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# **Criticality Handbook**

## **Volume II**

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C R I T I C A L I T Y    H A N D B O O K

Volume II

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PREFACE

The use of the loose-leaf form for ARH-600 has permitted easy addition and modification of data. A loose-leaf notebook, however, can only be filled to the point at which ring holes begin to tear out because of restricted movement. The amount of data accumulated in the first volume of ARH-600 and new data expected to be added in the near future has required the expansion to two volumes, and the re-distribution of data between the two. The expansion into two volumes without overloading one has temporarily required division of data at a somewhat awkward location, the middle of Section III. However, completion of the U-233 part of Section III and the addition of data to Sections IV, V and VI as time permits, will probably require the addition of a third volume. At that time, it is hoped that the data can be re-distributed more artistically.

### III. HOMOGENEOUS SYSTEMS

- A. PLUTONIUM SYSTEMS (SEE VOLUME II)
- B. URANIUM-235 SYSTEMS (SEE VOLUME II)
- C. URANIUM-233 SYSTEMS
- D. MIXED AND MISCELLANEOUS SYSTEMS

## III. HOMOGENEOUS DATA

## A. PLUTONIUM SYSTEMS

1. Correlation Between Calculation and Experiment
2. H/Pu versus Plutonium g/l Relationship
3. Critical Sphere Dimensions

Earlier graphs within this and following divisions have the percentage by weight of the major fissile atom (Pu-239) as the fourth identification number (e.g., III.A.3.97-2 would signify the second graph showing data for plutonium containing 97 weight percent Pu-239). Later graphs have been modified to set off the weight percent by parentheses, III.A.3(97)-2, in the interest of clarity.

4. Critical Cylinder Dimensions
5. Critical Slab Dimensions
6. Critical Mass - Sphere
7. Critical Mass per Unit Height - Cylinder
8. Critical Mass per Unit Area - Slab
9. Critical Volume
10. Material Bucklings and Infinite Multiplication Factor

BASIC PLUTONIUM CRITICAL PARAMETERS

<u>Metal</u> (2)	<u>Full Reflection</u> *	<u>Bare</u>
Minimum critical mass, kgs $^{239}\text{Pu}$	5.425 + .027 (1)	10.2
Infinite cylinder, diameter inches	1.7	2.4
Infinite slab thickness, inches	0.28	1.1
Minimum spherical volume, liters	0.28	0.51
<u>Homogeneous Solutions</u> (3)	<u>Full Reflection</u>	<u>Bare</u> **
Minimum critical mass, g $^{239}\text{Pu}$		
$^{239}\text{Pu} - \text{H}_2\text{O}$	531	
$^{239}\text{Pu}(\text{NO}_3)_4 - \text{H}_2\text{O}$	547	905
Infinite cylinders diameter, inches		
$^{239}\text{Pu} - \text{H}_2\text{O}$	***	***
$^{239}\text{Pu}(\text{NO}_3)_4 - \text{H}_2\text{O}$	6.41	9.15
Infinite Slab thickness, inches		
$^{239}\text{Pu} - \text{H}_2\text{O}$	***	***
$^{239}\text{Pu}(\text{NO}_3)_4 - \text{H}_2\text{O}$	2.44	5.30
Minimum spherical volume, liters		
$^{239}\text{Pu} - \text{H}_2\text{O}$	***	***
$^{239}\text{Pu}(\text{NO}_3)_4 - \text{H}_2\text{O}$	8.3	16.9
Minimum critical aqueous concentration, g/l $^{239}\text{Pu}$	7.8 + 0.3	(H/Pu = 3392 + 100)

\* Reflector is water unless specified otherwise.

\*\* 0.125 inch thick stainless steel container shell.

\*\*\* There is no minimum value for theoretical Pu - H<sub>2</sub>O solutions unless a maximum concentration is assumed, see pages III.A.4.100-3, III.A.5.100-3 and III.A.9.100-3.

(1) W. U. Geer, D. R. Smith, Measurement of the Critical Mass of a Water - Reflected Plutonium Sphere, ANS Transactions Vol. II No. 1, 1968.

(2) H. C. Paxton, J. T. Thomas, Dixon Callihan, E. B. Johnson, Critical Dimensions of Systems Containing  $^{235}\text{U}$ ,  $^{239}\text{Pu}$  and  $^{233}\text{U}$ , TID-7028, 1964.

(3) C. R. Richey, Theoretical Analyses of Homogeneous Plutonium Critical Experiments, Nuclear Science and Engineering: 31, 32-39, 1968.

### III.A.1 Correlations Between Calculation and Experiment

The primary means of producing the data in this section has been with the combination of the GAMTEC-II and HFN computer codes. The GAMTEC-II code was used to produce 18 neutron energy group cross-section sets which were then used in the HFN multigroup one-dimensional diffusion theory code to calculate critical sizes, extrapolation distances and material bucklings. A thorough analysis has been made by C. R. Richey<sup>(1)</sup> using this method to calculate the effective multiplication factor for critical experiments. A selection of these are produced below:

<u>Geom.</u>	<u>Reflector</u>	<u>Pu g/l</u>	<u>% 240</u>	<u>Molarity</u>	<u>Calc. K<sub>eff</sub></u>	<u>Remarks</u>
Sphere	Water	33.0	4.6	2.061	0.999	14 in. dia.
"	"	47.9	4.6	6.698	1.005	14 in. dia.
"	Bare	39.0	4.6	0.376	0.997	15.2 in. dia.
"	"	172.8	4.6	4.898	0.993	15.2 in. dia.
"	Water	26.33	0.54	0.806	0.998	14 in. dia.
"	"	28.63	0.54	2.553	0.997	14 in. dia.
"	"	73.0	4.6	0.165	1.001	11.2 in. dia.
"	"	140.0	4.6	2.238	1.001	11.2 in. dia.
"	"	268.0	4.6	1.084	1.001	11.2 in. dia.
Cyl.	"	44.7	1.5	2.058	0.9846	11.6 in. dia., ht.=12.28
"	"	45.45	1.5	2.094	0.9739	12.8 in. dia., ht.=10.34

(1) C. R. Richey, "Theoretical Analysis of Homogeneous Plutonium Critical Experiments," Nuclear Science and Engineering, January, 1968.



Richey found that as the height of the cylinders increased the agreement between theory and experiment became better, approaching a least-squares-fitted value of  $k_{eff}$  equal to 1.0086 for infinite cylinders.

The dimensions shown in Section III.A have been calculated with the GAMTEC II - HFN combination for  $k_{eff}$  equal to 1.00. The comparison with experiment shows that this can sometimes be slightly non-conservative. Dimensions which are less than critical with some degree of confidence can be obtained by reducing the calculated critical values to values equivalent to  $k_{eff}$  equal to 0.986 for spheres and 0.980 for infinite slabs and cylinders. (See page II.B.1-6) Critically favorable values can be obtained by adjusting the critical values by the appropriate safety factor given in Section I.C.

The buckling and extrapolation distance curves (Section A.10) are derived from GAMTEC II - HFN calculations and can be used for calculating general geometries other than those represented by the curves for the simple sphere, infinite cylinder and infinite slab. It might be noted that the use of the buckling and extrapolation distance curves for these simple geometries may give a somewhat smaller critical dimension than the geometry data shows. Since each geometry has a slightly different extrapolation distance for the same plutonium concentration, the graphing of all data would result in an unreadable mess of lines. Therefore, only the most limiting extrapolation distances were used in Section A.10 for each particular solution.

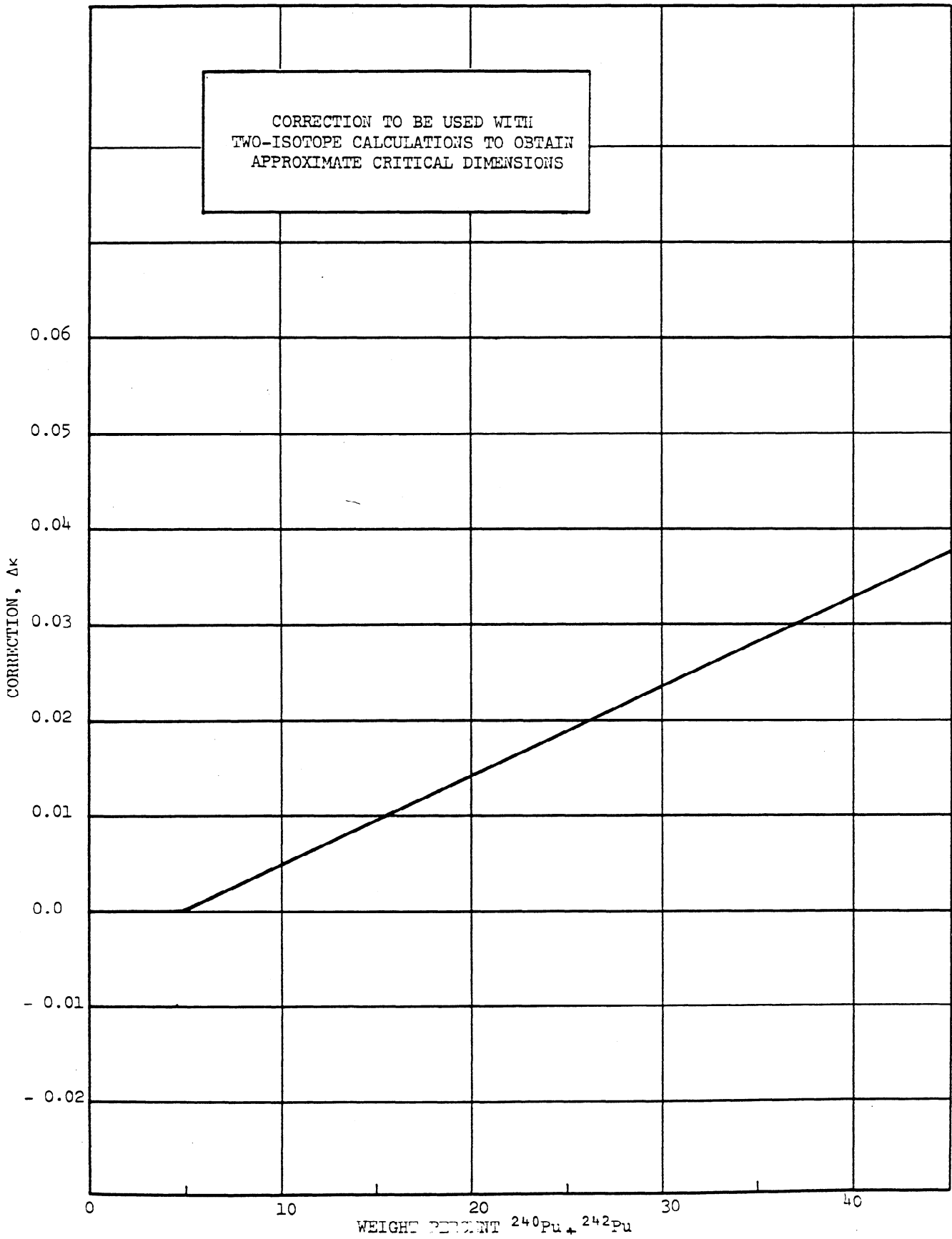
Adjustments of High Plutonium-240 Solution Parameters

The parameters calculated for plutonium solutions containing plutonium isotopes higher than Pu-239 have been shown to be non-conservative (1). Under certain assumptions, it has been common practice to perform plutonium solution parameter calculations using only two isotopes (Pu-239 and Pu-240). The normal assumptions are that the Pu-239 represents the Pu-239 and Pu-241, and the Pu-240 represents the Pu-238, Pu-240, and Pu-242. The parameter studies made in III.A of ARH-600 used the two-isotope approach. Correlations reported in reference 1 with solutions of high exposure plutonium with weight percent composition of Pu-238 (0.2), Pu-239 (41.4), Pu-240 (42.9), Pu-241 (10.8), and Pu-242 (4.7) show that the two-isotope GAMTEC II - HFN calculation with the above assumption will actually be low by up to four percent in k-effective if the effect of Am-241 is included. The results for a number of computer codes and cross sections are shown in the table. (Since the effect of Am-241 was significant and the cross sections were not available in the original GAMTEC II set, the effect must be determined from the other calculations.) From these correlations it is apparent that the parameters calculated for plutonium with Pu-240 greater than 5 weight percent must be interpreted with caution. To safely use these parameters one of the following assumptions must be made:

1. The Pu-240 shown on the curves must be assumed to be only Pu-240, not both Pu-240 and Pu-242; and the Pu-239 must be assumed to represent Pu-239, Pu-241, Pu-242, and Pu-238 (if any).
2. If the Pu-240 shown on the curves is assumed to represent both Pu-240 and Pu-242 then the parameters shown on the curves should be decreased by an amount commensurate with the  $\Delta k$  shown on the graph, page III.A.1-5.

(1) R. D. Carter, "Criticality Parameter Calculation With High Burn-up Plutonium Solutions," ARH-SA-135, November 7, 1972.

Calculated k-effective										
Cross Section Source		GAMTEC II (Original)		GAMTEC II (ENDF/B II)	GAMTEC II (ENDF/B II w/Am)	Hansen-Roach	GEM 4	HAMMER		GAMTEC II (ENDF/B II w/Am)
Code for k calc.		HFN	KENO	HFN	HFN	KENO II	GEM 4	HAMMER	HAMMER w/Am	DTF4
Pu g/l	No. Iso.									
140	5	1.0435	1.0410 $\pm$ .0079	1.0395	1.0280	1.1013 $\pm$ .0069	—	--	1.0167	1.0249
116	5	1.0463	—	1.0406	1.0297	1.0595 $\pm$ .0071	—	1.0356	1.0234	1.0264
99.26	5	1.0440	—	1.0365	1.0261	—	—	1.0341	1.0228	1.0238
75.64	5	1.0412	1.0498 $\pm$ .0060	1.0308	1.0215	—	—	1.0314	1.0213	1.0189
65.12	5	1.0396	1.0460 $\pm$ .0071	1.0273	1.0183	1.0643 $\pm$ .0079	—	1.0298	1.0203	1.0152
40.58	5	1.0393	1.0405 $\pm$ .0059	1.0215	1.0138	1.0529 $\pm$ .0060	—	1.0277	1.0186	1.0101
140	3	1.0329	1.0414 $\pm$ .0060	1.0271	—	1.0849 $\pm$ .0070	0.9930 $\pm$ .0131	1.0158	—	—
116	3	1.0334	1.0419 $\pm$ .0074	1.0266	—	1.0549 $\pm$ .0076	0.9920 $\pm$ .0094	1.0193	—	—
99.26	3	1.0303	—	1.0224	—	—	0.9820 $\pm$ .0136	1.0176	—	—
75.64	3	1.0263	1.0367 $\pm$ .0068	1.0155	—	1.0289 $\pm$ .0071	0.9922 $\pm$ .0141	1.0147	—	—
65.12	3	1.0244	1.0195 $\pm$ .0057	1.0123	—	1.0415 $\pm$ .0074	0.9794 $\pm$ .0133	1.0132	—	—
40.58	3	1.0239	1.0259 $\pm$ .0059	1.0057	—	1.0624 $\pm$ .0064	0.9869 $\pm$ .0112	1.0118	—	—
140	2	0.9770	0.9746 $\pm$ .0059	0.9872	0.9761	1.0156 $\pm$ .0064	—	0.9746	0.9622	0.9736
116	2	0.9797	—	0.9886	0.9782	—	0.9943 $\pm$ .0100	0.9799	0.9684	0.9768
99.26	2	0.9772	—	0.9856	0.9758	—	0.9789 $\pm$ .0122	0.9791	0.9684	0.9739
75.64	2	0.9735	0.9836 $\pm$ .0078	0.9798	0.9708	0.9731 $\pm$ .0065	0.9955 $\pm$ .0199	0.9771	0.9676	0.9696
65.12	2	0.9714	0.9692 $\pm$ .0070	0.9769	0.9683	1.0023 $\pm$ .0067	0.9755 $\pm$ .0107	0.9757	0.9666	0.9677
40.58	2	0.9684	0.9743 $\pm$ .0050	0.9693	0.9620	1.0115 $\pm$ .0058	0.9670 $\pm$ .0135	0.9730	0.9658	0.9607



Plutonium In Soil

The critical parameters ( $k_{eff} = 1.000$ ) for plutonium-water-soil systems were calculated using the GAMTEC II - DTF IV combination with eighteen group cross sections. According to Hansen and Clayton (1) this combination calculated experimental plutonium systems above an H/Pu = 25 with a slight conservatism, but in under moderated systems the results compared very well with experiment. The dry soil composition (representing Hanford area soils) and densities for two void volumes, 30 vol% and 40 vol% void, are shown below in atoms per barn-centimeter and  $g/cm^3$  respectively (2):

<u>Nuclide</u>	<u>30 Vol% Void</u>	<u>40 Vol% Void</u>
O	.032860	.028166
Si	.014070	.012060
Al	.001242	.001065
Ca	.000966	.000828
Fe	.000552	.000473
Mg	.000516	.000443
Na	.000273	.000234
Dry Soil Density	1.701	1.458

For the saturated soil systems the void volume is assumed to be completely filled with plutonium containing 3 wt% Pu-240 and water.

- (1) L. E. Hansen and E. D. Clayton, "Critical Parameters of Plutonium Systems," Nuclear Applications, Vol. 6, p. 371-390, April 1969.
- (2) K. R. Ridgway and R. D. Carter, "Criticality Prevention Parameters of Plutonium in Soils," ARH-2622, October 5, 1972.

III.A.2 H/Pu Versus Pu g/l Relationships

The calculations for the critical parameters for homogeneous plutonium systems were taken from the following H/Pu relationships:

For Pu nitrate solutions:

$$H/Pu = \frac{26,539 - 638.7 \times \text{Molarity of Excess Nitric Acid}}{\text{Pu g/l}} - 9.606$$

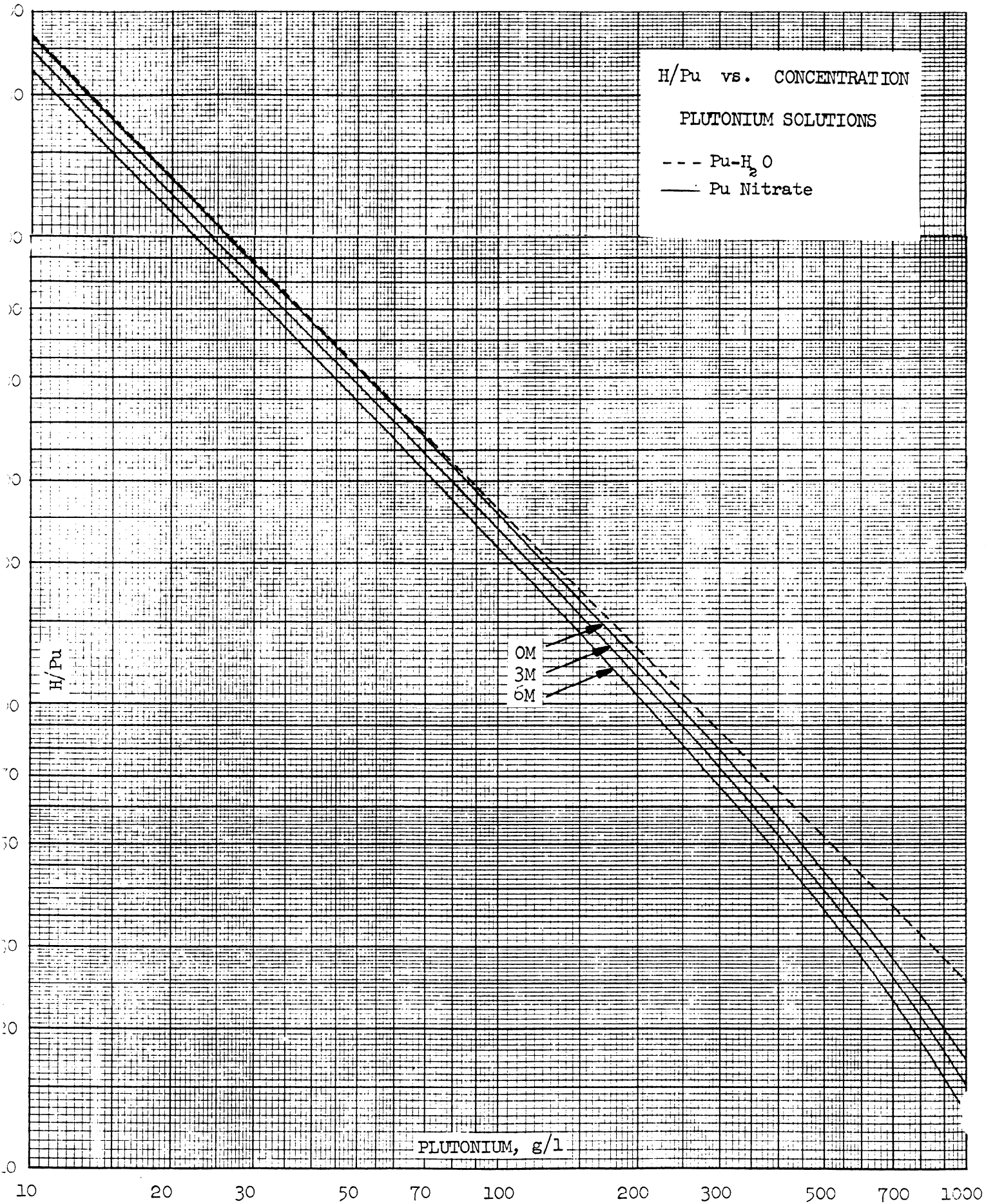
This equation was derived from work performed by C. R. Richey and G. M. Hess.

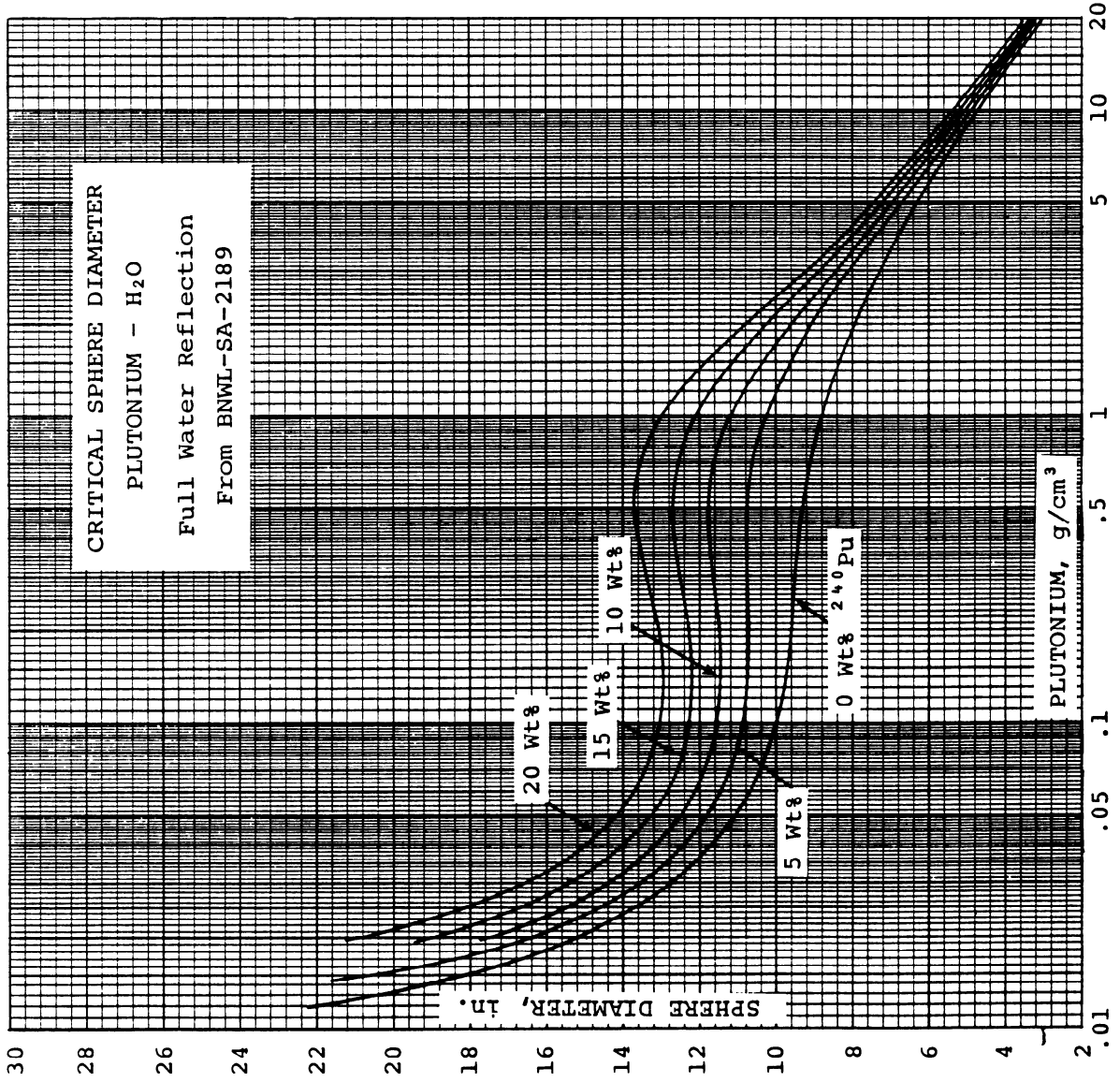
For Pu-H<sub>2</sub>O solutions:

$$H/Pu = \frac{26,530}{\text{Pu g/l}} - 1.35$$

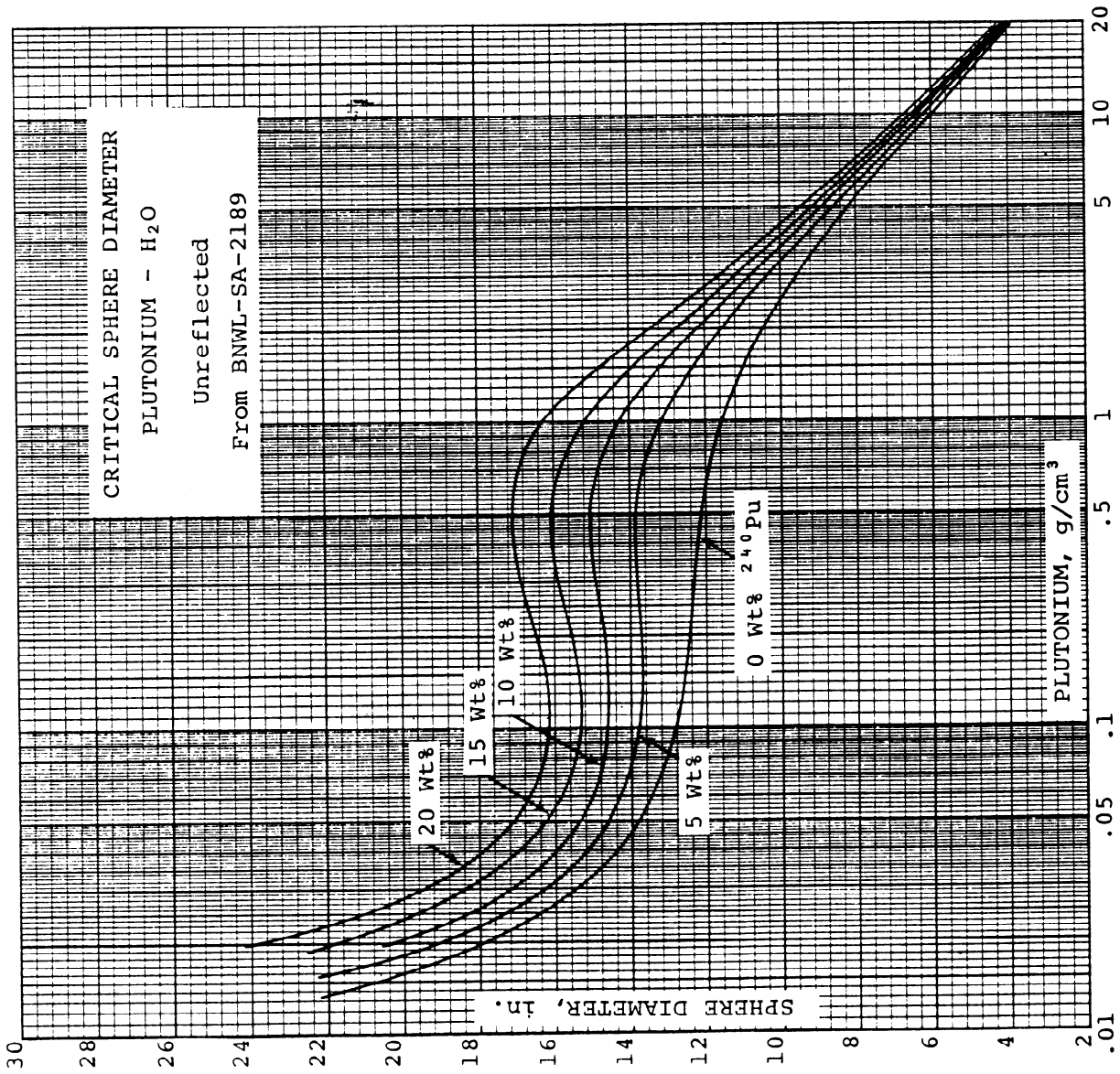
These are essentially earlier versions of the equations on page II.C.3-2 and actually only differ in the round-off of numbers and in the fact that the newer versions take into account the variation with Pu isotopic variation. Neither would significantly affect these calculations.

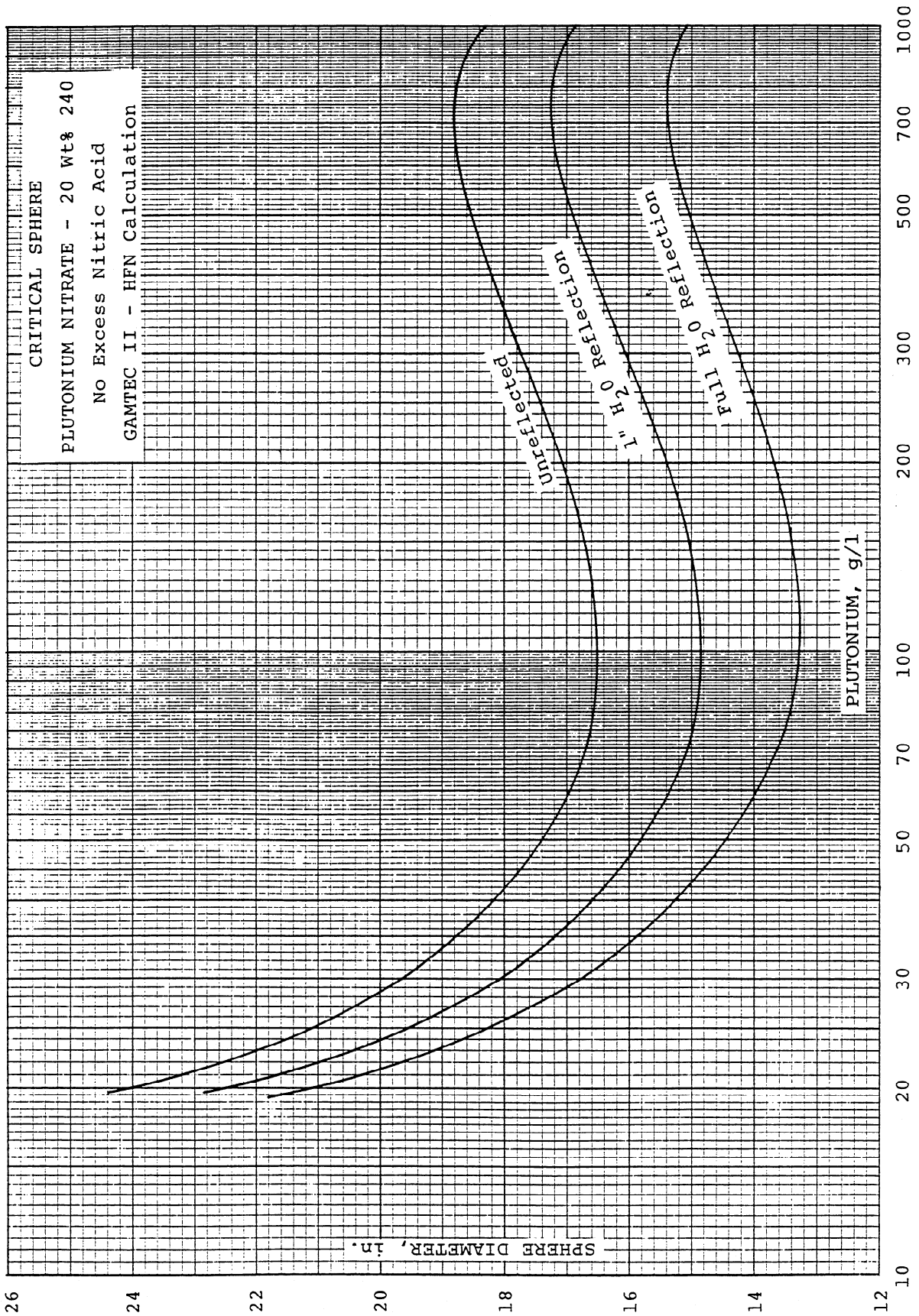
These equations are shown graphically on page III.A.2-2.

