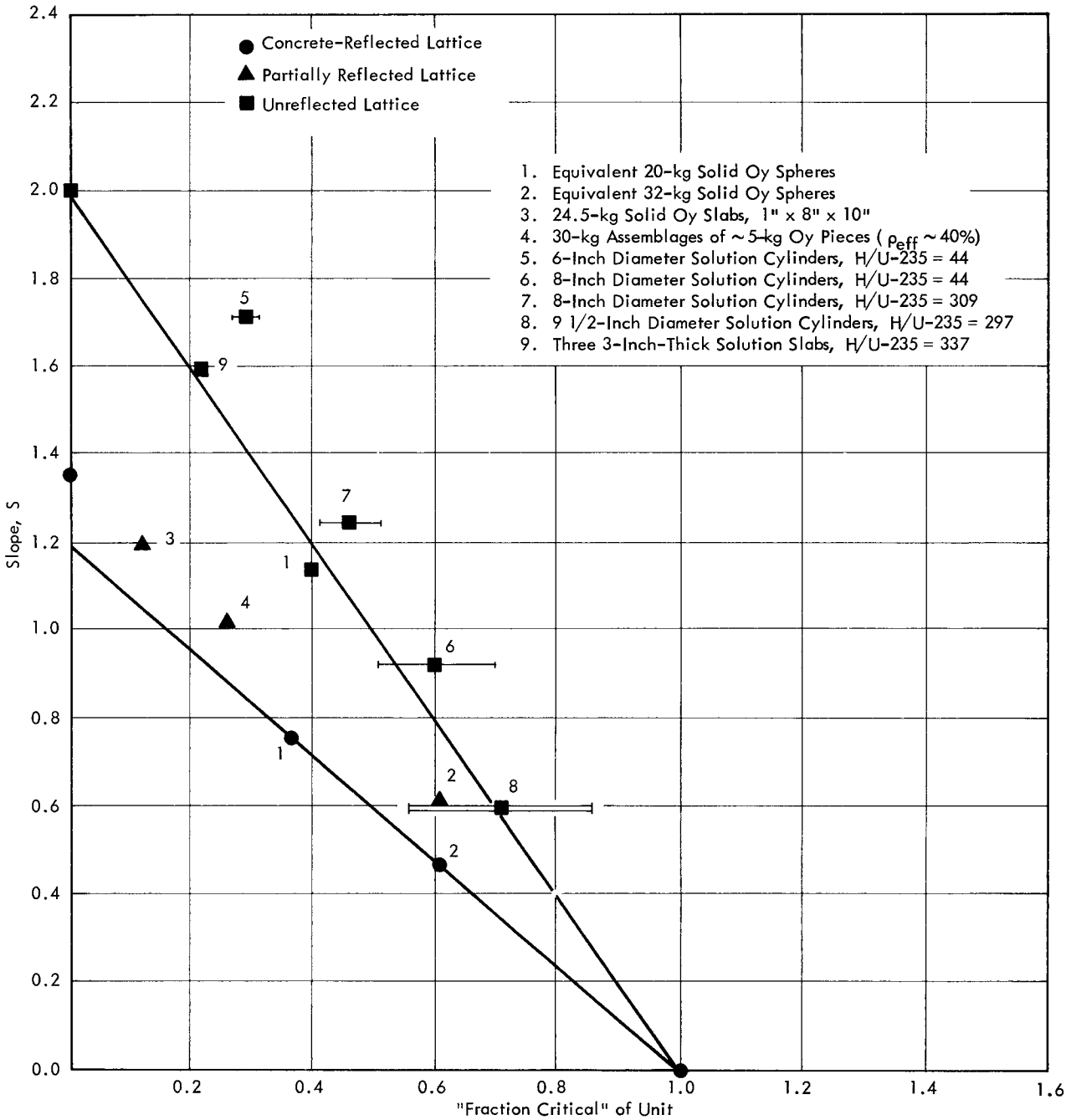


Figure X-1.2. S AS A FUNCTION OF THE "FRACTION CRITICAL" OF THE UNIT. (Each Slope, S, of Figure X-1.1 Corresponds to a Density Exponent if the Lattice is thought of as a Single Low-Density Unit. Curve (a) of Figure X-1.1 is a Correlation of S with the Quantity of the Reflector about the Lattice and Reactivity (fraction critical) of an Individual Unit.)

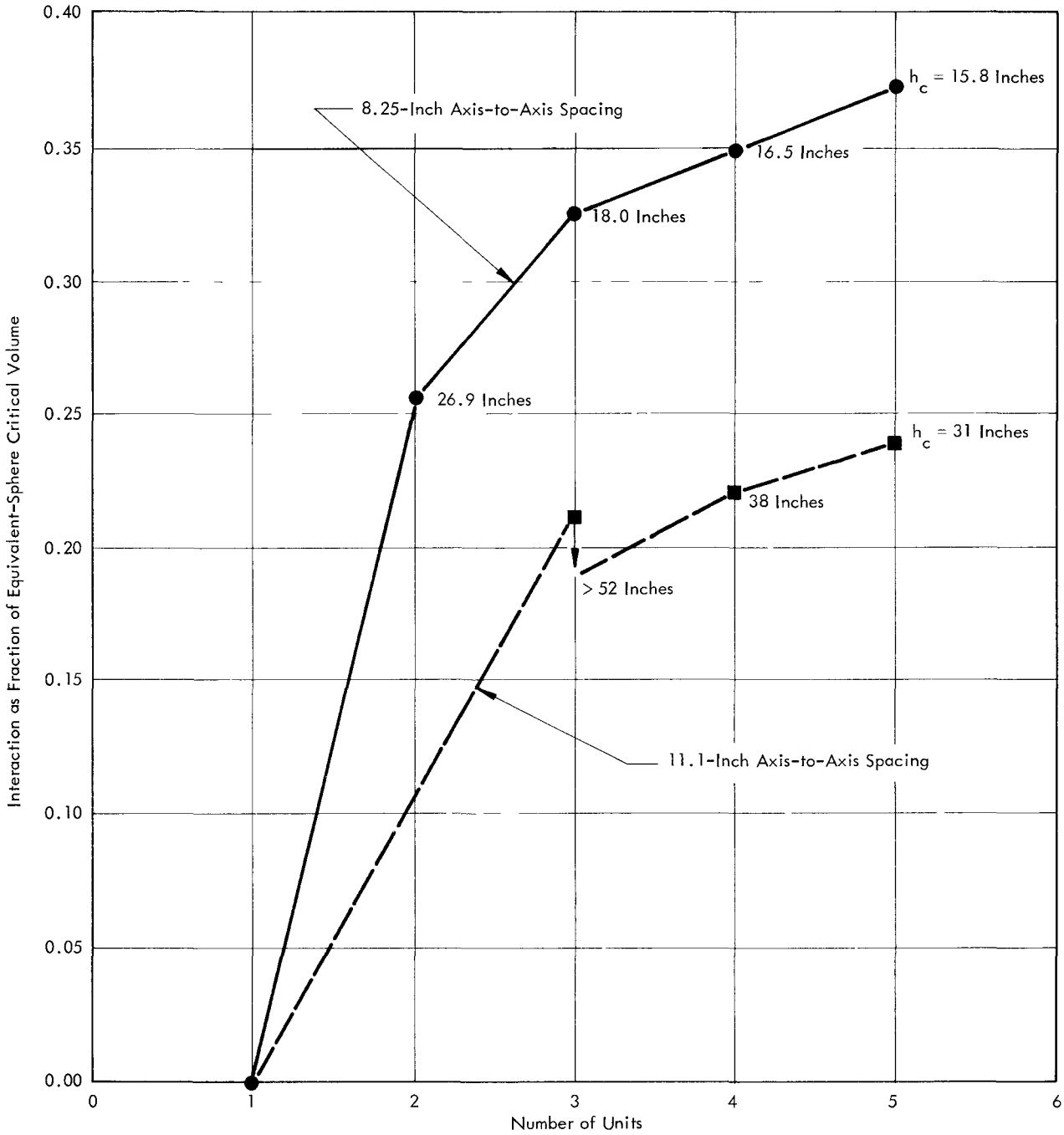


Figure X-1.3. **INTERACTION AS THE FRACTION OF THE EQUIVALENT SPHERE CRITICAL VOLUME AS A FUNCTION OF THE NUMBER OF UNITS.** (The Interaction within In-Plane Array of Unreflected Eight-Inch-Diameter, 93% U-235 UO_2F_2 *Solution Cylinders, at H/U-235 = 44.3, is Shown.* (*Interaction* = 1 - V_s/V_{cs}, *where* V_s = *equivalent* sphere volume of one cylinder in the critical array; V_{cs} = spherical critical volume.) Fox, J. K., Gilley, L. W., and Callihan, A. D., Critical Mass Studies, Part IX, Aqueous U-235 Solutions, Report ORNL-2367, February 1958.)