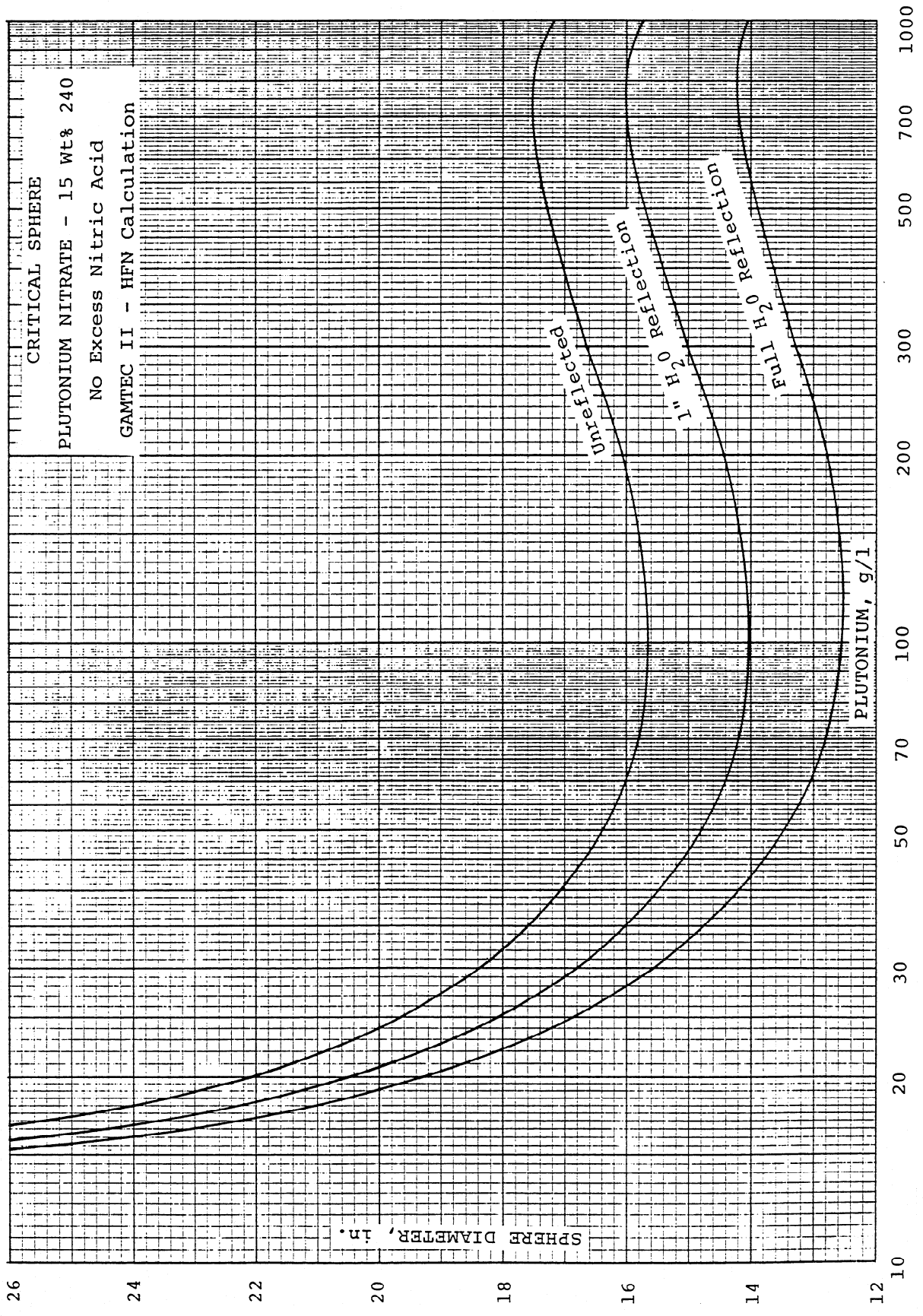


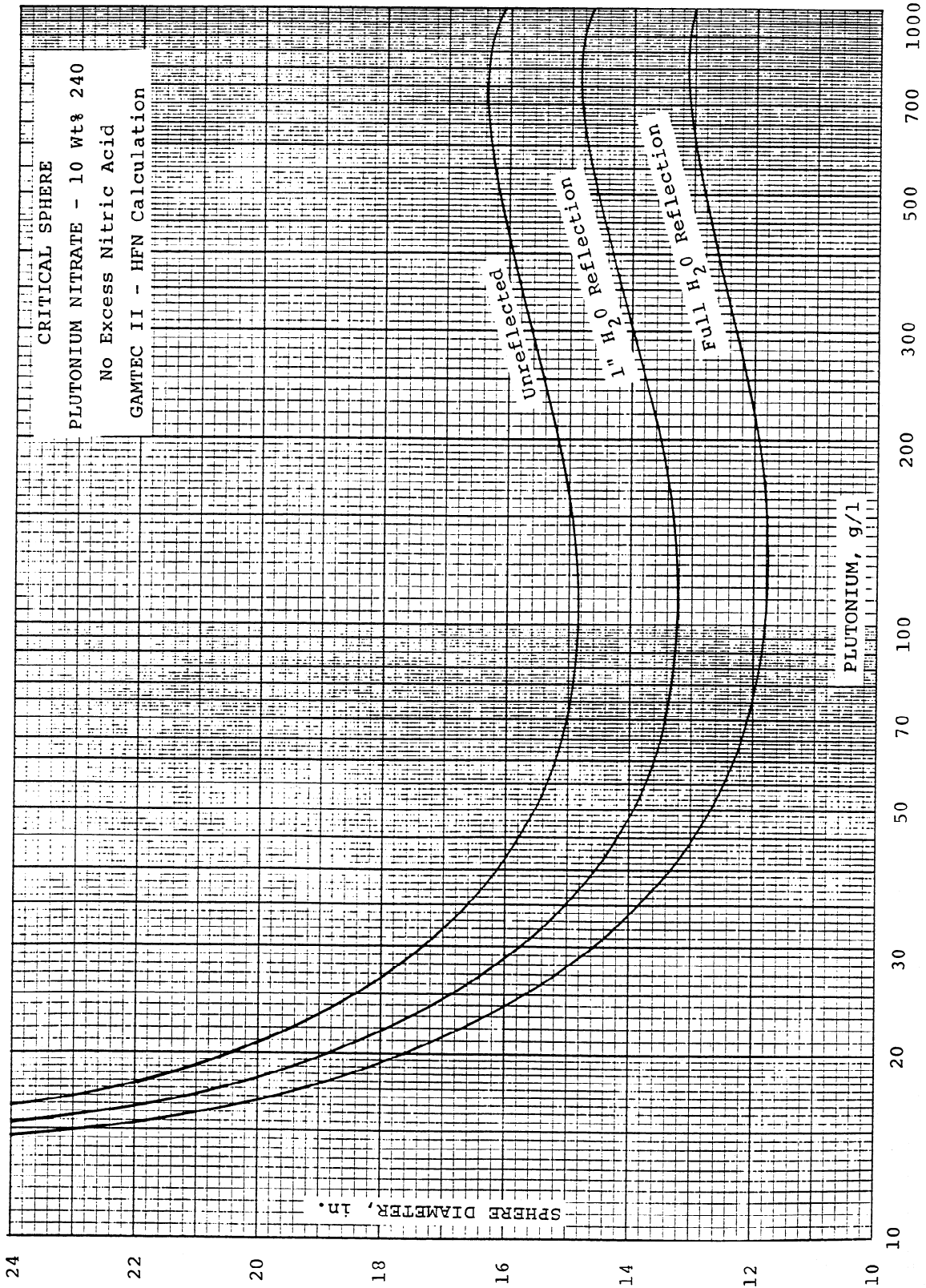


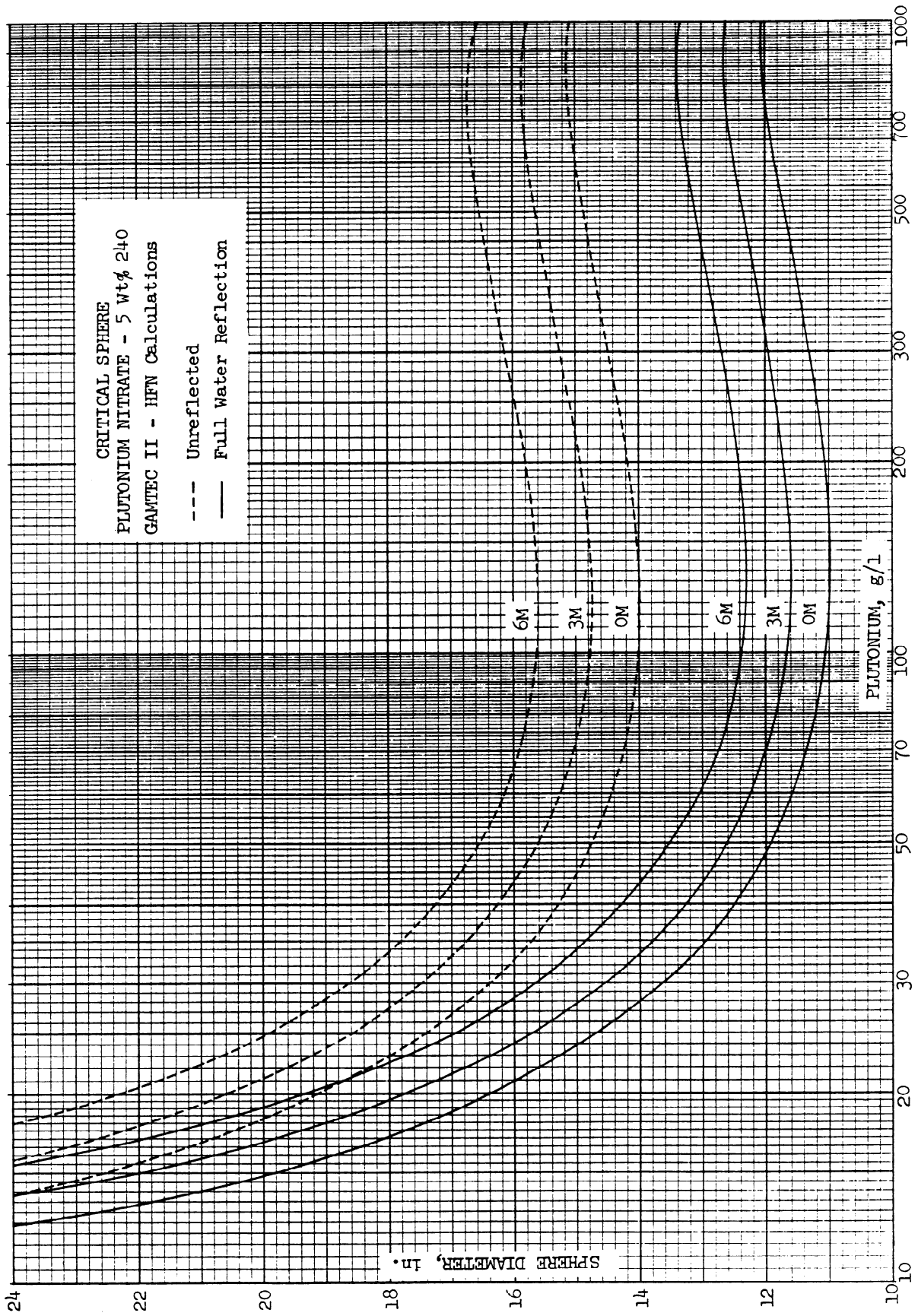


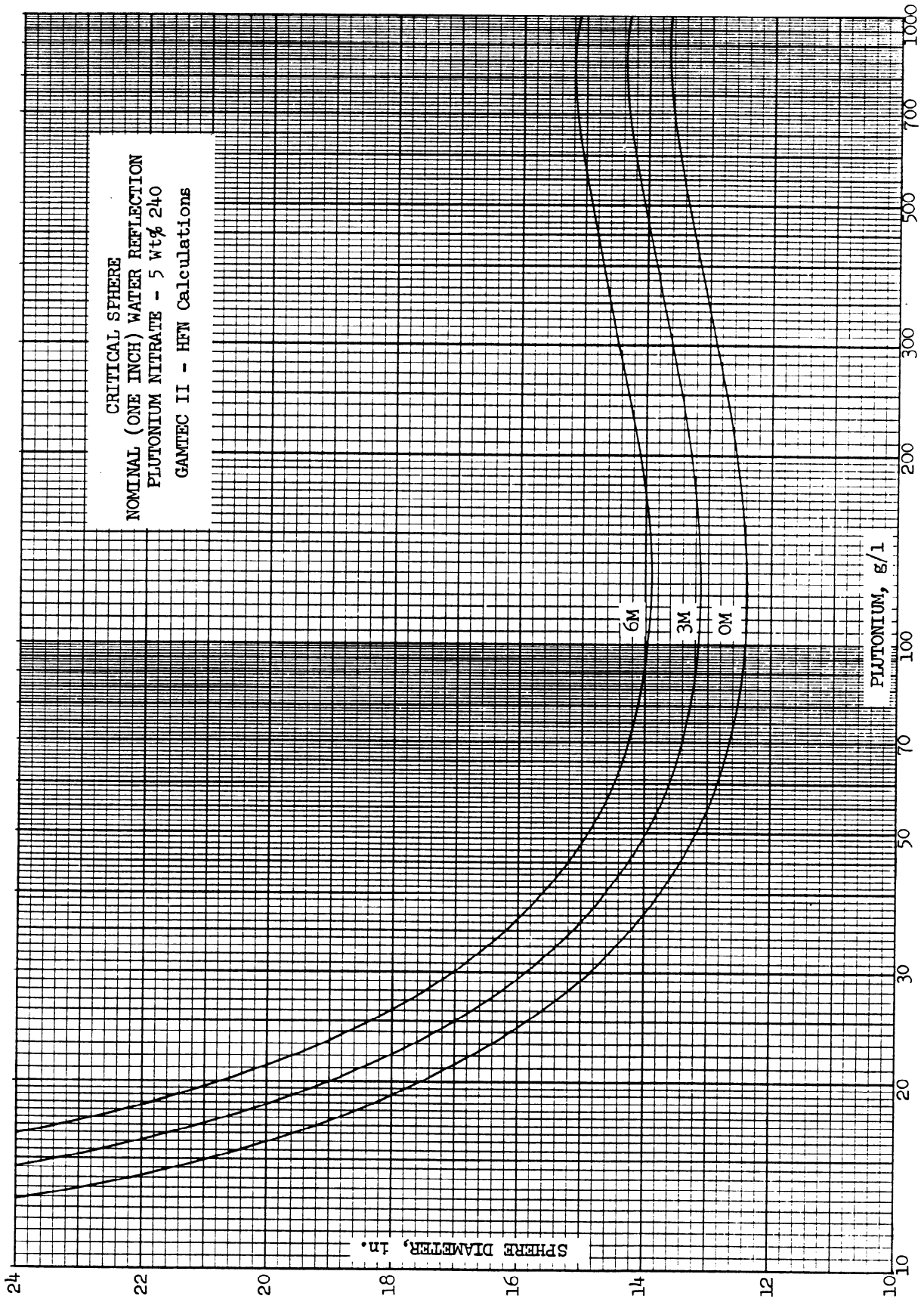


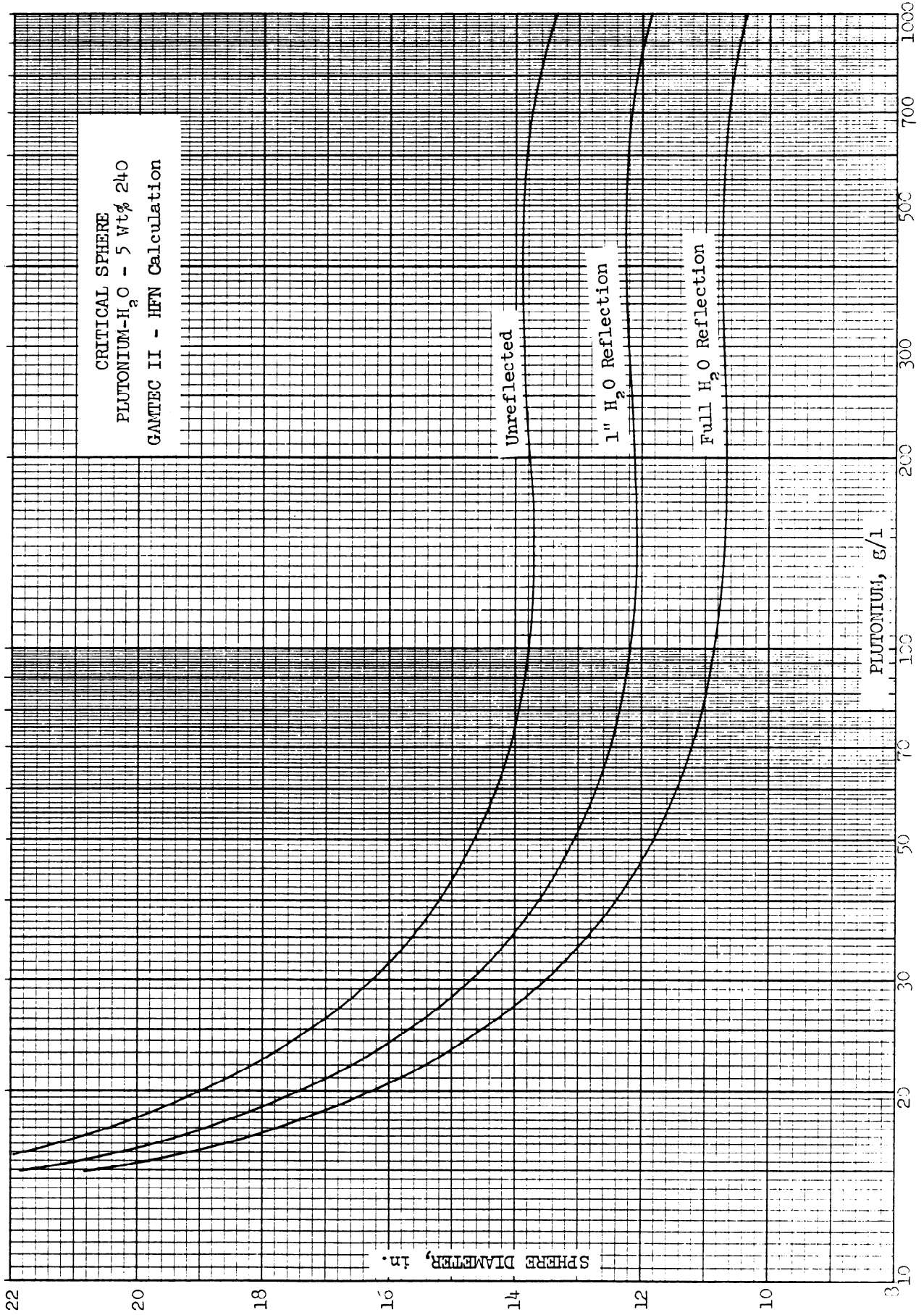


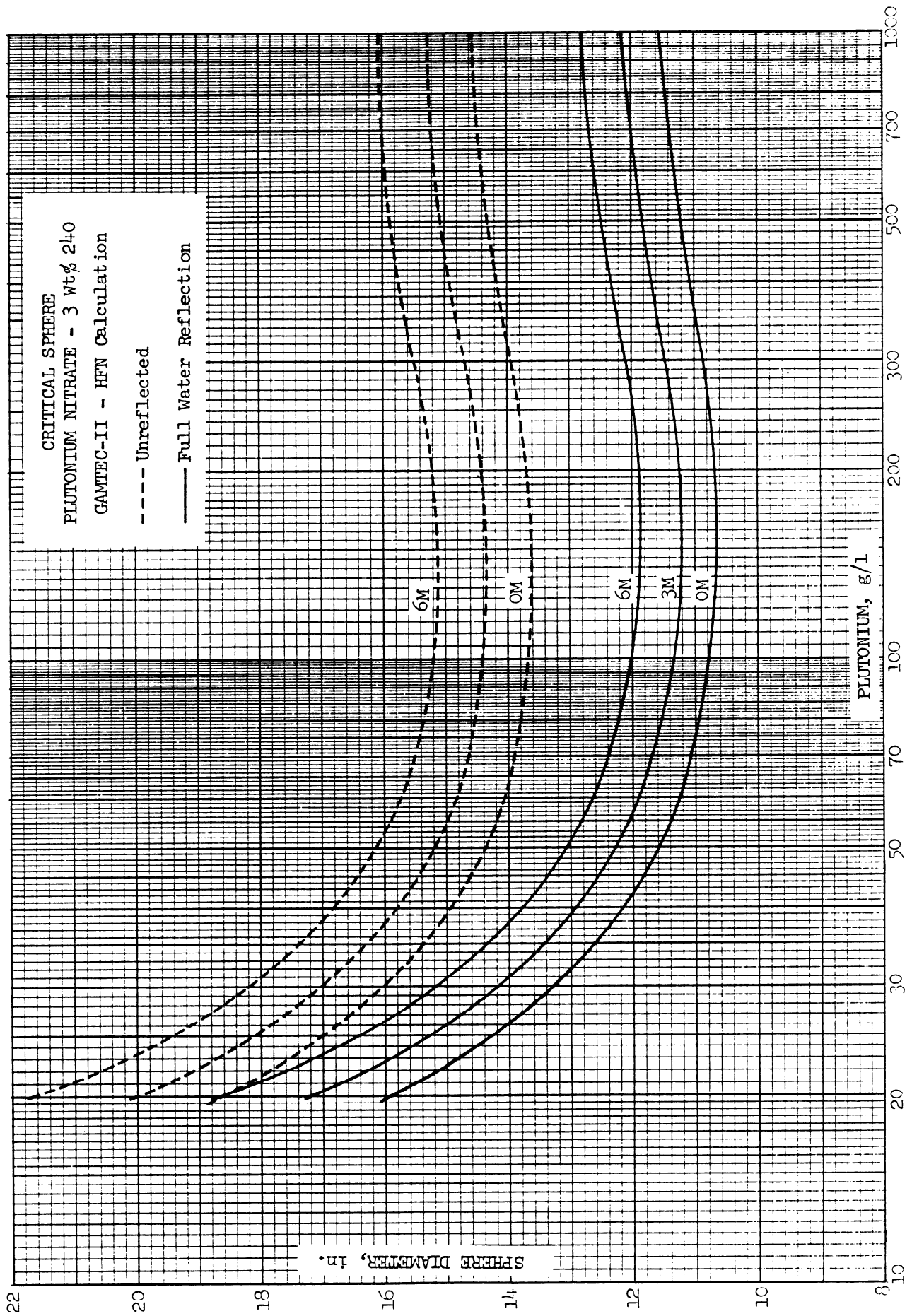




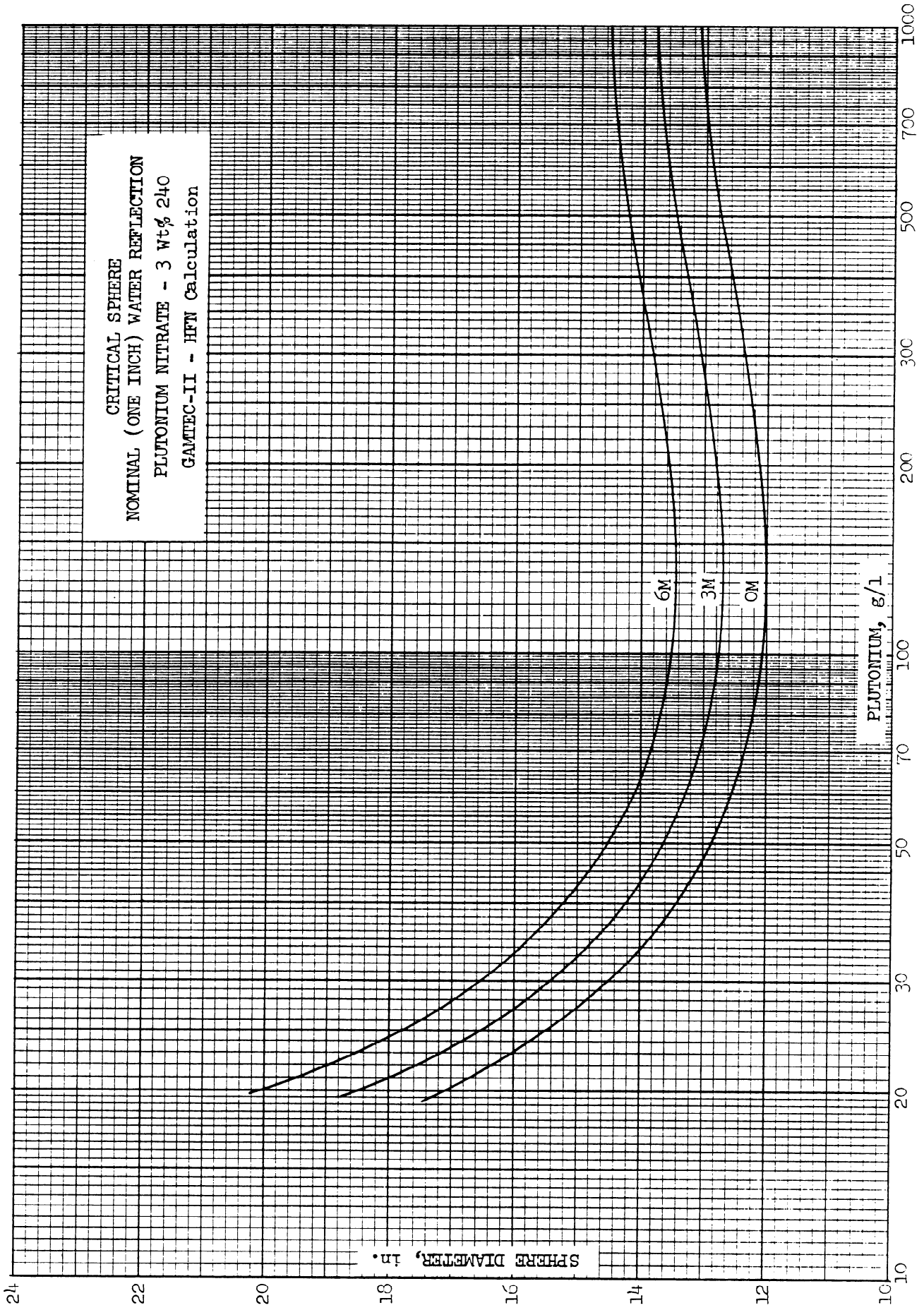


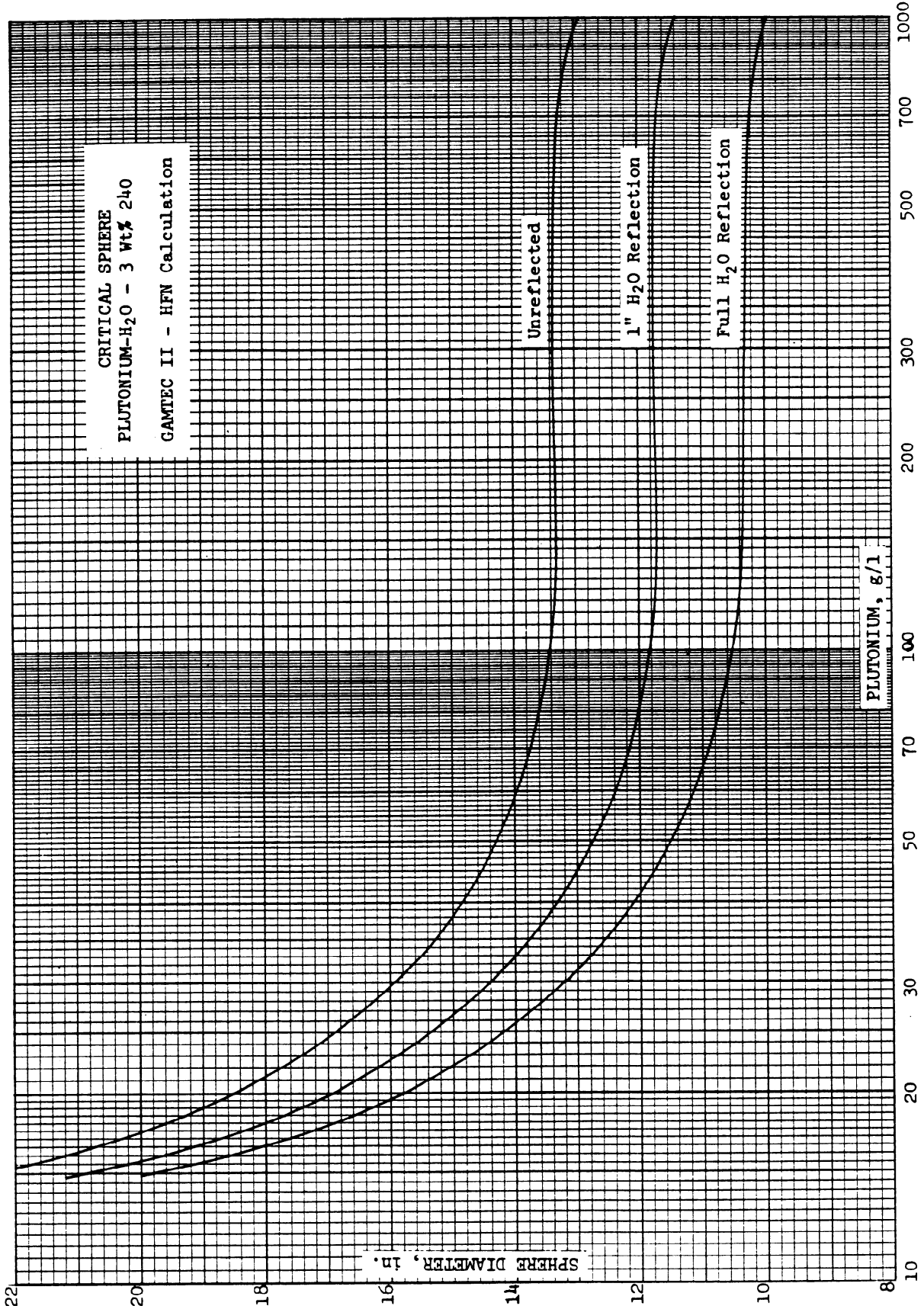




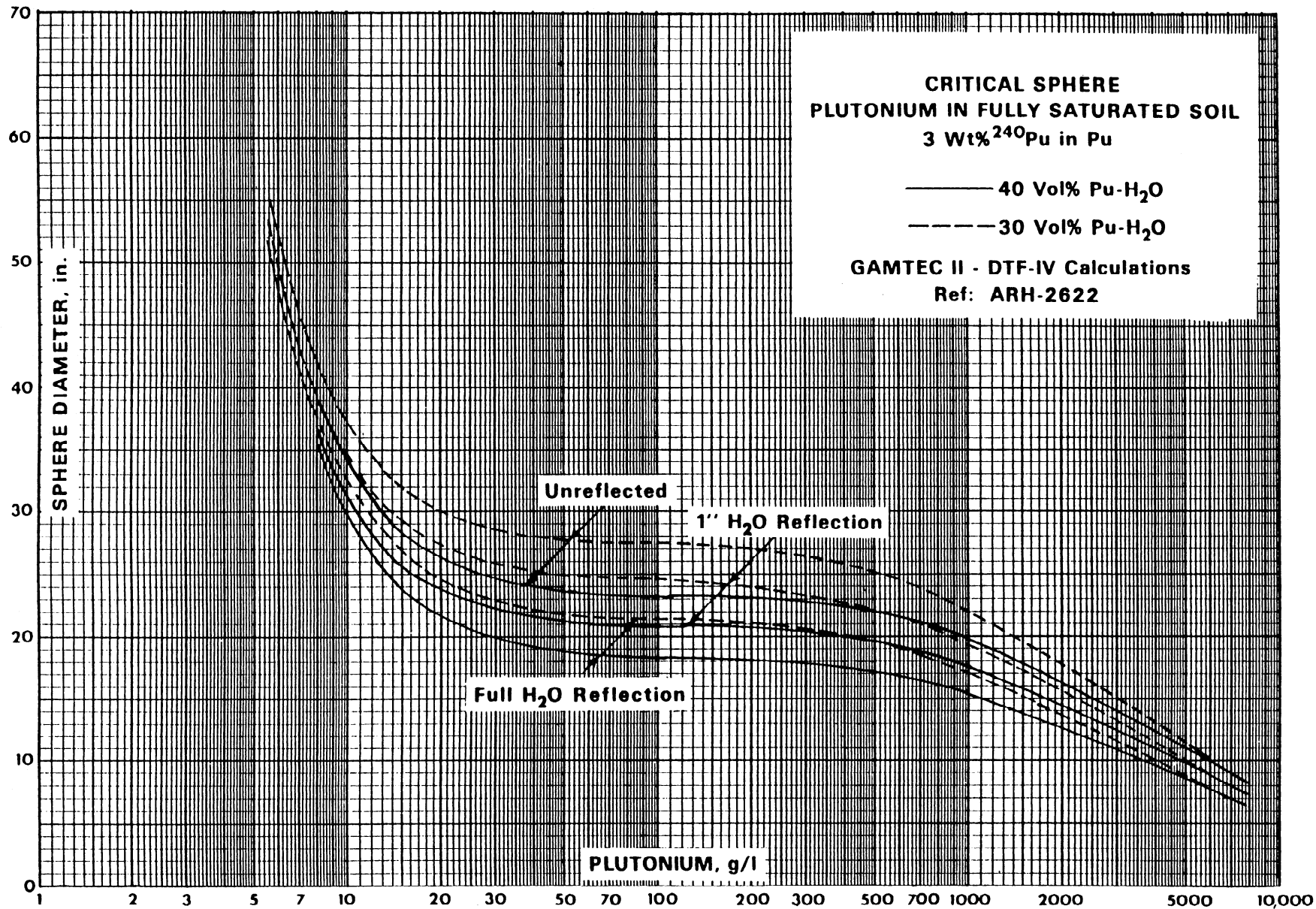


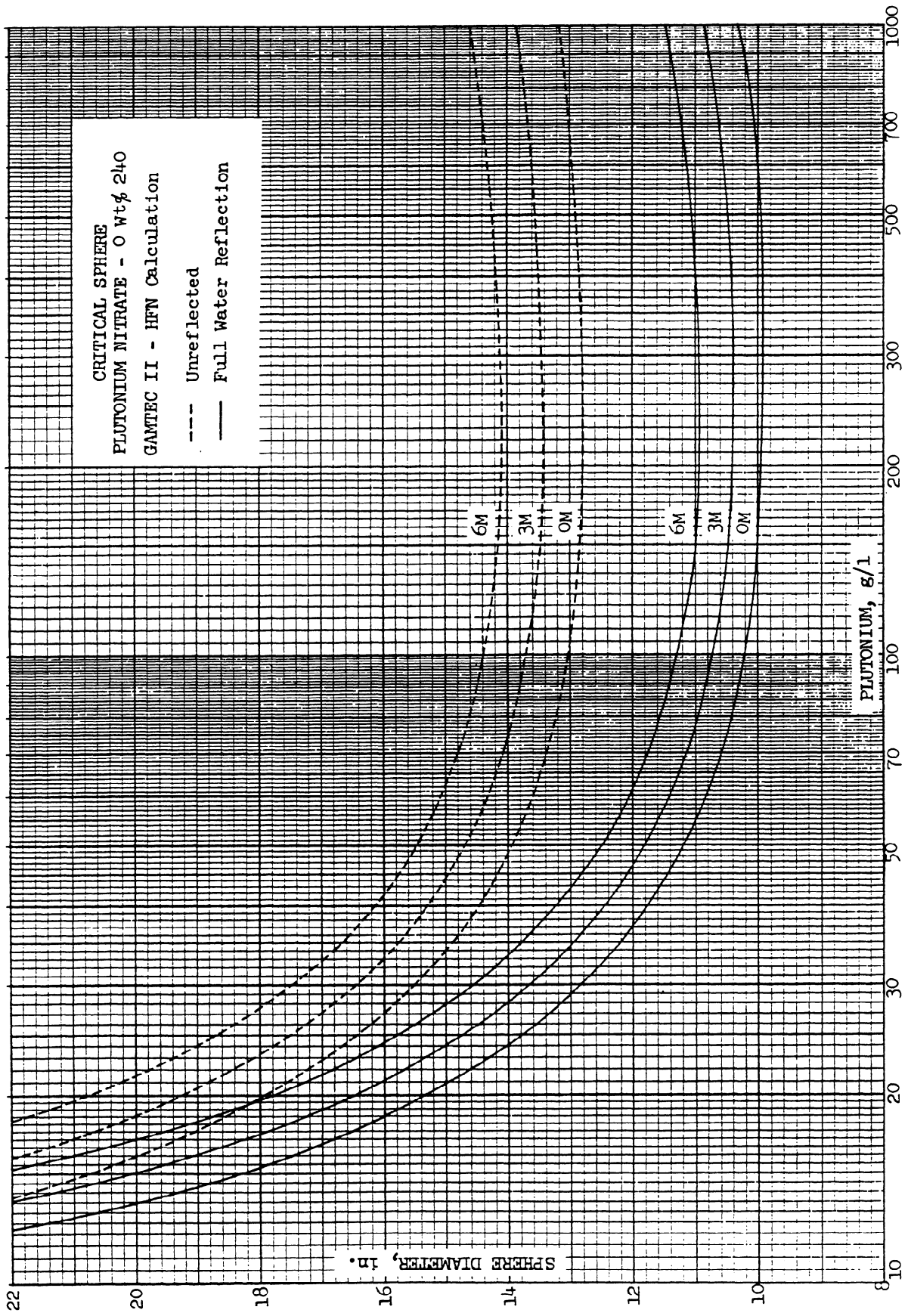


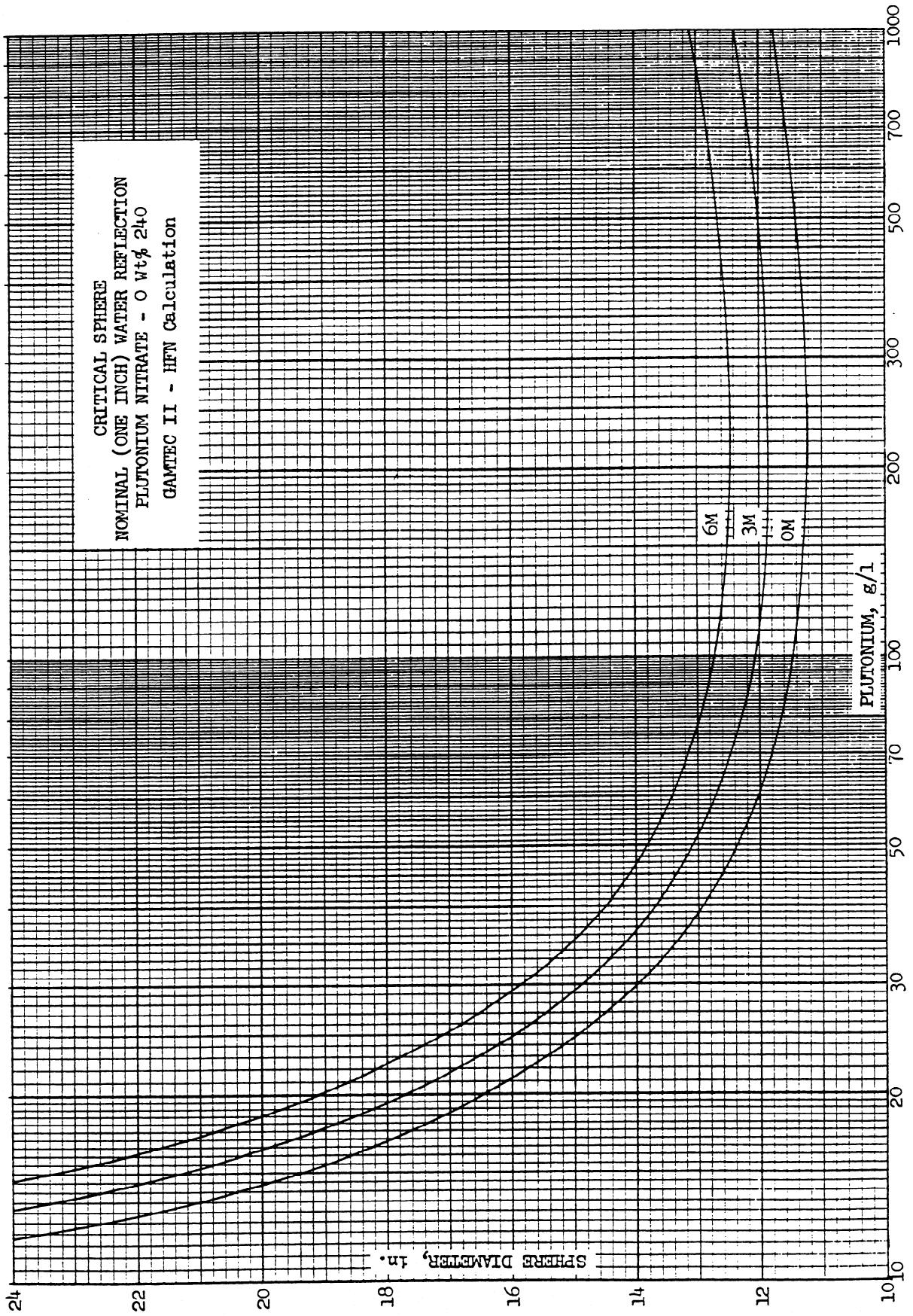


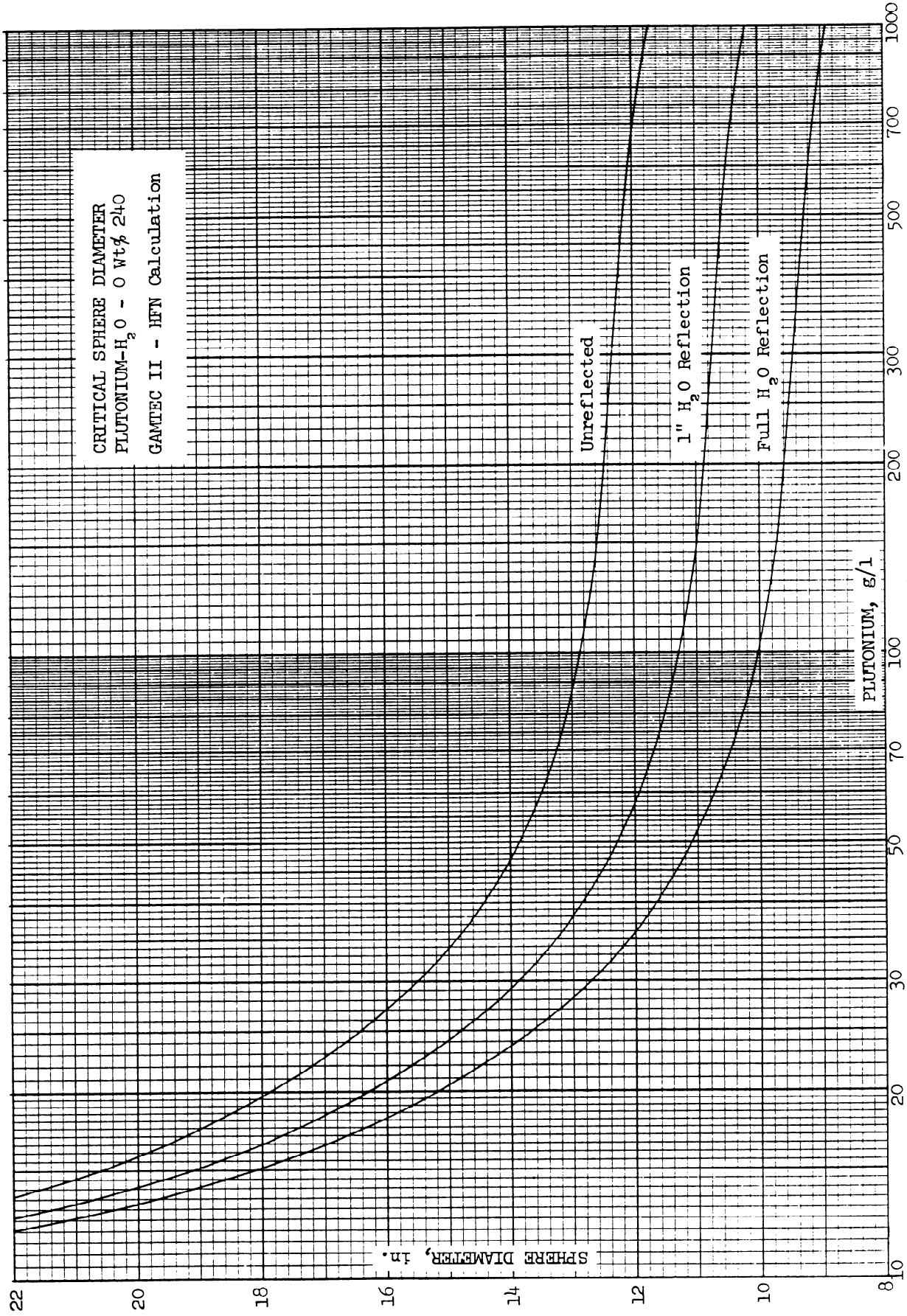


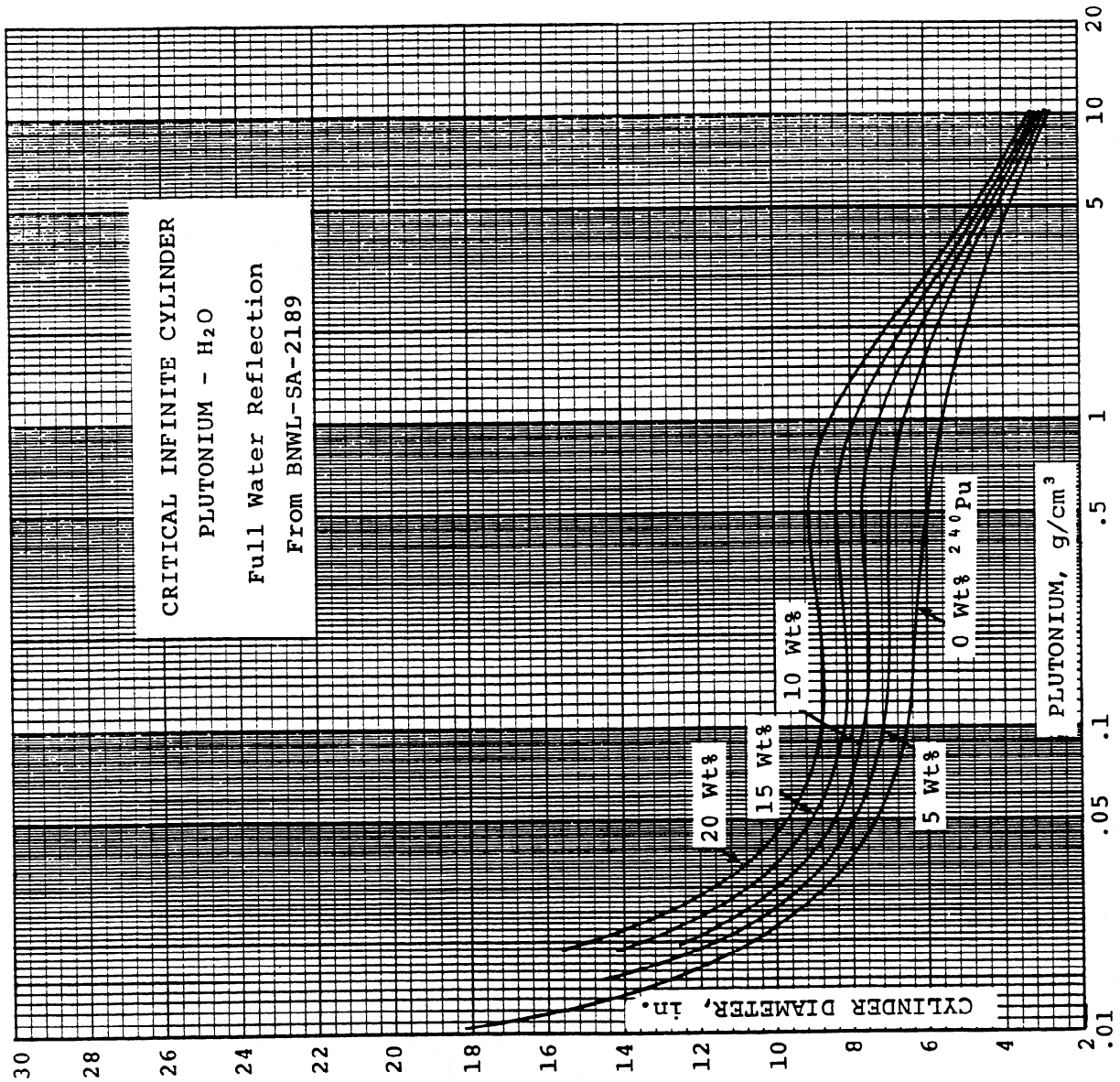
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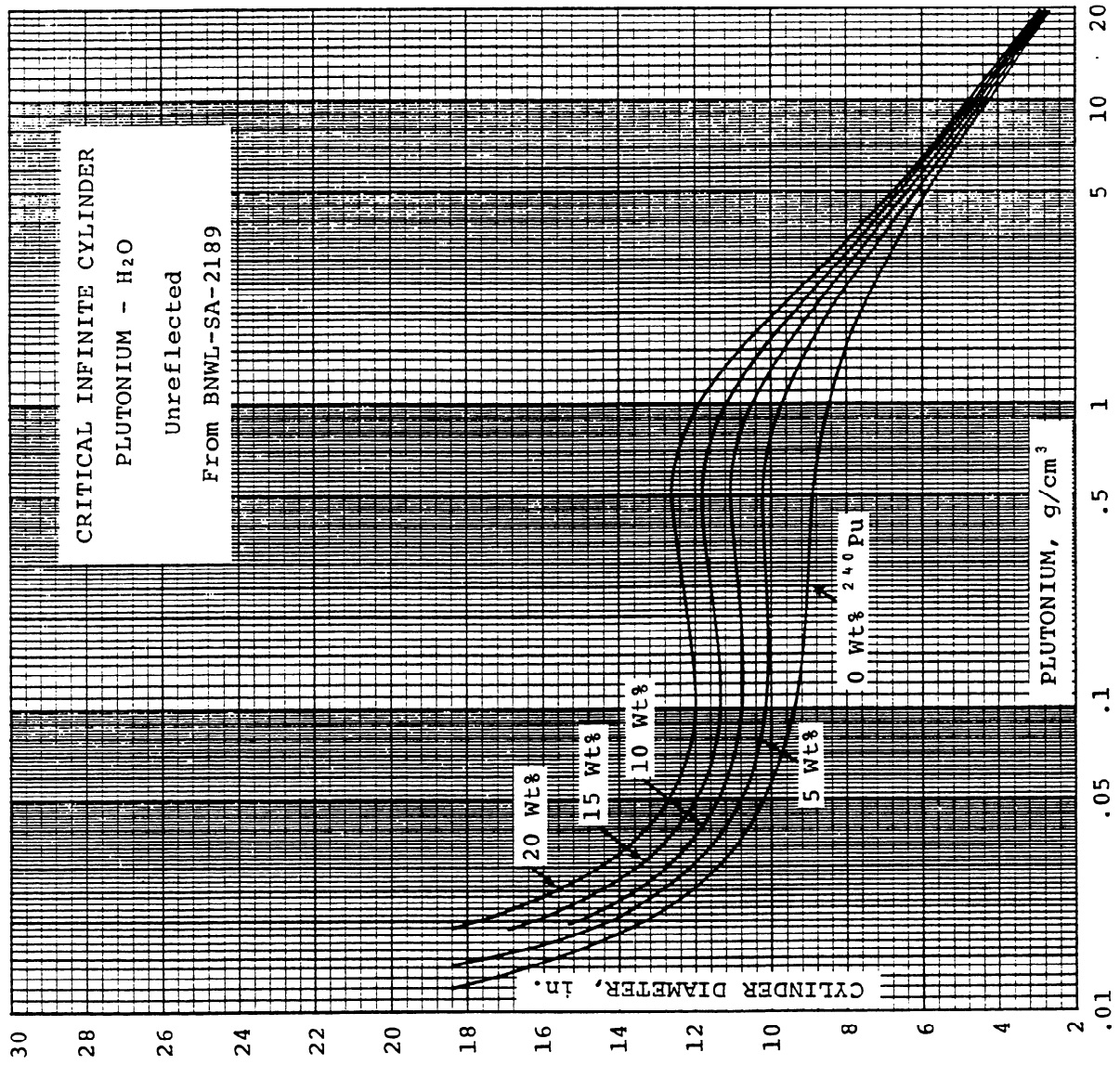