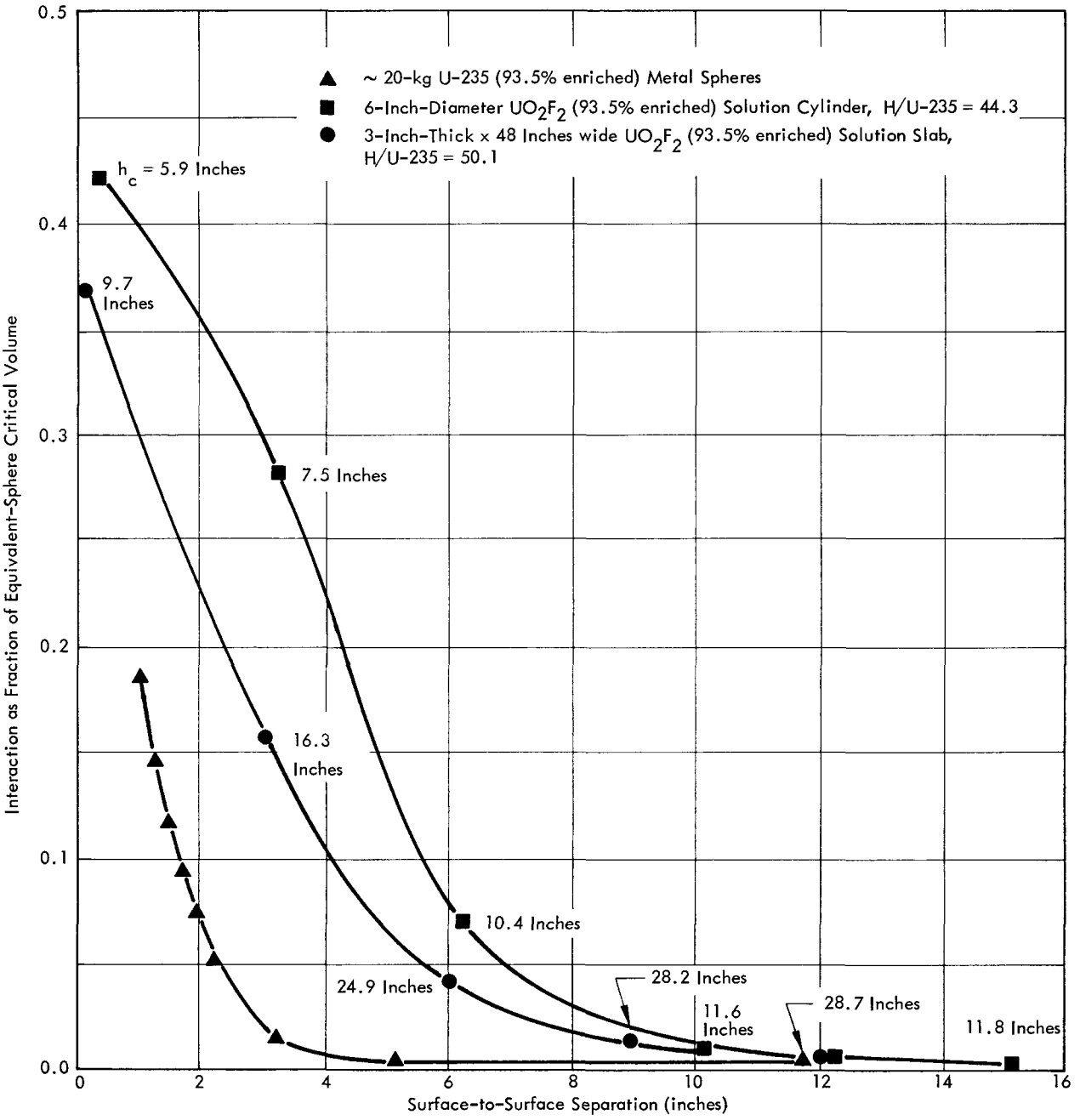


Figure X-1.4. INTERACTION AS THE FRACTION OF THE EQUIVALENT SPHERE CRITICAL VOLUME AS A FUNCTION OF THE SURFACE-TO-SURFACE SEPARATION IN INCHES. (A Measure of the Interaction between Pairs of Units, Maximum Areas Face, Immersed in Water as a Function of the Separation of the Units is Shown. (Interaction = $1 - V_s/V_{cs}$ where V_s = equivalent sphere volume of a unit; V_{cs} = corresponding spherical critical volume.) Fox, J. K., Gilley, L. W., and Callihan, A. D., Critical Mass Studies, Part IX, Aqueous U-235 Solutions Report ORNL-2367, February 1958. Paxton, H. C., Critical Masses of Fissionable Metal as Basic Nuclear Safety Data, Report LA-1958, January 1958.)

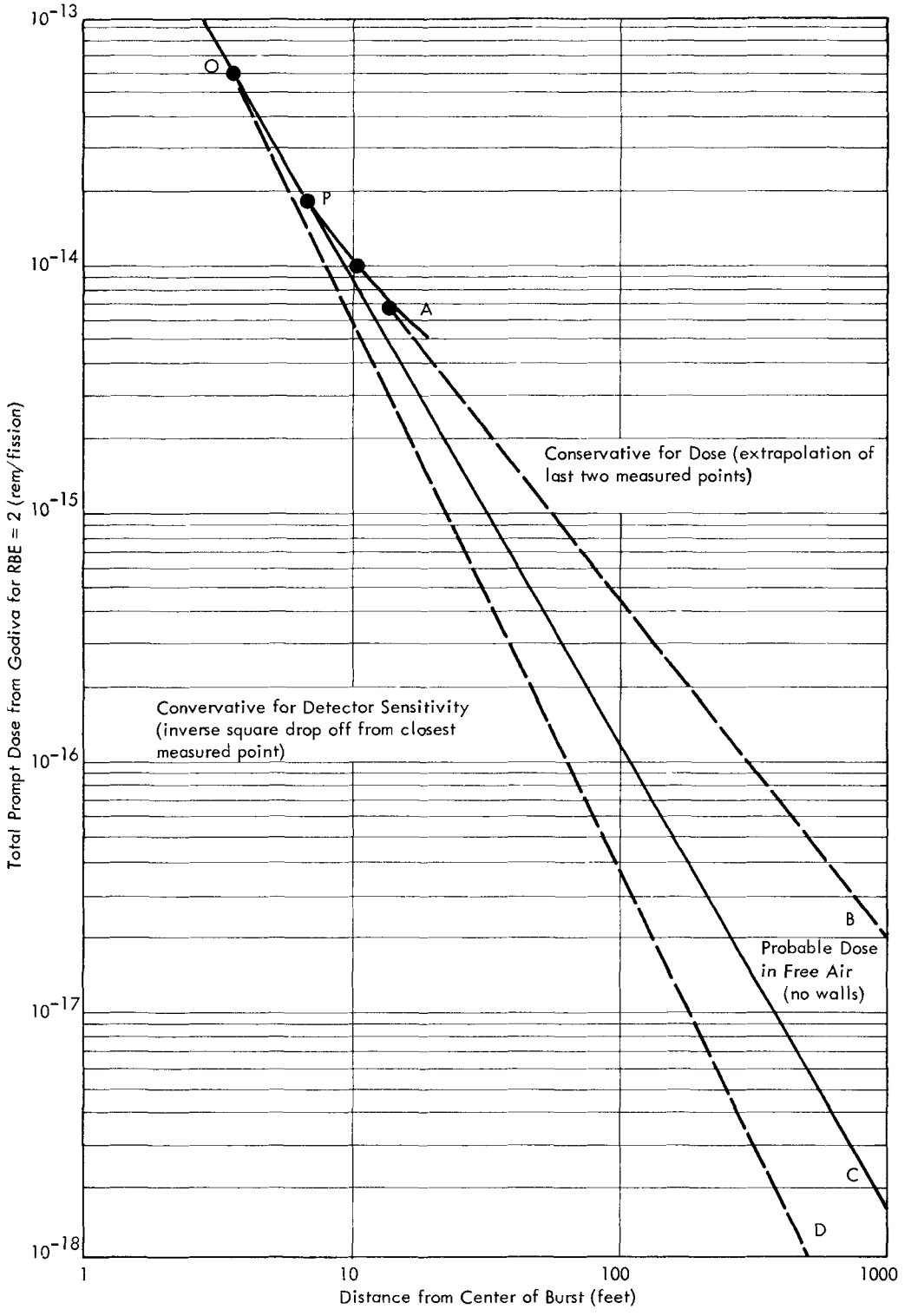


Figure Y-1.1. EXTRAPOLATIONS OF PROMPT RADIATION DOSE FROM A GODIVA I PROMPT-CRITICAL METAL BURST. (Dose is Expressed in REM/Fission on the Basis of a Relative Biological Effectiveness (RBE) of 2 for the Neutron Dose. The Unbroken Line is Drawn through Experimental Points Determined by G. S. Hurst for Neutron Dose and Corrected for Gamma Dose (as reported by Harris and quoted in Y-1092, p 14) and for Ground Scattering (but not wall scattering) as Found by Cure and Hurst (Nucleonics, 12 (8), p 36). Divide Curves by 2.05 to Obtain Prompt Neutron Dose in REP/Fission; by 41 to Obtain Prompt Gamma Dose in REP/Fission.)