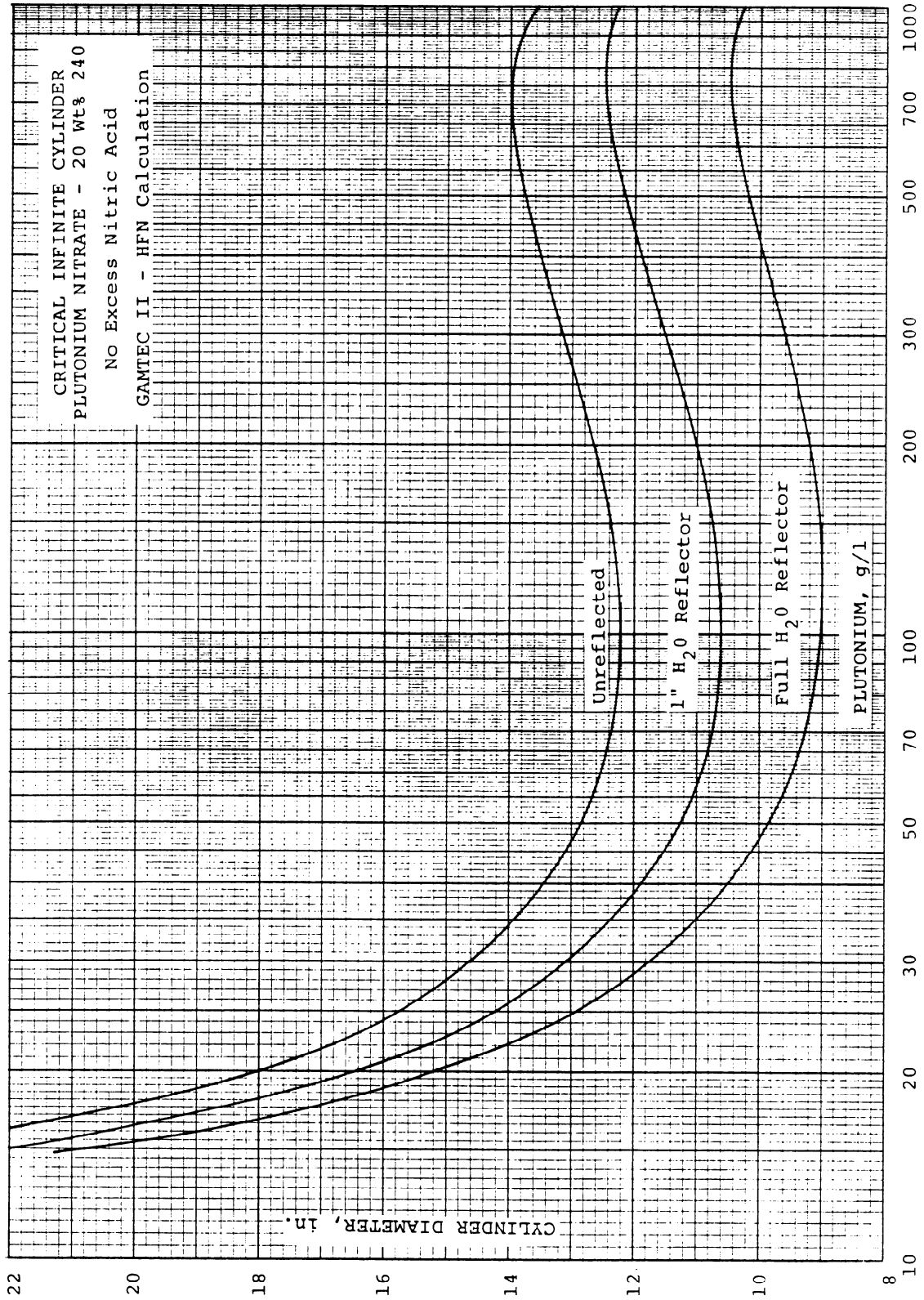


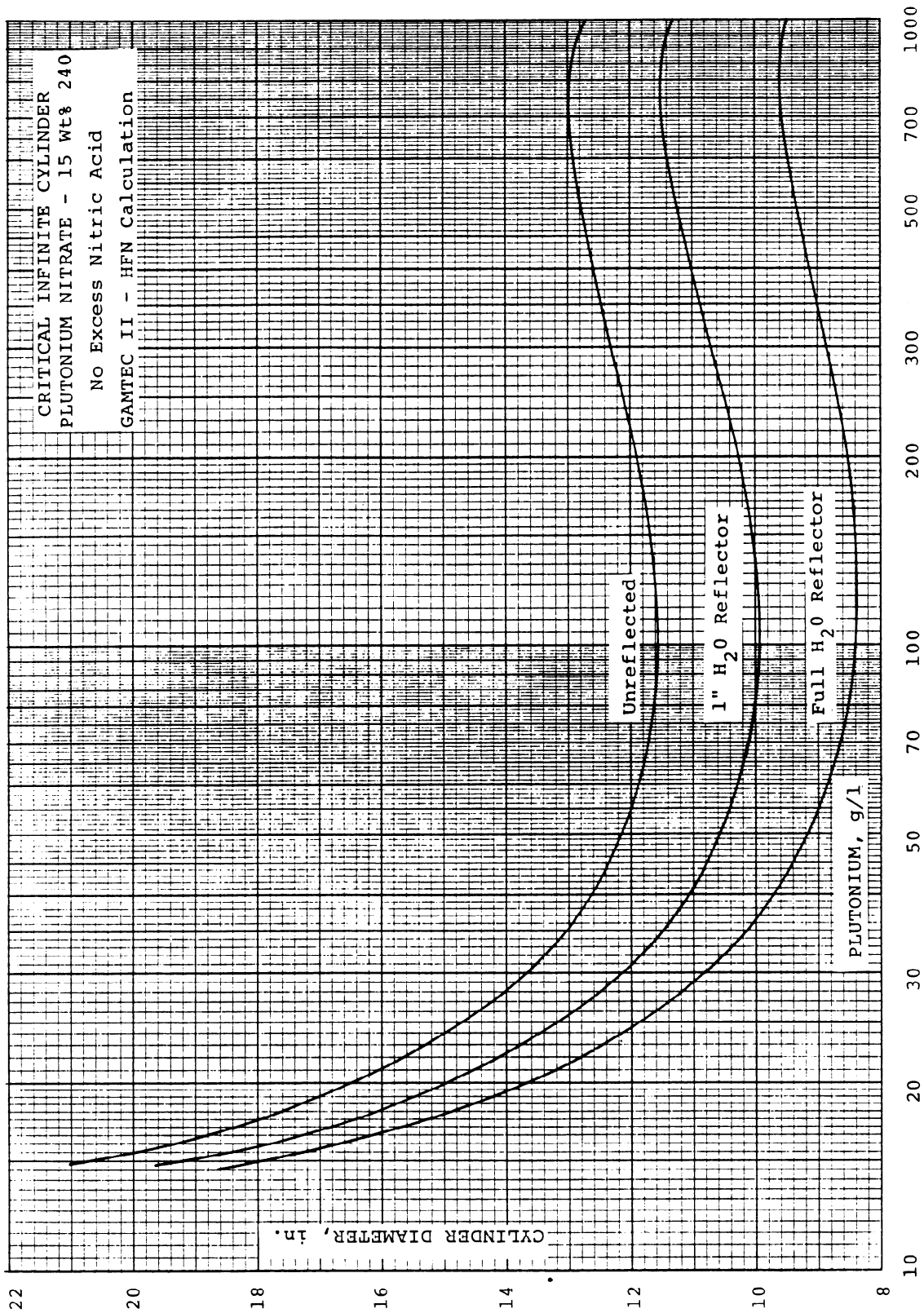


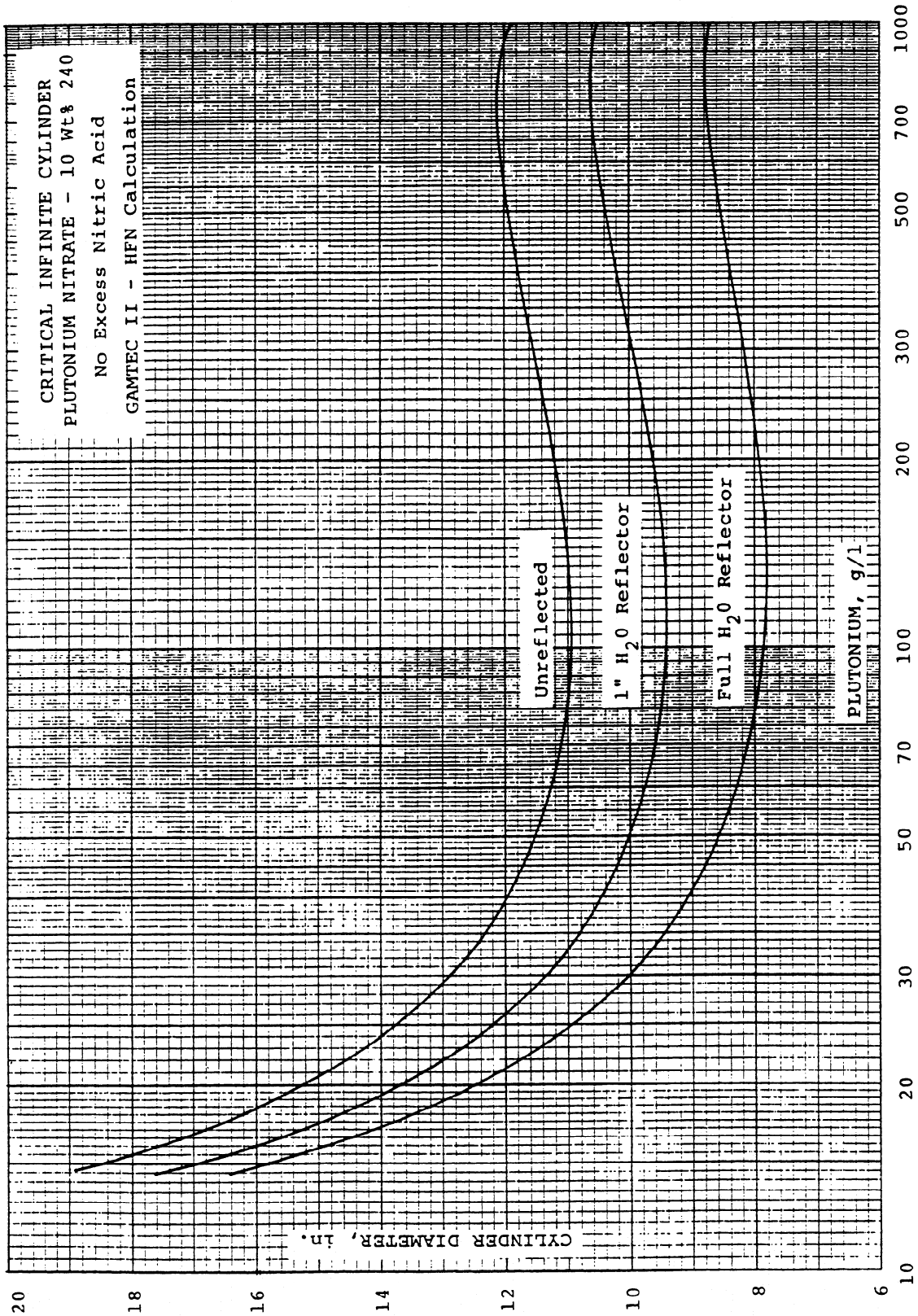


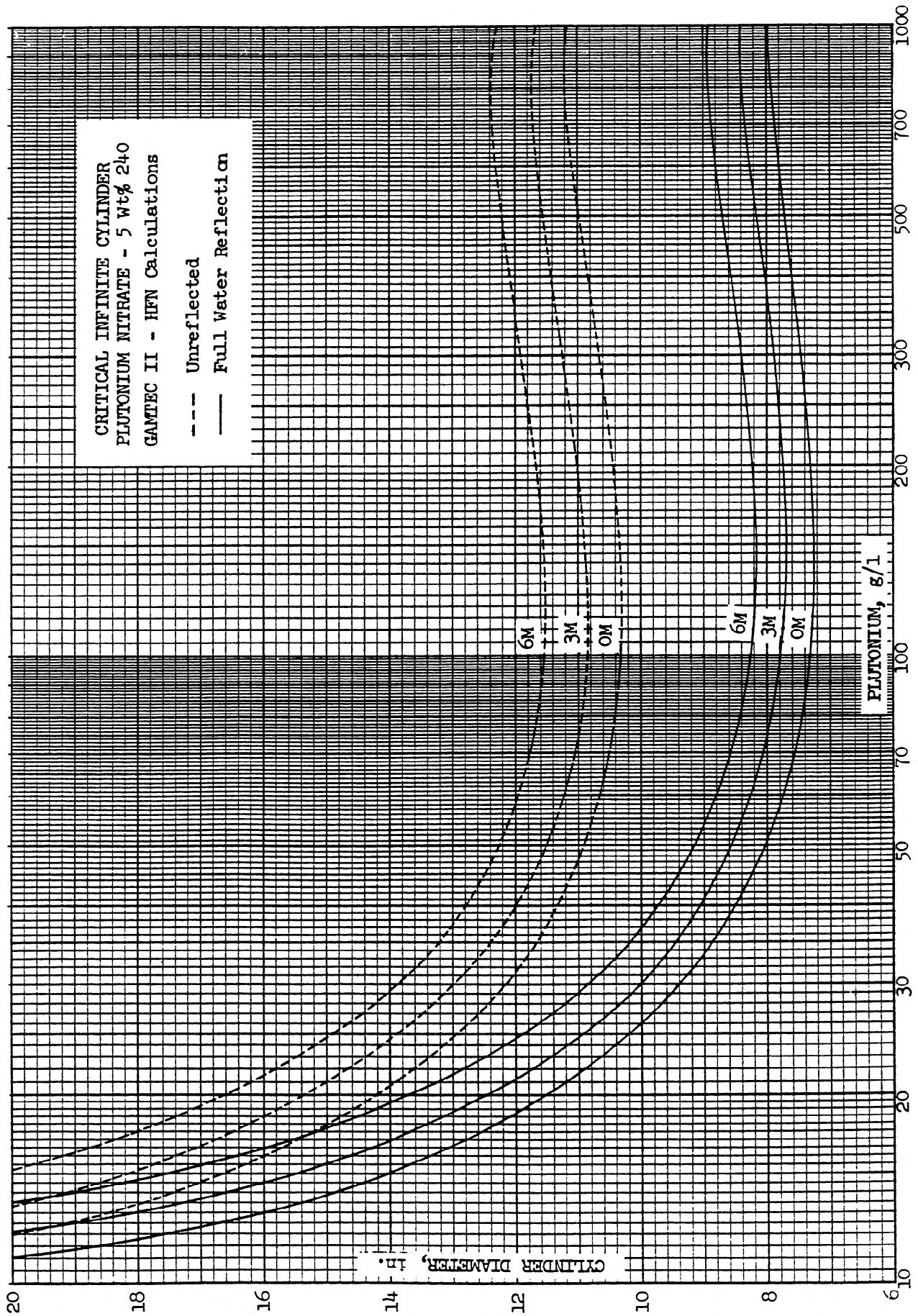


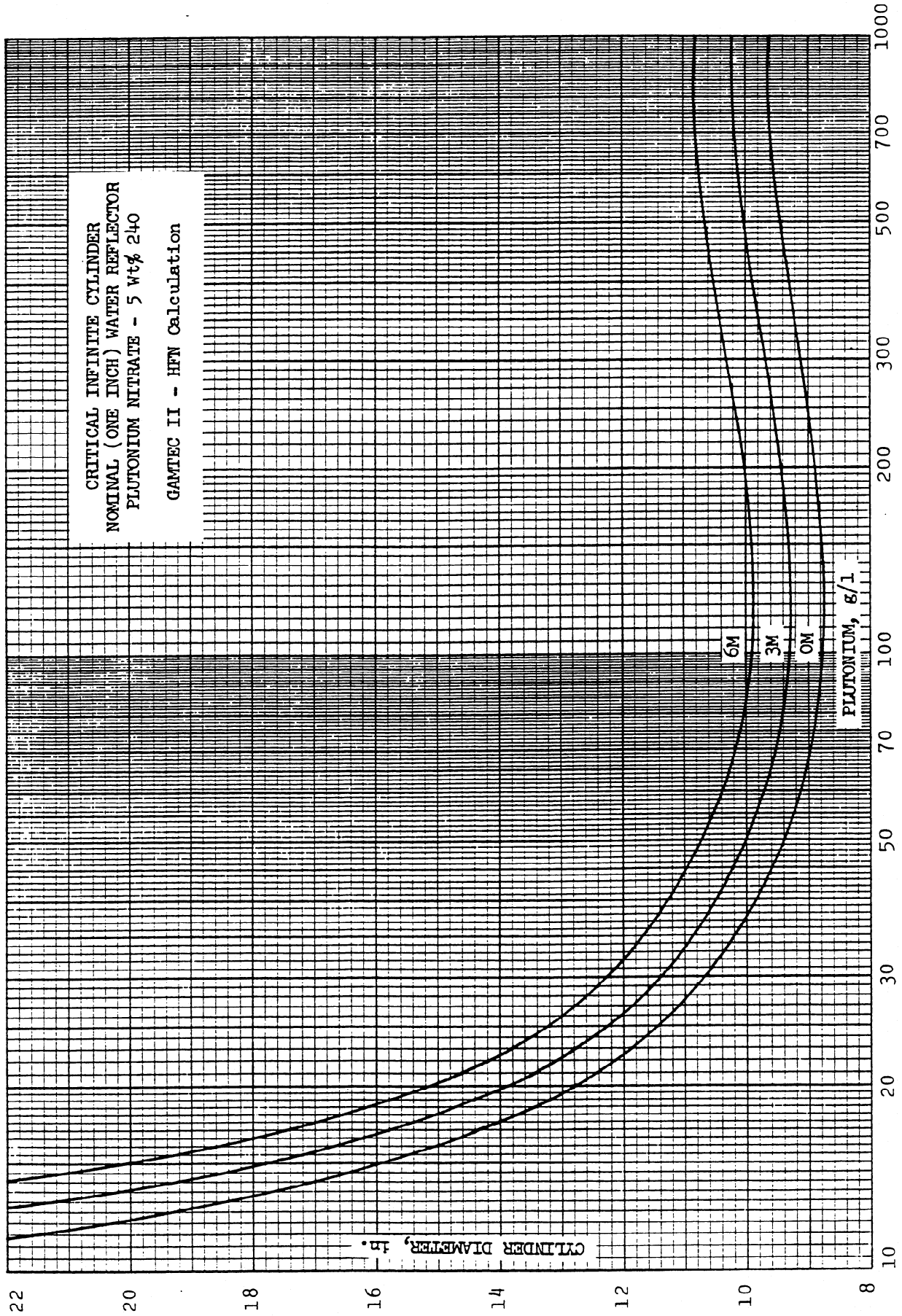


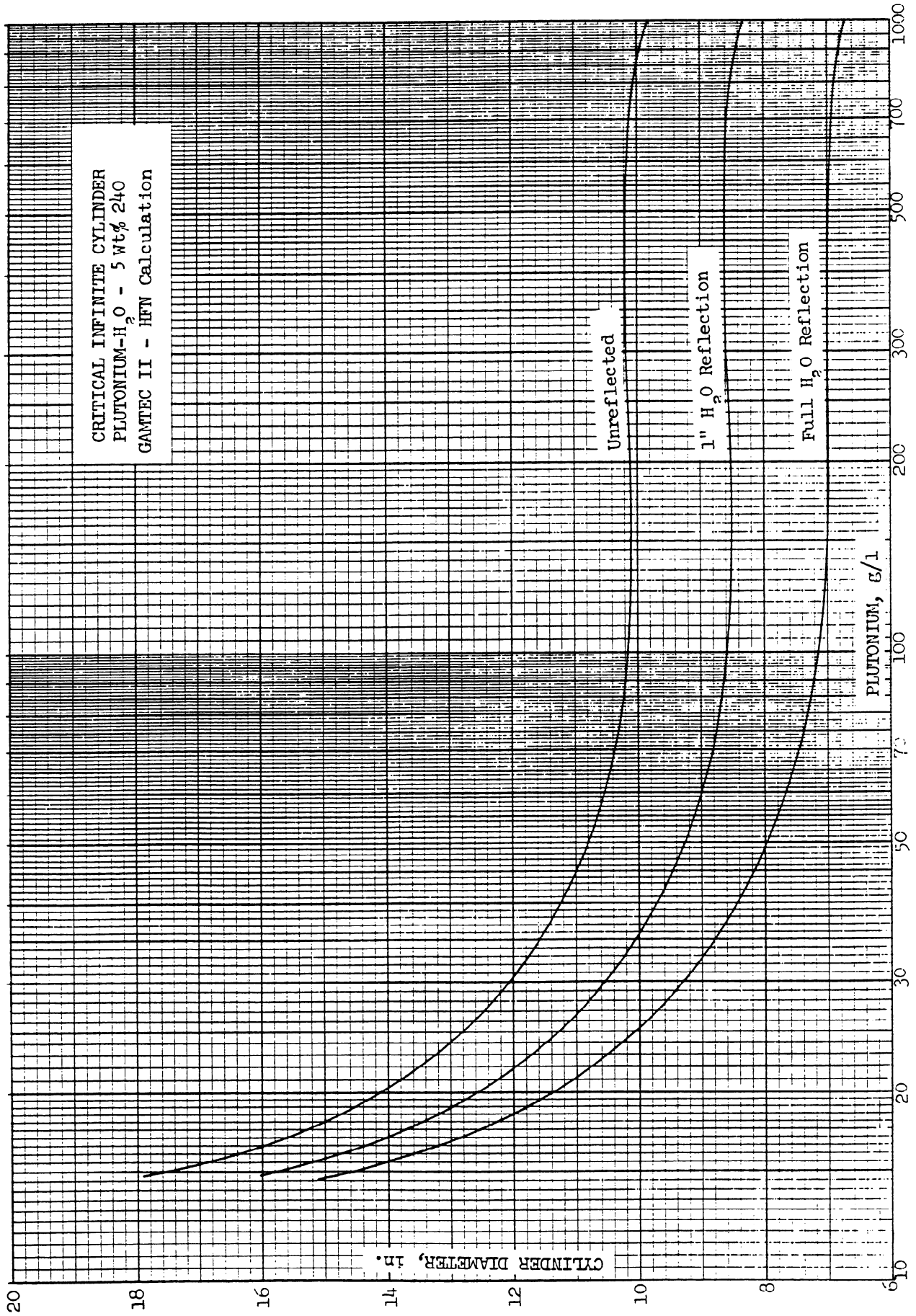


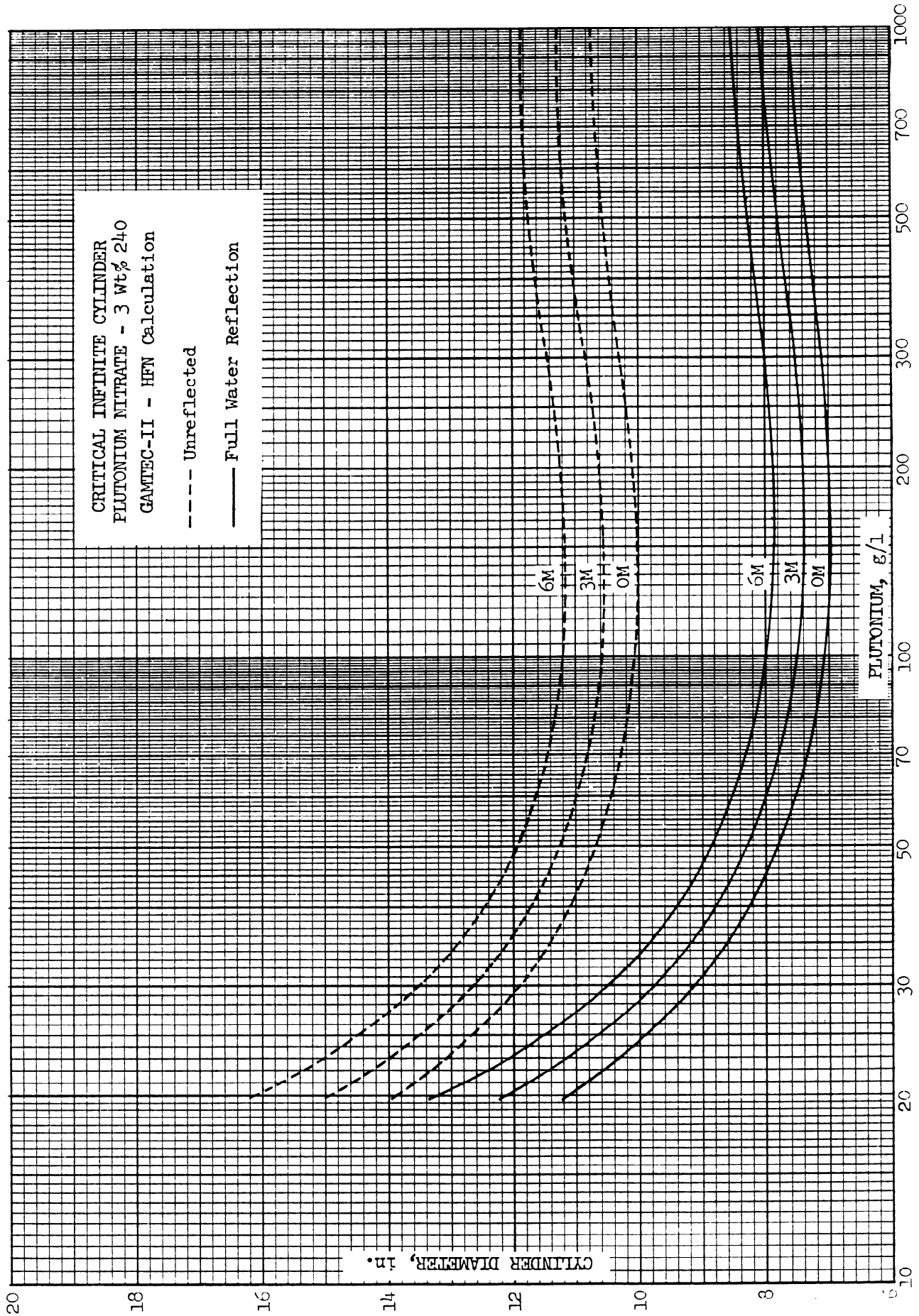


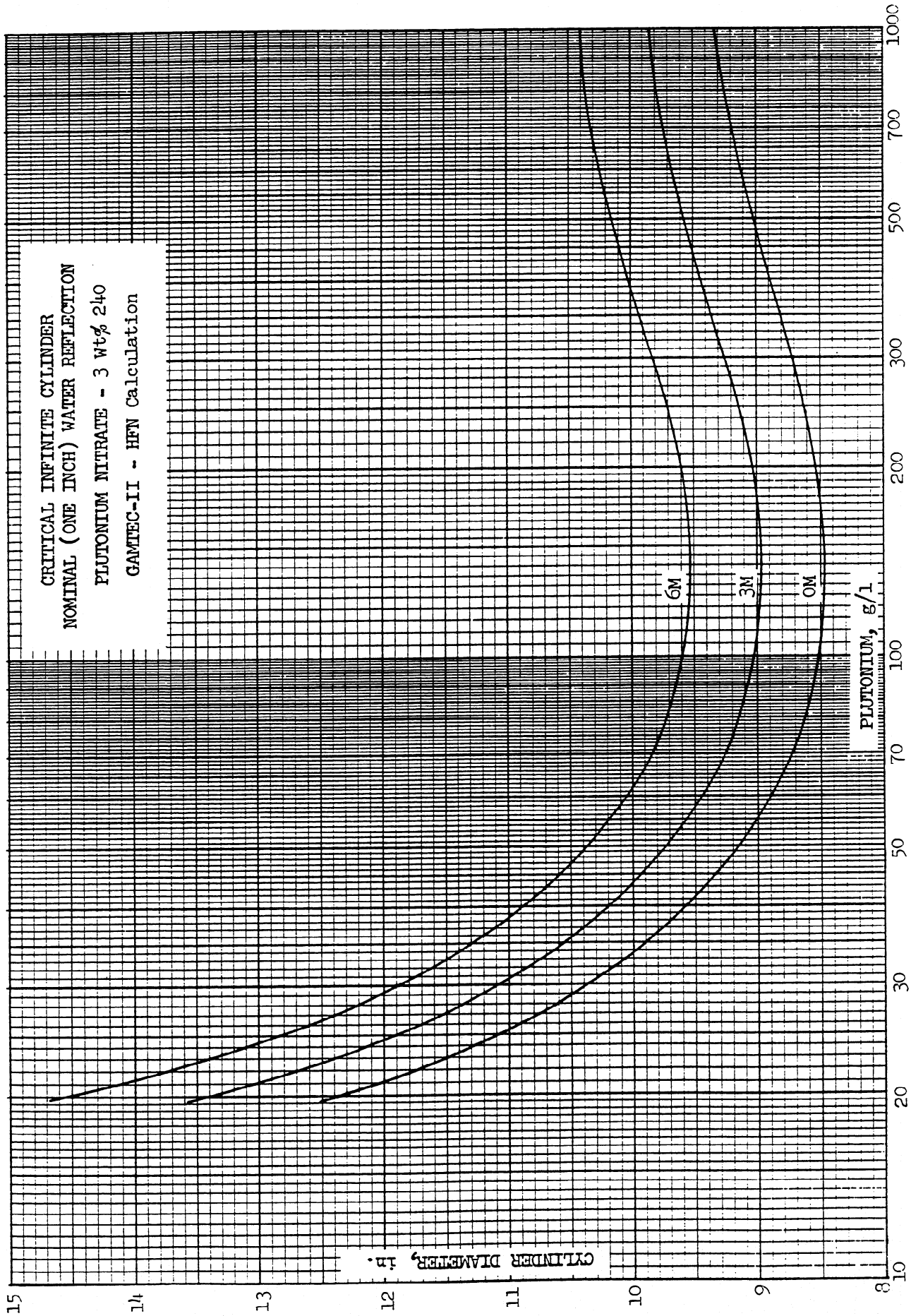




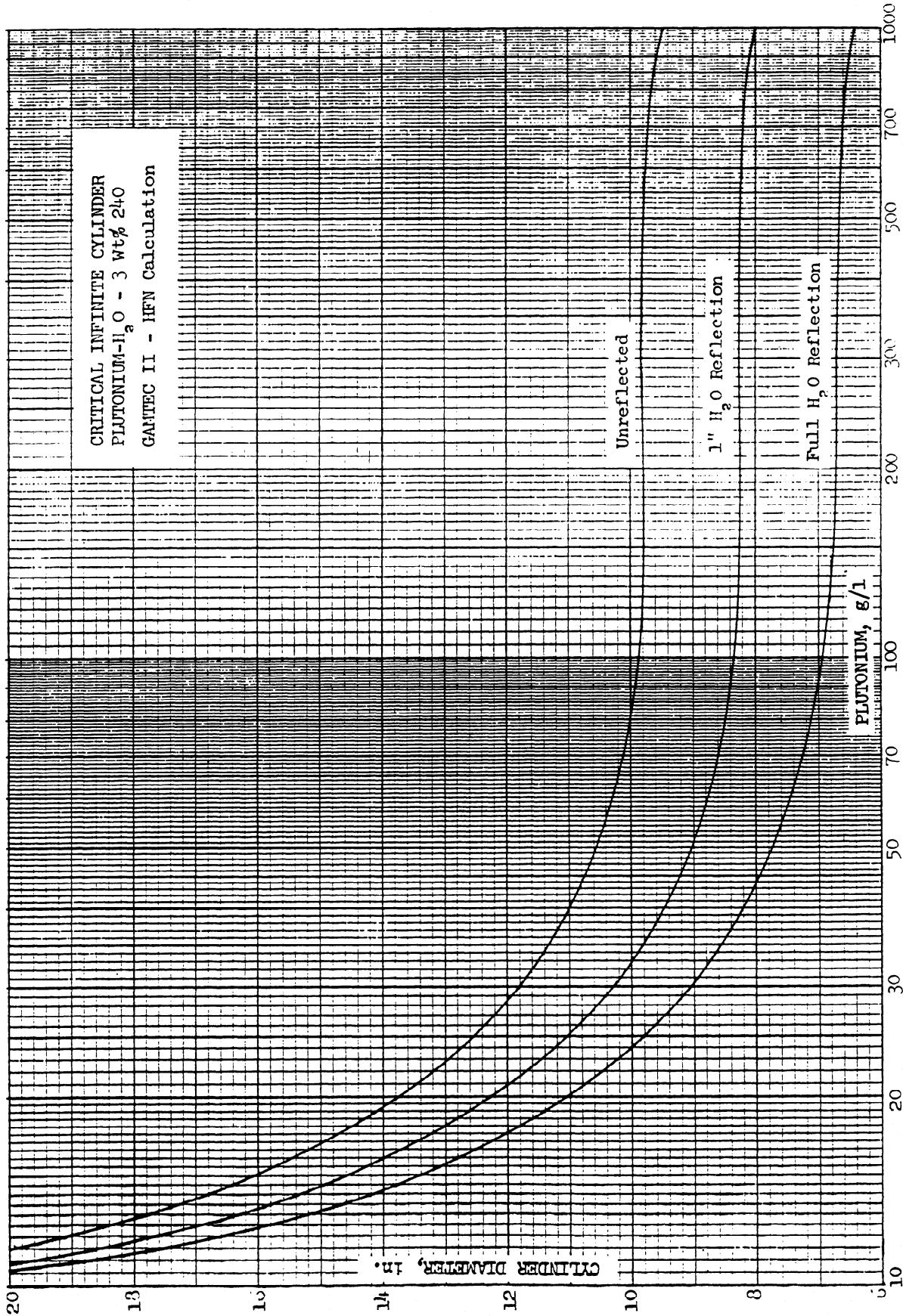


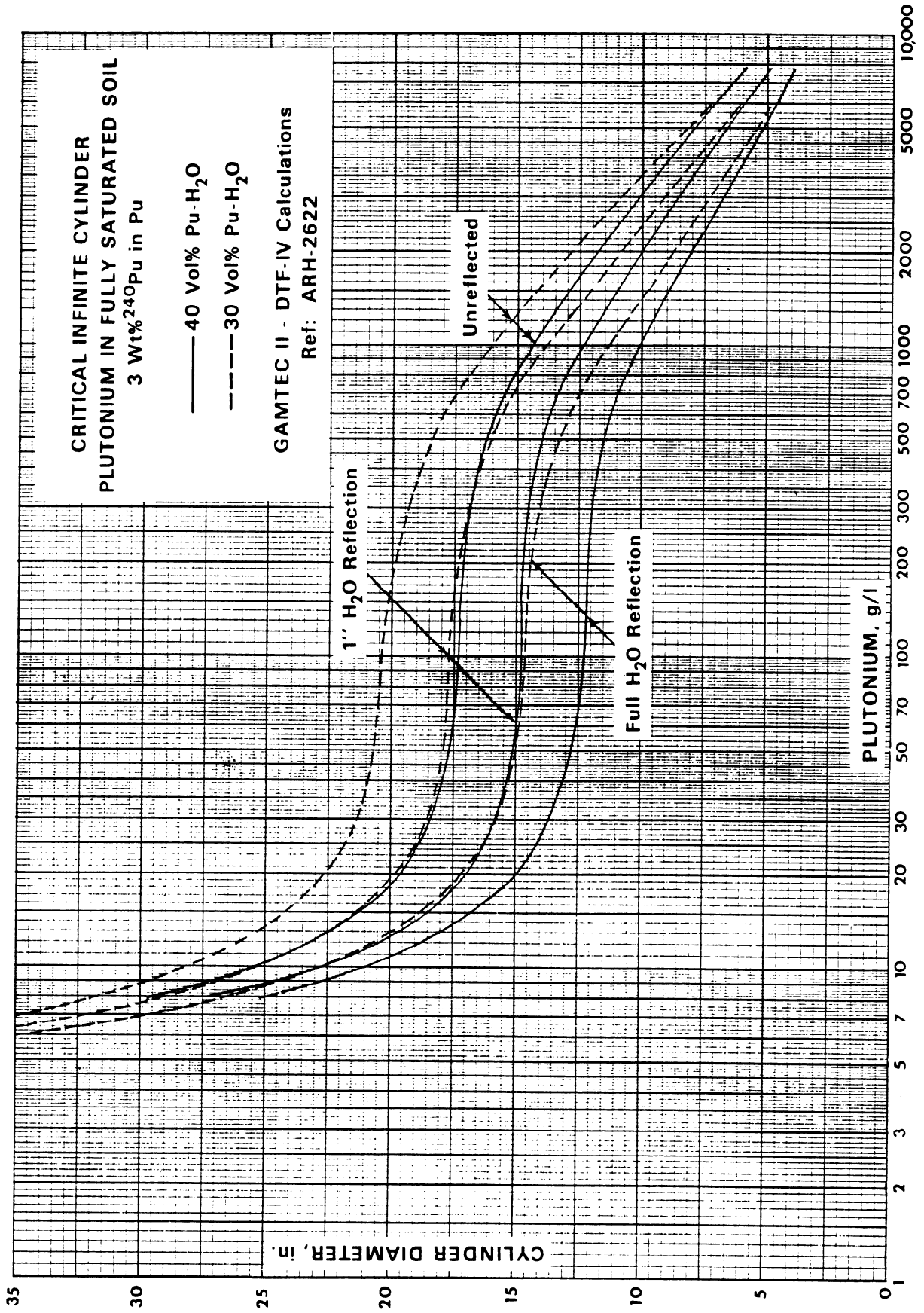


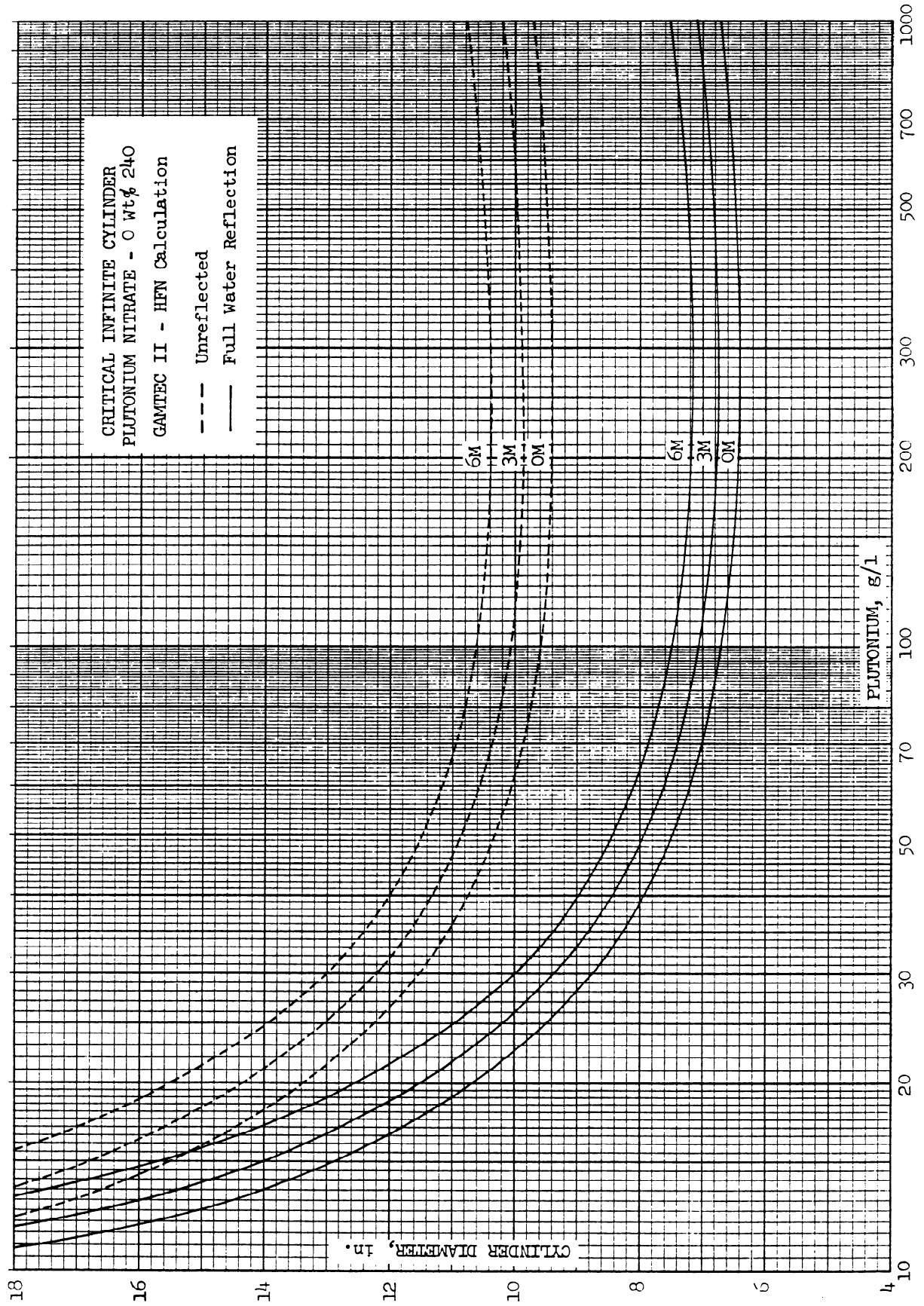


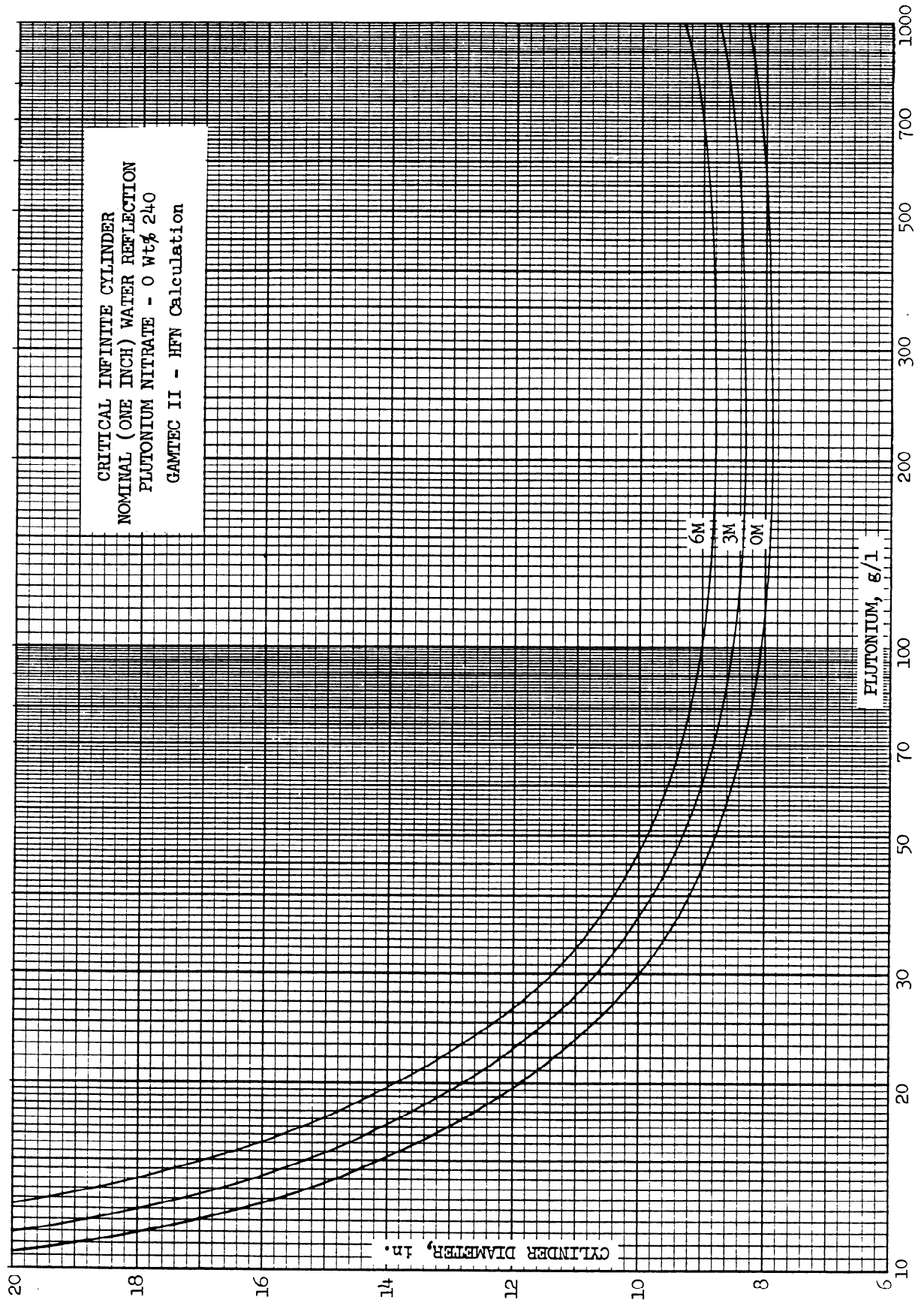