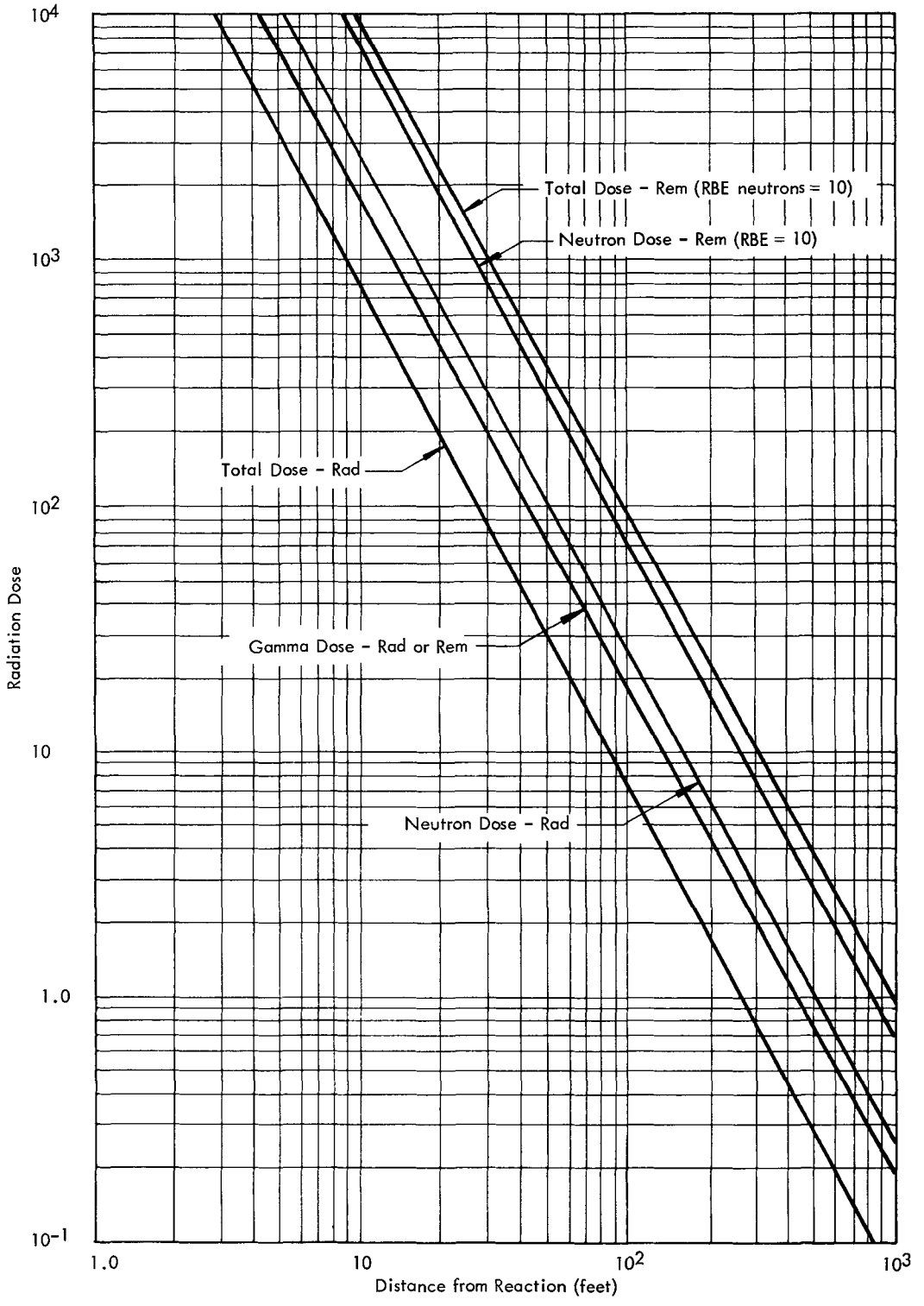
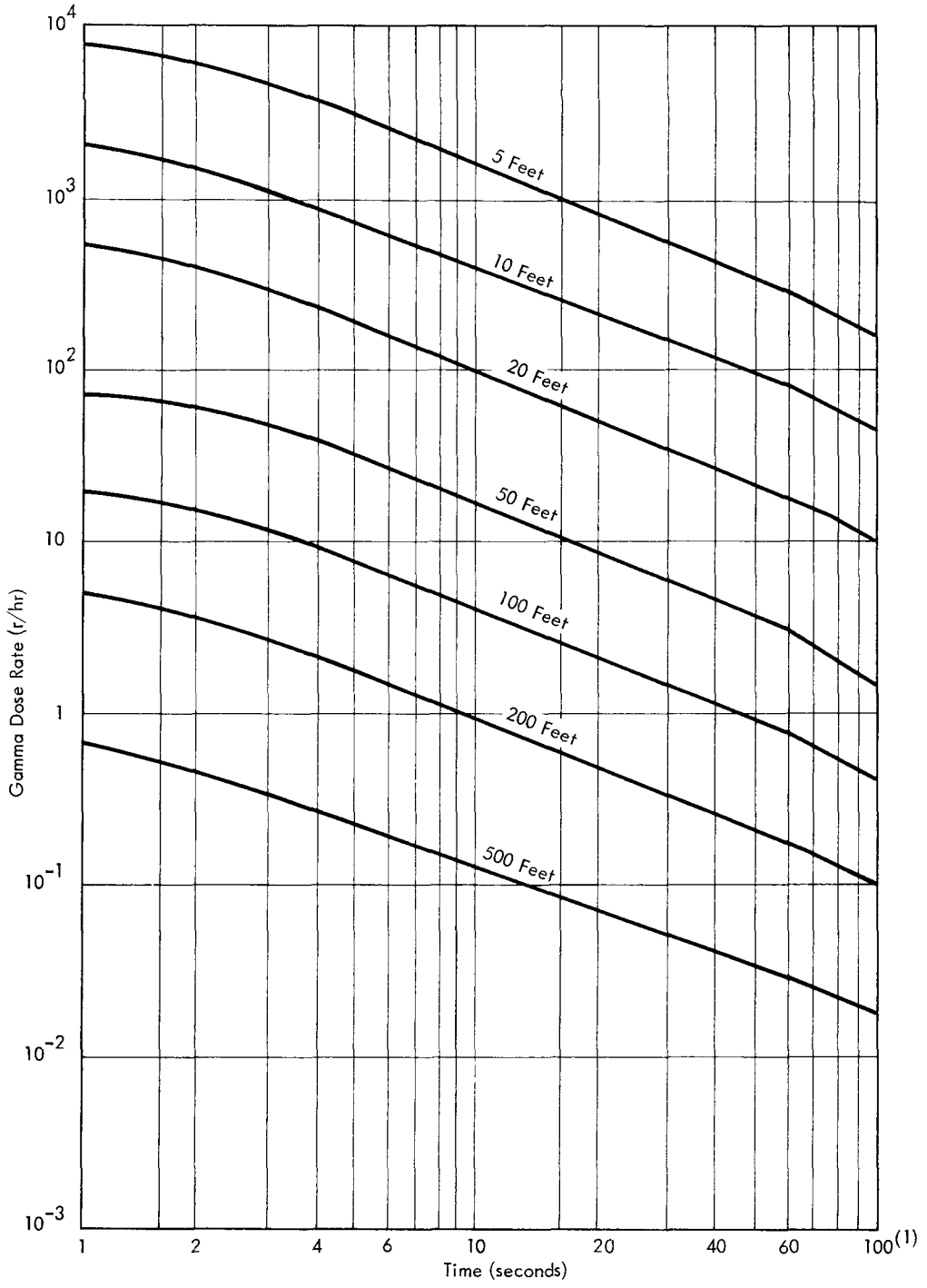


Figure Y-1.2. ESTIMATED PROMPT NEUTRON AND GAMMA DOSES FROM A CRITICAL BURST OF 10^{18} FISSIONS IN A URANIUM SOLUTION. (Curves are Drawn to Fit Measured Doses to a Burro in the Mockup Experiment of the June 16, 1958 Y-12 Incident as Reported by Patton, et al, Y-1234. Adapted from Table 1 of Bailey, KSA-144.)



(1) For times greater than 100 seconds see Figure Y-1.4.

Figure Y-1.3. ESTIMATED GAMMA DOSE RATE FROM FISSION PRODUCT ACTIVITY RESULTING FROM A CRITICAL BURST OF 10^{16} FISSIONS IN A URANIUM SOLUTION. (Curves are Drawn to Fit the Measured Activities following the Y-12 Incident of June 16, 1958 as Reported by Patton, et al, in Y-1234, Utilizing the Way-Wigner Relationship. Extrapolation to Times less than One Minute was Guided by the Data of Maienshein, et al, A/CONF. 15/P/670 (June 1958). Figure 1 of Bailey, KSA-144.)

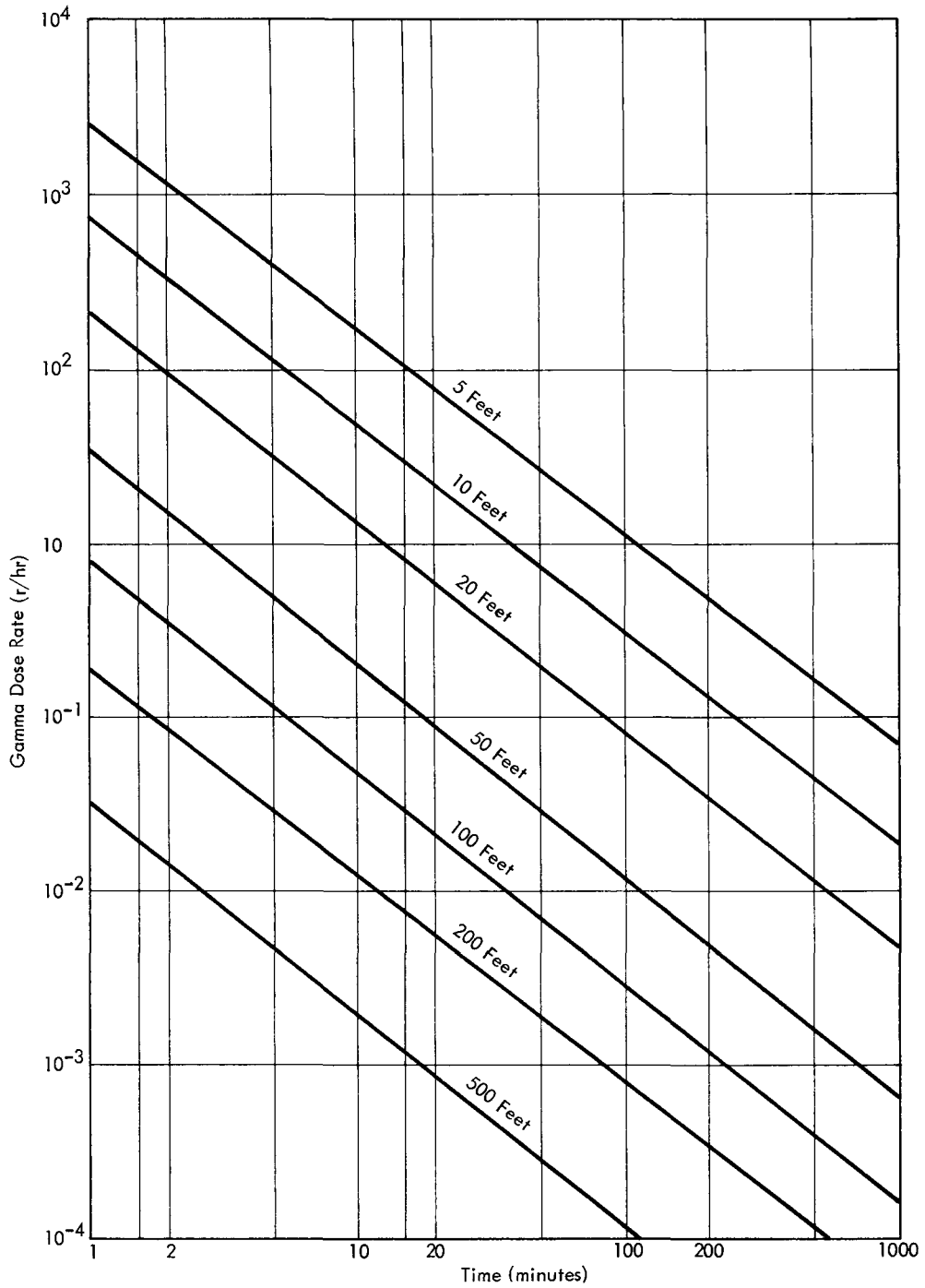


Figure Y-1.4. ESTIMATED GAMMA DOSE RATE FROM FISSION PRODUCT ACTIVITY RESULTING FROM A CRITICAL BURST OF 10^{16} FISSIONS IN A URANIUM SOLUTION. (Curves are Drawn to Fit the Measured Activities Following the Y-12 Incident of June 16, 1958 as Reported by Patton, et al, in Y-1234, Utilizing the Way-Wigner Relationship. Figure 2 of Bailey, KSA-144.)

Table Z-1 1

Y-12 CRITICALITY EVALUATION PARAMETERS

For internal use at the Y-12 Plant in conjunction with problem analysis by the double-contingency method. See Section A-1 for definition of terms.