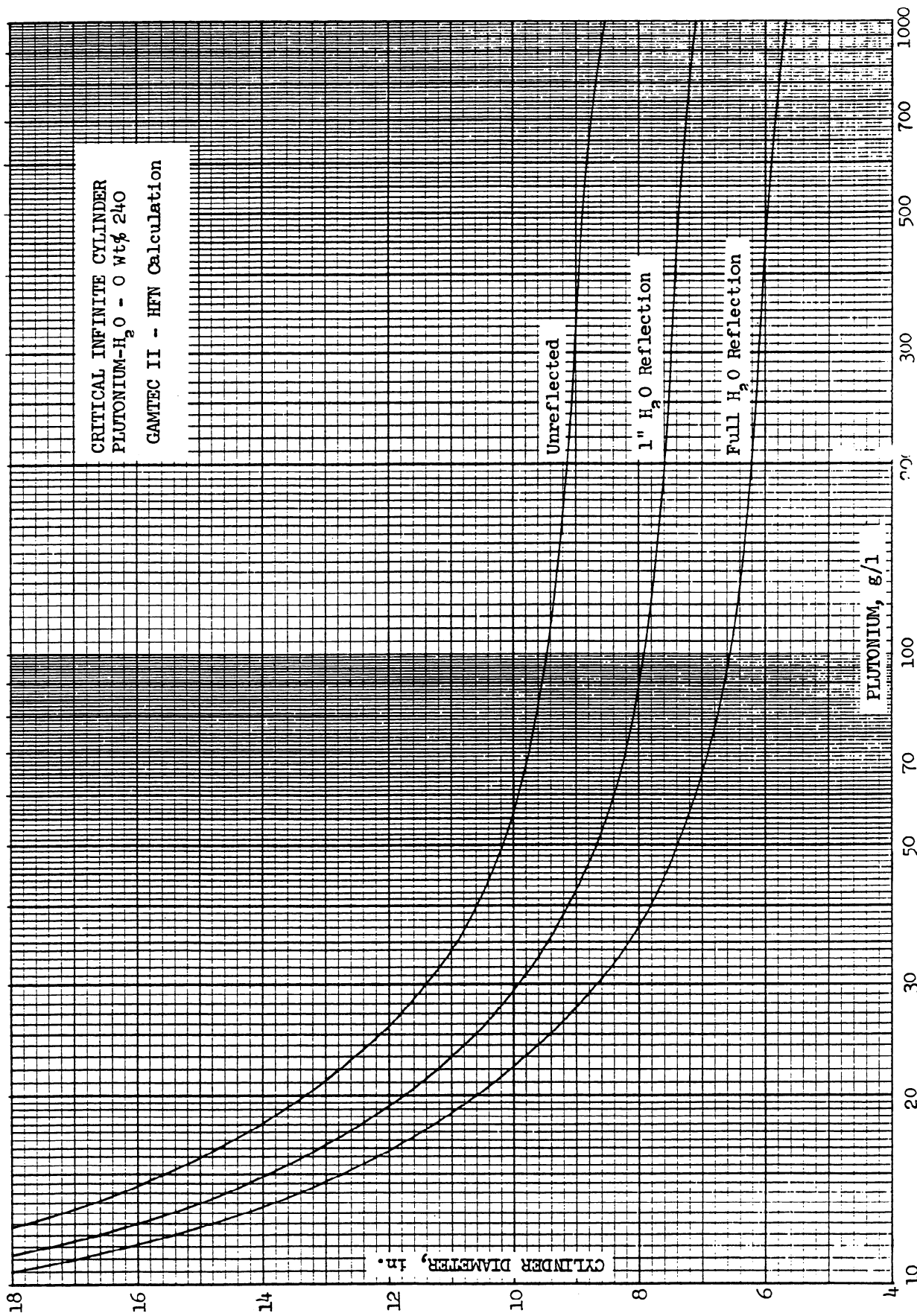


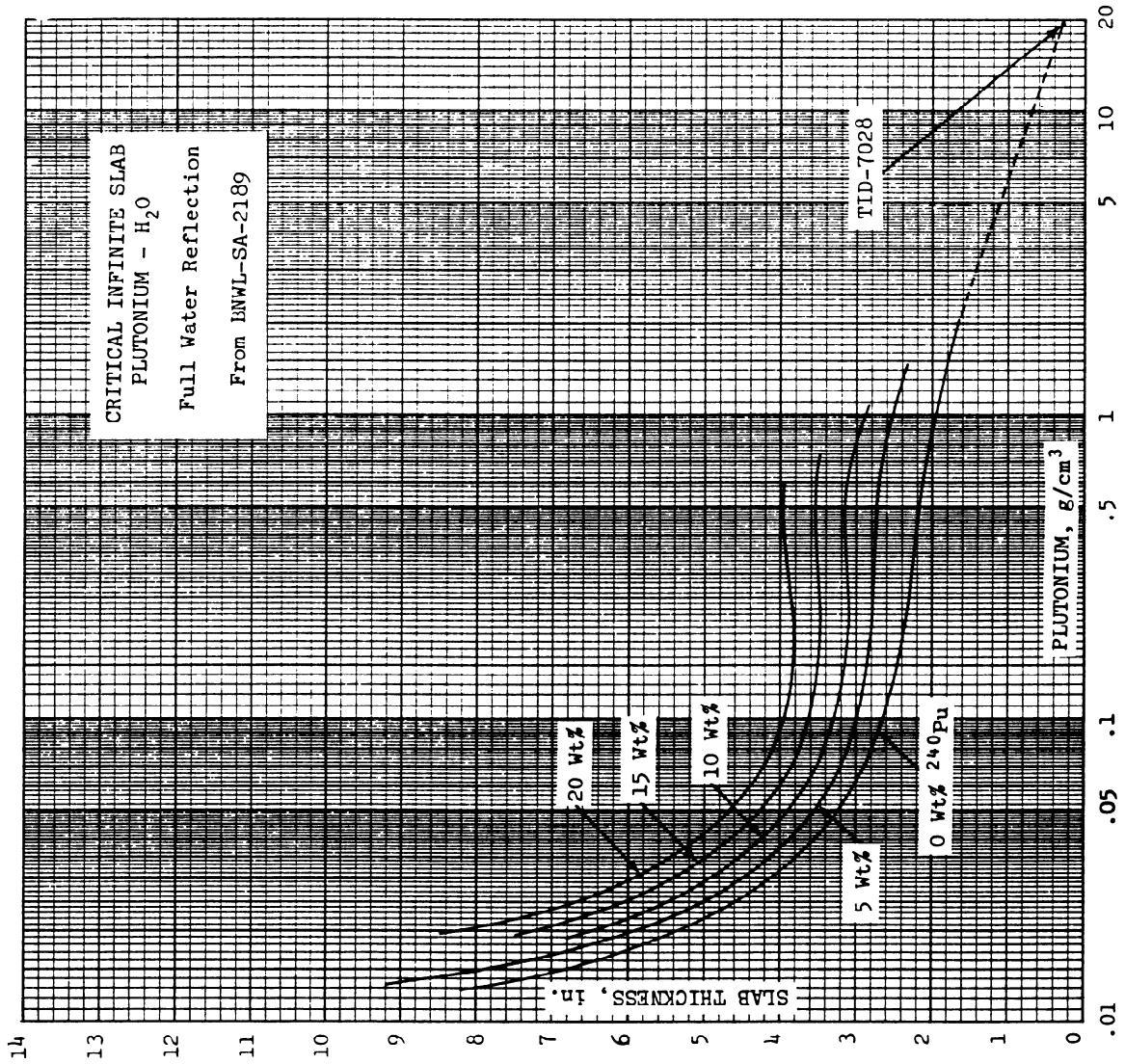


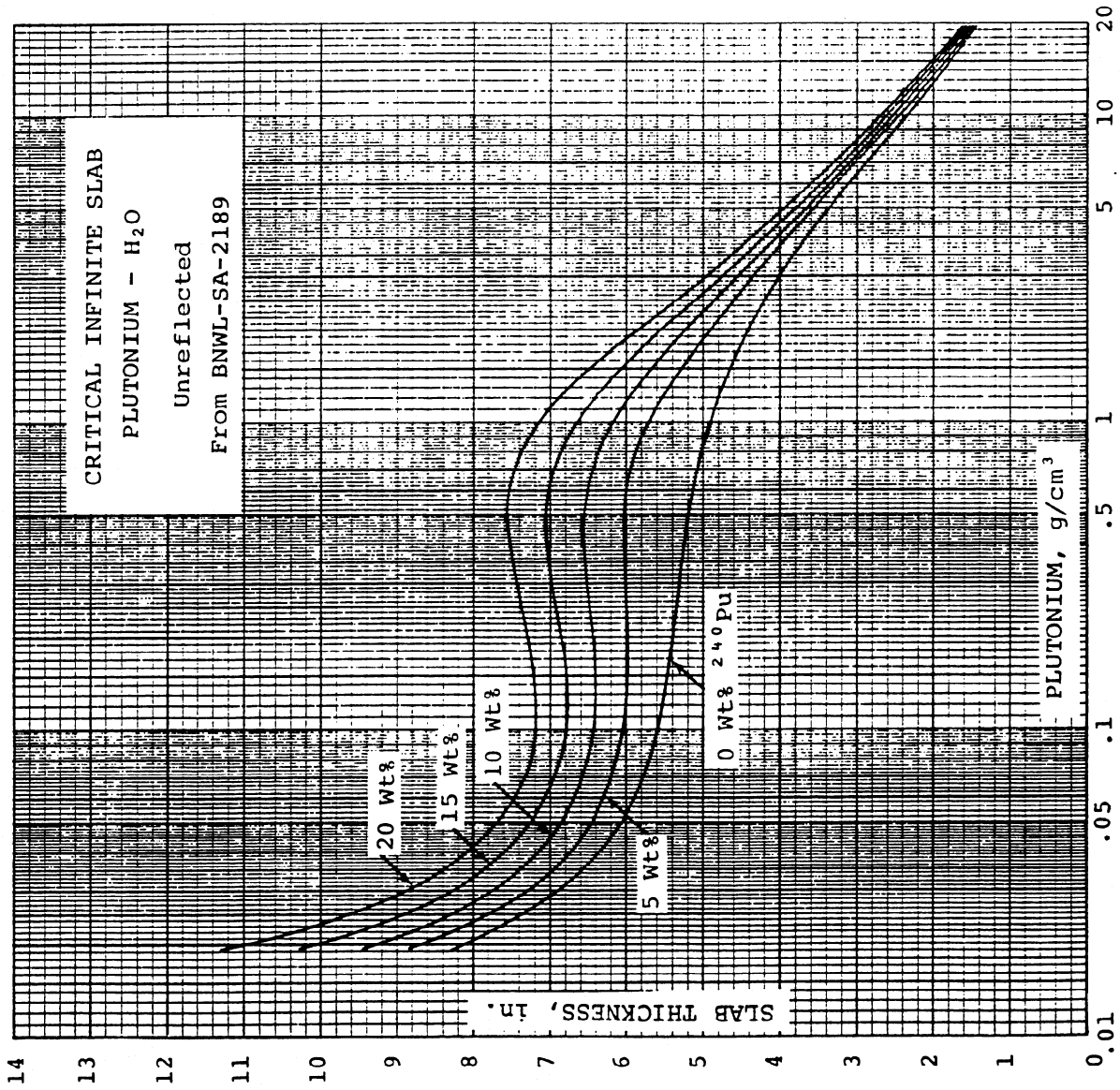


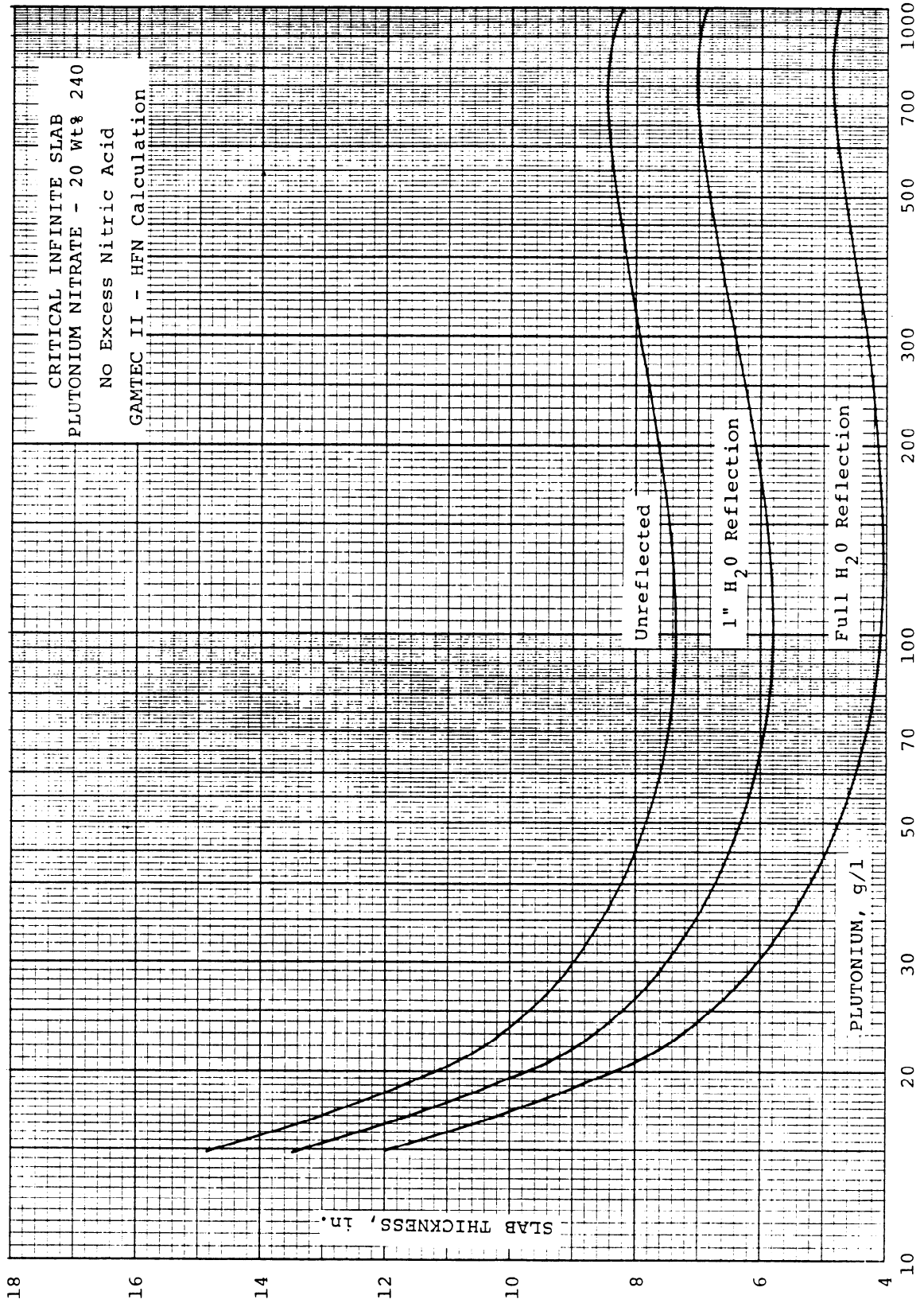




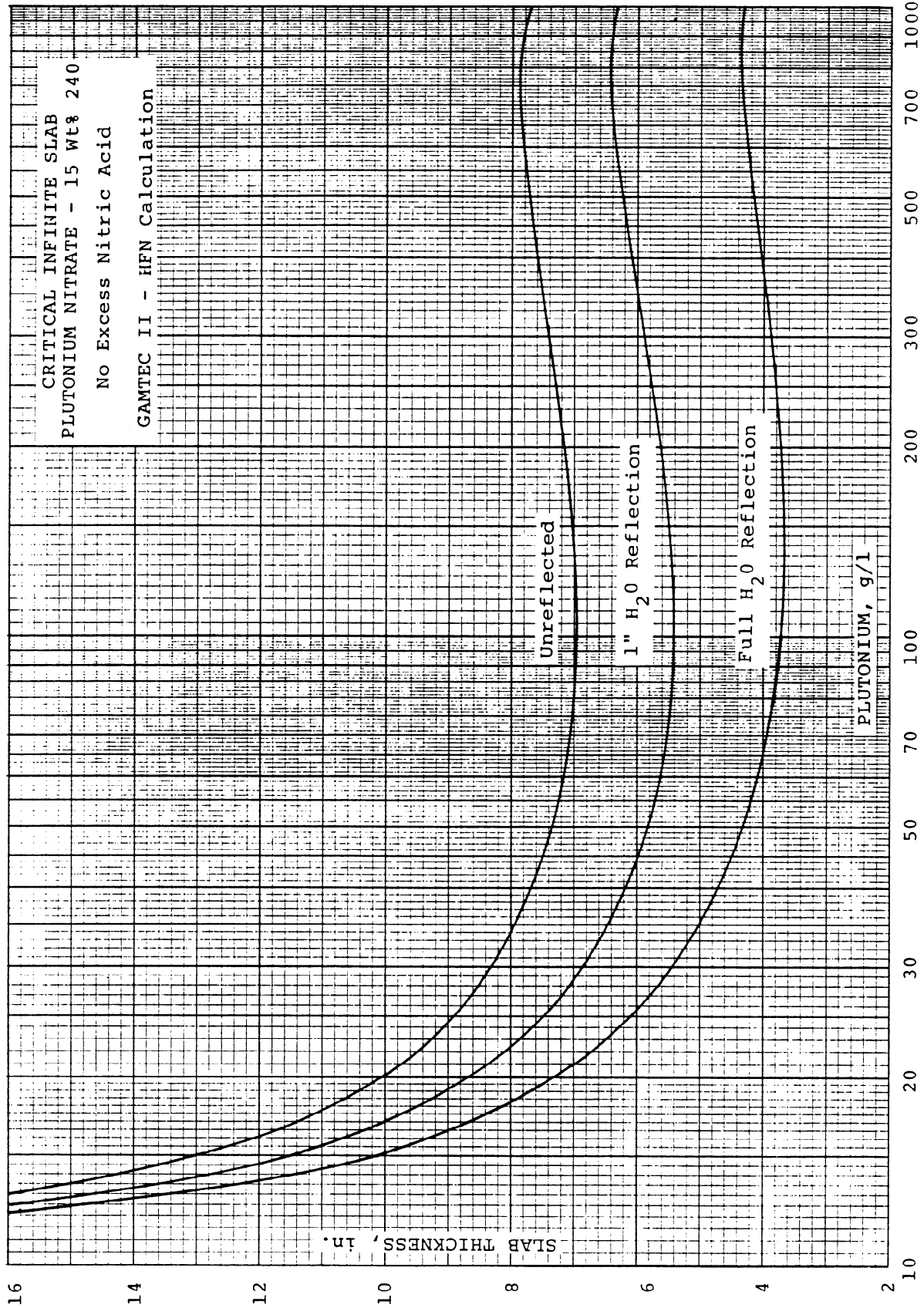


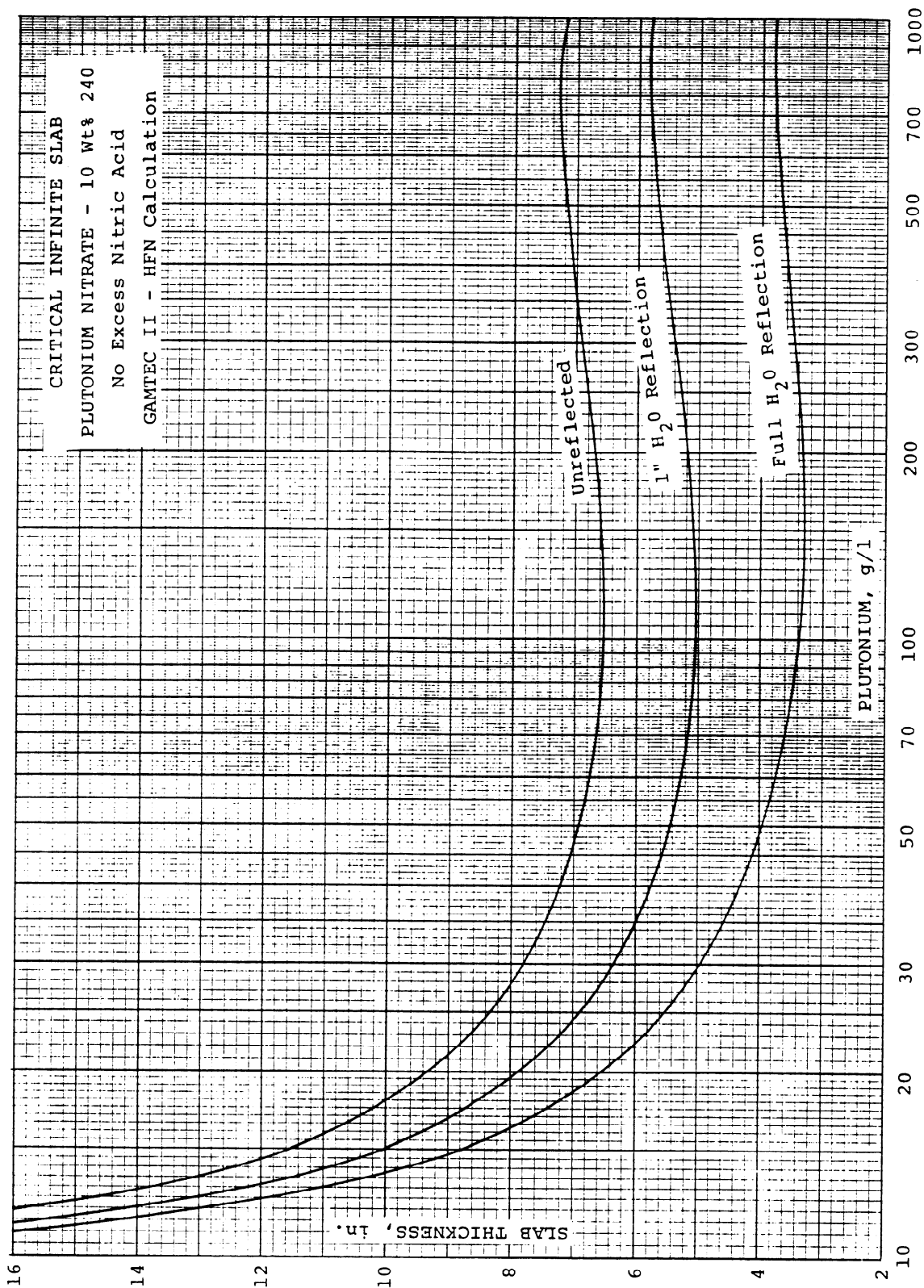


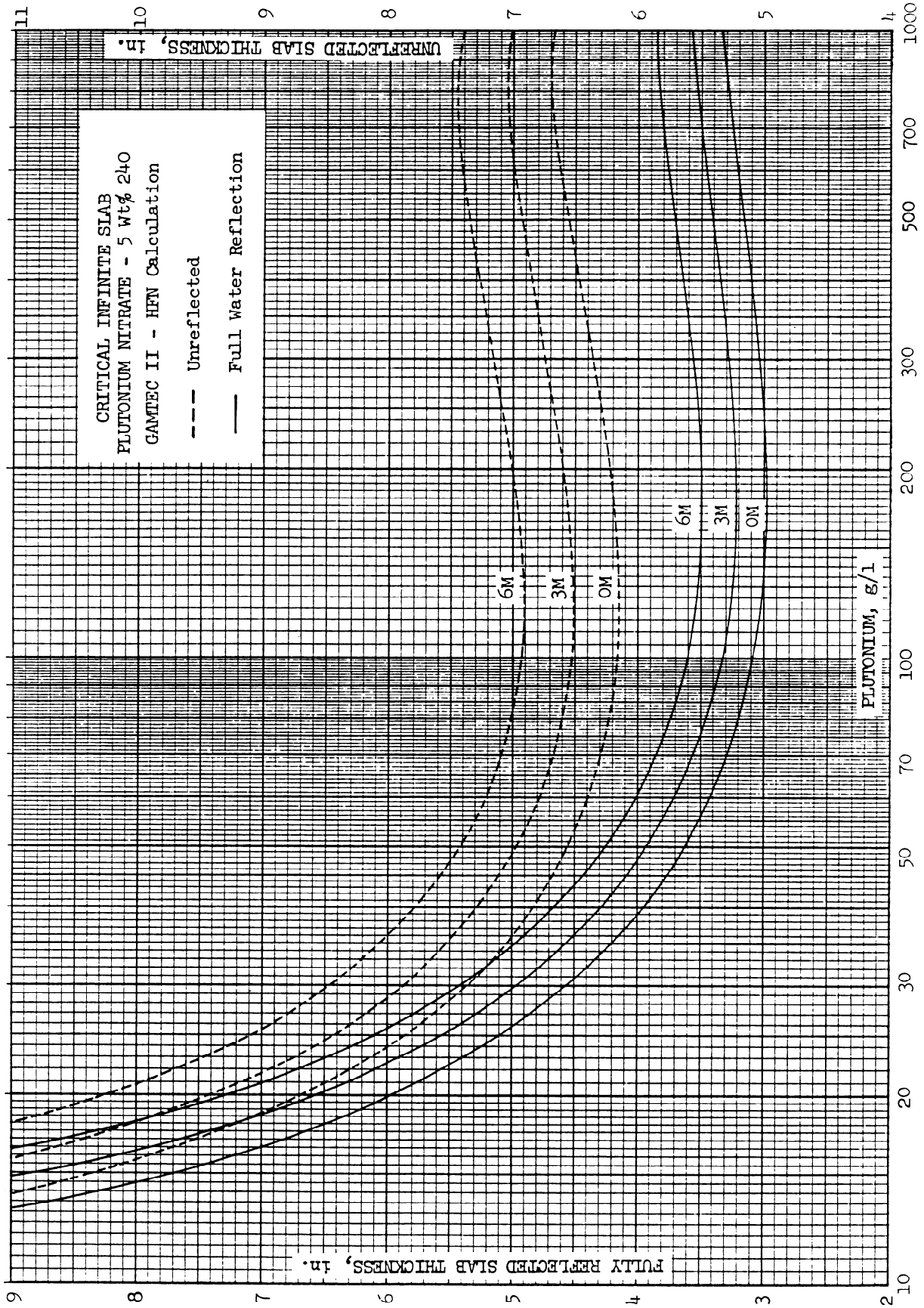


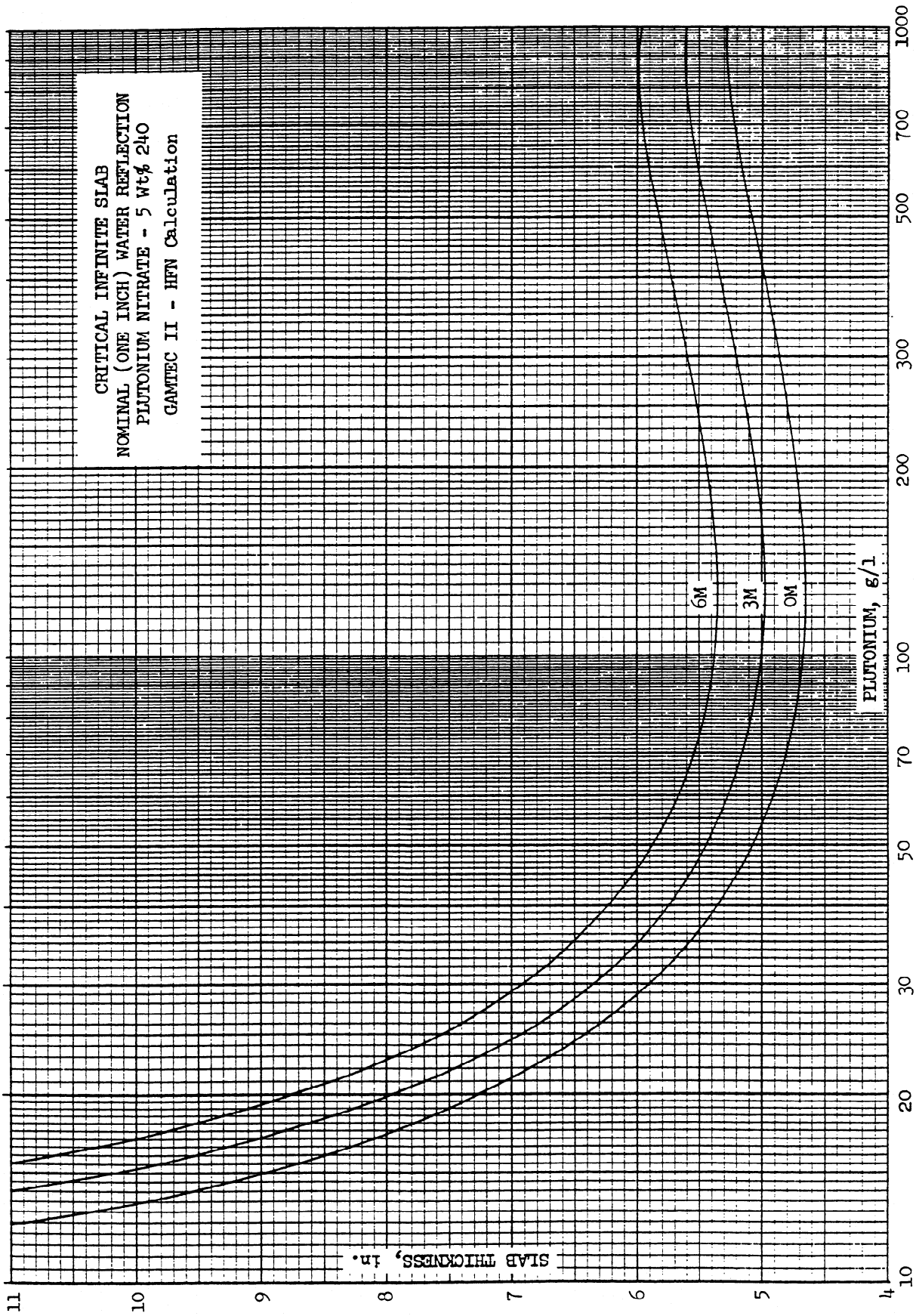


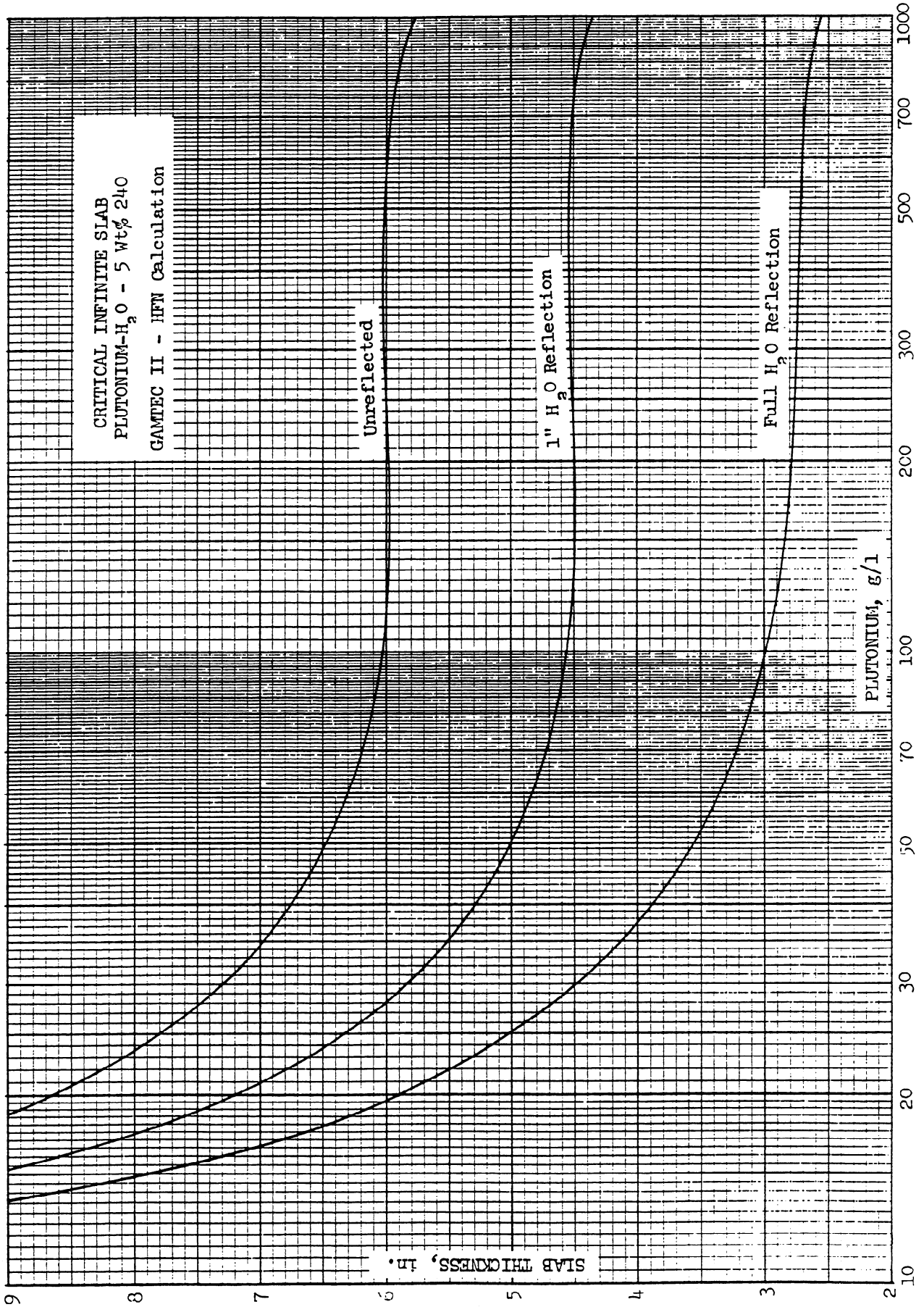


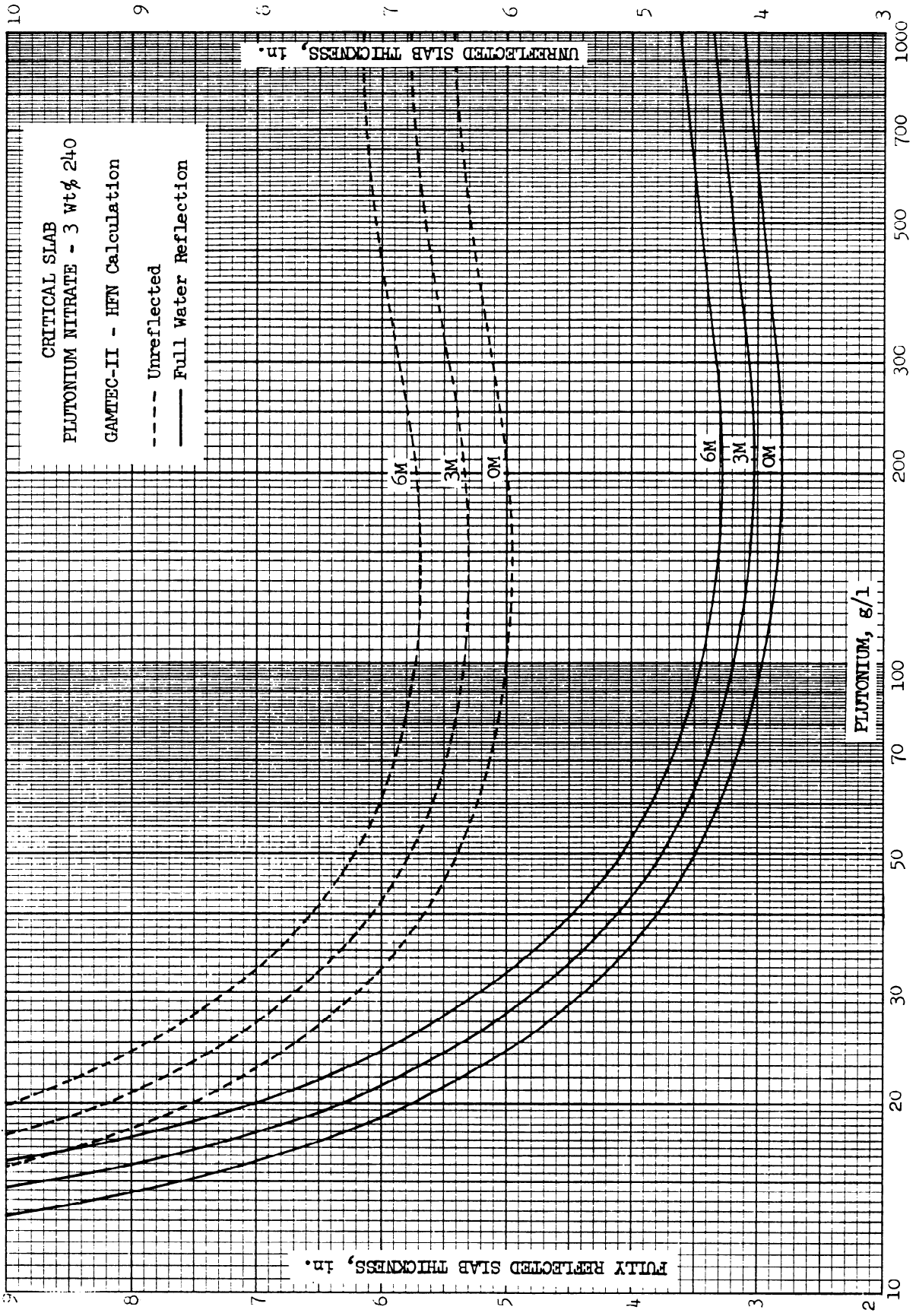


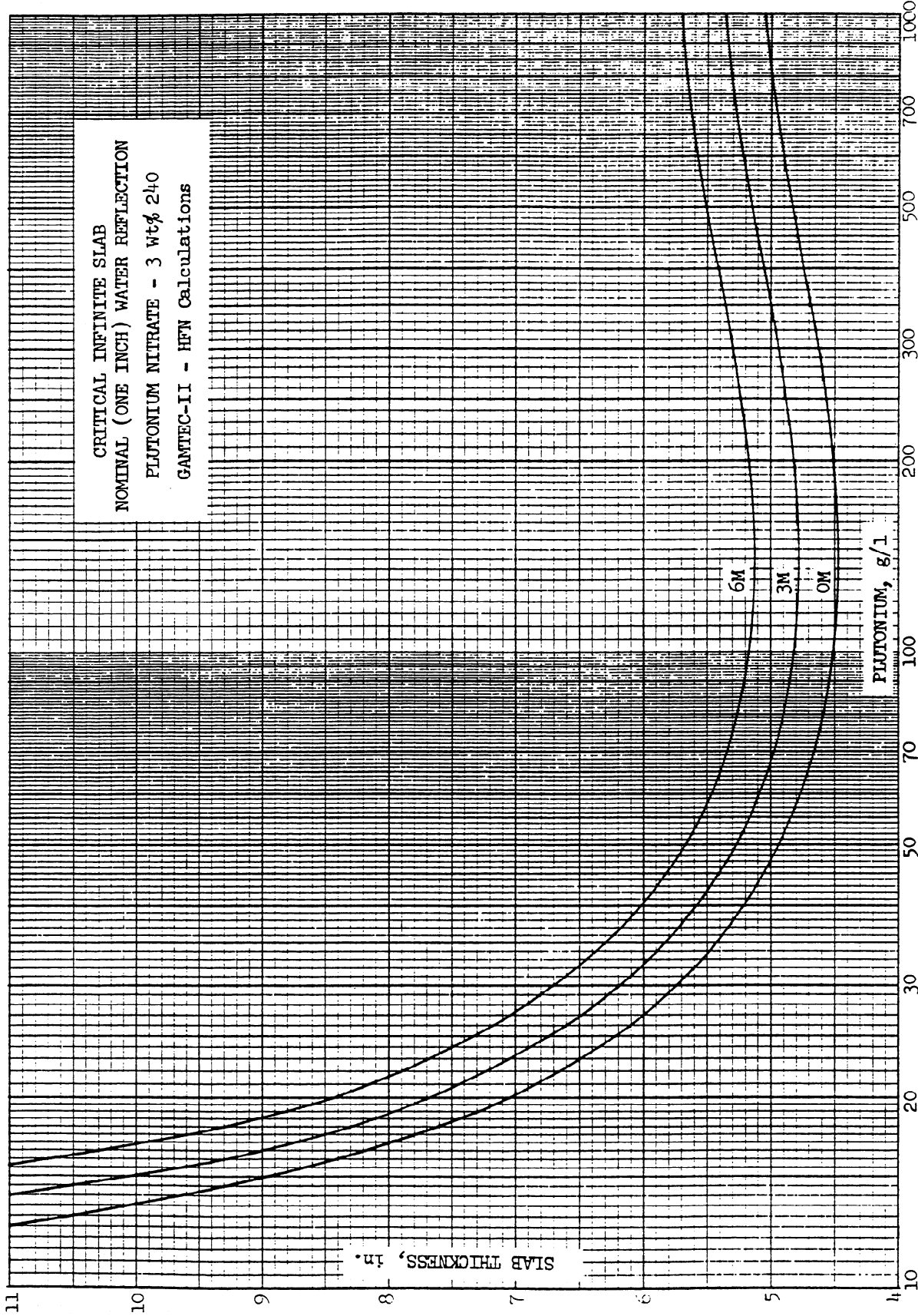


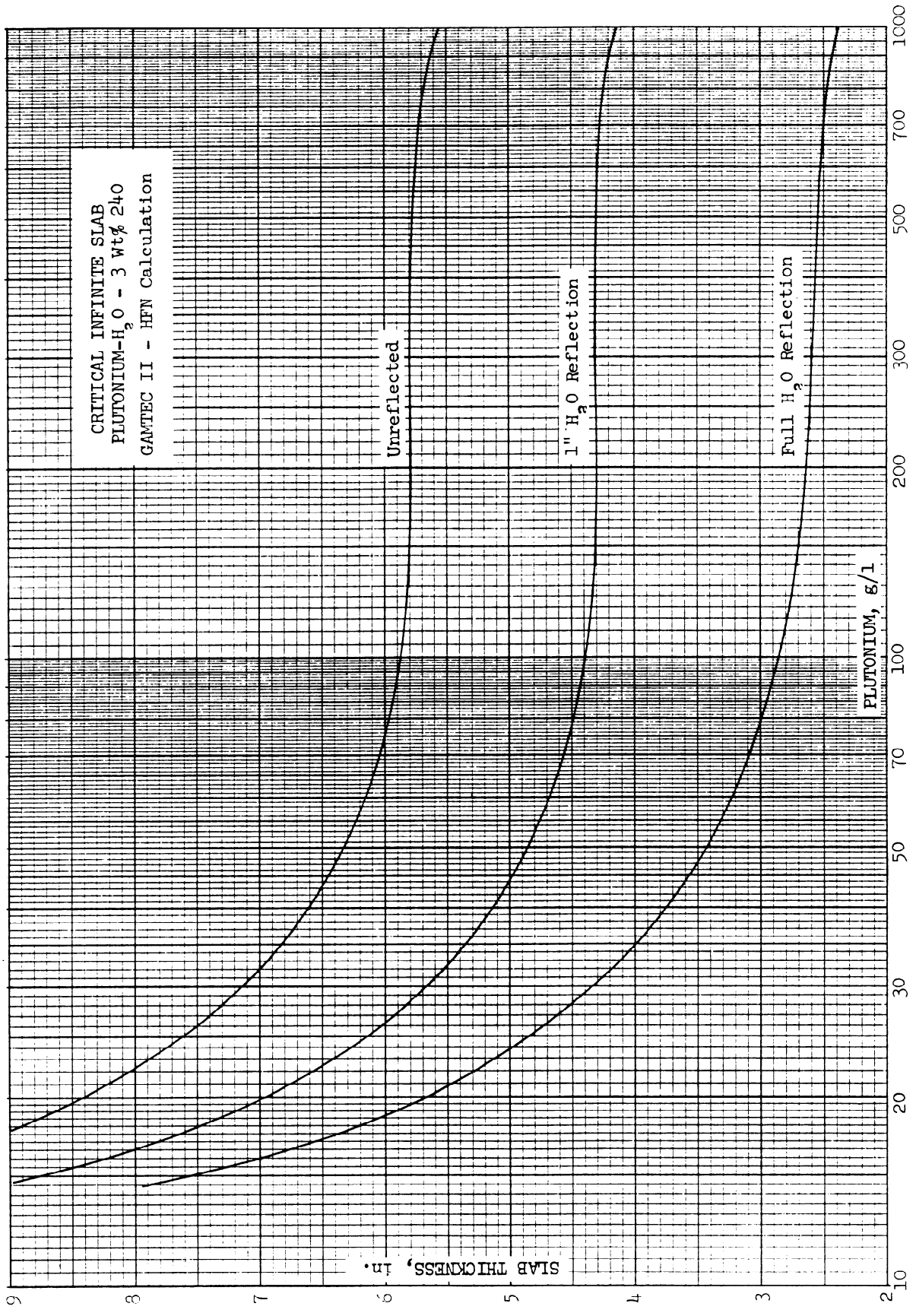




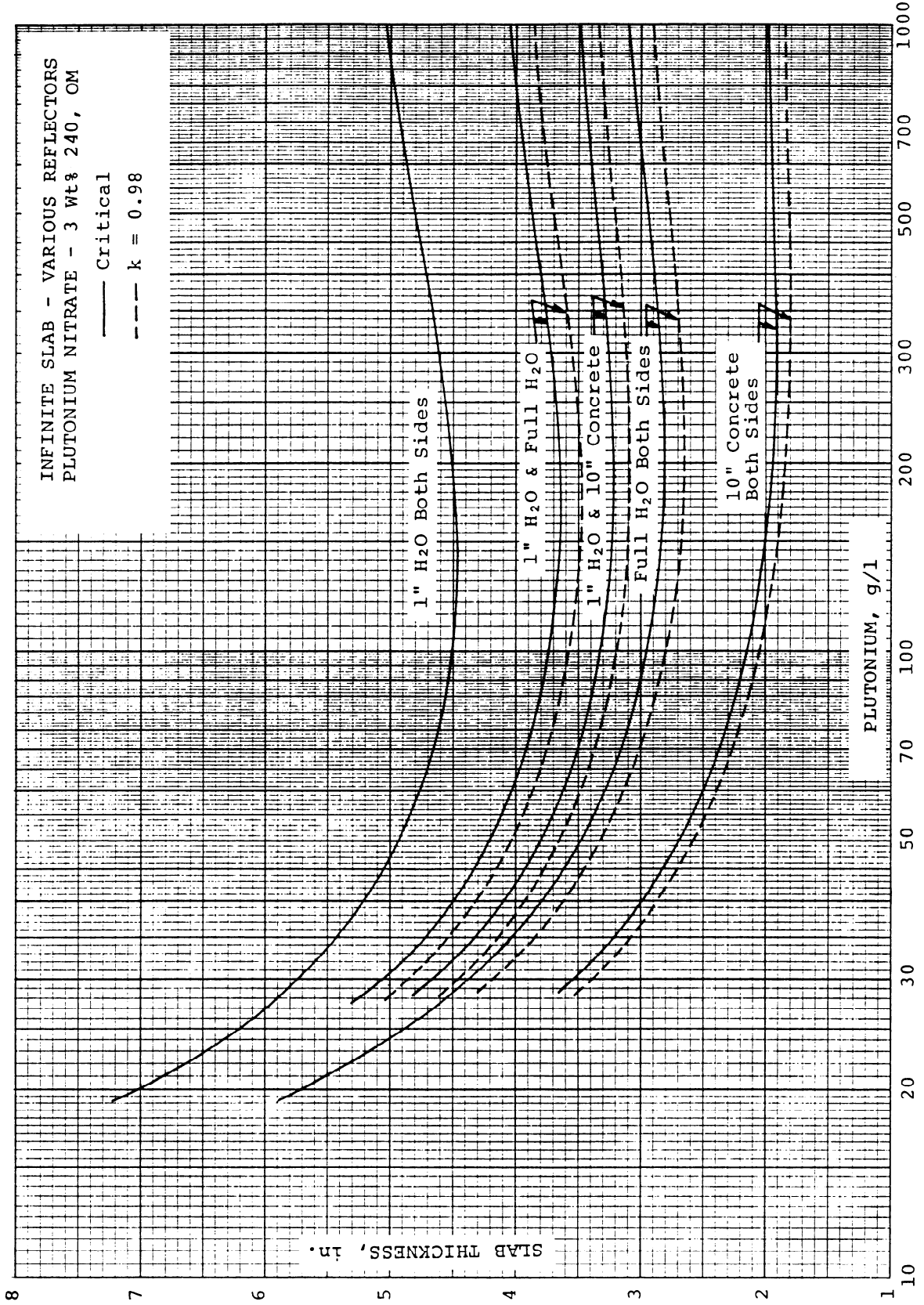