Variables	Contingencies	Possible Mishaps	Safeguards
Primary Dimension	A. Nonrigidity (safe dimension exceeded)	a Increase in diameter b. Increase in height	1. Restricted use of plastic containers 2. Use of slab overflow pans 3. Drain holes (high level overflow) 4. Permanent geometry by construction 5. Administrative control
Volume	B. Volume excess	c. Operator error	4 Safe geometry equipment 6. Restricted geometry containers 5. Administrative control 3. Overflows
Shape	C. Change in shape	d. Process failure (such as mold breakage)	2. Provision of a more safe geometry to be formed 5. Administrative control
Reflection	D. Full reflection	e. Flooding	7. Calculated risks 8. Elevation of equipment above floors, hoods, trays, etc 4. Annular cylinders
	E. Partial or additional reflection	f. Soaking insulation g Walls h Equipment	9 Water-proofing insulation 10. Mechanical separation (bird cages, guard rails, screens, etc)
	F. Incidental reflection	i. Personnel	5. Administrative control
Interaction	G Nonseparation of enriched material	c Operator error	10. Mechanical separation (bird cages, guard rails, screens, etc) (special dollies, jigs, and storage racks)
	N. Extending array		11 Permanent or semi-permanent location (storage racks, equipment, bolted cages, etc)
	O. Additional unit at center of array		5 Administrative control 12 Route designation
Components	H. Wetness (ie, inleakage)	k. Leakage into containers	13. Covered containers 3. Drain holes in containers (low level overflow) 14. Dry box batching
		l Inadequate drying m. Condensation	15. Heat of process (temperature control) 16. Plugging or removing water inlets such as safety showers, etc

Table Z-1.1 (Continued)

Variables	Contingencies	Possible Mishaps	Safeguards
		c. Operator error (as pulling water into a vacuum cleaner)	5. Administrative control
	I. Burning metal to oxide	n. Fire	17. Chemistry (oxides are insoluble, tends to slab)
Assay	J. Enrichment too high for the design of equipment or procedure	c. Operator error (crossover)	18. Segregation of varying isotopic areas 4. Procedures and equipment designed for maximum accessible assay 19 Reanalysis (particularly incoming salvage) 20. Instrumentation alarms 5 Administrative control
Mass	K. Mass excess	c. Double batching (2x) o. Analytical error (10x) c. Batch card error p. Batch card crossover d. Process failure r Nonstandard shipping limits	5. Administrative control 21. Double aliquot samples 22. Double signature on cards 23. Semi-permanent mounting of cards 20. Instrument alarms 4. Safe geometry equipment 24. Vacuum breakers, check valves, etc 25. Filters and traps 27. Accountability
Concentration	L. Concentration excess	c. Double batching (2x) o. Analytical error (10x) c. Batch card error p Batch card crossover d. Process failure q. Inhomogeneity (ppt) r. Nonstandard shipping limits c. Operator error	5. Administrative control 21. Double aliquot samples 22. Double signature on cards 23. Semi-permanent mounting of cards 20. Instrument alarms 4. Safe geometry equipment 24. Vacuum breakers, check valves, etc. 25. Filters and traps 17. Chemistry
Poison	M. The absence of poison	c. Operator error (failure to add)	26. Used for added safety only 5 Administrative control

Table Z-2 1

PARTIAL LIST OF SHIPPING CODES OF AEC CONTRACTORS AND CAP LICENSEES

Shipper's Code		
AGT	General Electric Company	Evendale, Ohio
ALI	Argonne National Laboratory	Idaho Falls, Idaho
ANL	Argonne National Laboratory	Lemont, Illinois
BWL	Babcock and Wilcox Company	Lynchburg, Virginia
CCC	Union Carbide Nuclear Company, ORGDP	Oak Ridge, Tennessee
CPI	Phillips Petroleum Company, Arco	Idaho Falls, Idaho
CYT	Union Carbide Nuclear Company, Y-12	Oak Ridge, Tennessee
FMPC	Fernald Material Production Center	(see NLO)
HGE	General Electric Company	Richland, Washington
LAB	University of California Radiation Lab	Livermore, California
MAC	Metals and Control Corporation	Attleboro, Mass
MBW	Babcock and Wilcox Company	Lynchburg, Virginia
MCW	Mallinkrodt Chemicals Works	St. Louis, Missouri
MIO	Nuclear Metals, Inc	Cambridge, Mass
NLO	National Lead of Ohio	Cincinnati 31, Ohio
ORL	Oak Ridge National Laboratory	Oak Ridge, Tennessee
SDA	E.I. du Pont de Nemours, Savannah River	Dunbarton, S Carolina
SGE (KAPL)	Knolls Atomic Power Laboratory, GEC	Schenectady, New York
SOM	Olin Mathieson Chemical Corporation	
SRS	Sylvania Electric Products, Inc	Hicksville, New York
SYL	Sylvania Electric Products, Inc	Bayside, New York
WEL	Westinghouse Electronic Tube Division	Elmira, New York
WEM	Westinghouse Electric Corporation	Homestead, Pa

REPORT INDEX

The following is a partial list of sources where nuclear safety data may be found. These references are cited in the section where material from each report was used. They are listed here to supply the reader with a convenient reference.

1. AEC 7430-01, Recovery of Source and Special Nuclear Materials.

2. Bailey, Radiation from a Nuclear Excursion, October 1958, KSA-144.

3. Beck, Callihan, and Murray, Critical Mass Studies, Part I, A-4716.

4. Bell, A Simple Method of Calculating Critical Masses of Proton Moderated Assemblies, LA-1548.

5. Bell, Sweeping of Radioactive Gases from a Homogeneous Pile, LA-548, Katzoff, April 11, 1946.

6. Blizard, Applied Nuclear Physics Division Annual Progress Report for Period Ending September 1, 1957, ORNL-2389.

7. Callihan, et al, Critical Mass Studies Part III, K-343.

8. Callihan, Cronin, Fox, Macklin, and Morfitt, Critical Mass Studies, Part IV, K-406.

9. Callihan, Cronin, Fox, and Morfitt, Critical Mass Studies, Part V, K-643, June 1950.

10. Callihan, et al, Nuclear Safety Guide, LA-2063.

11. Callihan, et al, Nuclear Safety Guide, TID-7016.

12. Callihan, Nucleonics 14 (7) pp 38-41, 1956.

13. Callihan, et al, Ring Tamping, Y-B23-22, November 5, 1952.

14. Callihan, Values of Nuclear Variables, Memorandum, June 25, 1958.

15. Cure and Hurst, Nucleonics 12 (8), p 36.

16. Davis and Hauser, Nucleonics 16 (3), pp 87-9, March 1958.

17. Fox, Gilley, and Callihan, Critical Mass Studies, Part IX, ORNL-2367, February 1958.

18. Fox and Gilley, Neutron Physics Division Annual Progress Report for Period Ending September 1, 1959, ORNL-2842.

19. Average Fractional Solid Angle Between Similar and Parallel Cylinders vs the Surface-to-Surface Separation in Cylinder Diameters Extended to Surface-to-Surface Separation Greater than 1, GAT-DM-455.

20. Gilley, Cronin, and Harness, Boron Poisoning in Critical Slabs, ORNL-1715.

21. Gwin and Mee, Critical Assemblies of Uranium Metal, Y-1248.

22. Handbook of Chemistry and Physics, 41st Edition, pp 678-9, Chemical Rubber Co, Cleveland, Ohio, 1959.

23. Hart, Safety Tests for Melting and Casting Oralloy, LA-1623.

24. Henry, et al, Guide to Shipment of U-235 Enriched Uranium Materials, TID-7019, June 1959.

25. Henry, Mallett, and Newlon, Basic Critical Mass Information and its Application to K-25 Design and Operation, K-1019.

26. Hughes and Schwartz, Neutron Cross Section, Second Edition, BNL-325.

27. Katz, The Chemistry of Uranium, First Edition, McGraw-Hill Book Company, New York, 1951.

28. Knight, Criticality Calculations for Hydrogeneous Systems, K-1260.

29. Maienshein, et al, A/CONF 15/P/670, June 1958.

30. Mihalczo and Lynn, Multiplication Measurements with Highly Enriched Uranium Metal Slabs, CF-59-7-87.

31. Newlon, Interaction Problems, K-1380.

32. Newlon, Safe Parameters for U-235 Assays Below 5%, KSA-128, 1958.

33. Patton, et al, Accidental Radiation Excursion at the Y-12 Plant, Y-1234, June 16, 1958.

34. Paxton, Basic Criticality Data for Homogeneous Systems, Private Communication.

35. Paxton, et al, Critical Data for Nuclear Safety Guidance, LAMS-2415.

36. Paxton, Critical Masses of Fissionable Metals as Basic Nuclear Safety Data, LA-1958 (Del).

37. Paxton, Estimated Critical Masses of Diluted Oralloy, LADC-2528.

38. Paxton, Private Communication.

39. Paxton, et al, Nuclear-Critical Accident at the Los Alamos Scientific Laboratory on December 30, 1958, LAMS-2293.

40. Paxton, Safety Tests for the Storage of Fissile Units, LA-1875 (Del).

41. Paxton, Standards for Fissionable Materials Outside Reactors, Standards Work in the American Nuclear Society, A Special Session of Invited Papers, pp 55-63, June 1959.

42. Pond, Average Fractional Solid Angle between Similar and Parallel Slabs vs the Slab Height, λ, Measured in Units of the Surface-to-Surface Separation, Private Communication.

43. Rose and Rose, The Condensed Chemical Dictionary, Fifth Edition, State College, Pa, Reinhold Publishing Corporation, New York, New York, 1956.

44. Schuske, Application of Critical Information to Y-12 Plant Problems, Y-853.

45. Schuske, et al, Interaction of Two Metal Slabs of Plutonium in Plexiglas, RFP-174, December 28, 1959.

46. Schuske, Arthur, and Smith, Study of Two Plane Arrays of Oralloy Units Interacting through Concrete, CD56-869, July 1956.

47. Susano, et al, The Density of Uranyl Nitrate and the Determination of Uranium Concentration by Density Measurement, ORNL-1332.

48. Wachter and Emerson, Neutron Dose Calibration of Indium Personnel Dosimeters for Prompt Critical Metal Bursts, Y-1092.

49. Zeitz, Attachment 8, Letter to Subcommittee, ORO Criticality Working Committee, NLO, October 31, 1958.

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