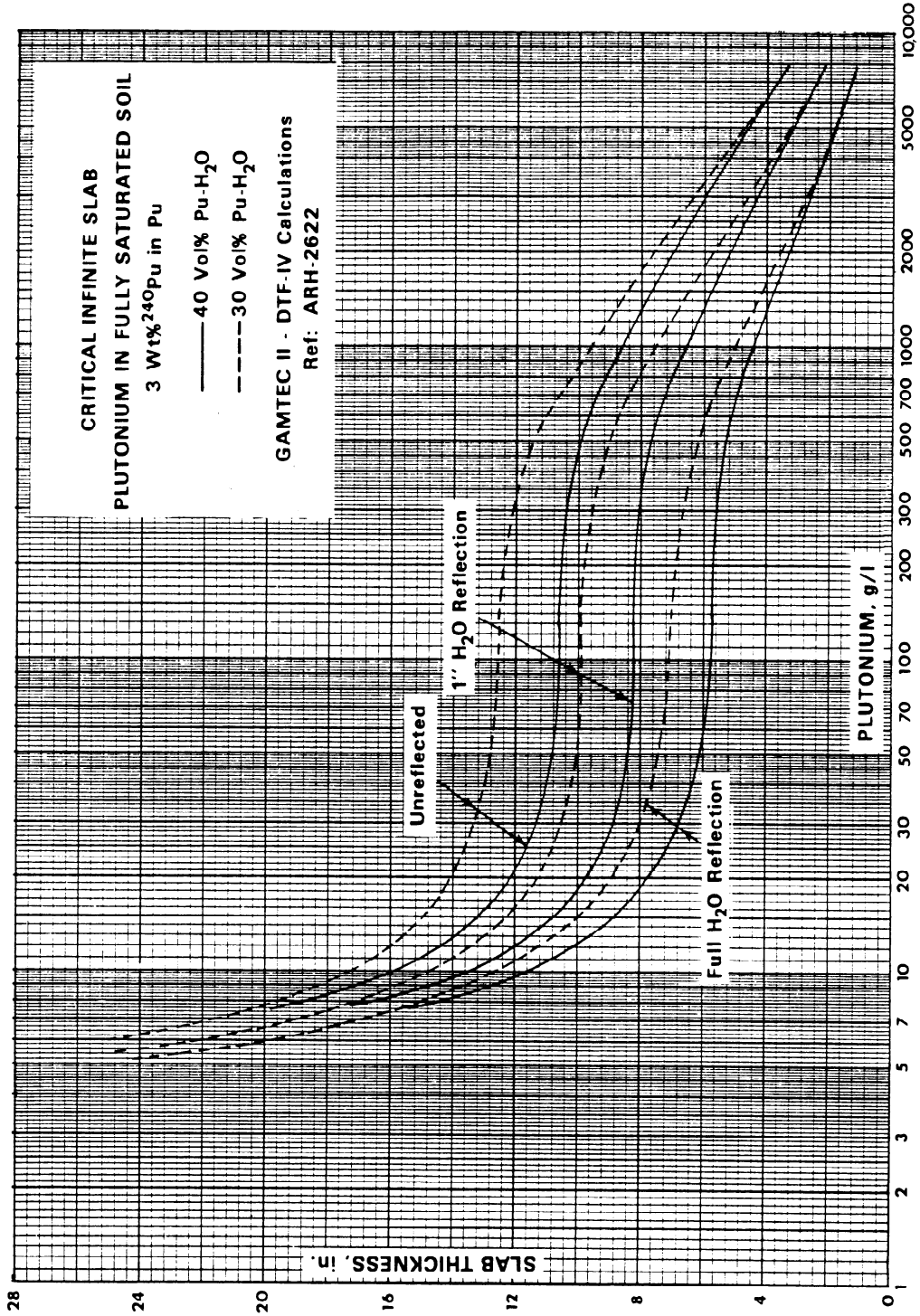


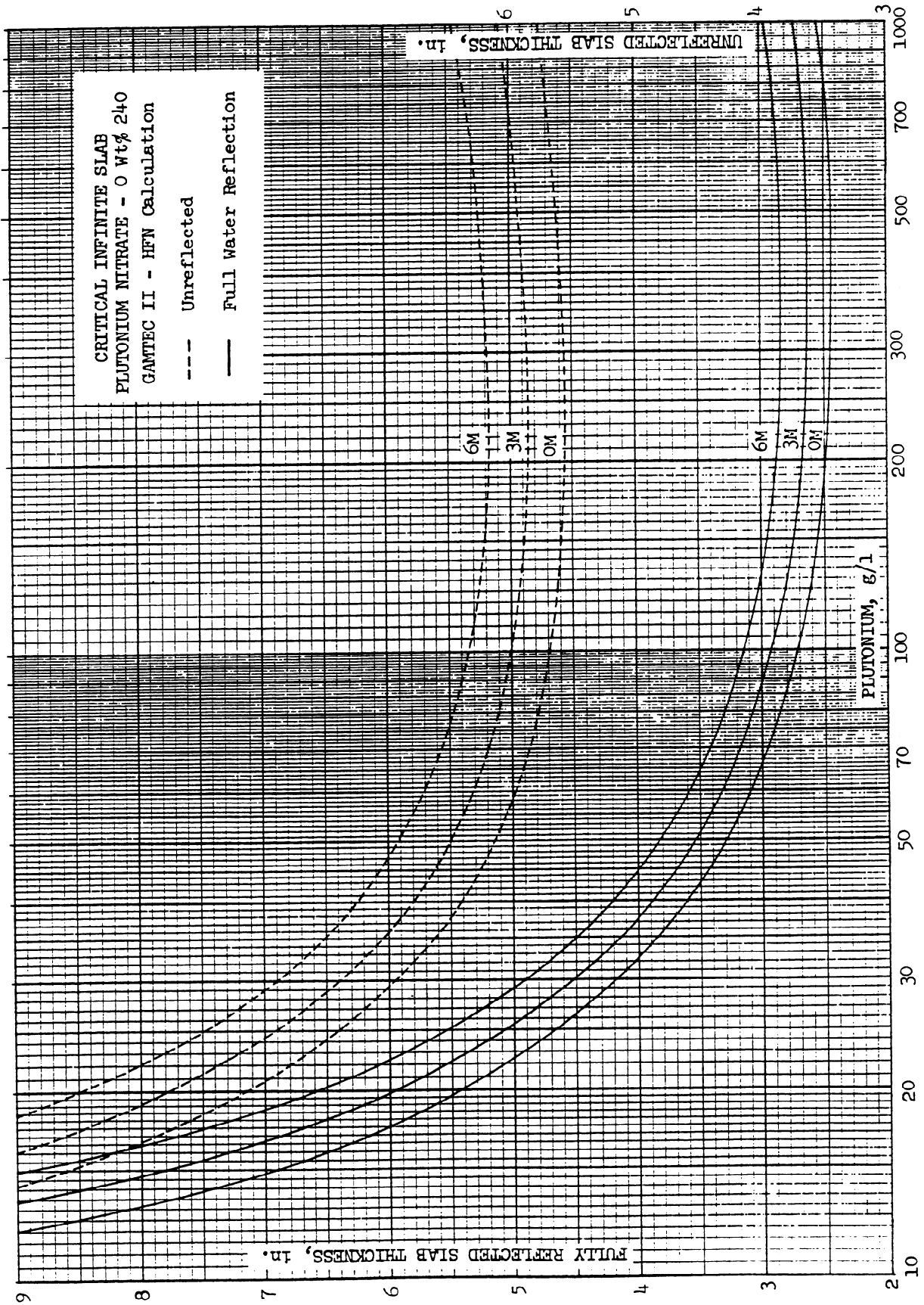


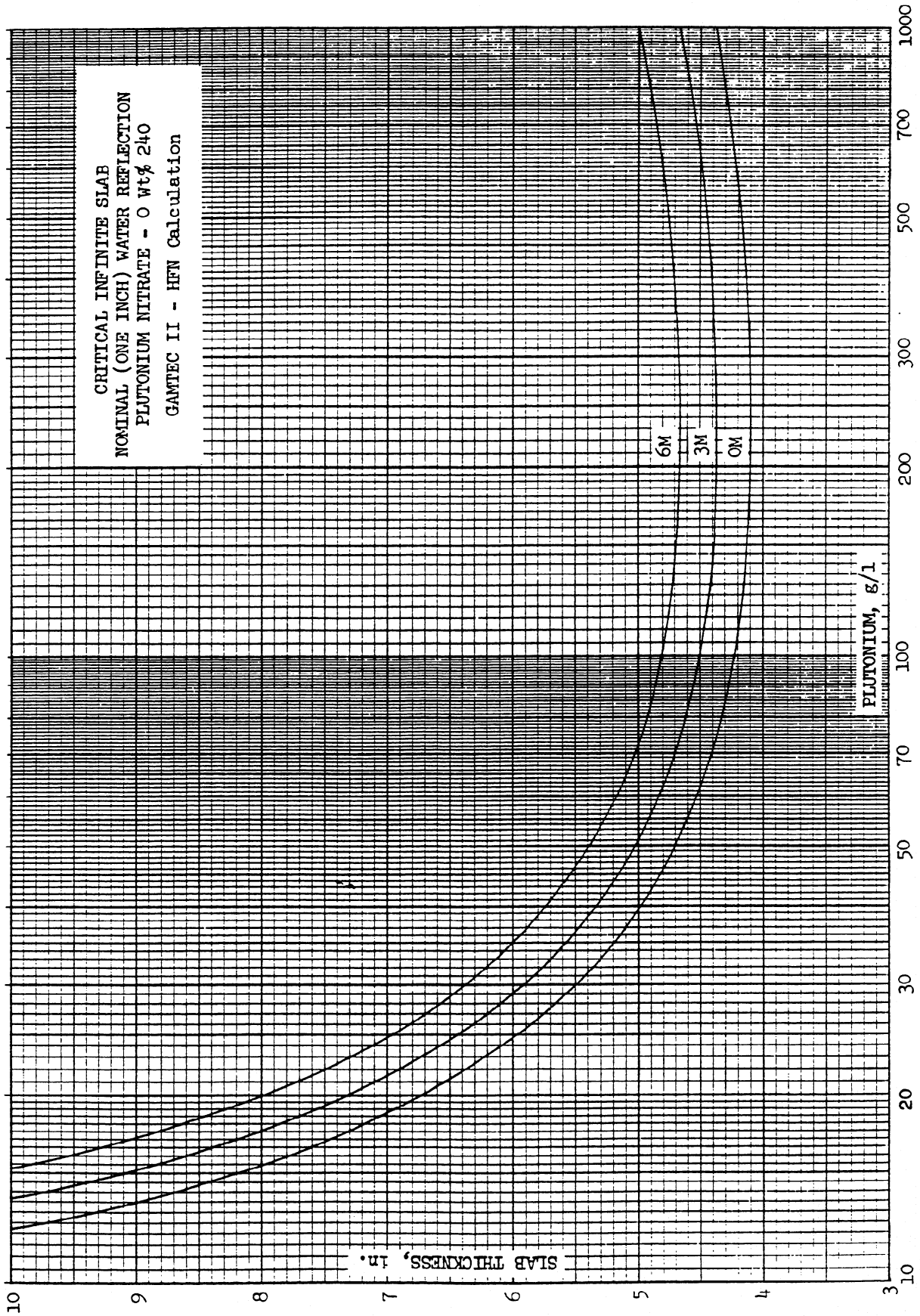


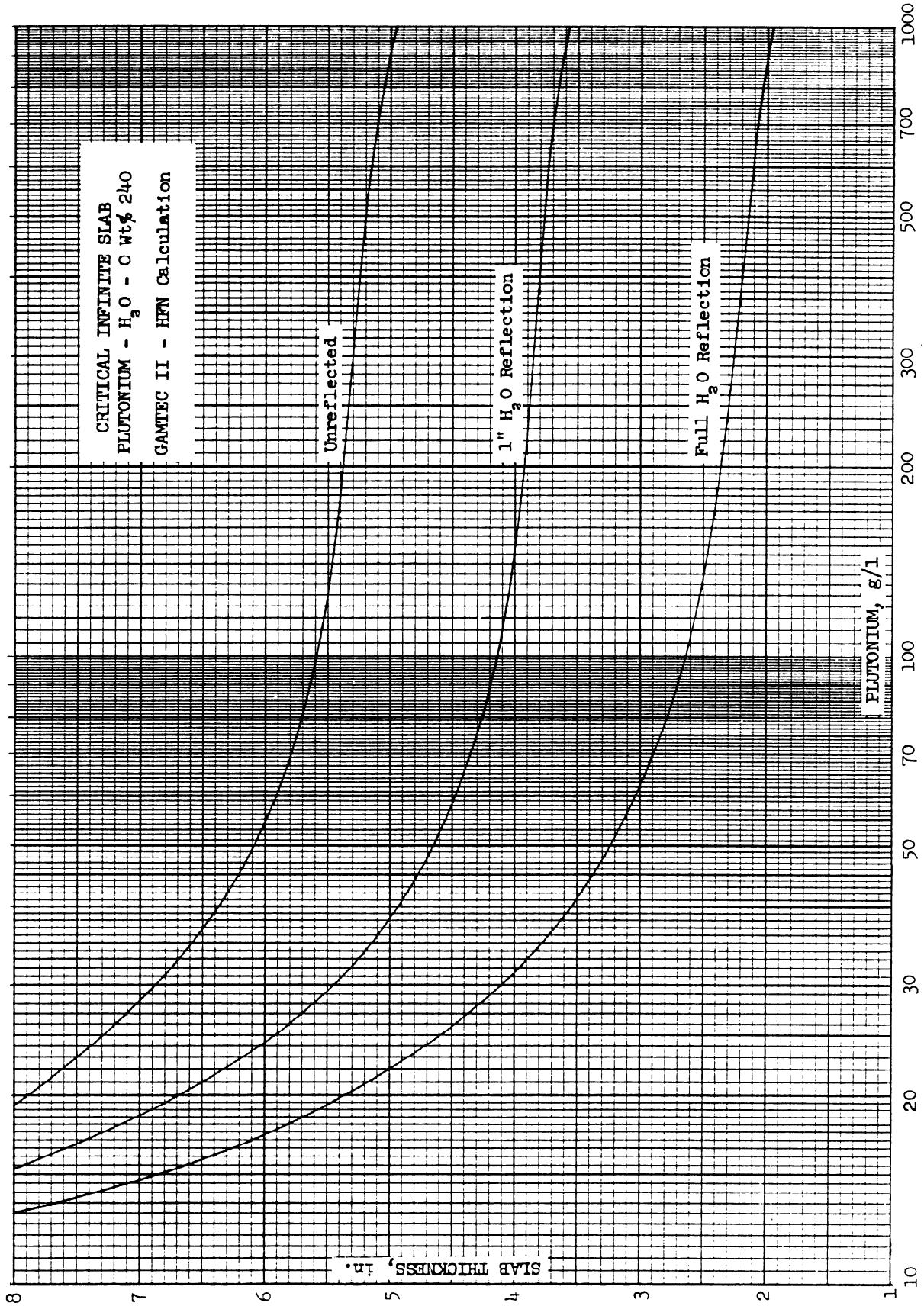


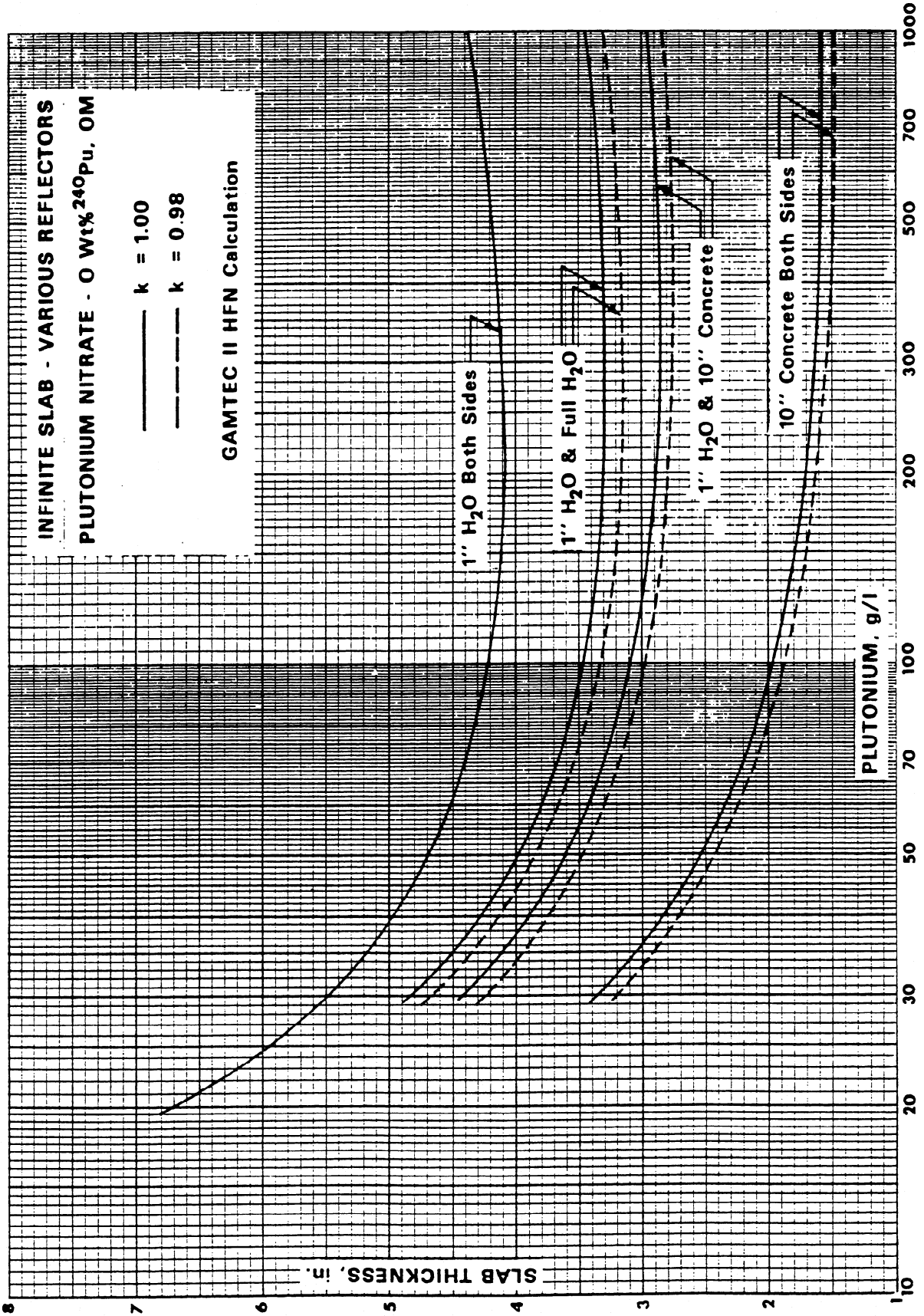


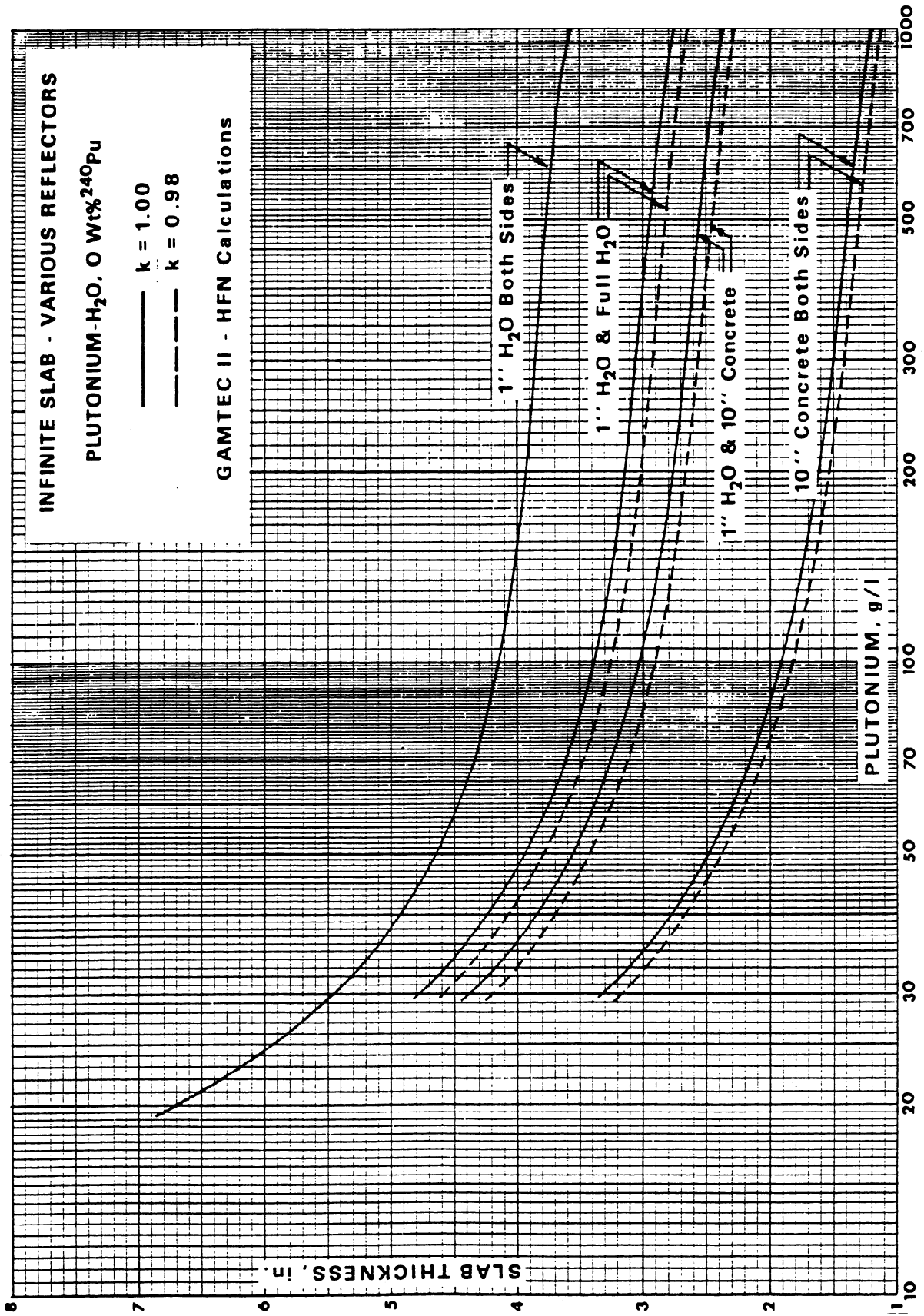


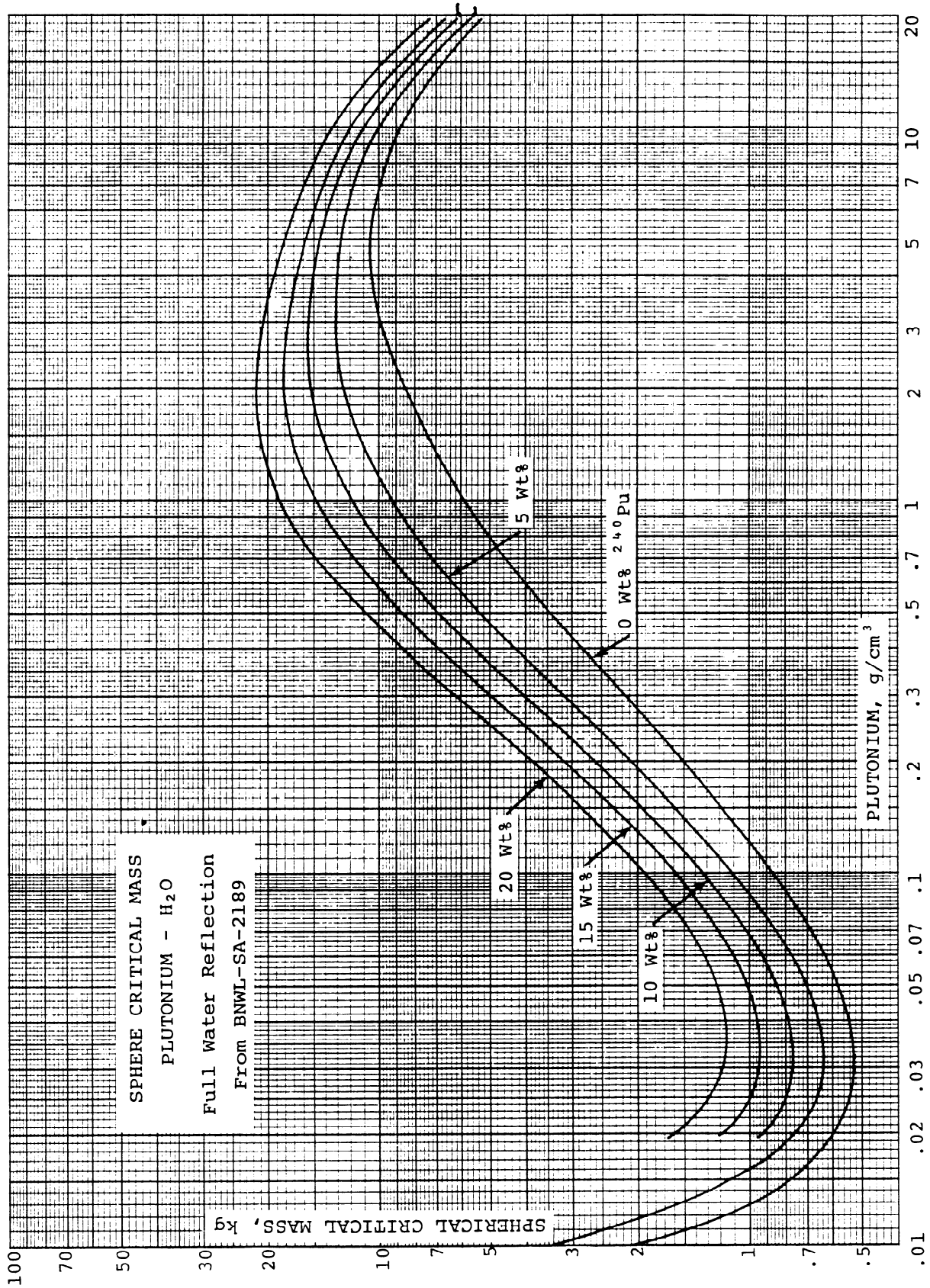




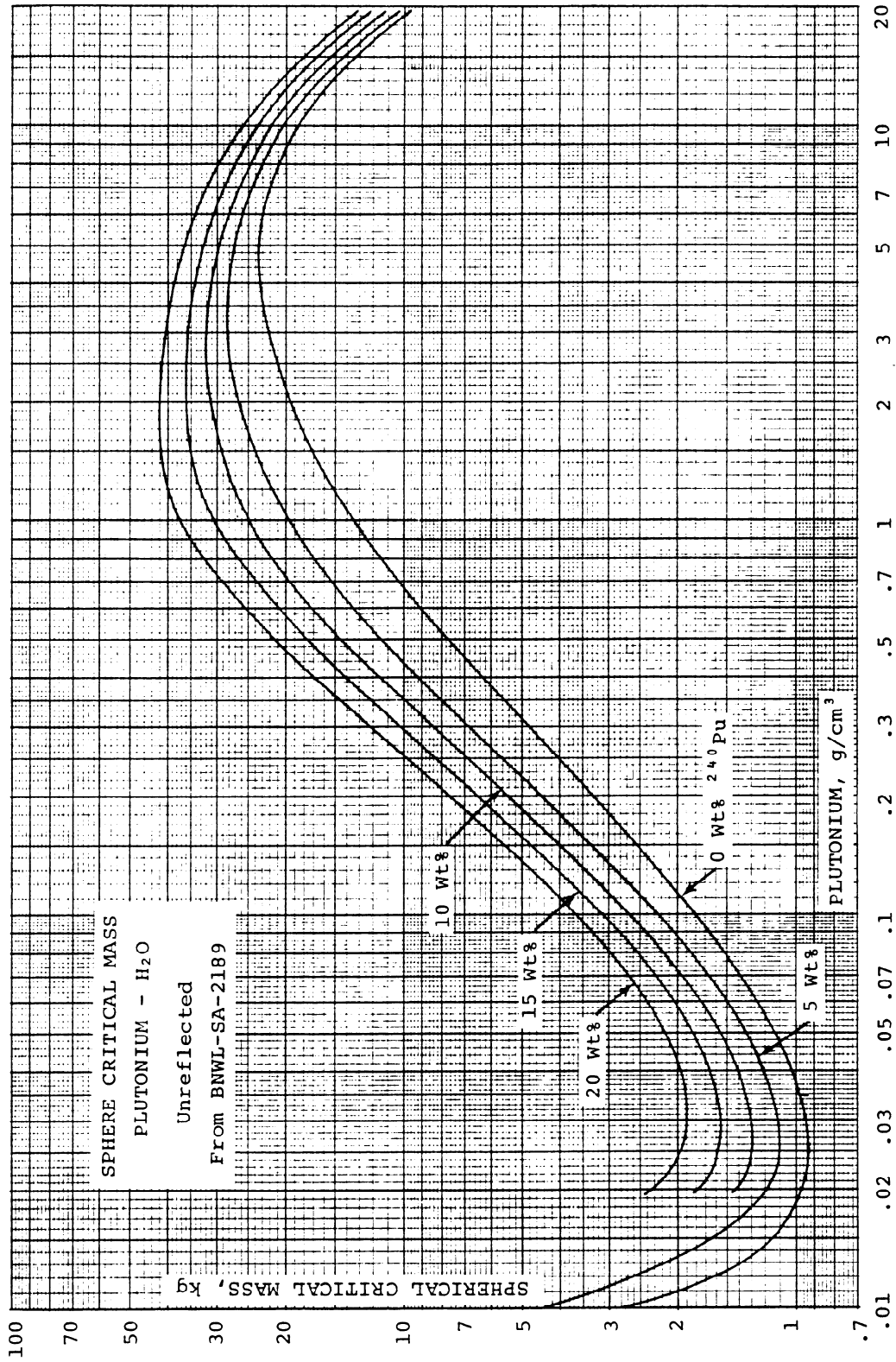


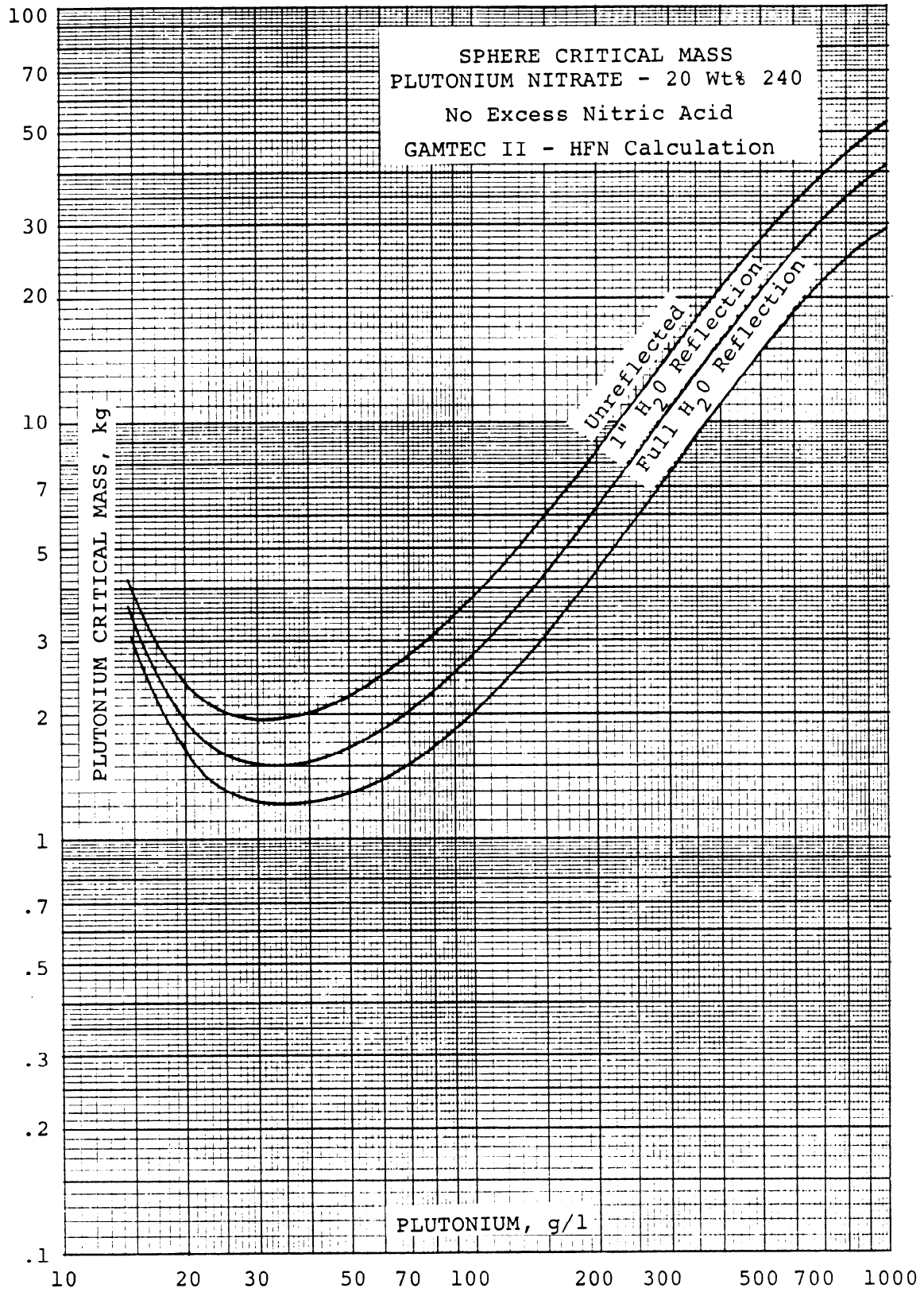


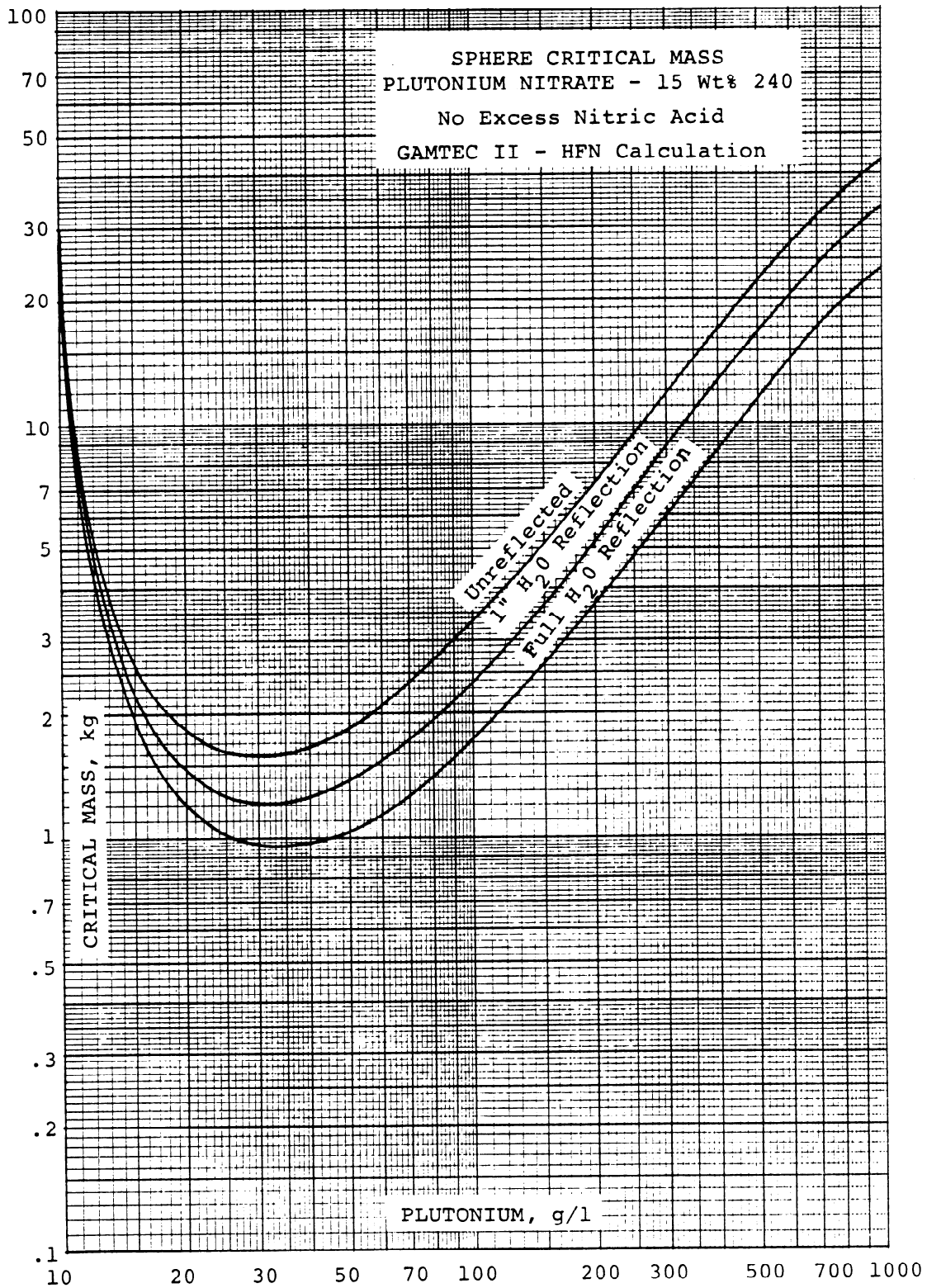


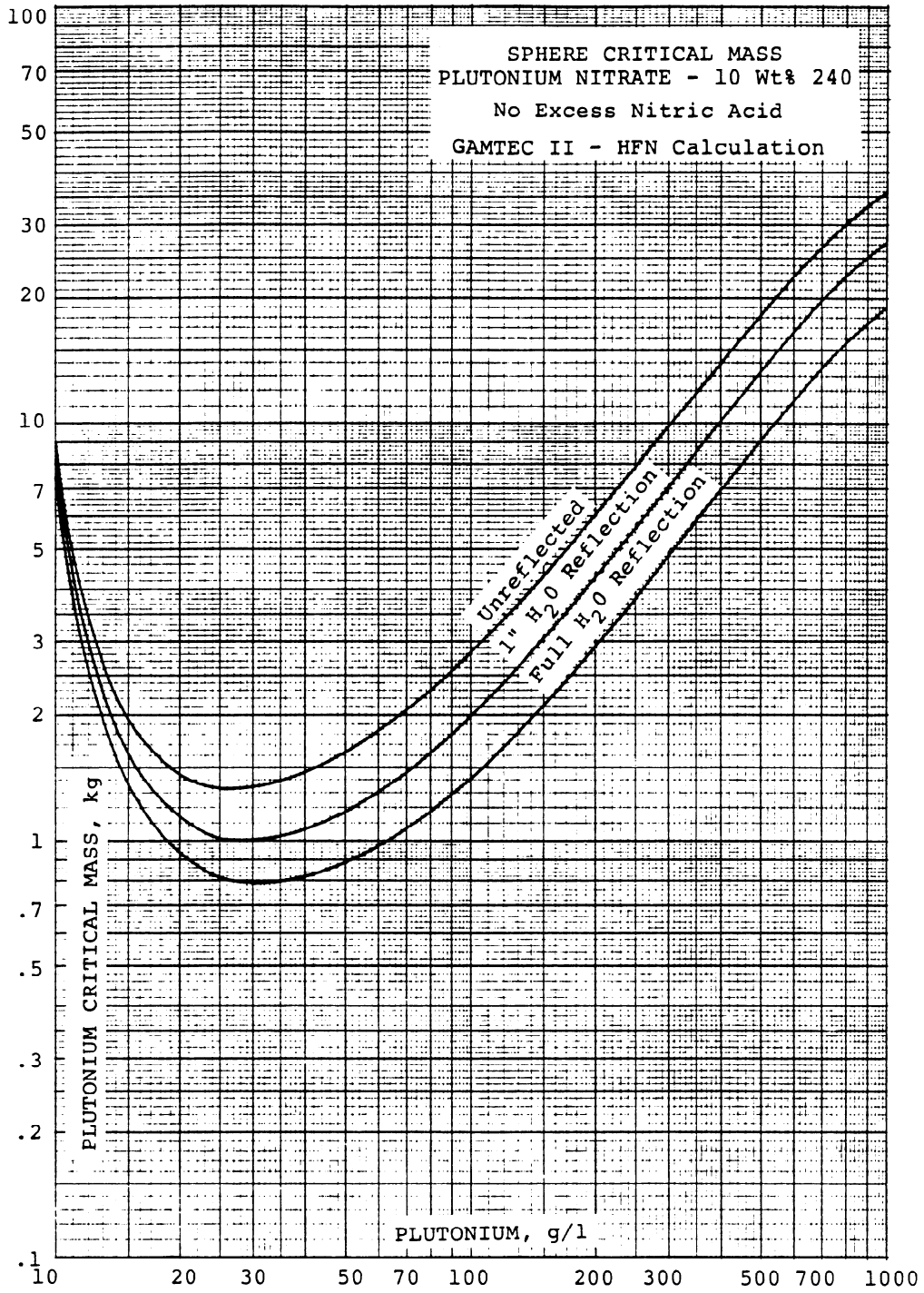


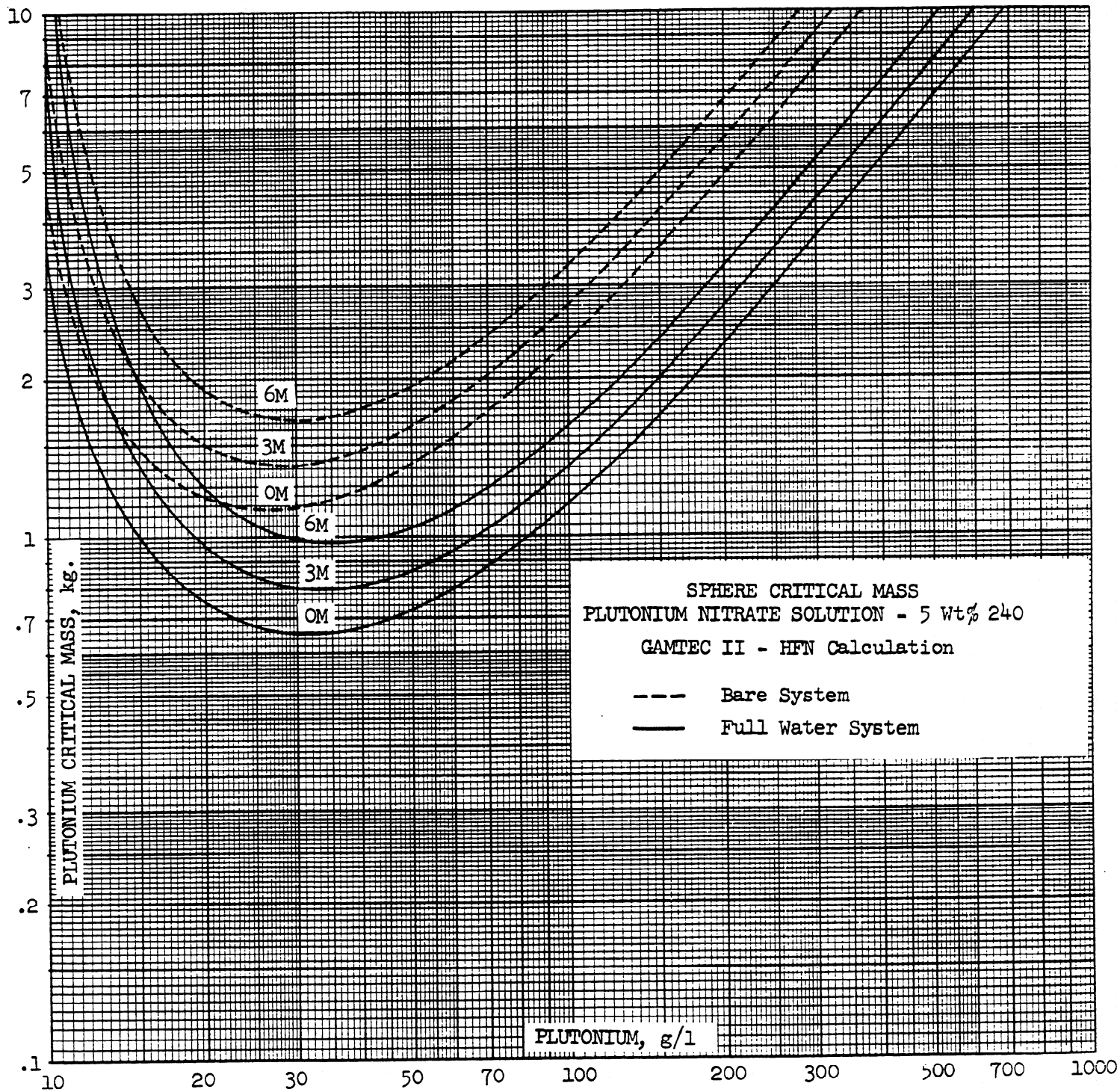


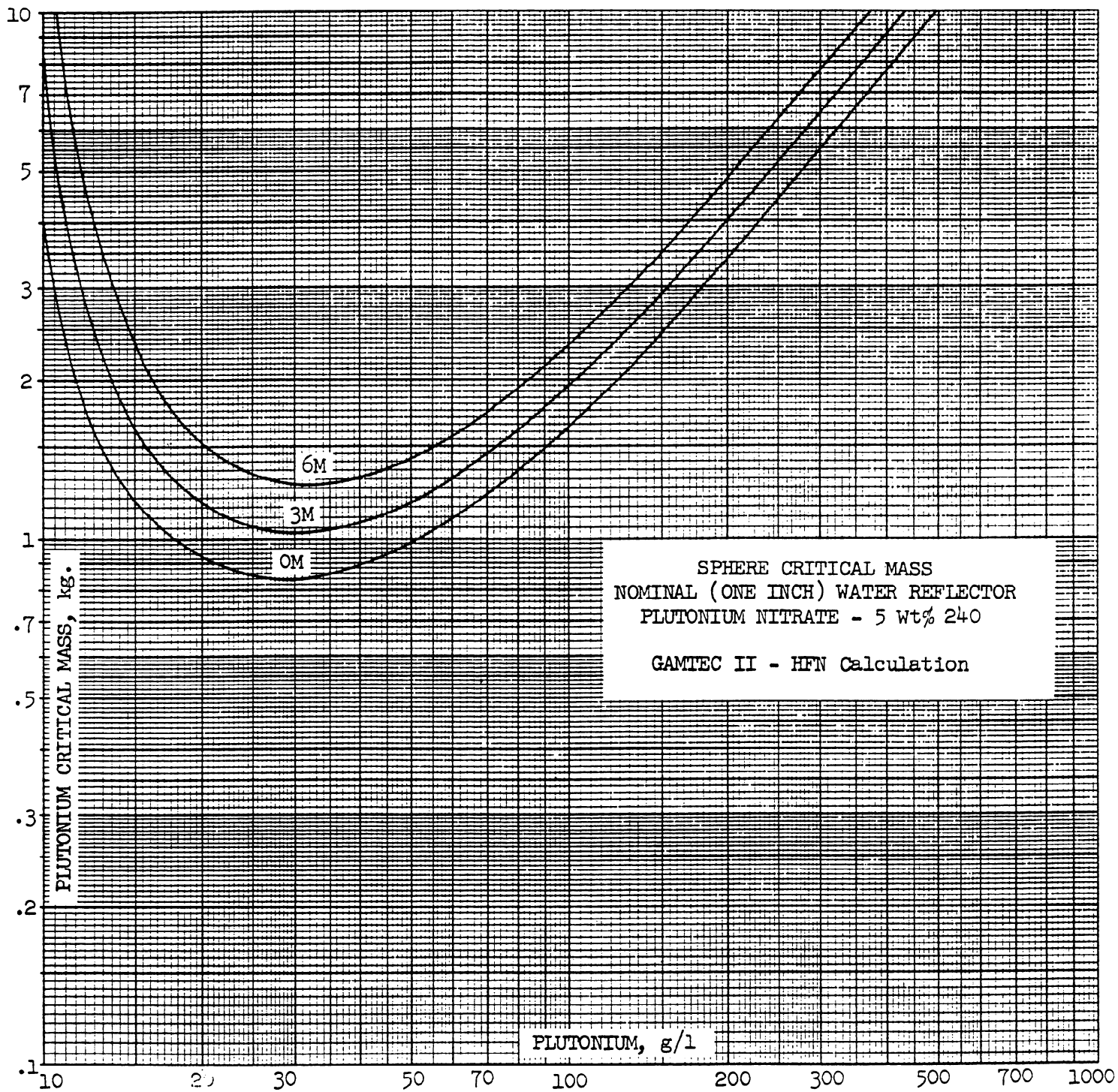


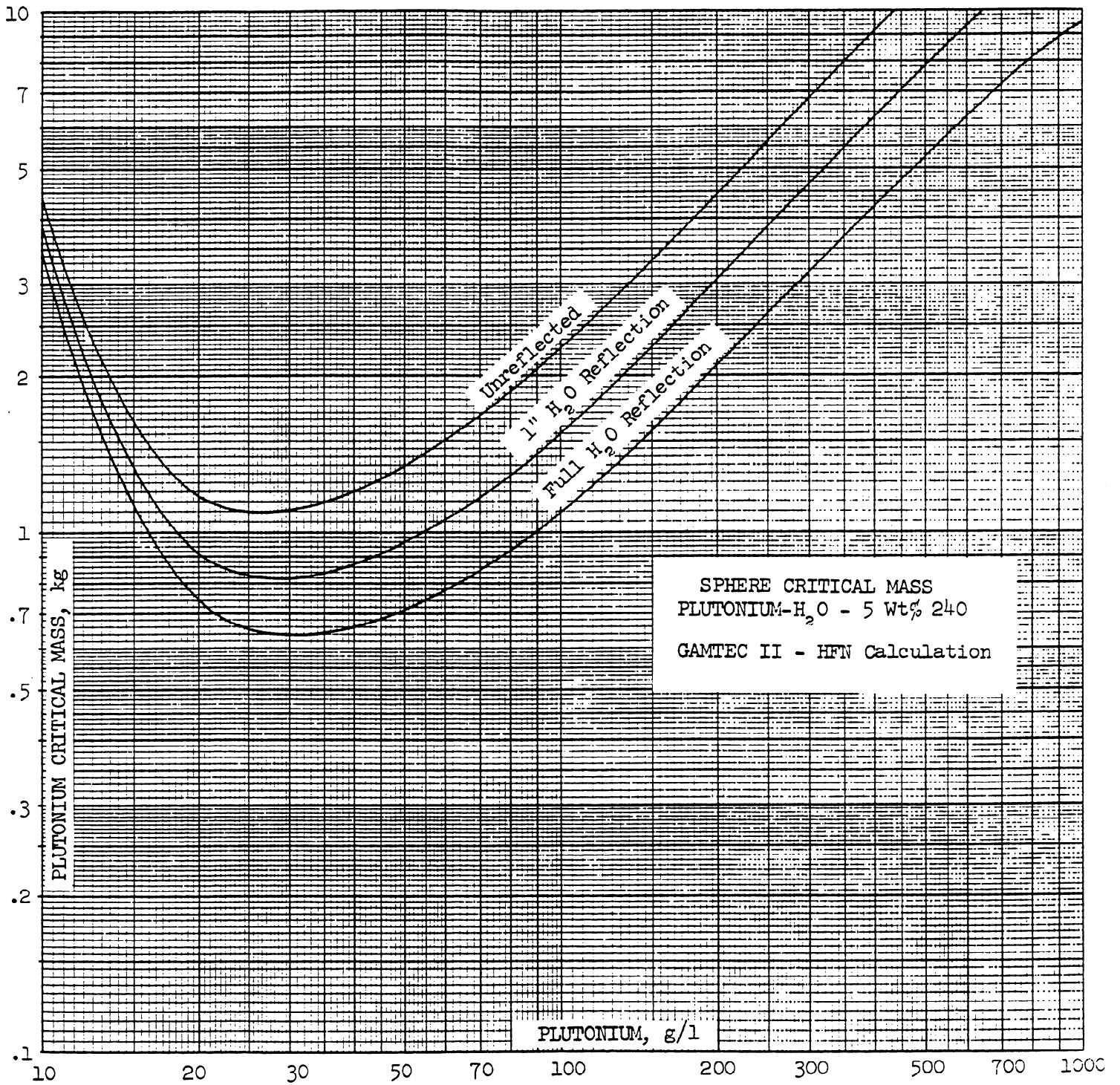


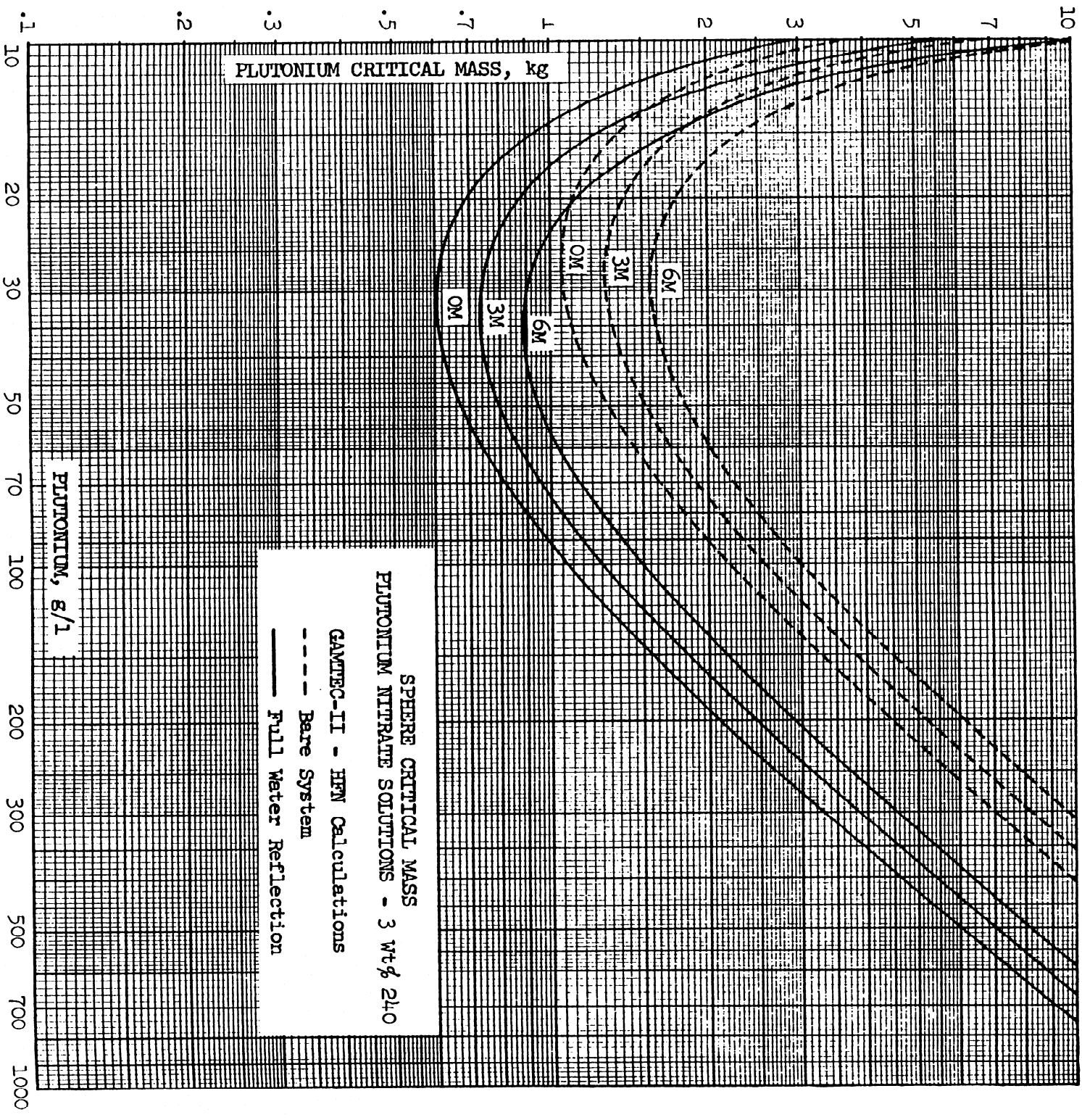




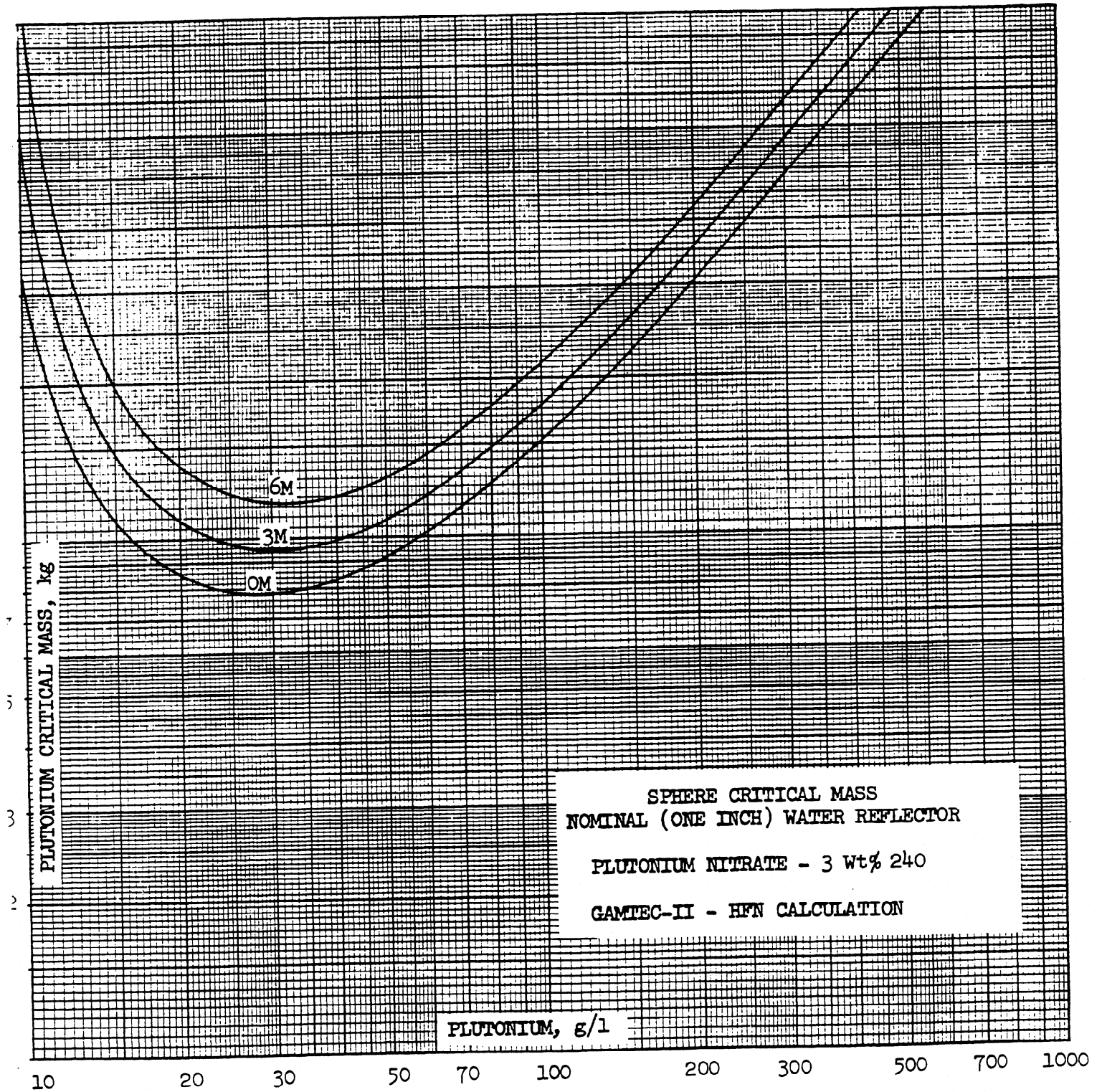


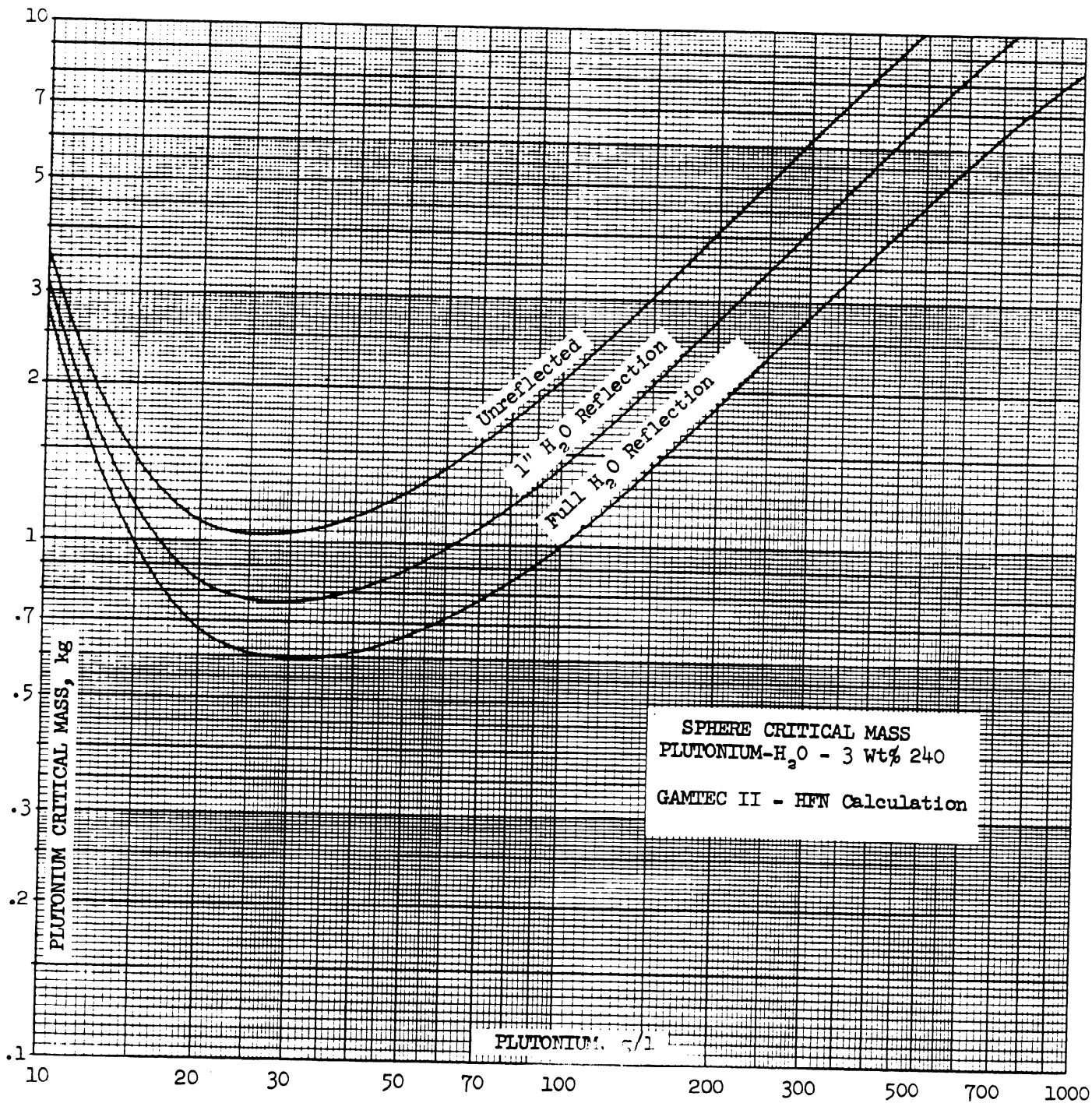


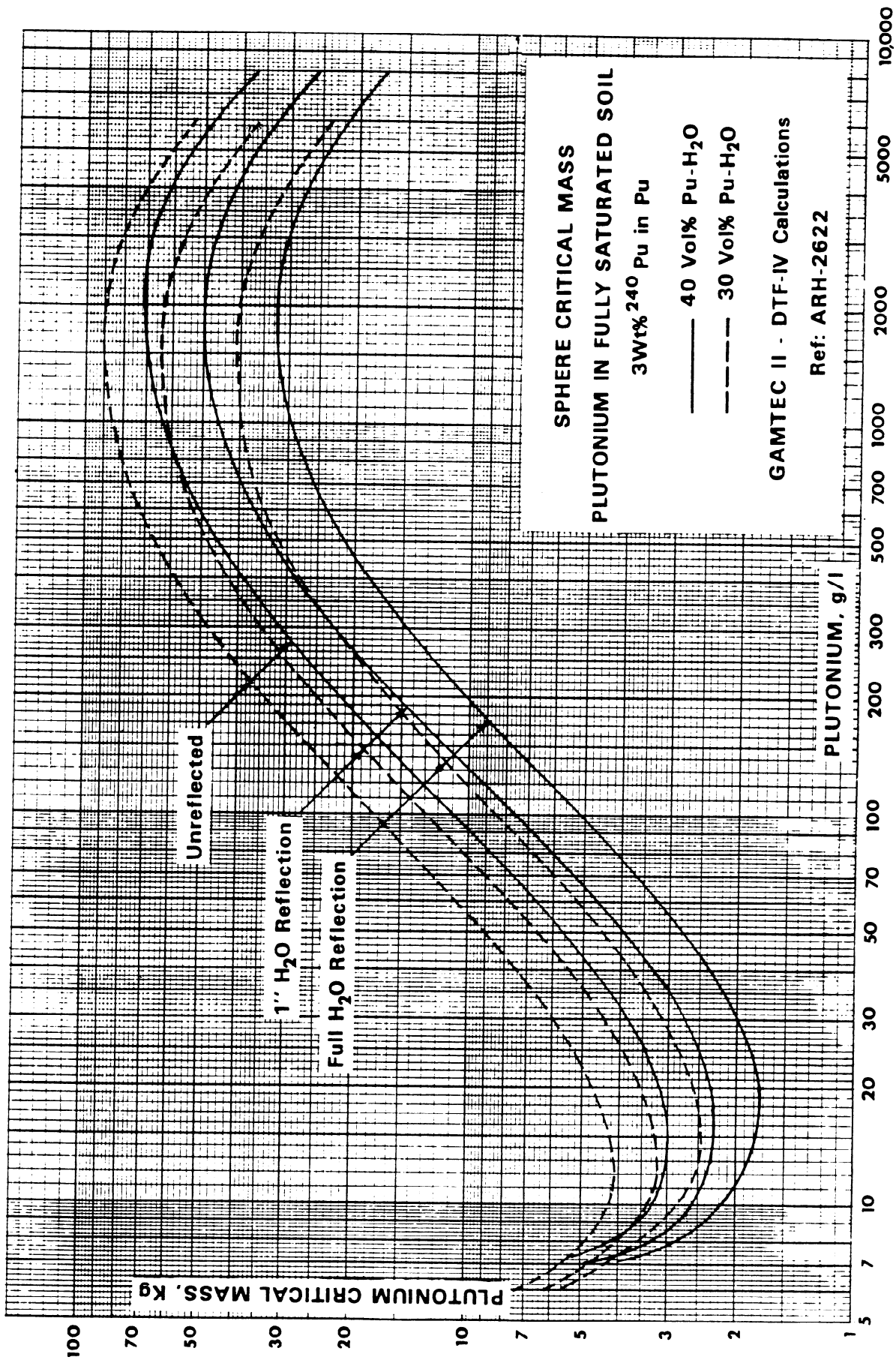












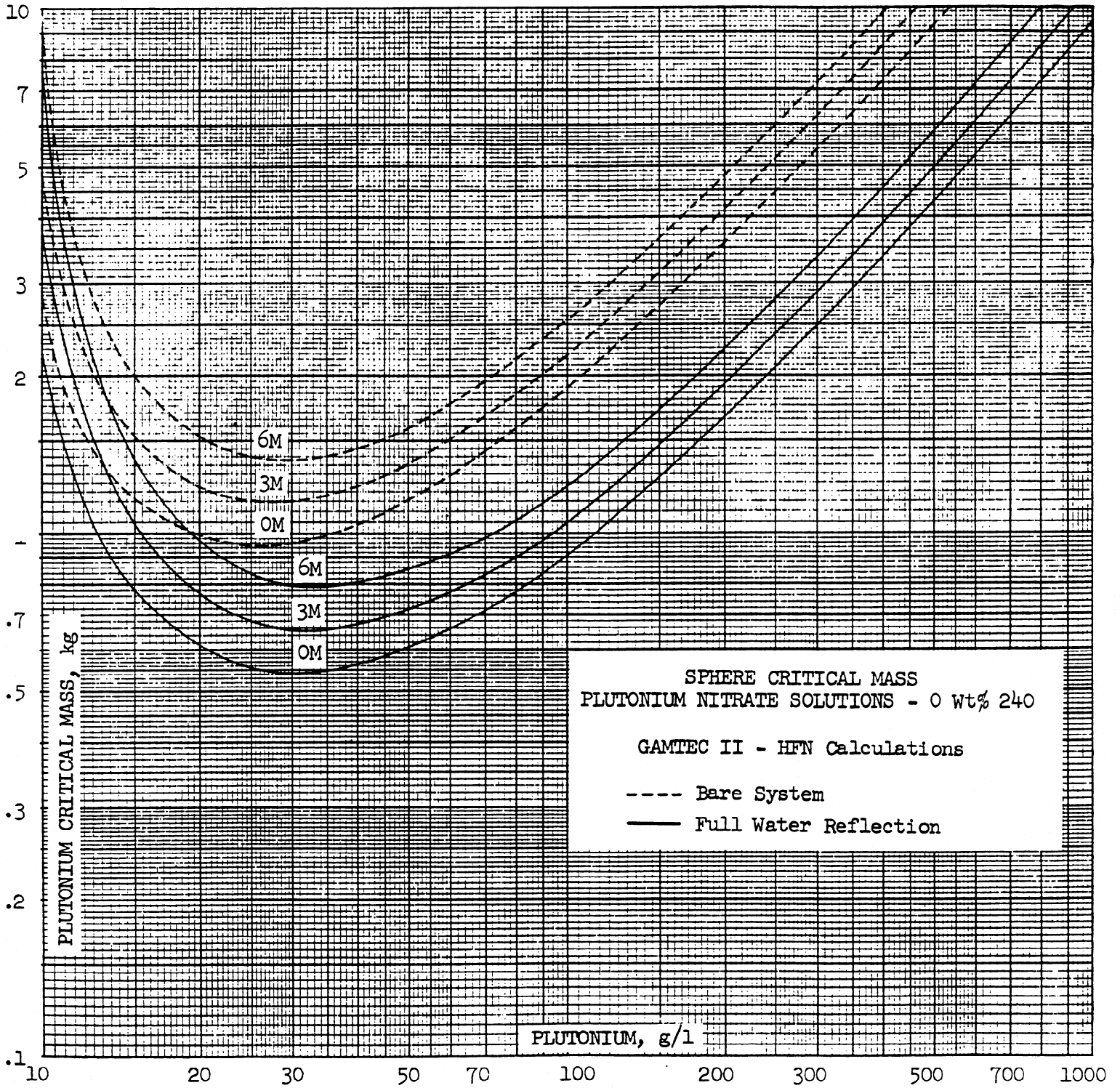
**SPHERE CRITICAL MASS  
PLUTONIUM IN FULLY SATURATED SOIL**

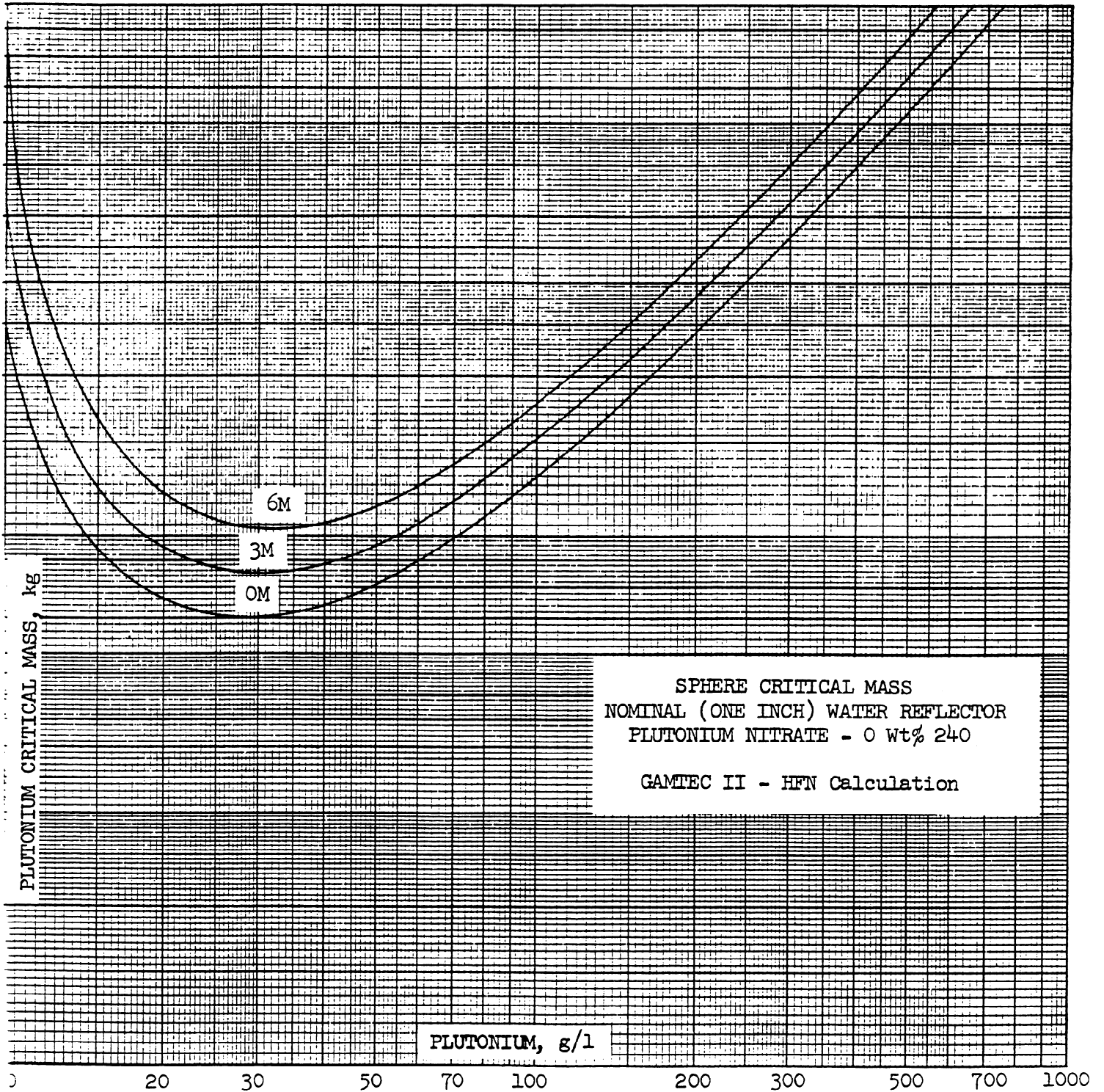
3Wt% <sup>240</sup>Pu in Pu

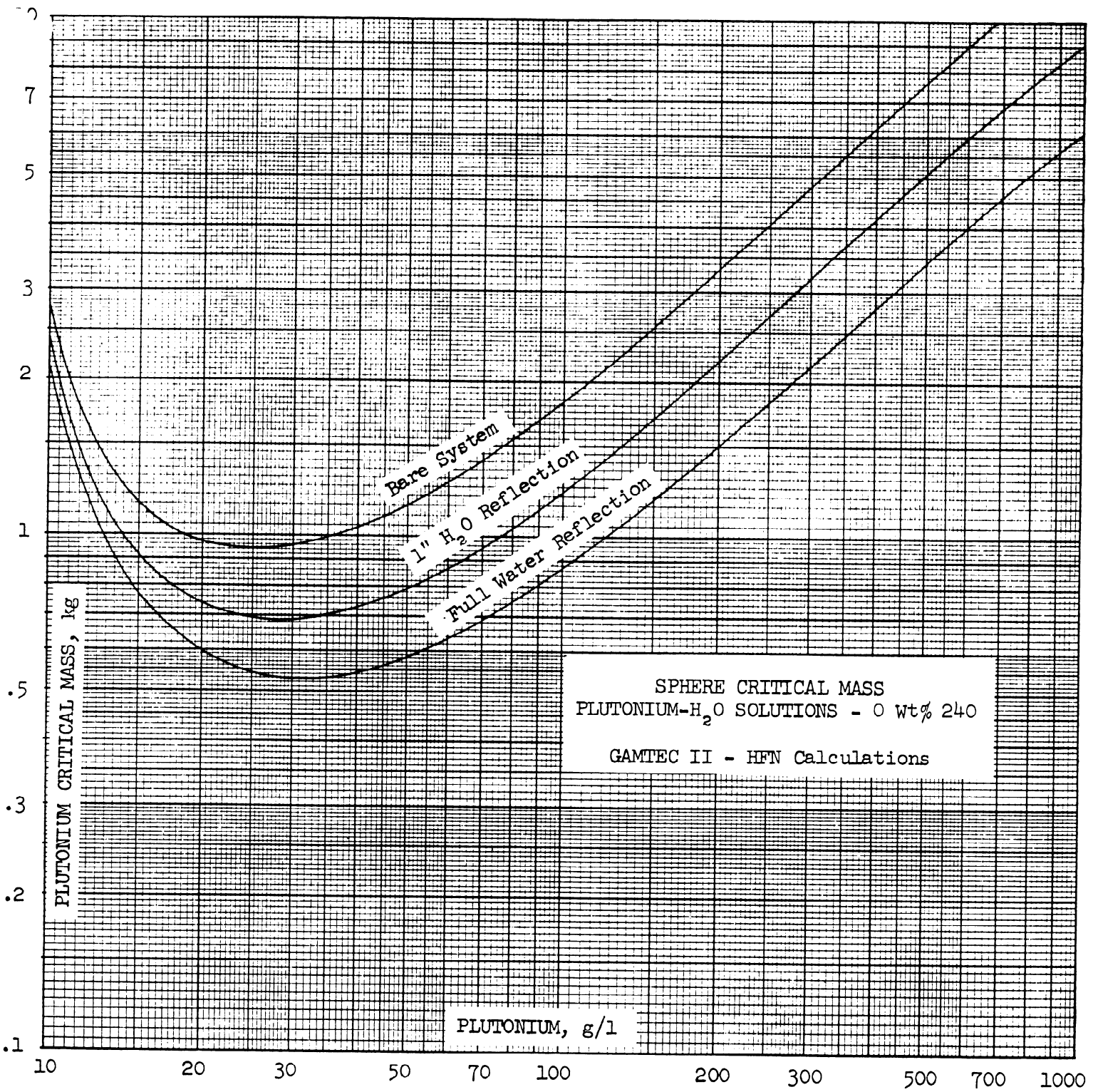
- 40 Vol% Pu-H<sub>2</sub>O
- - - 30 Vol% Pu-H<sub>2</sub>O

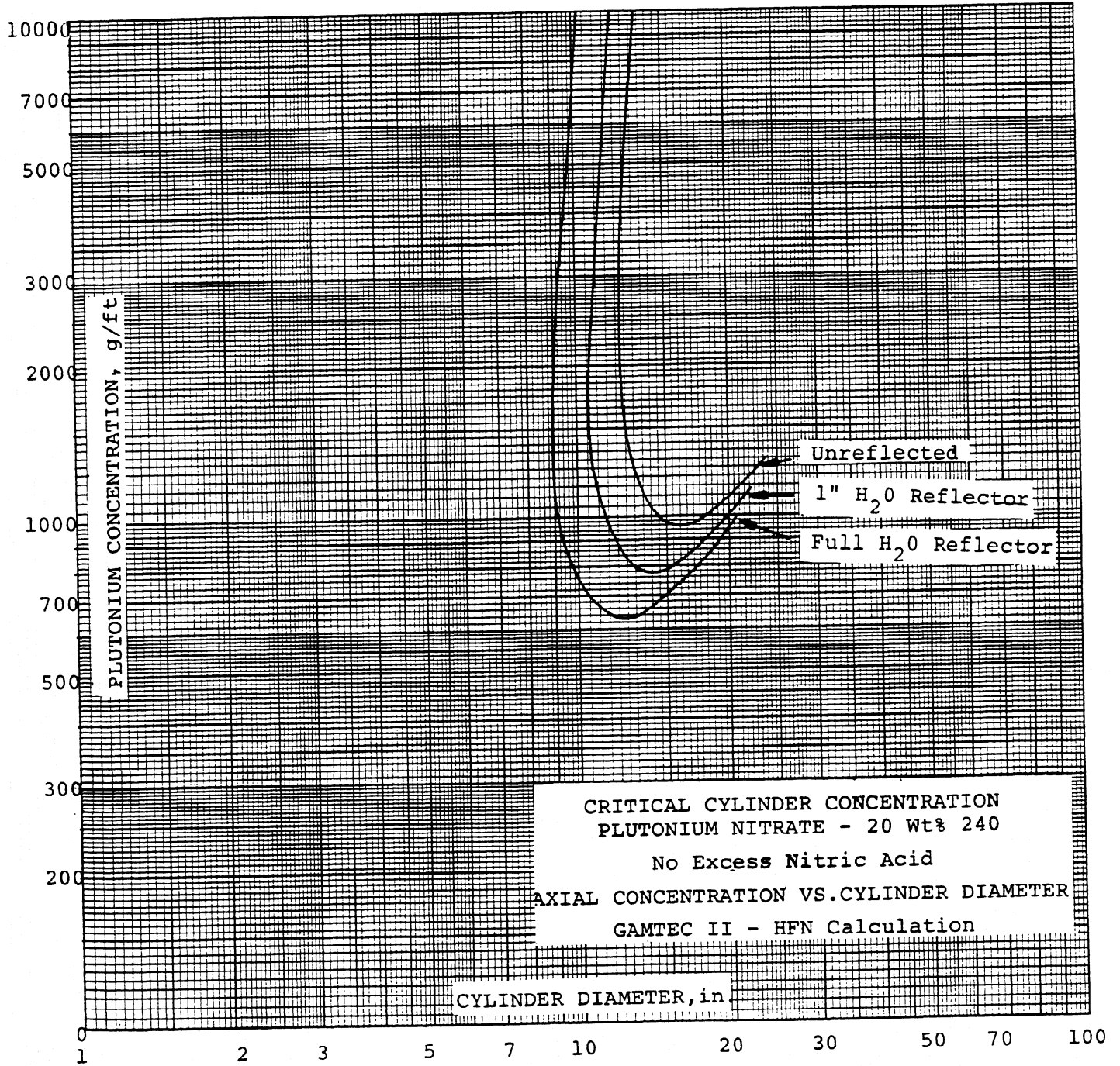
GAMTEC II - DTF-IV Calculations

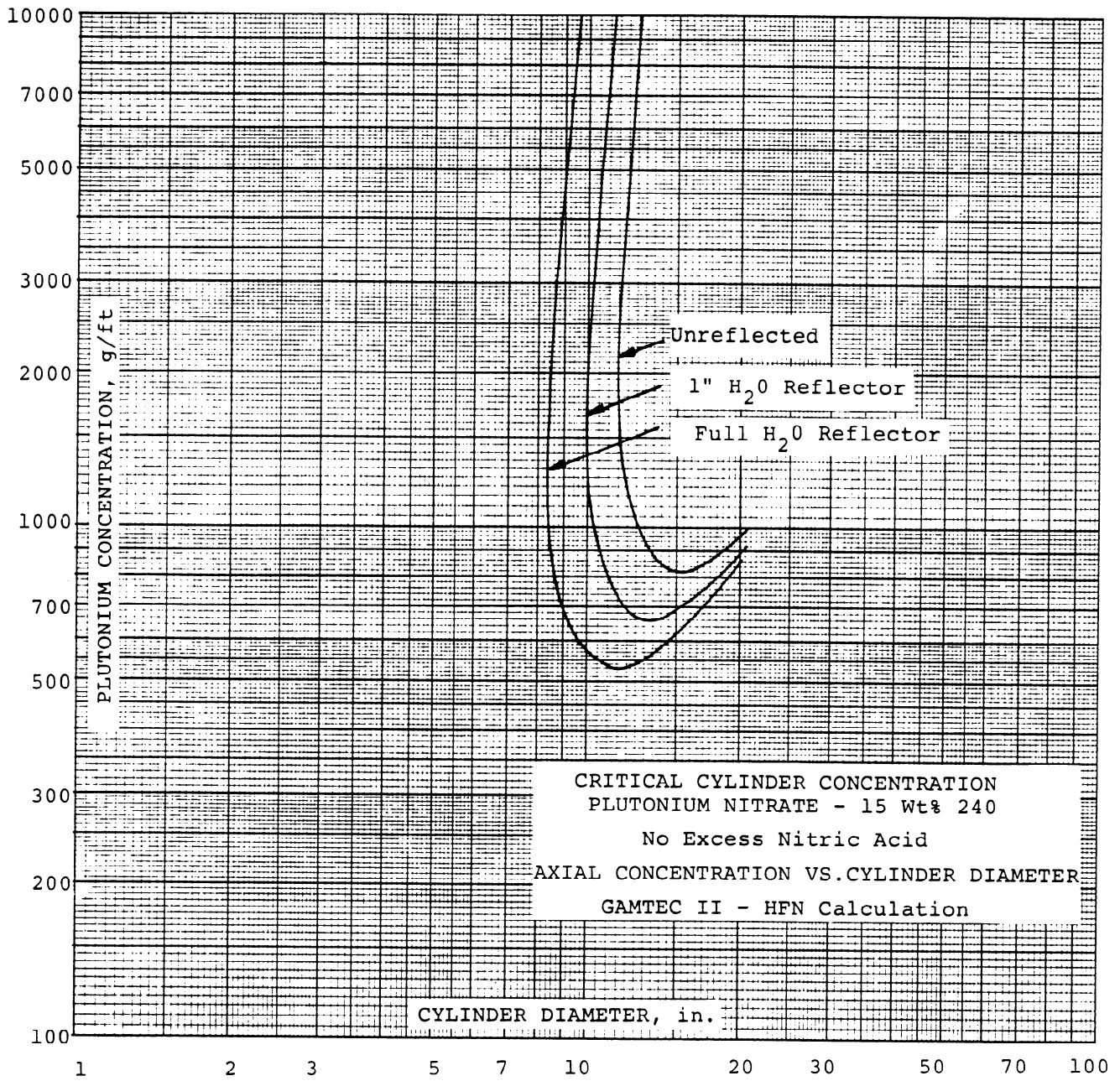
Ref: ARH-2622



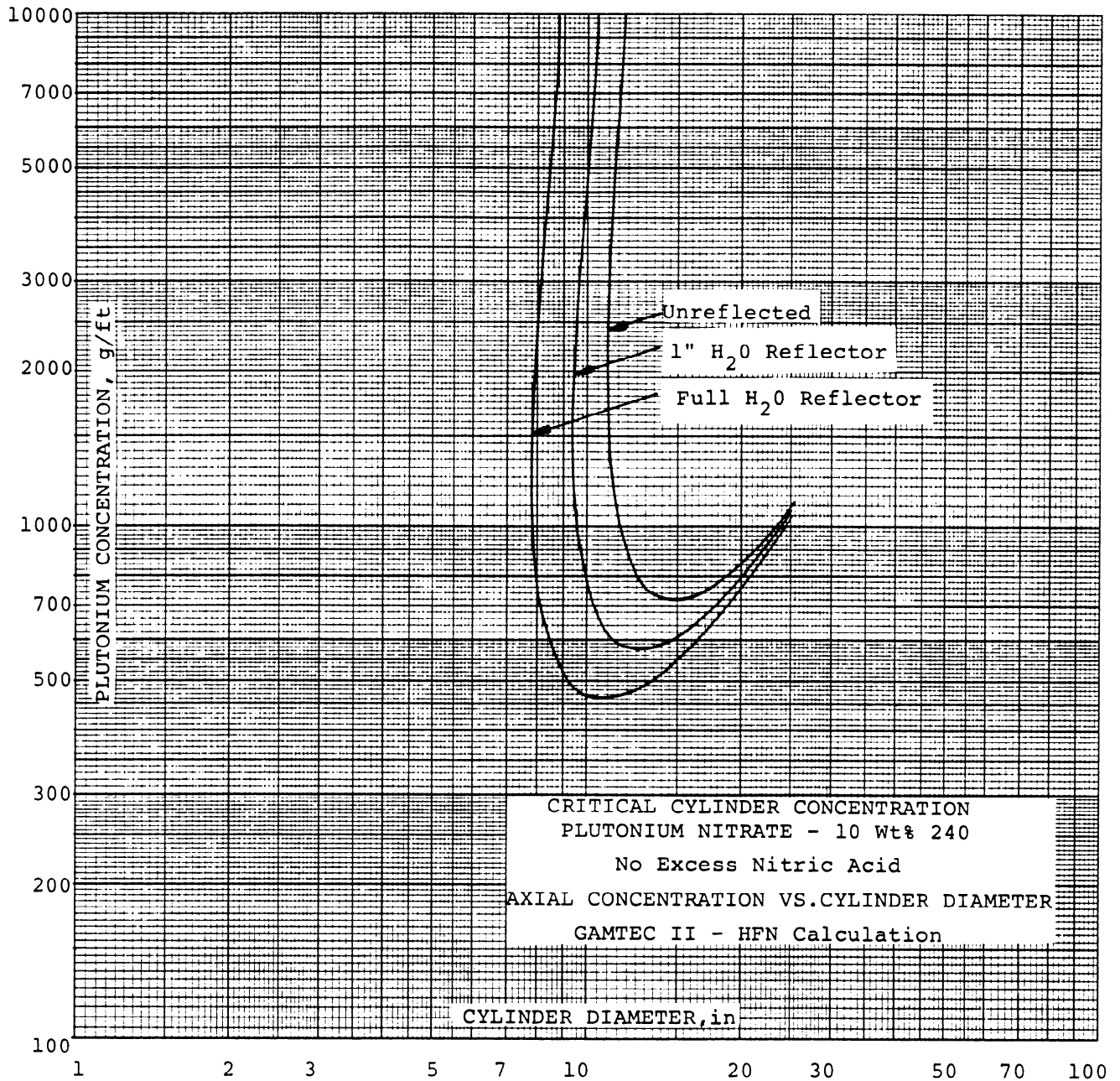


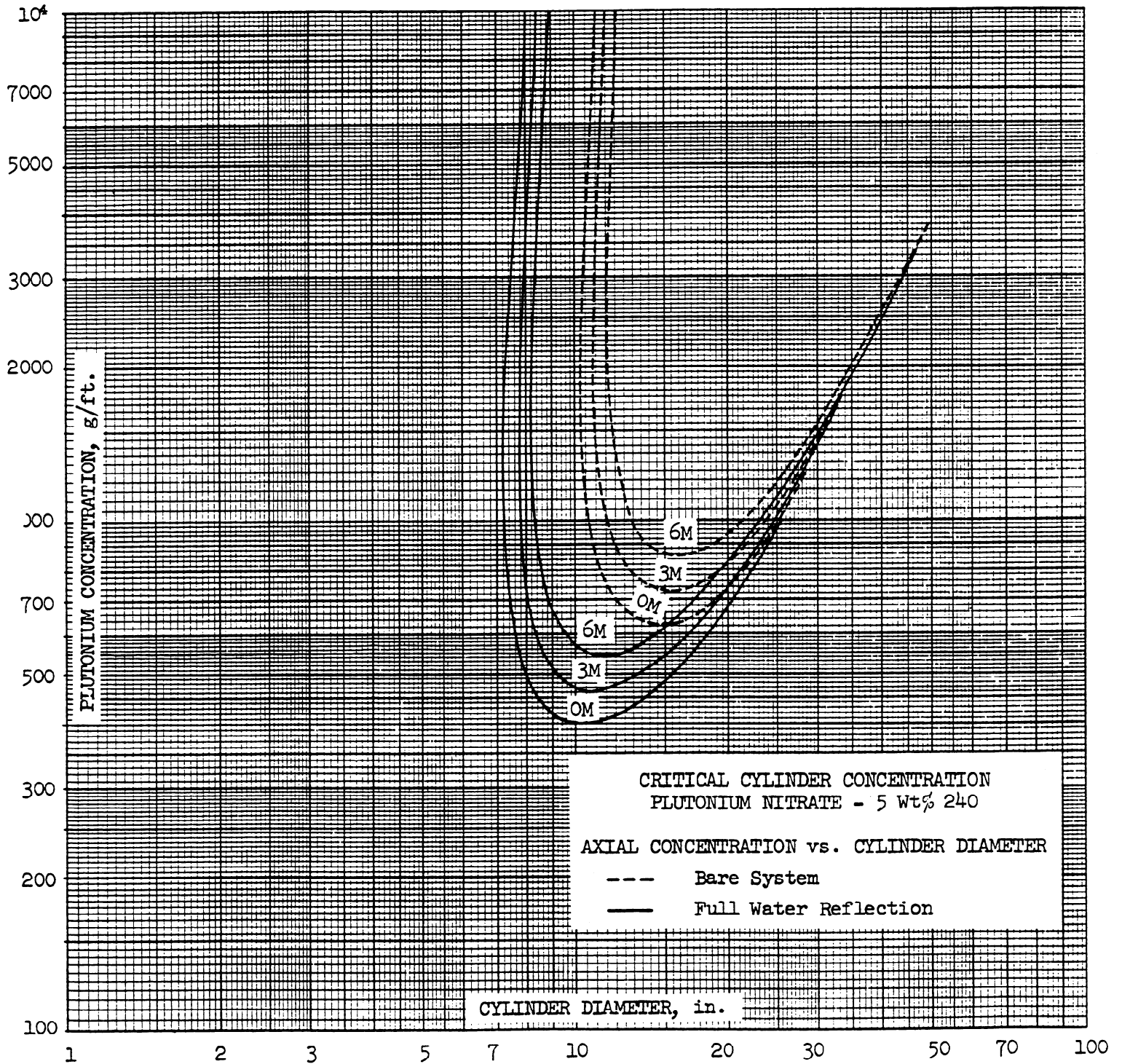


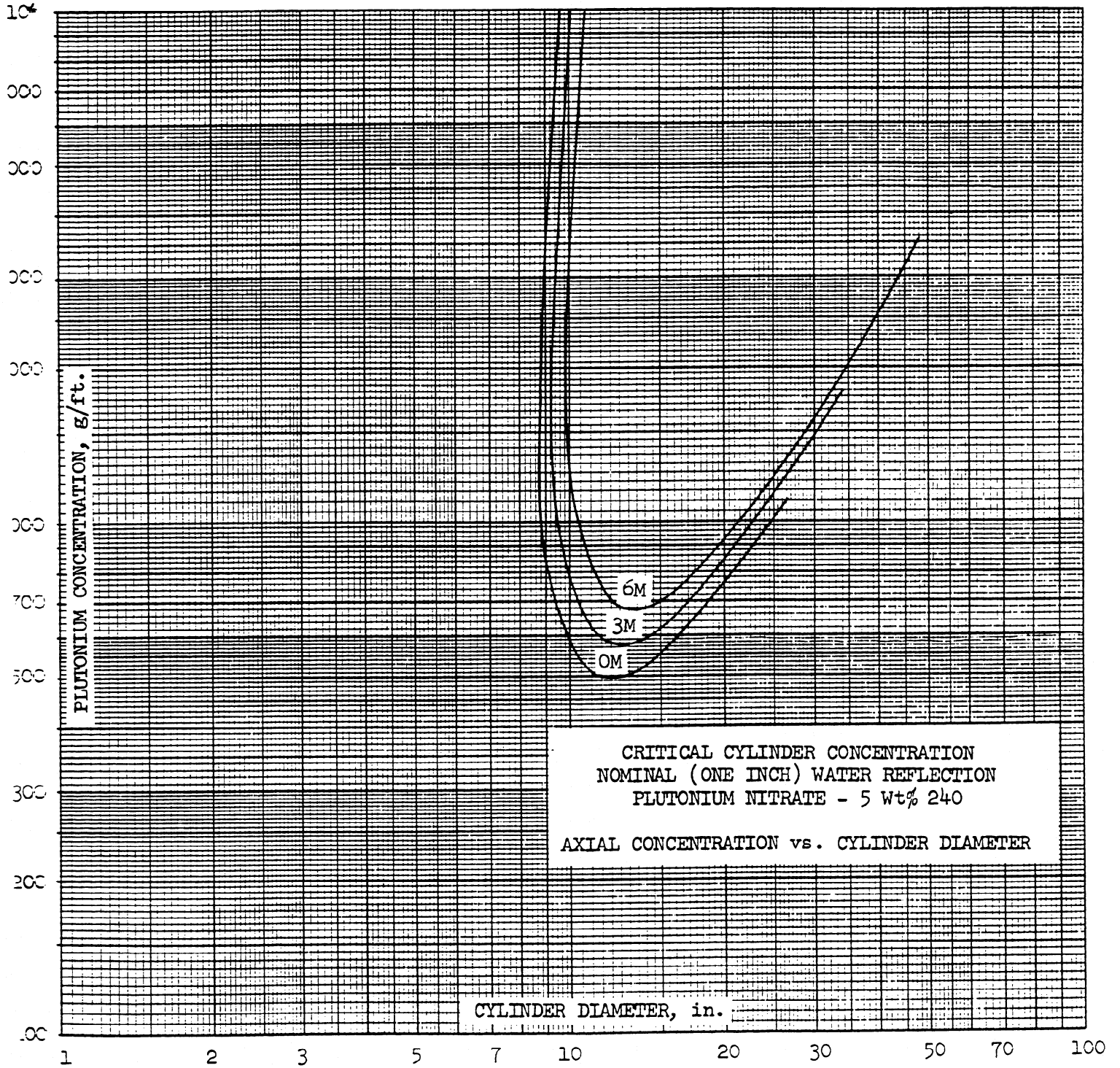


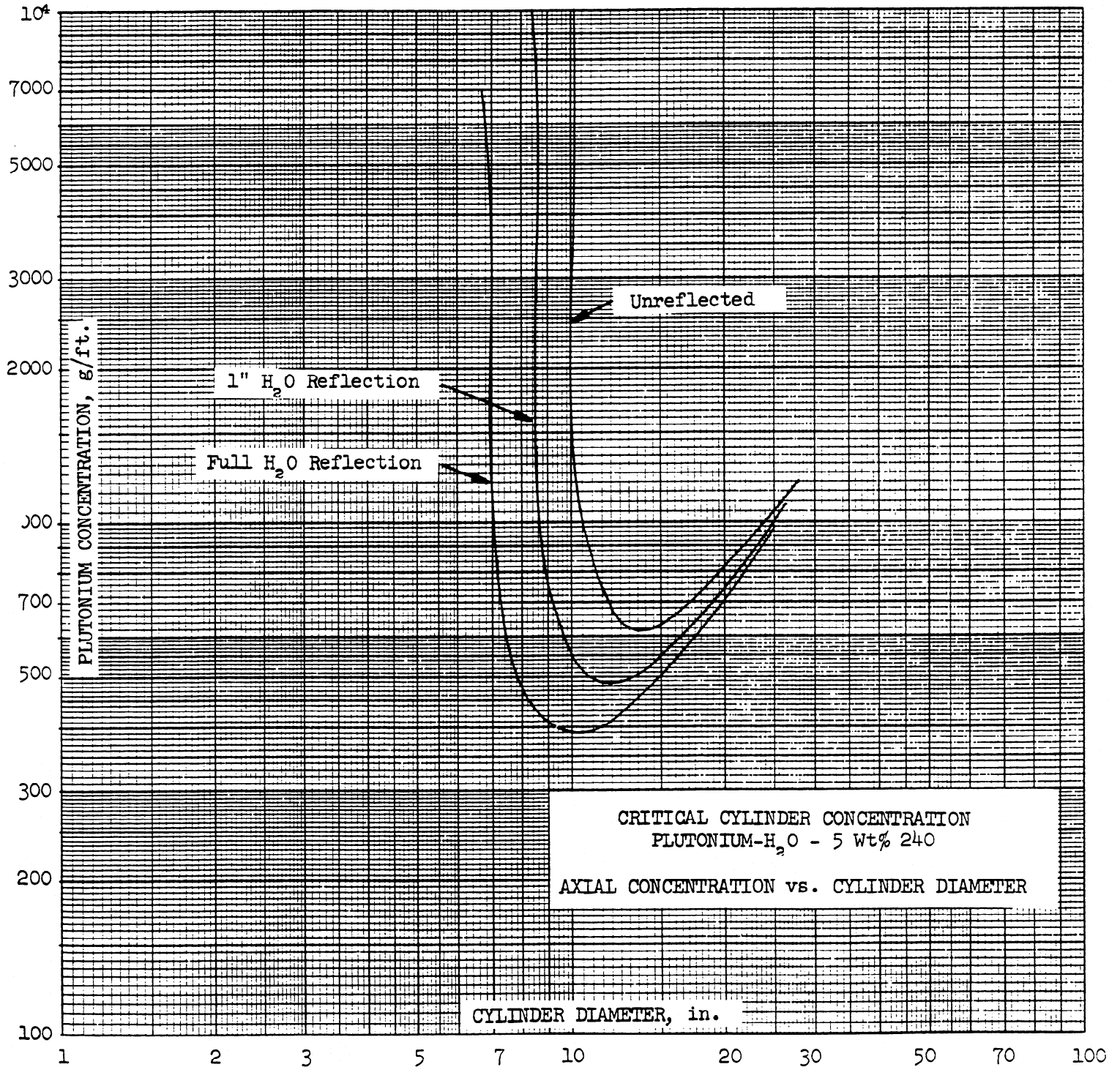


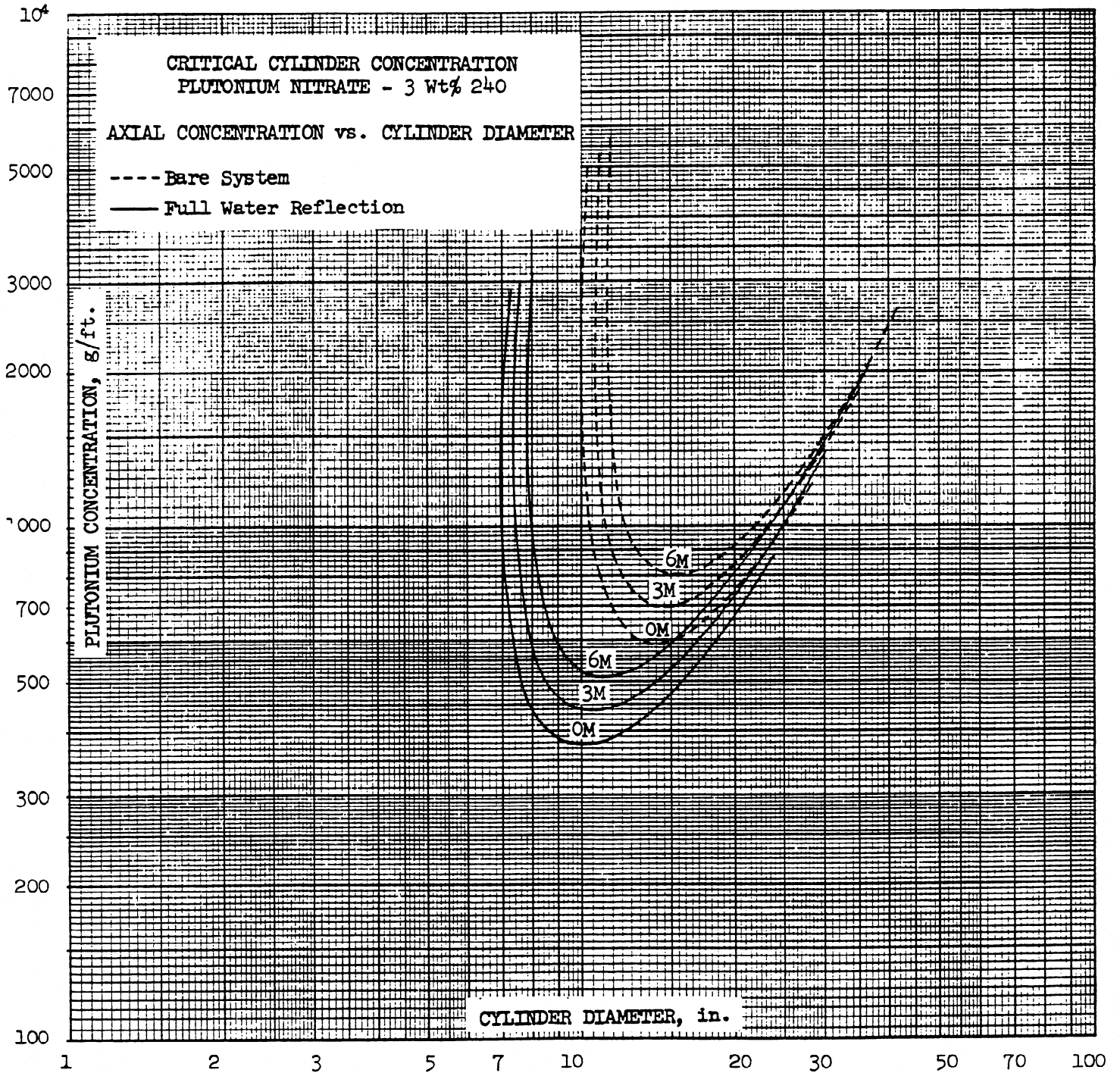


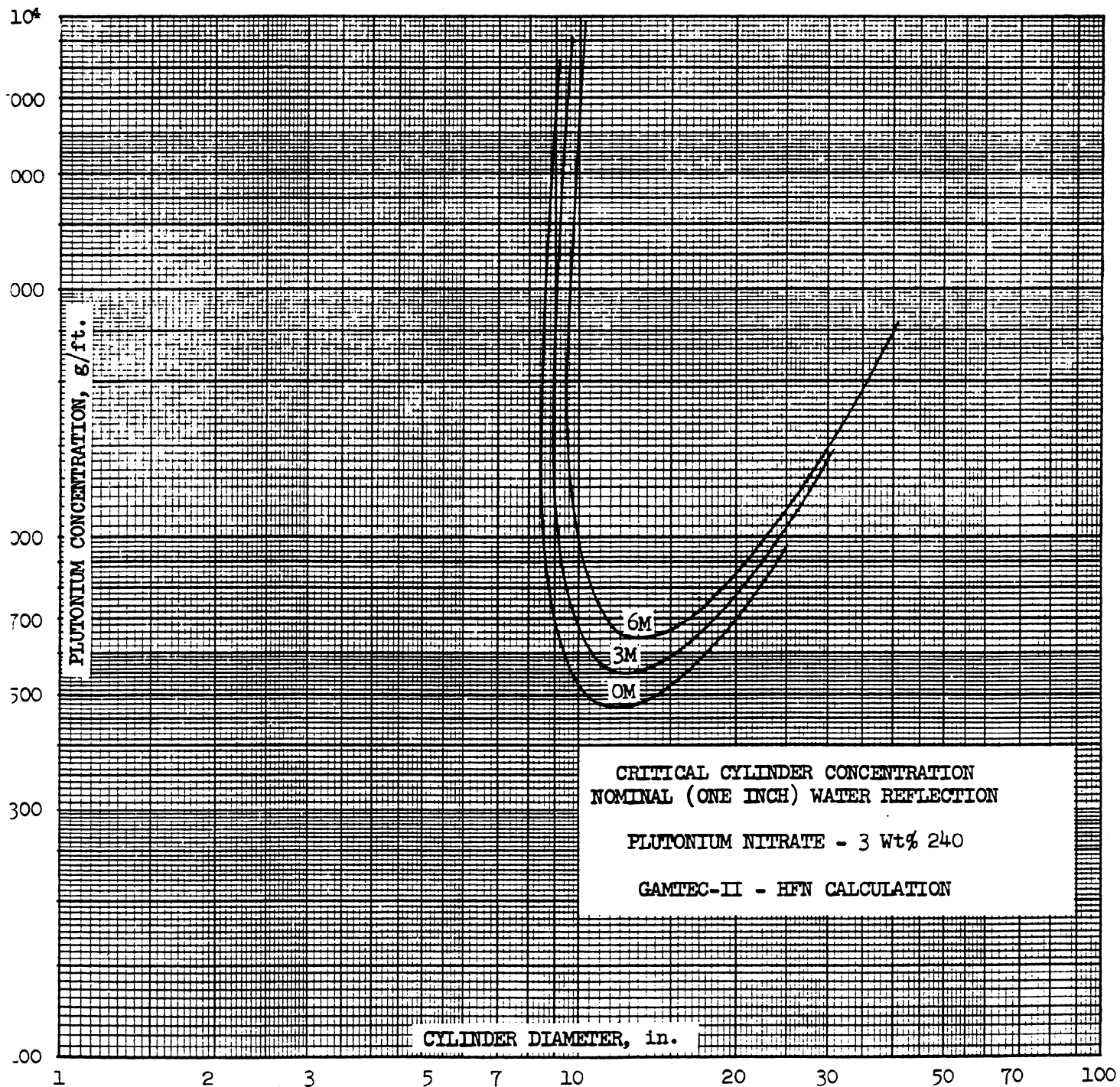


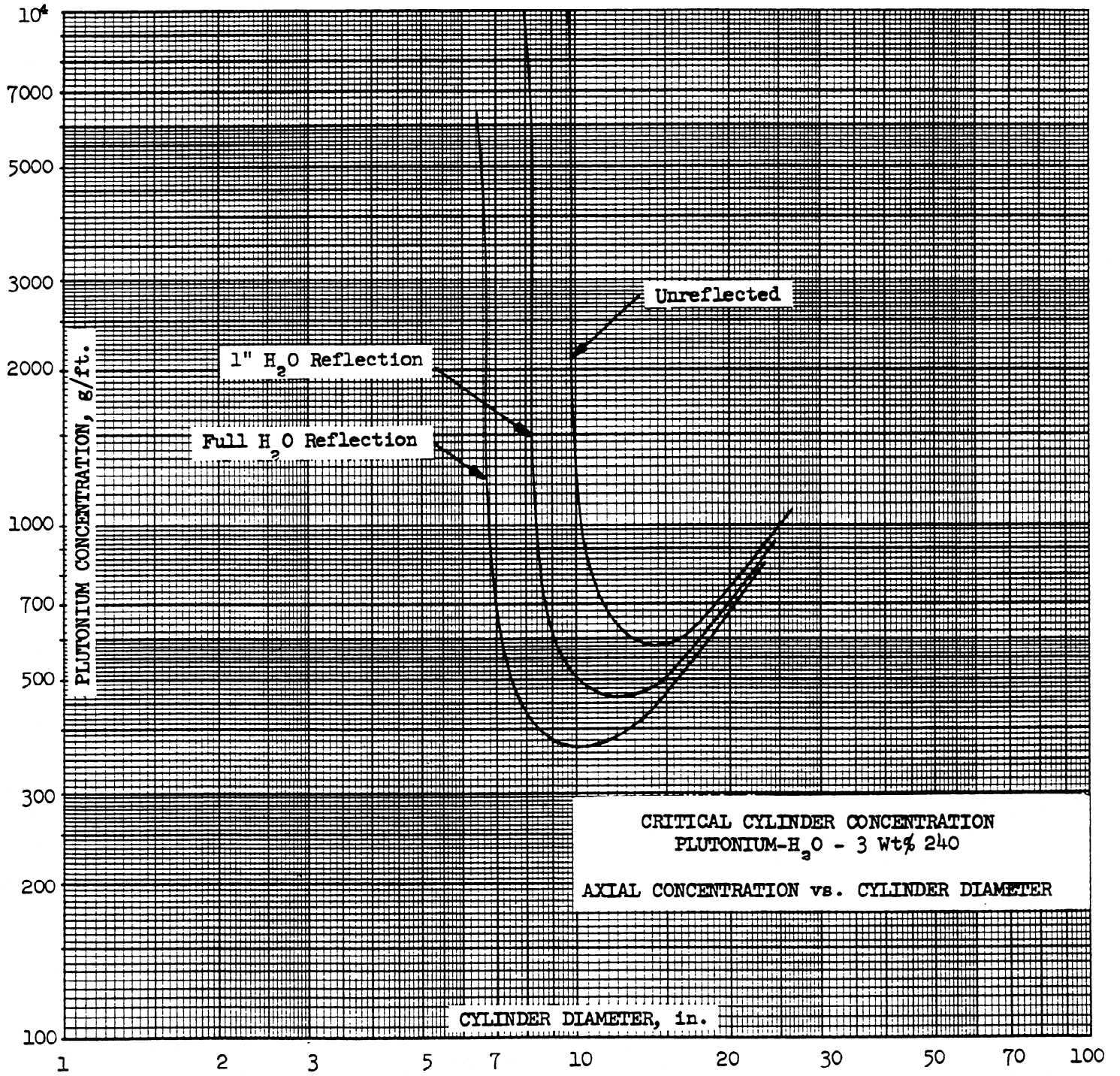




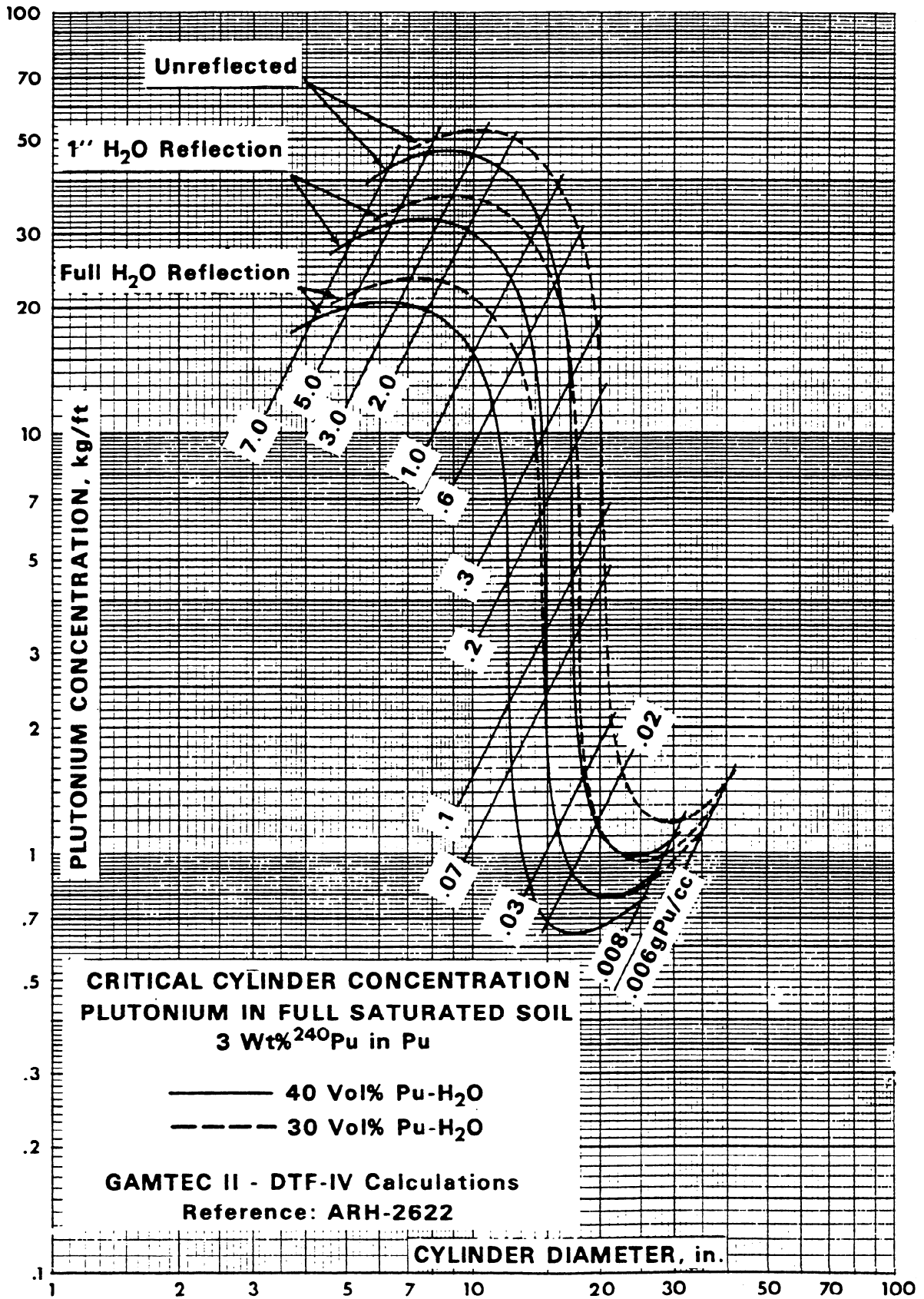




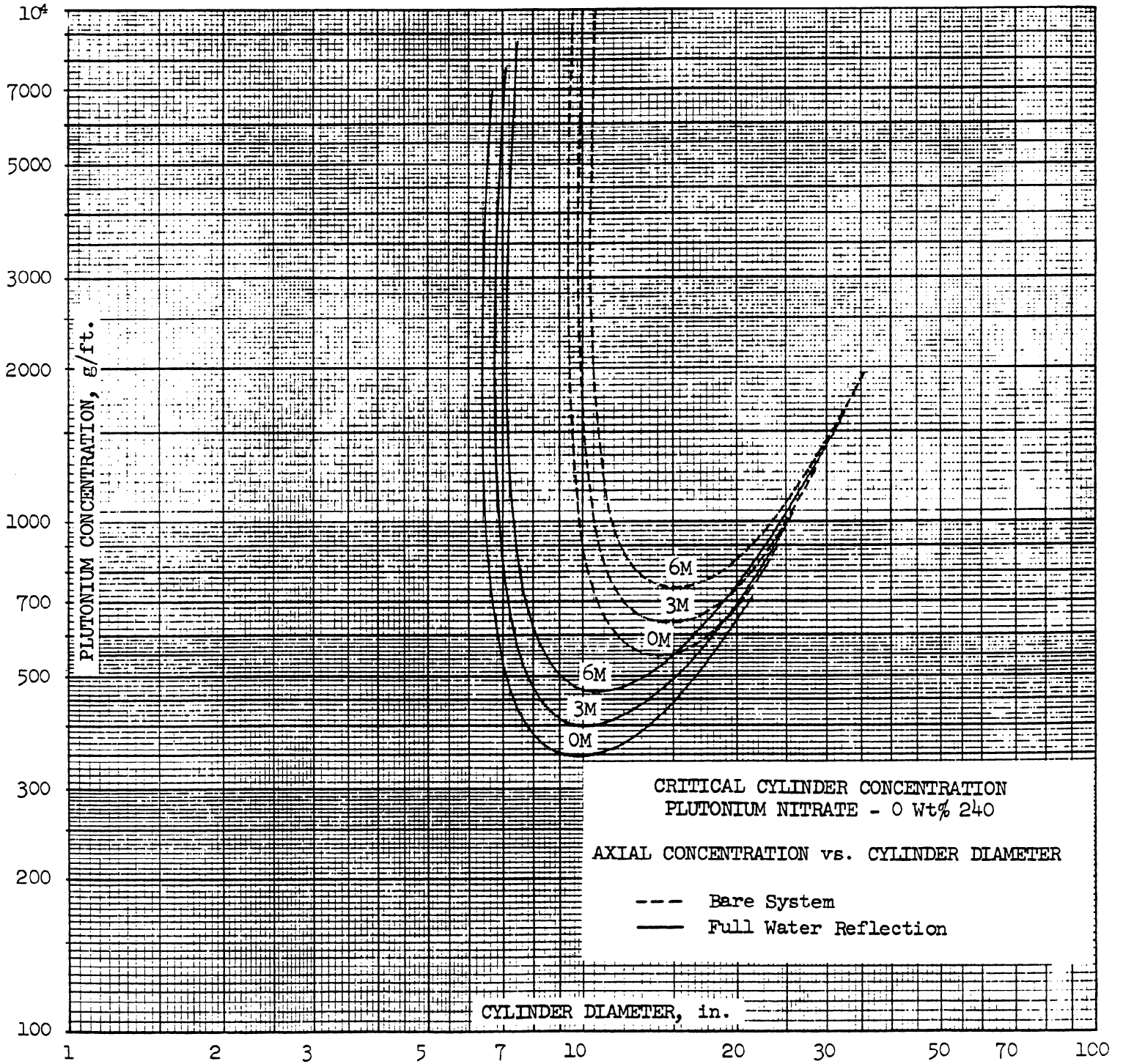


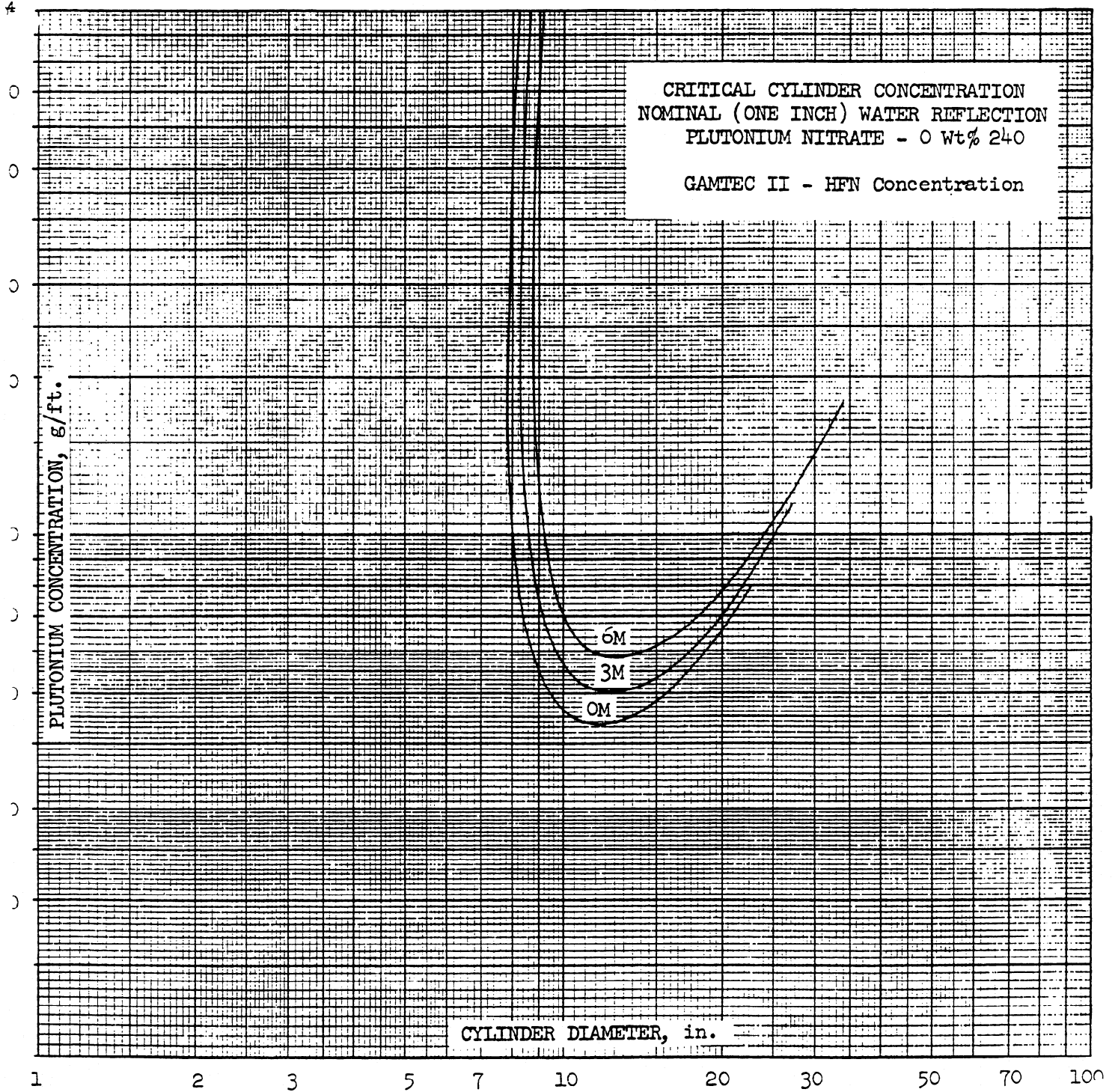


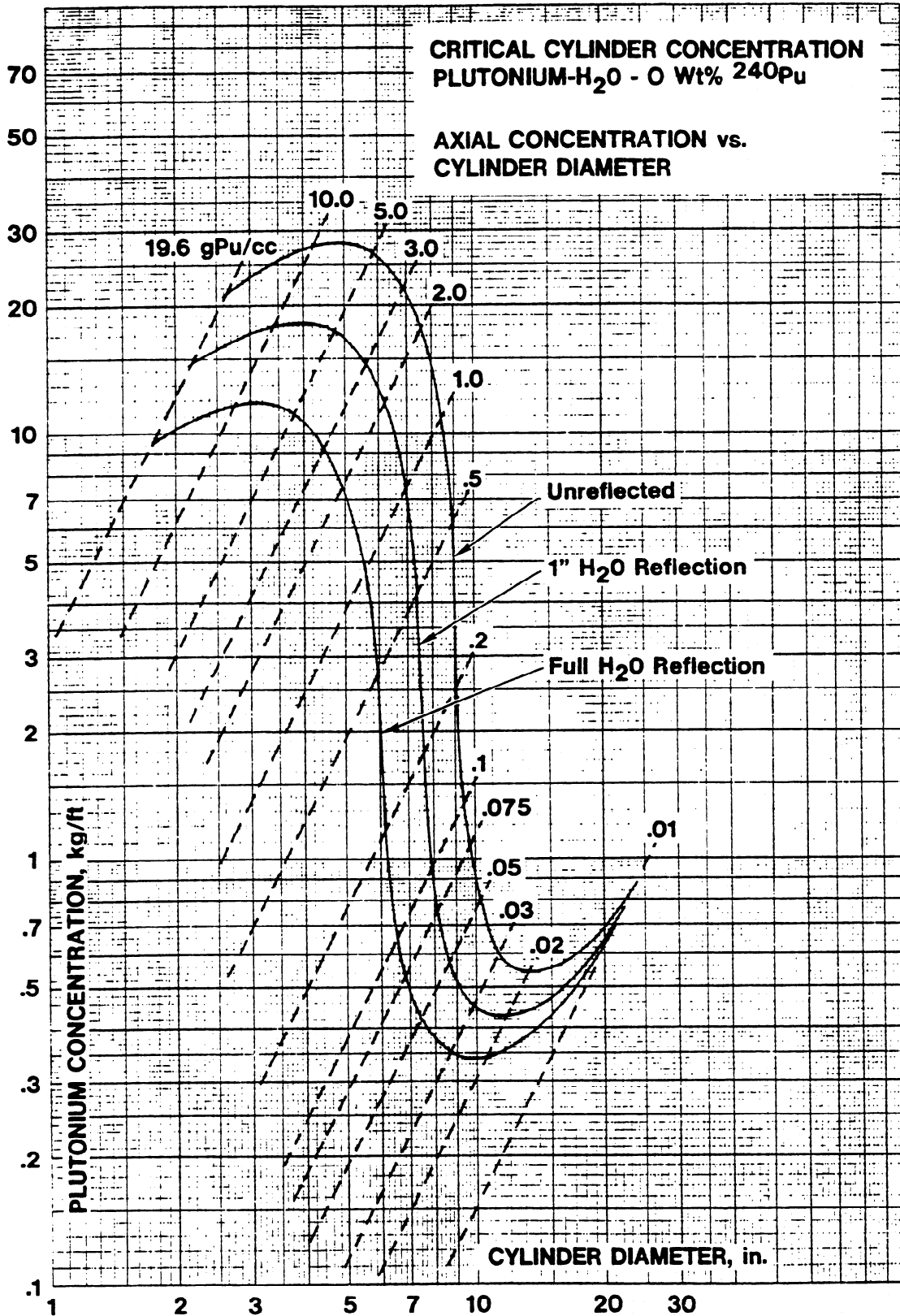
CRITICAL CYLINDER CONCENTRATION  
PLUTONIUM-H<sub>2</sub>O - 3 wt% 240  
AXIAL CONCENTRATION vs. CYLINDER DIAMETER

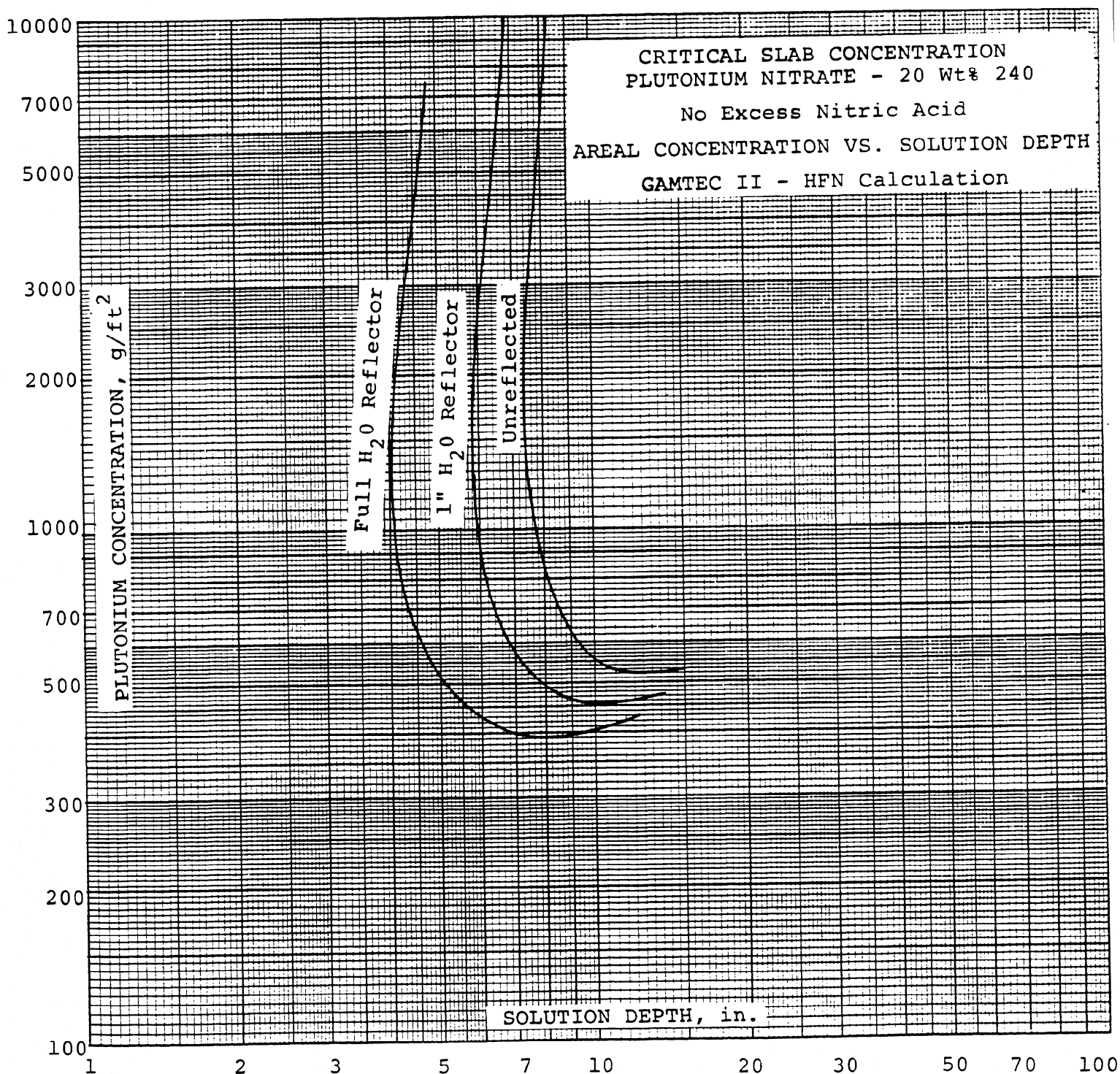


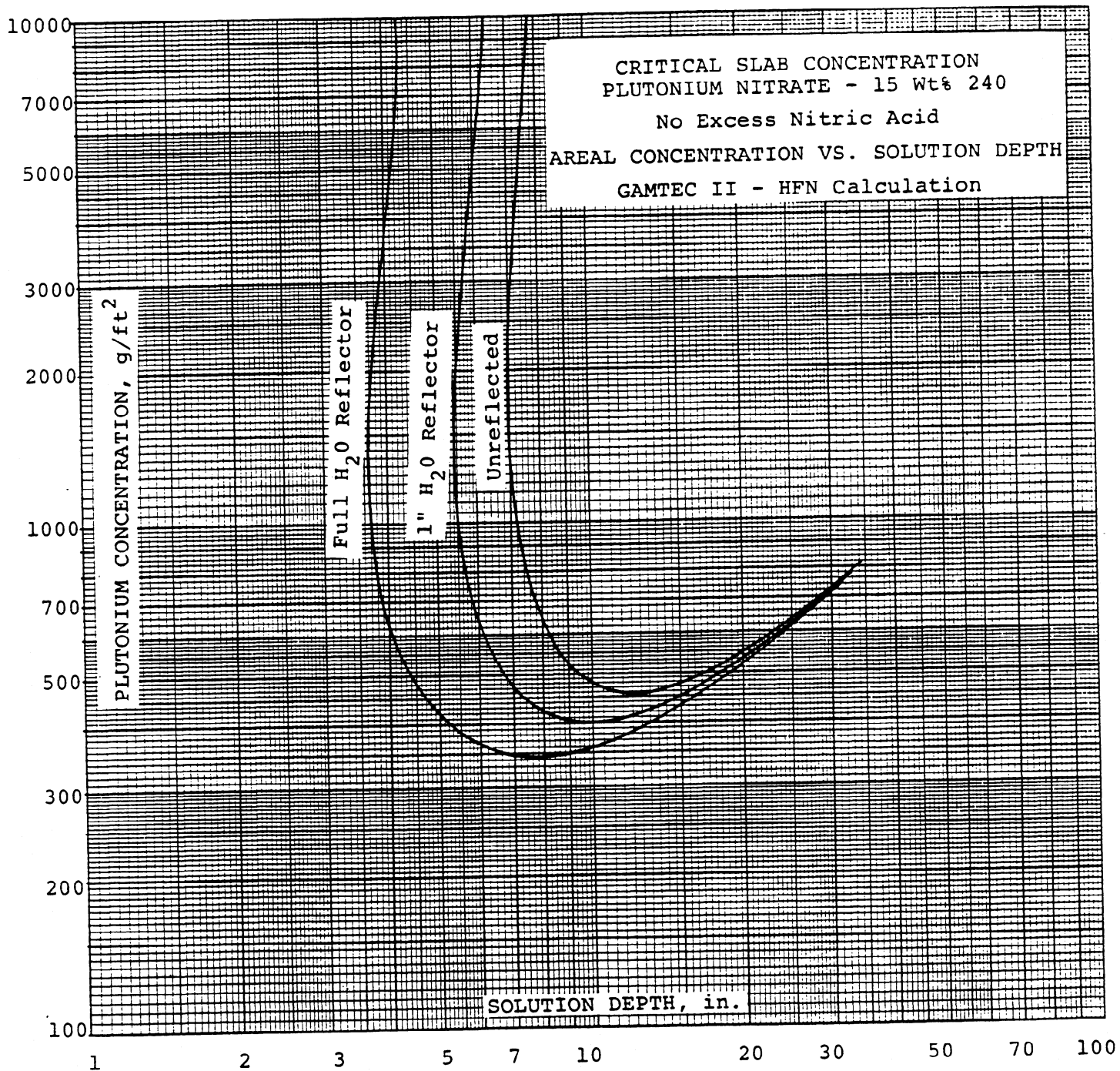


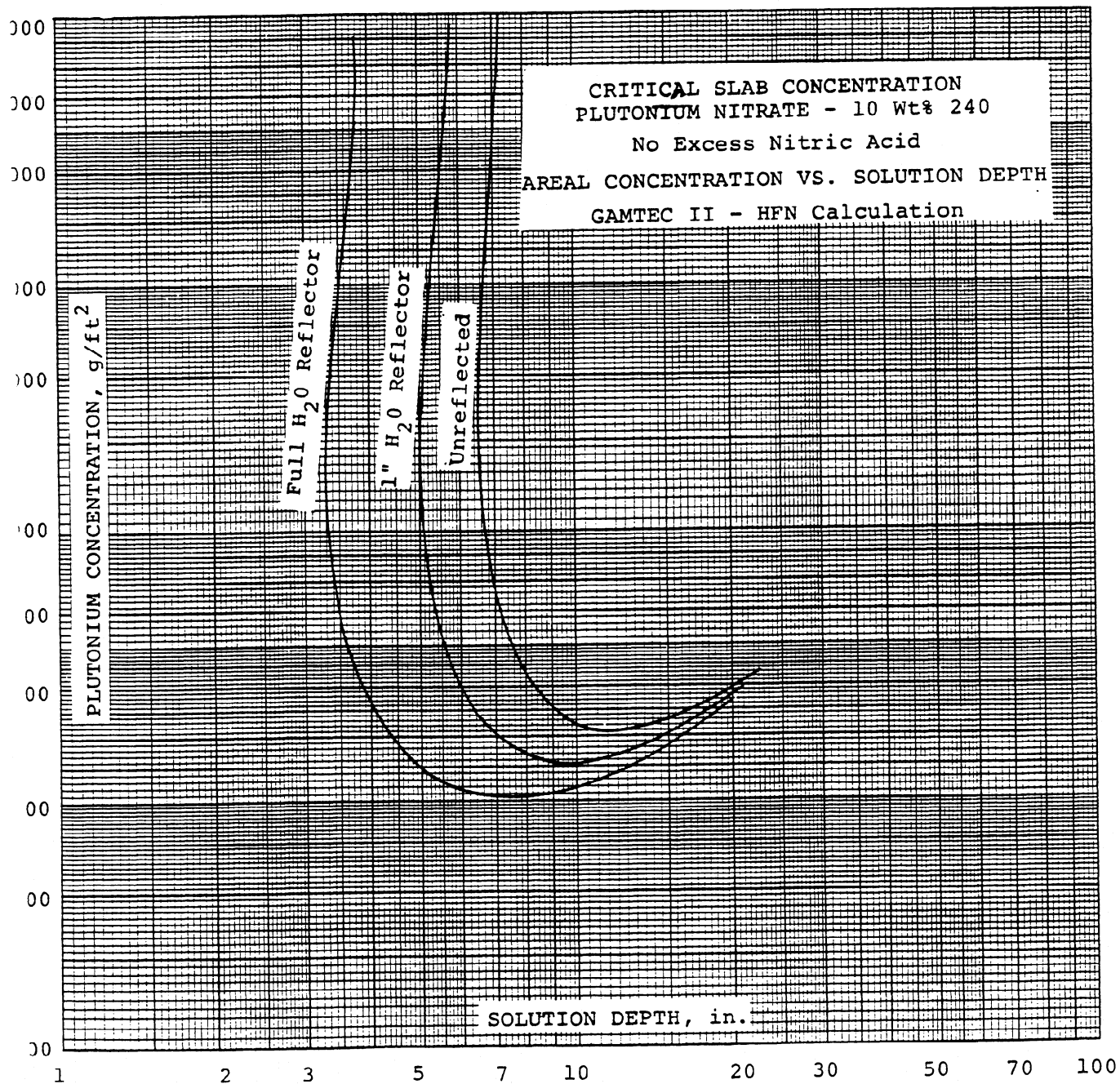


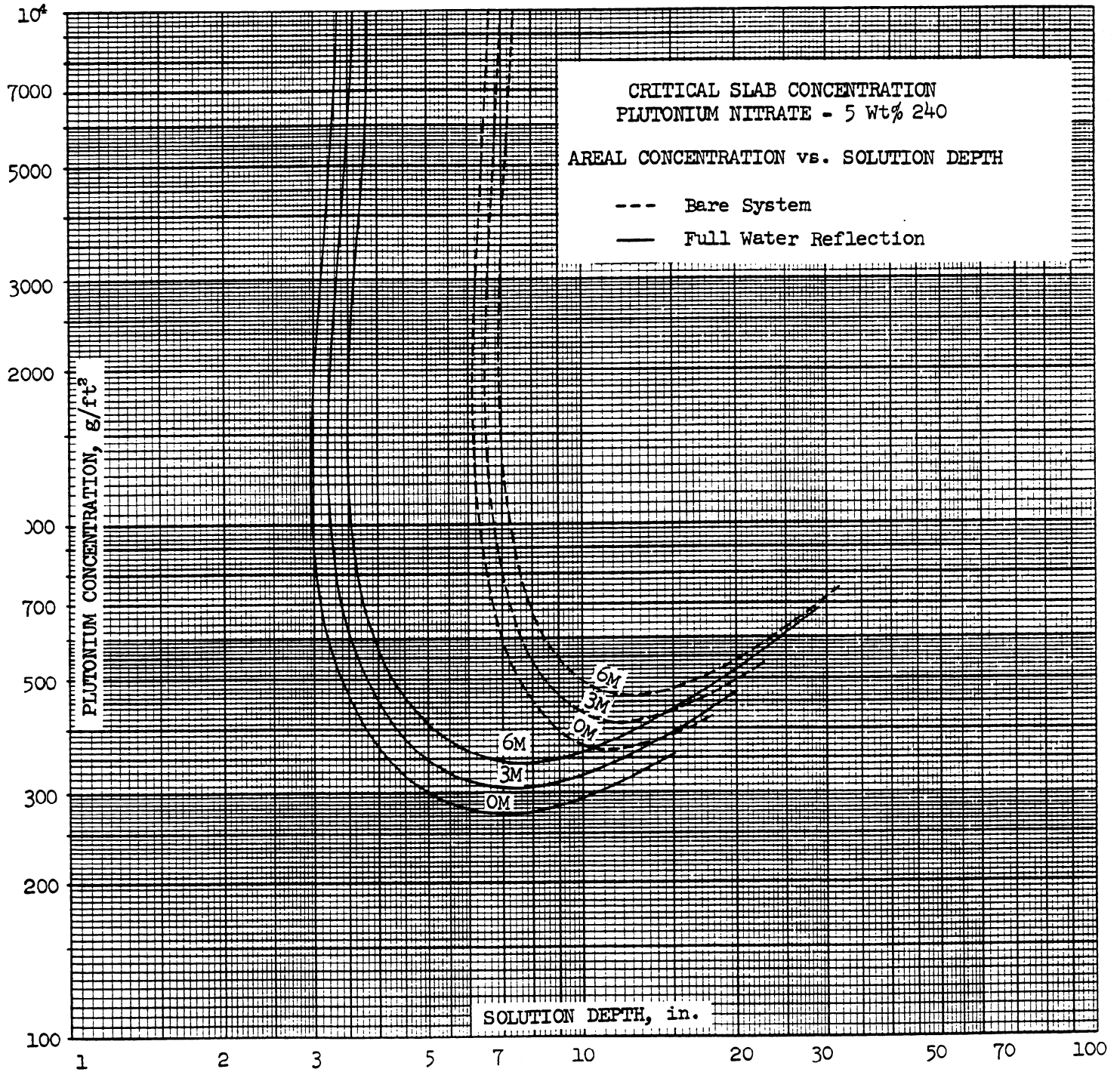


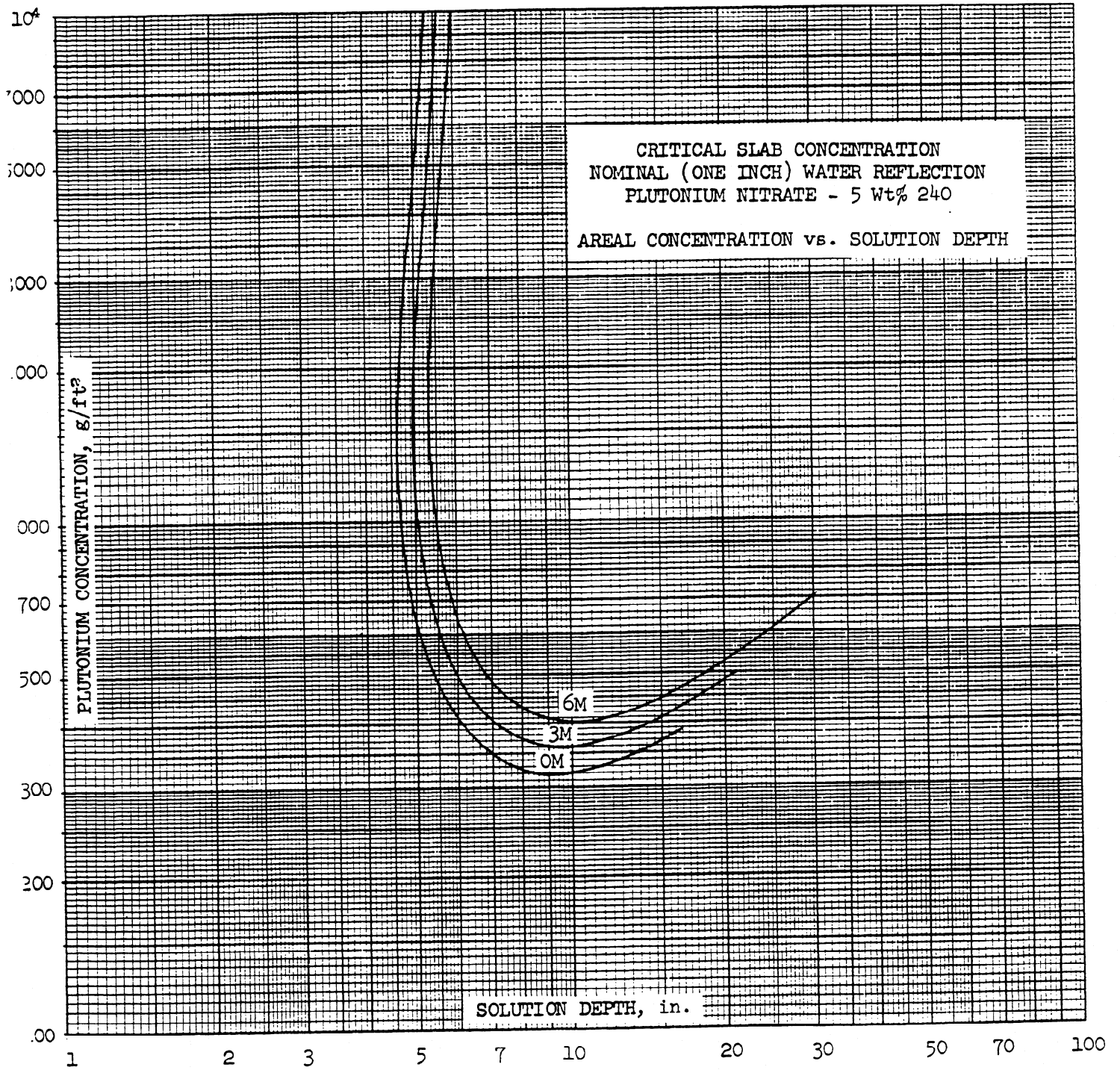




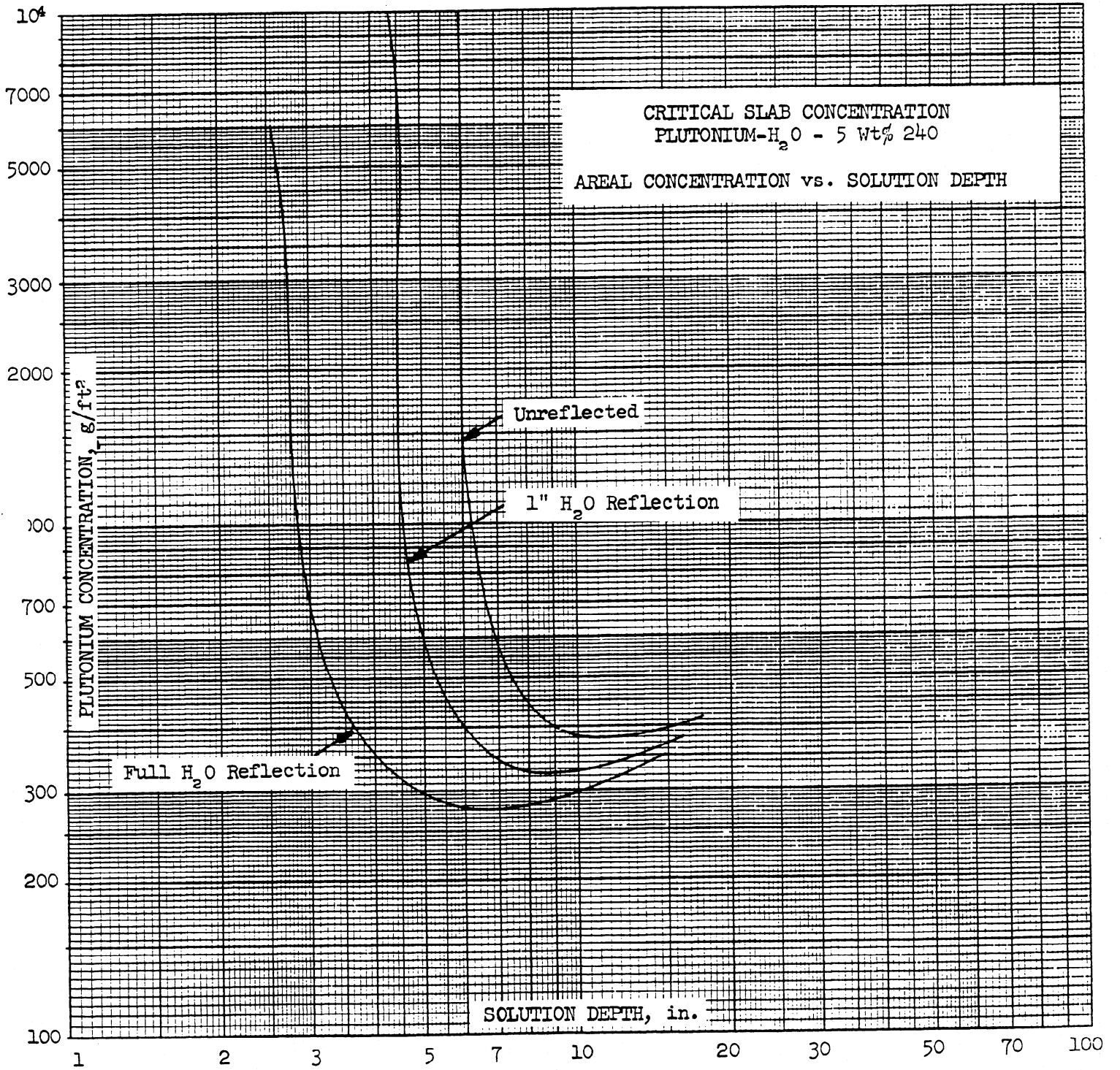


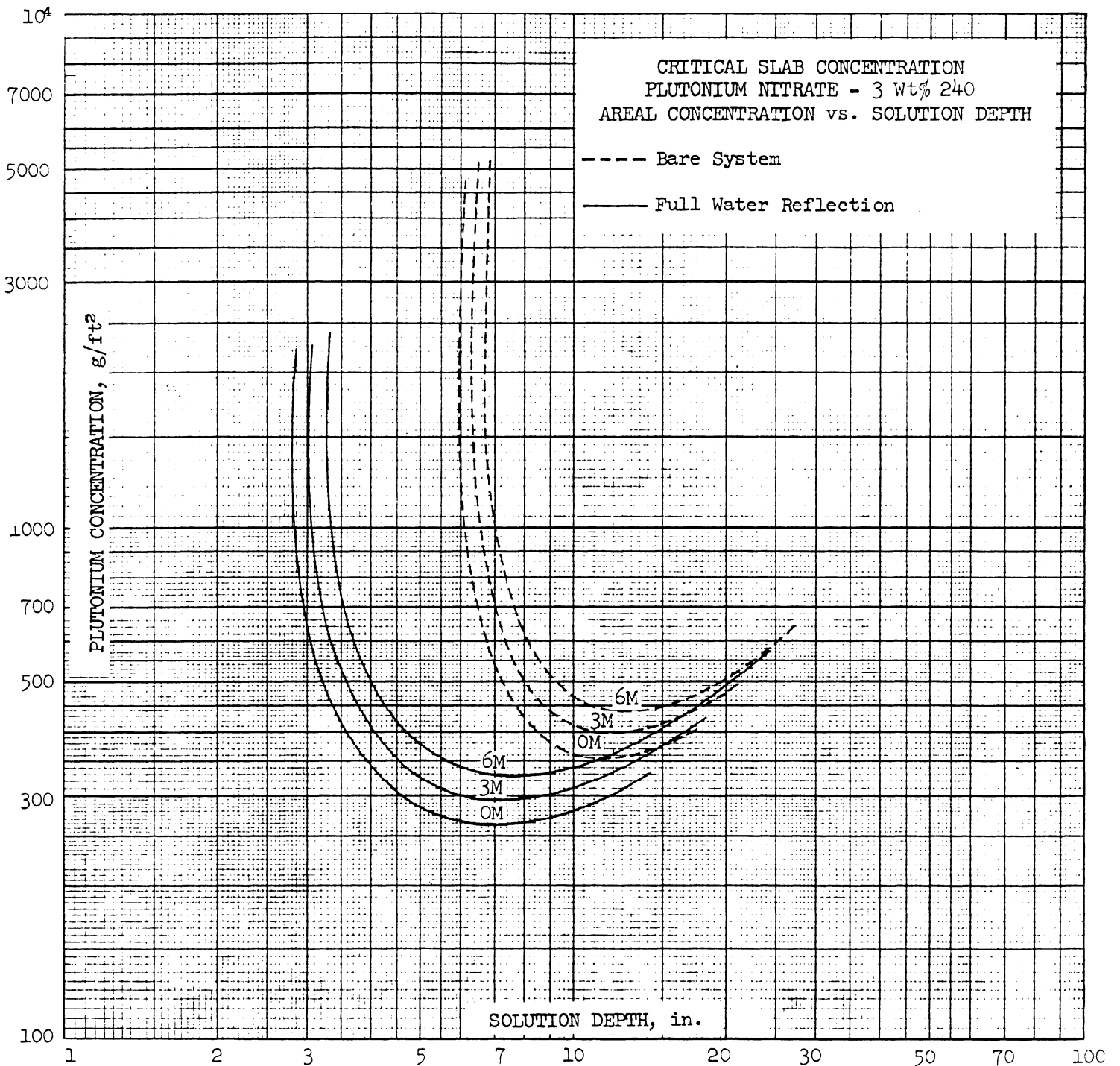


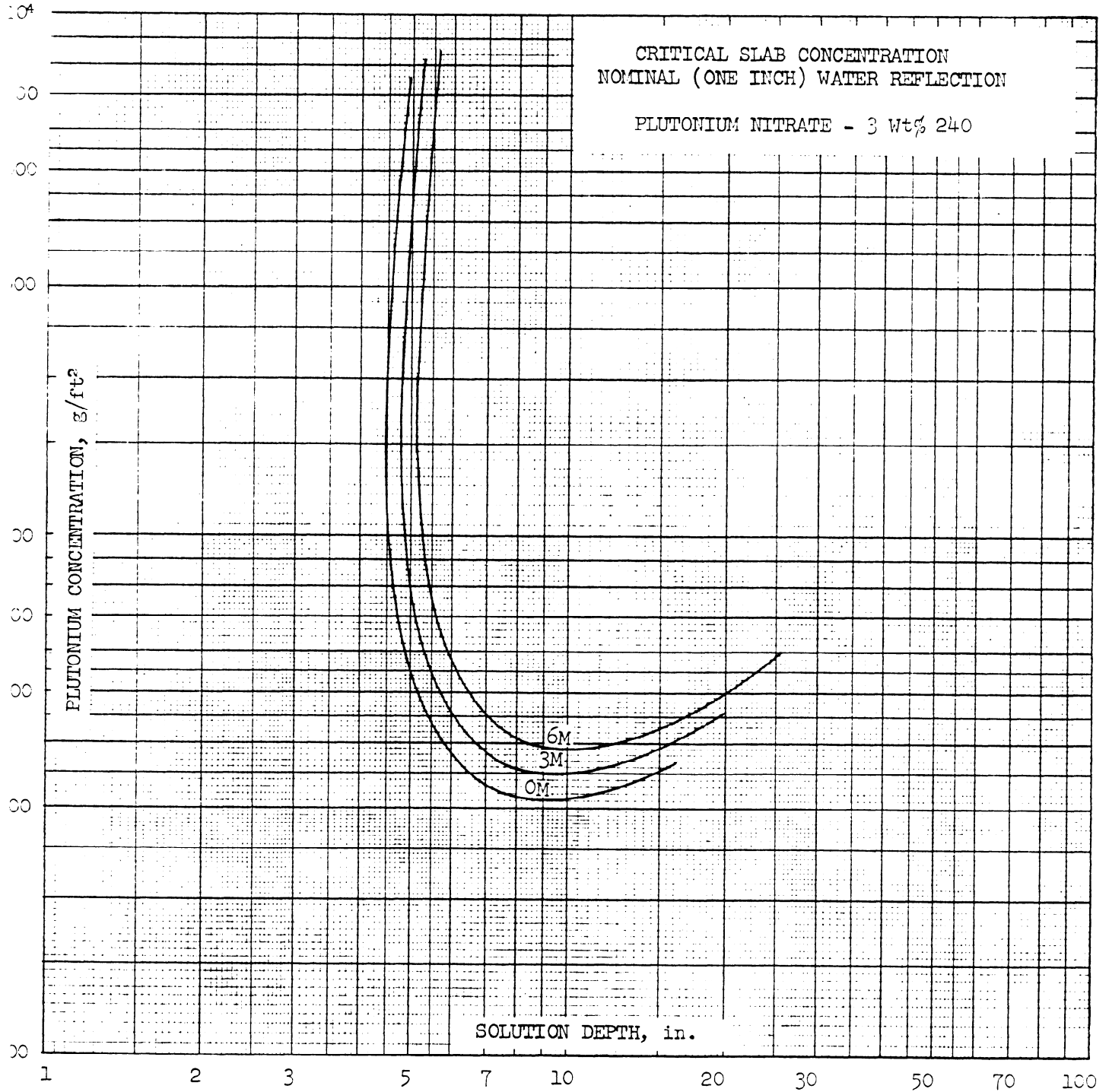


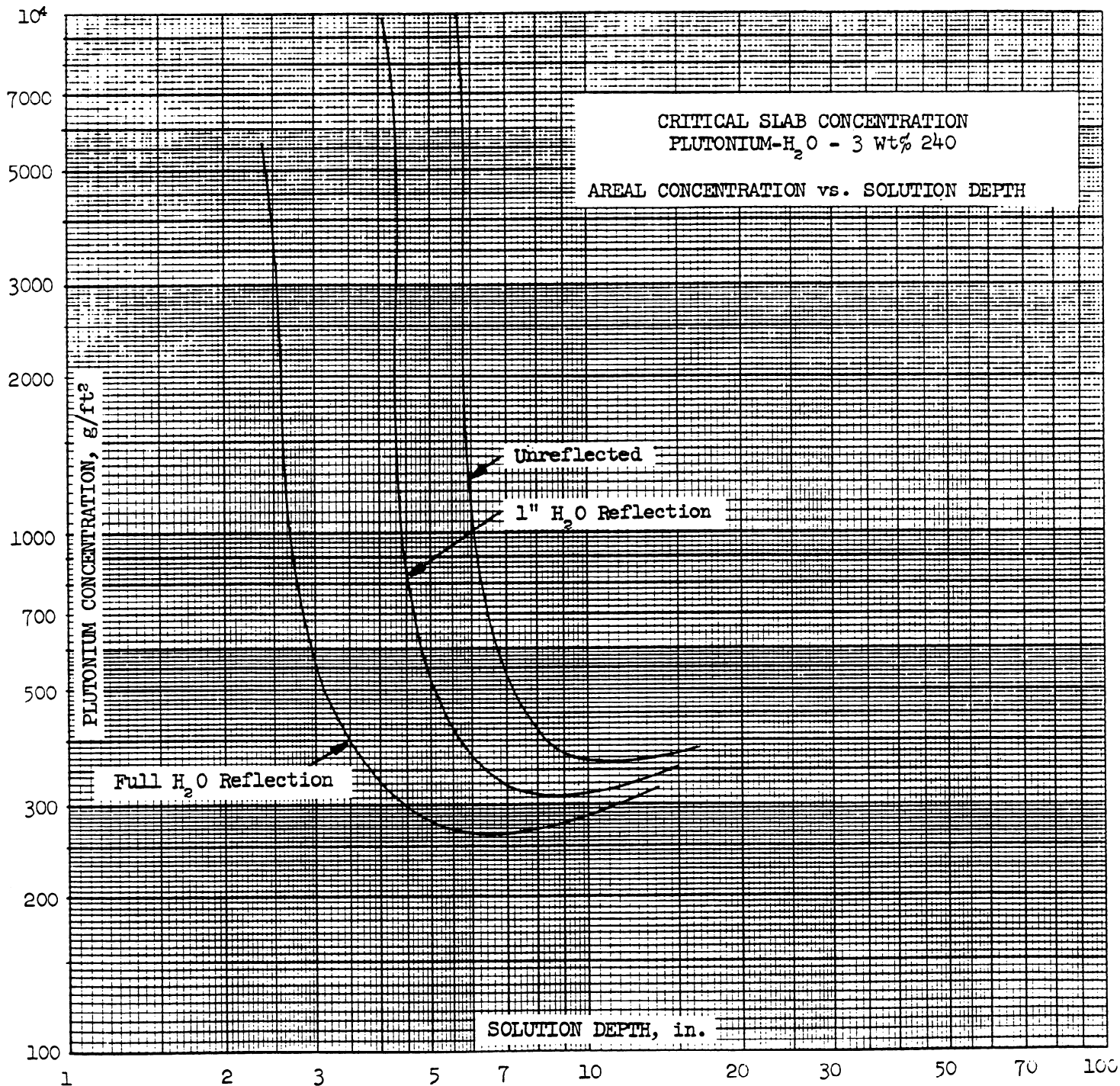


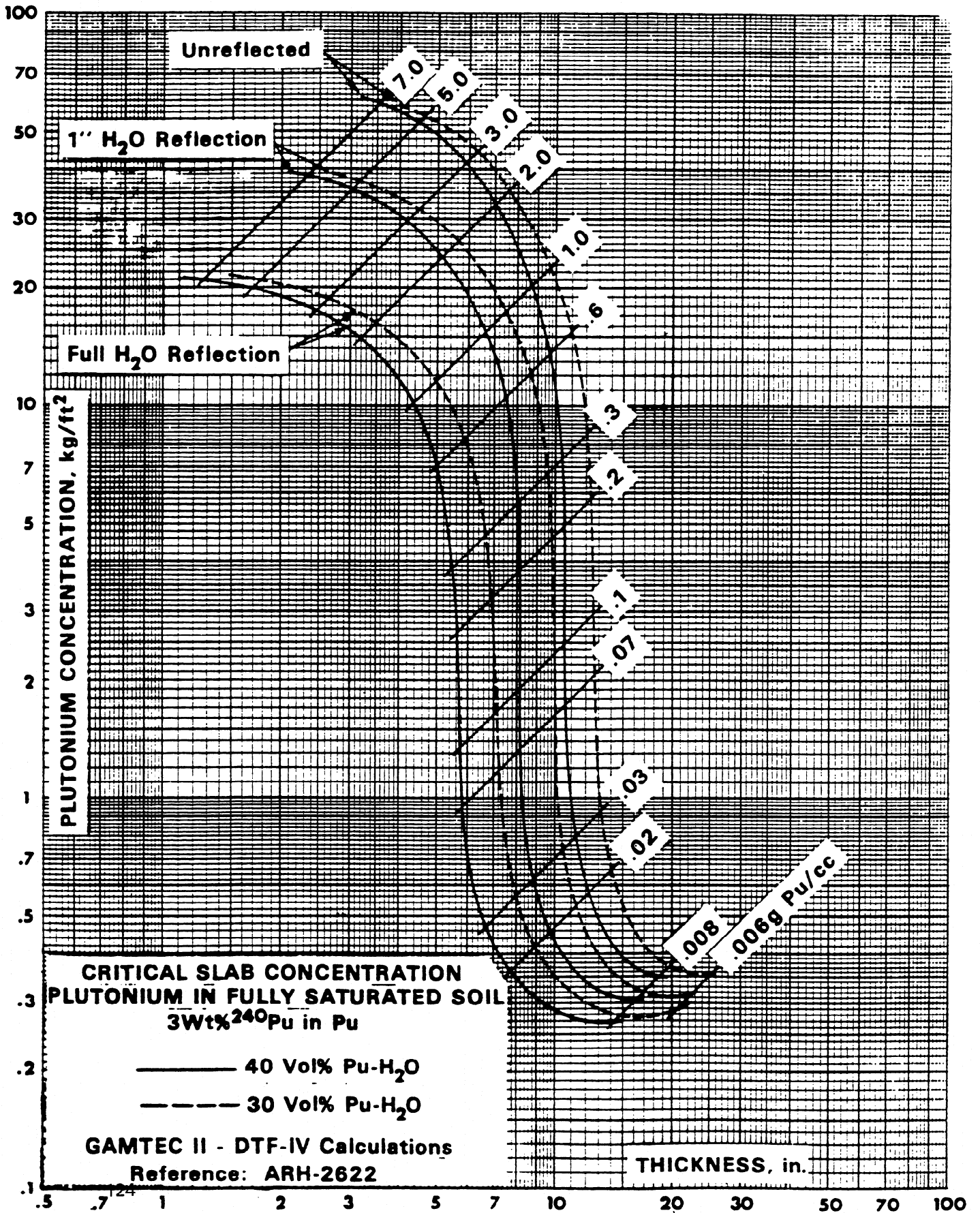


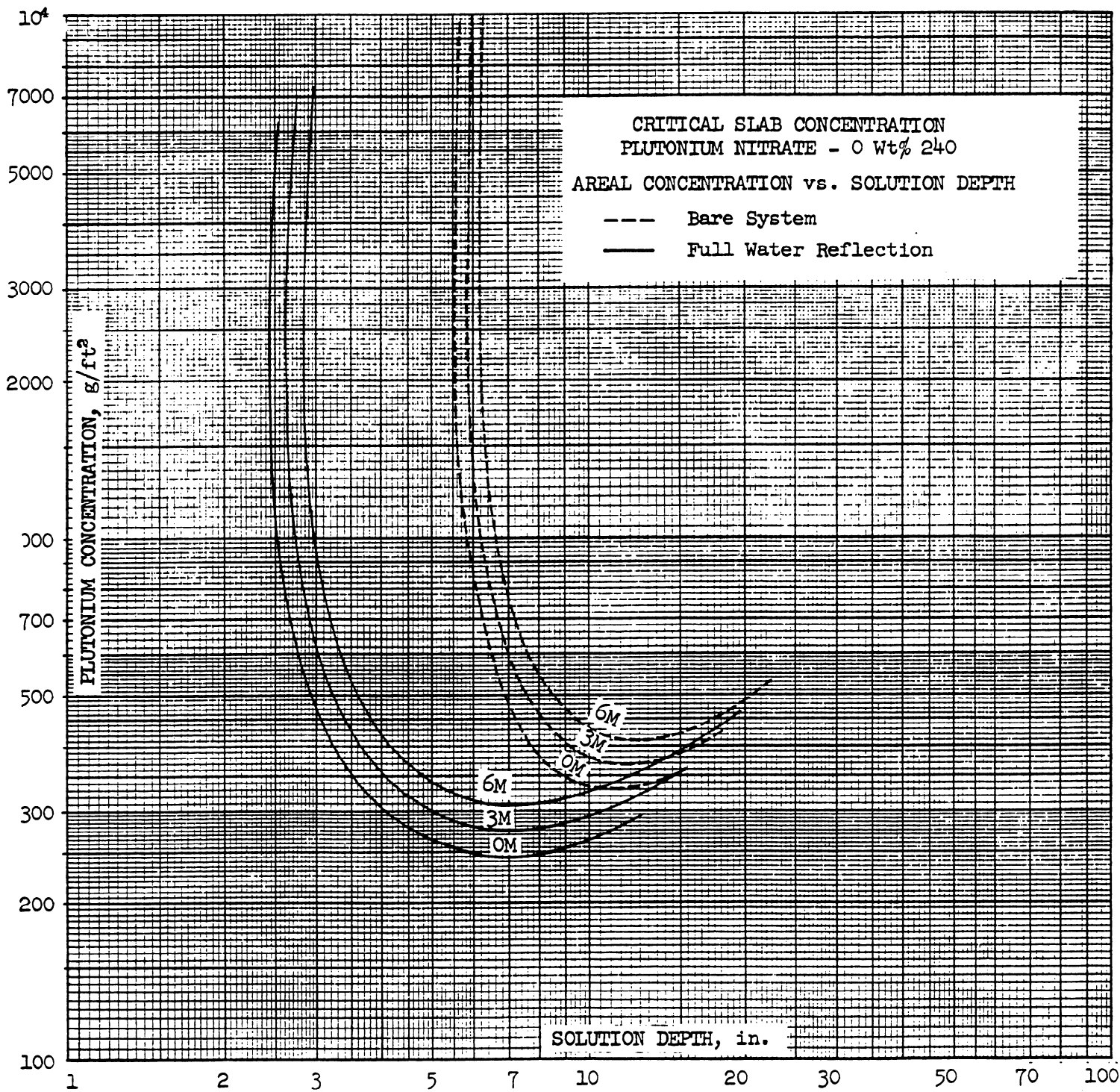


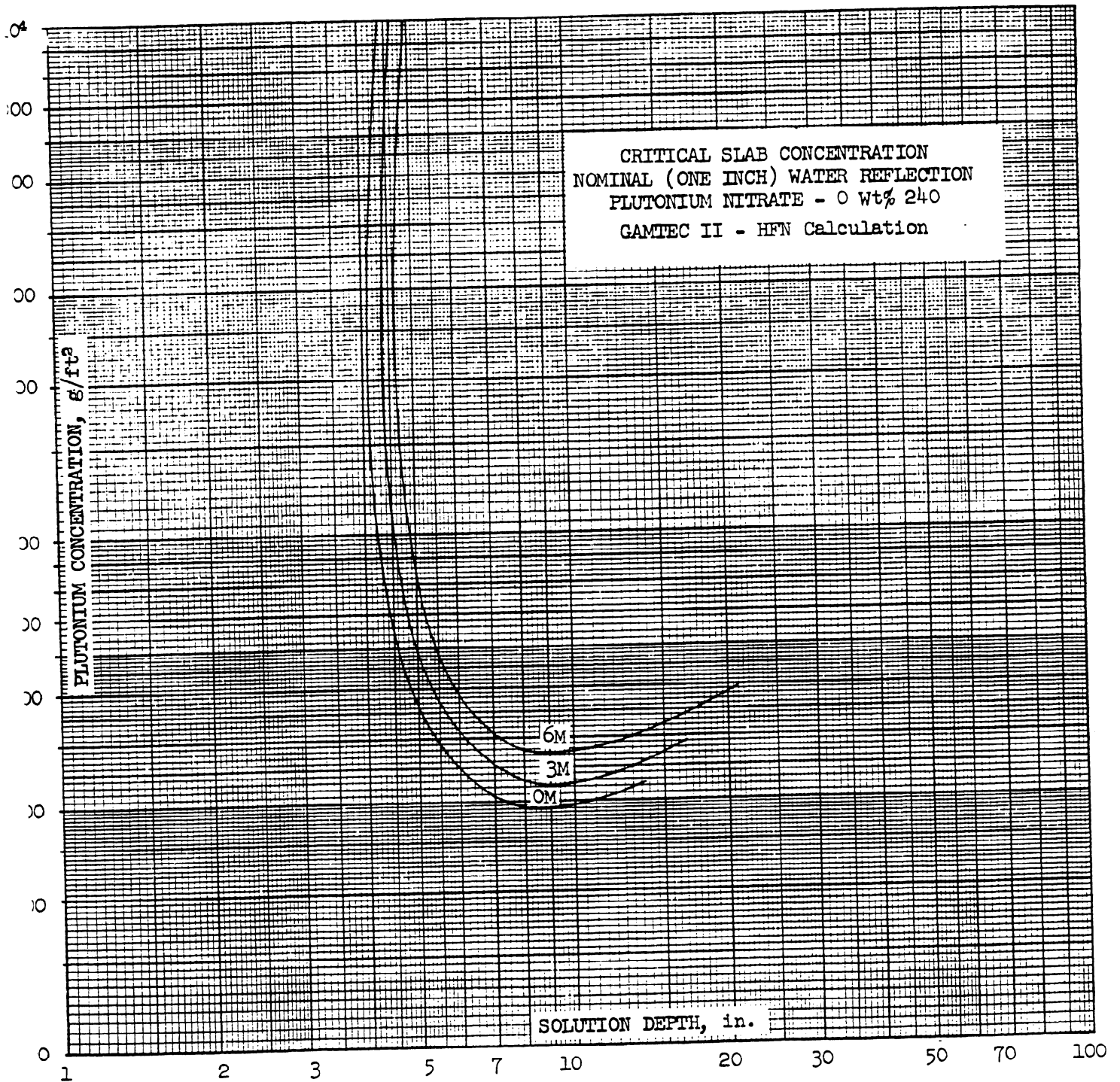


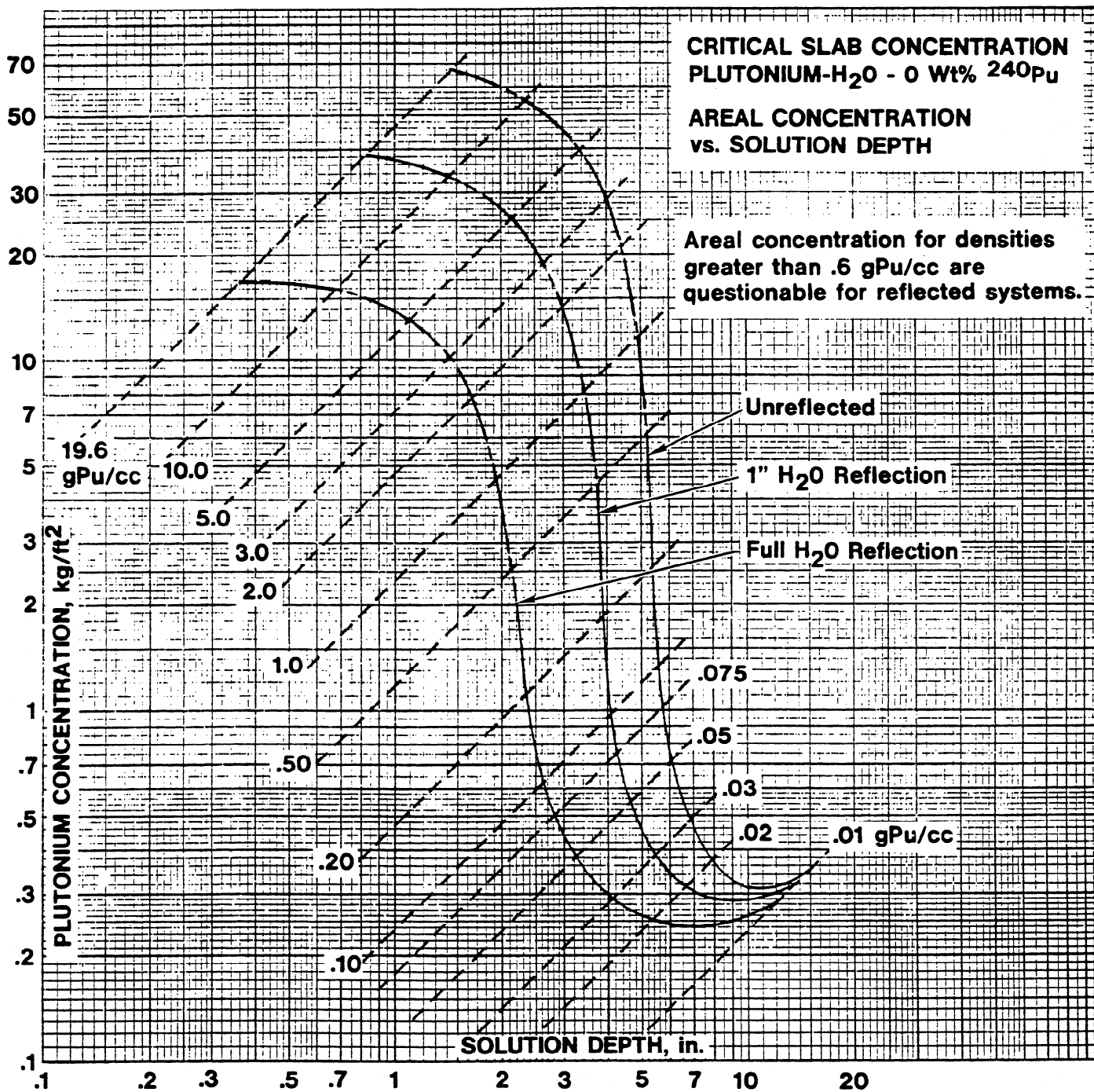






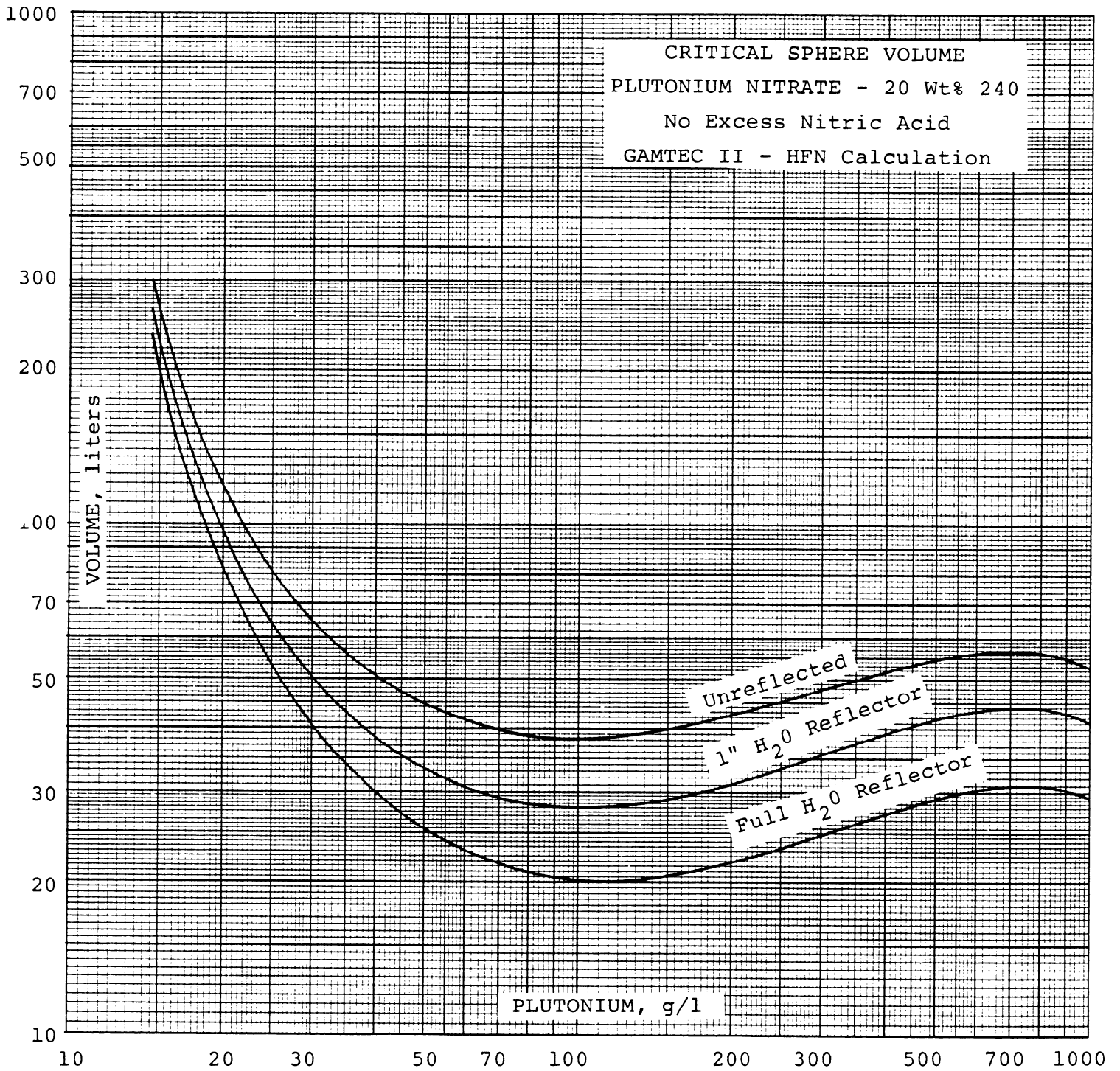


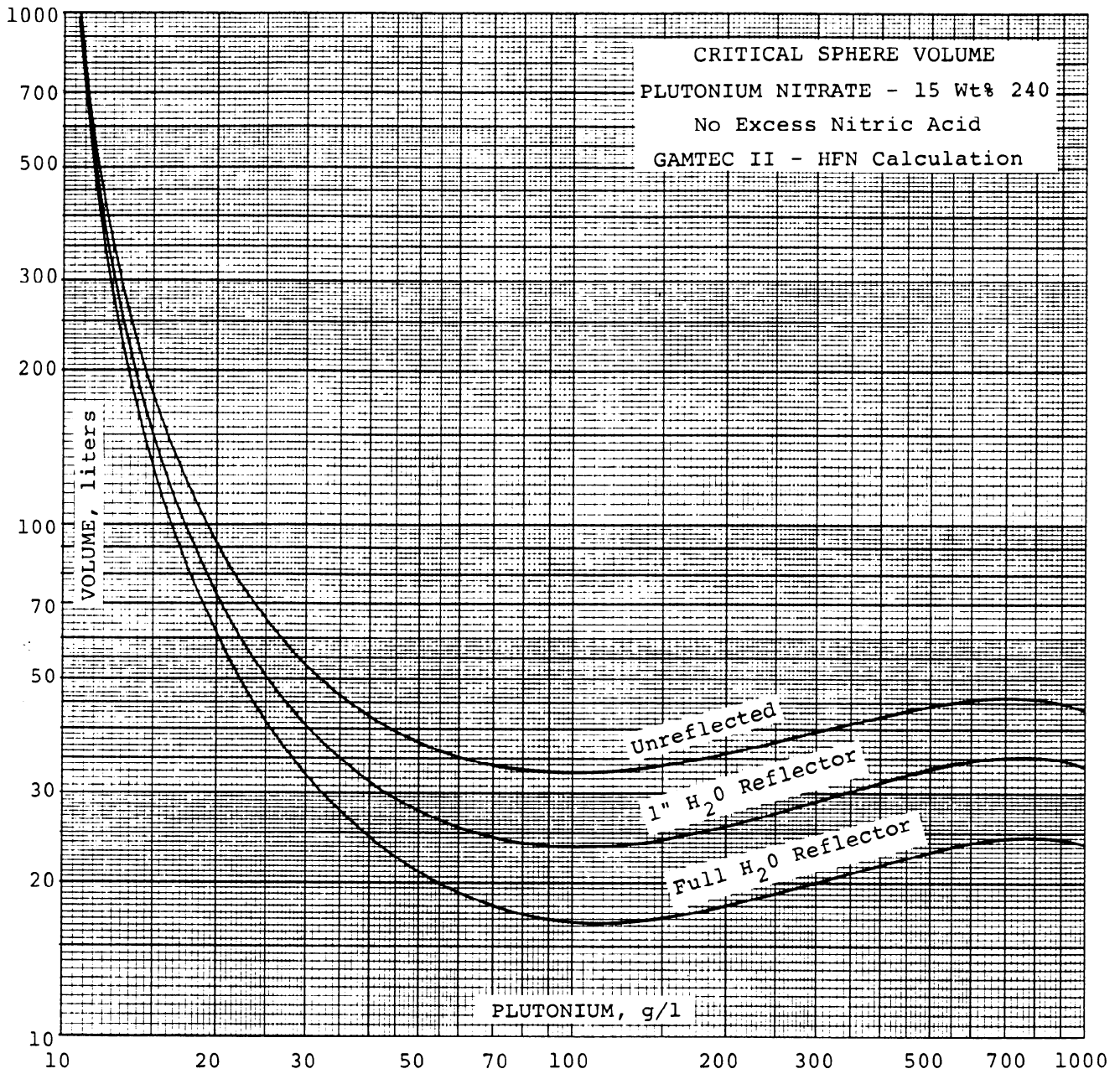


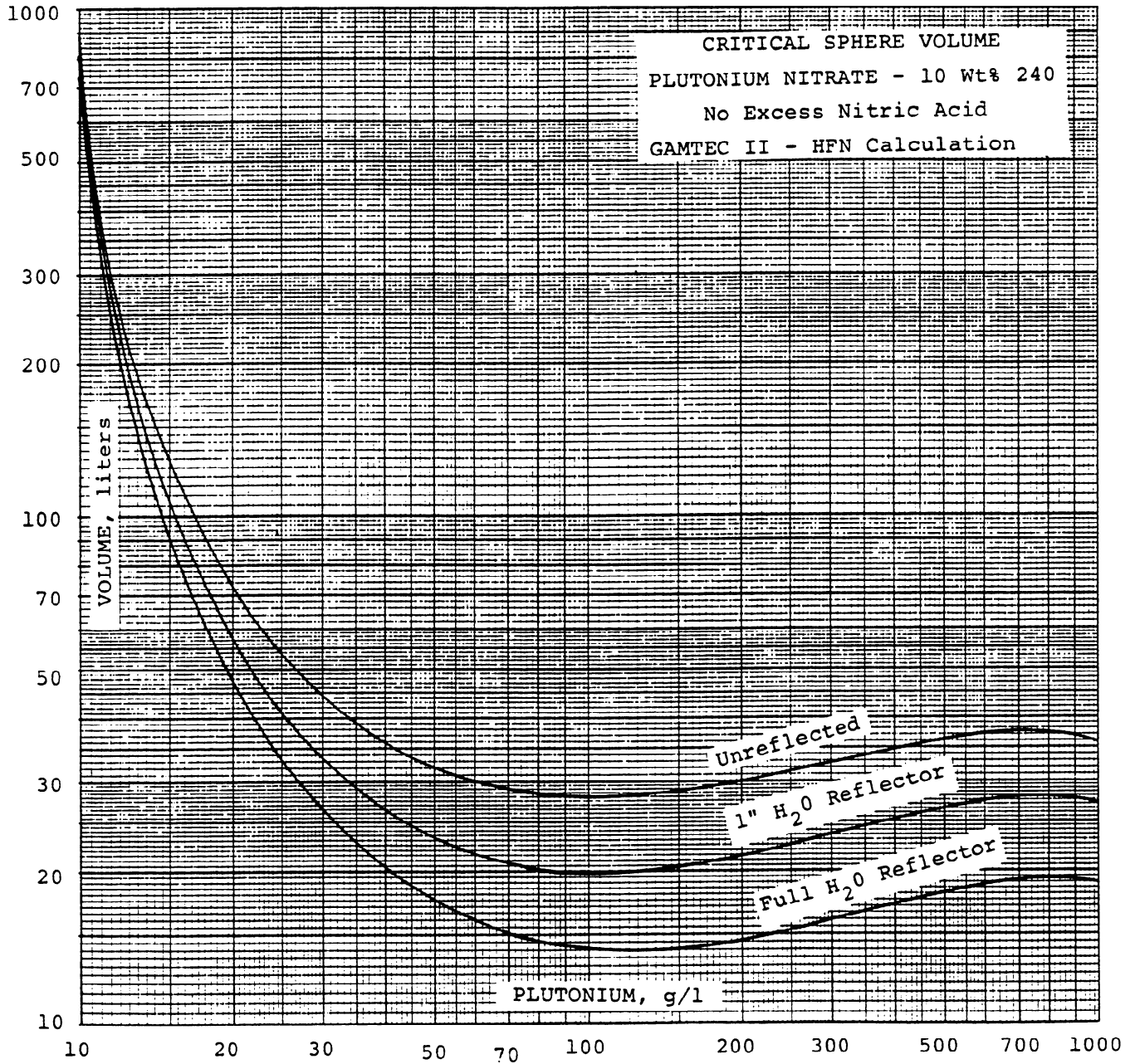


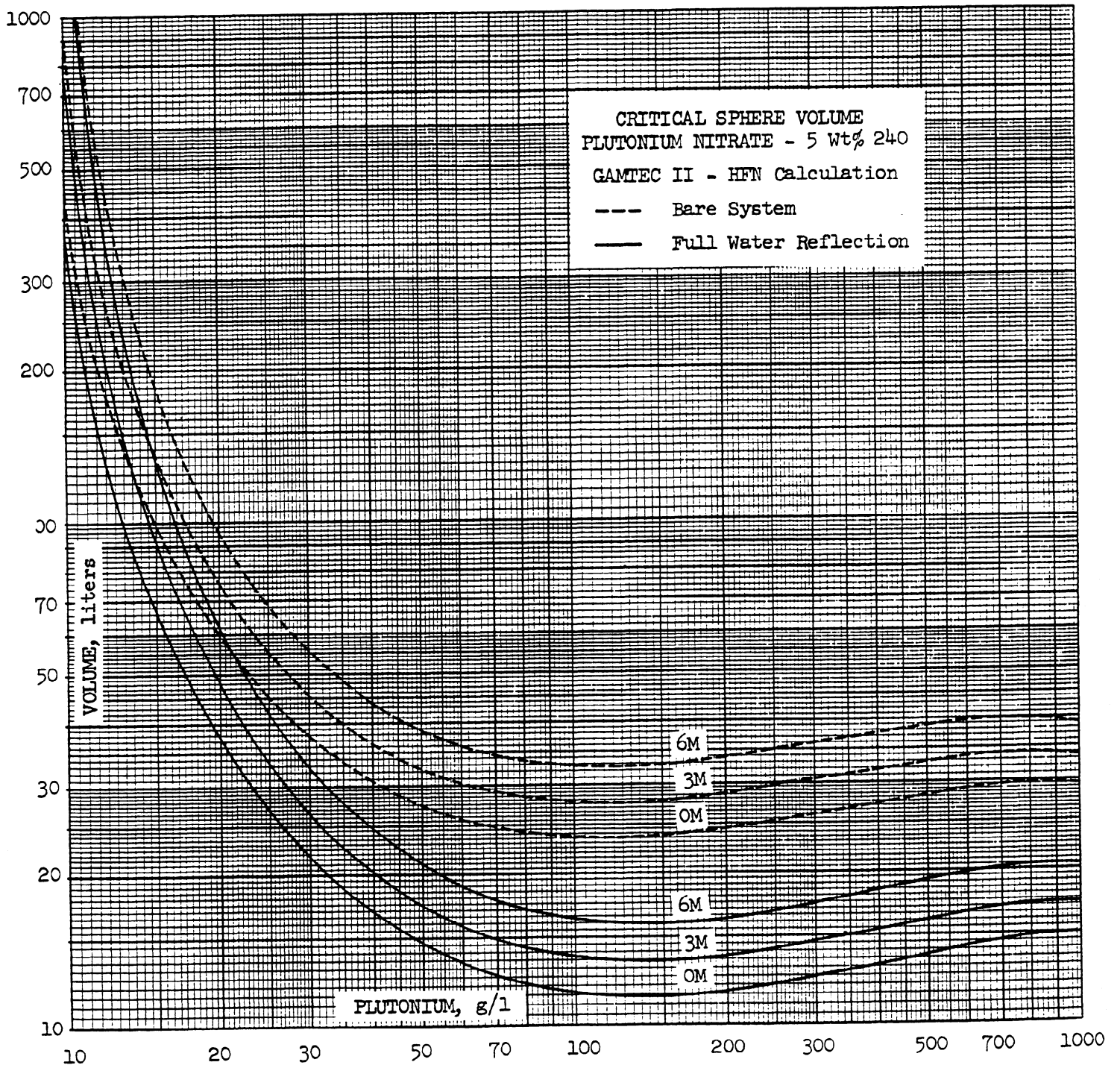
Revised:  
5-28-80

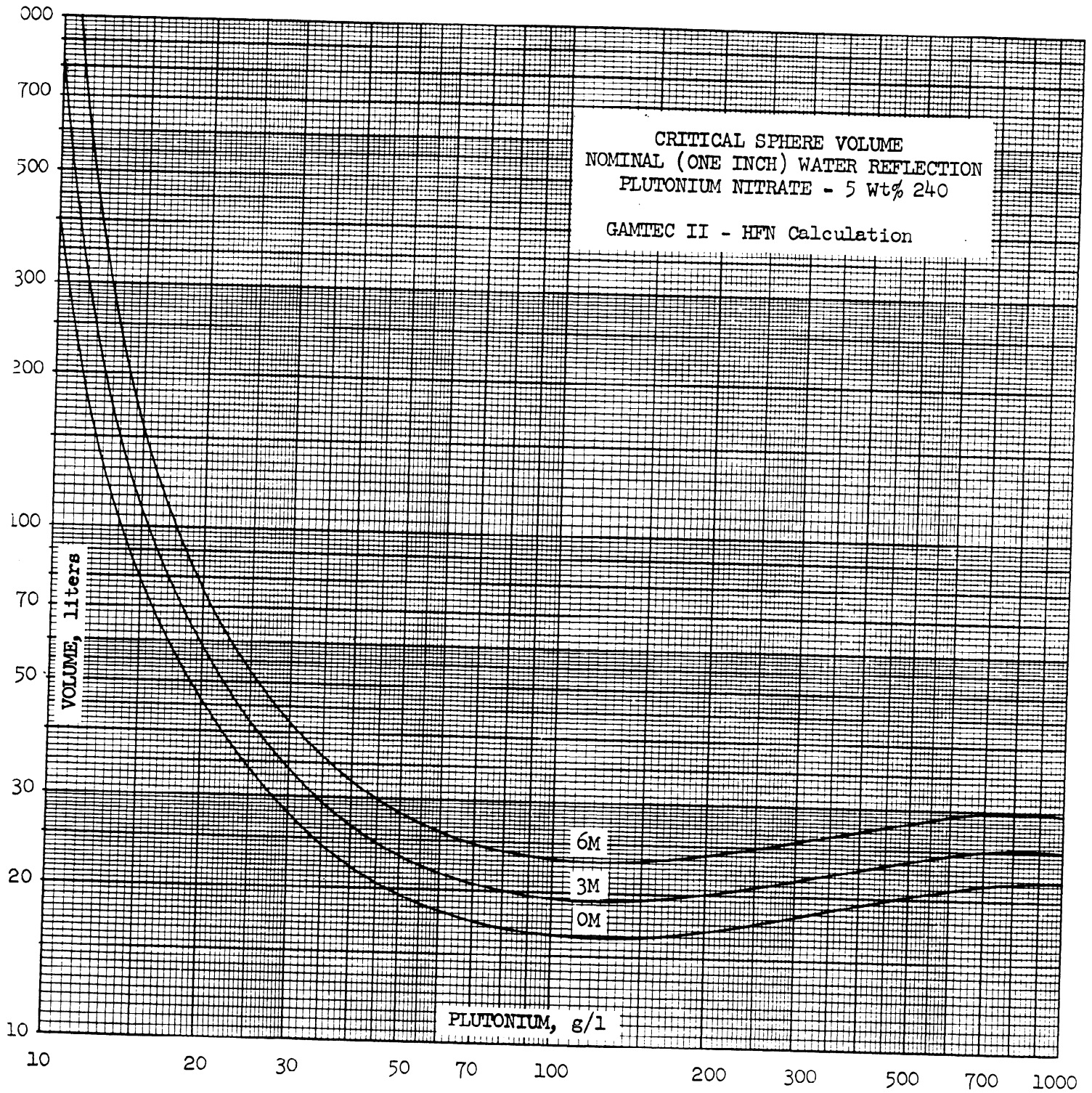


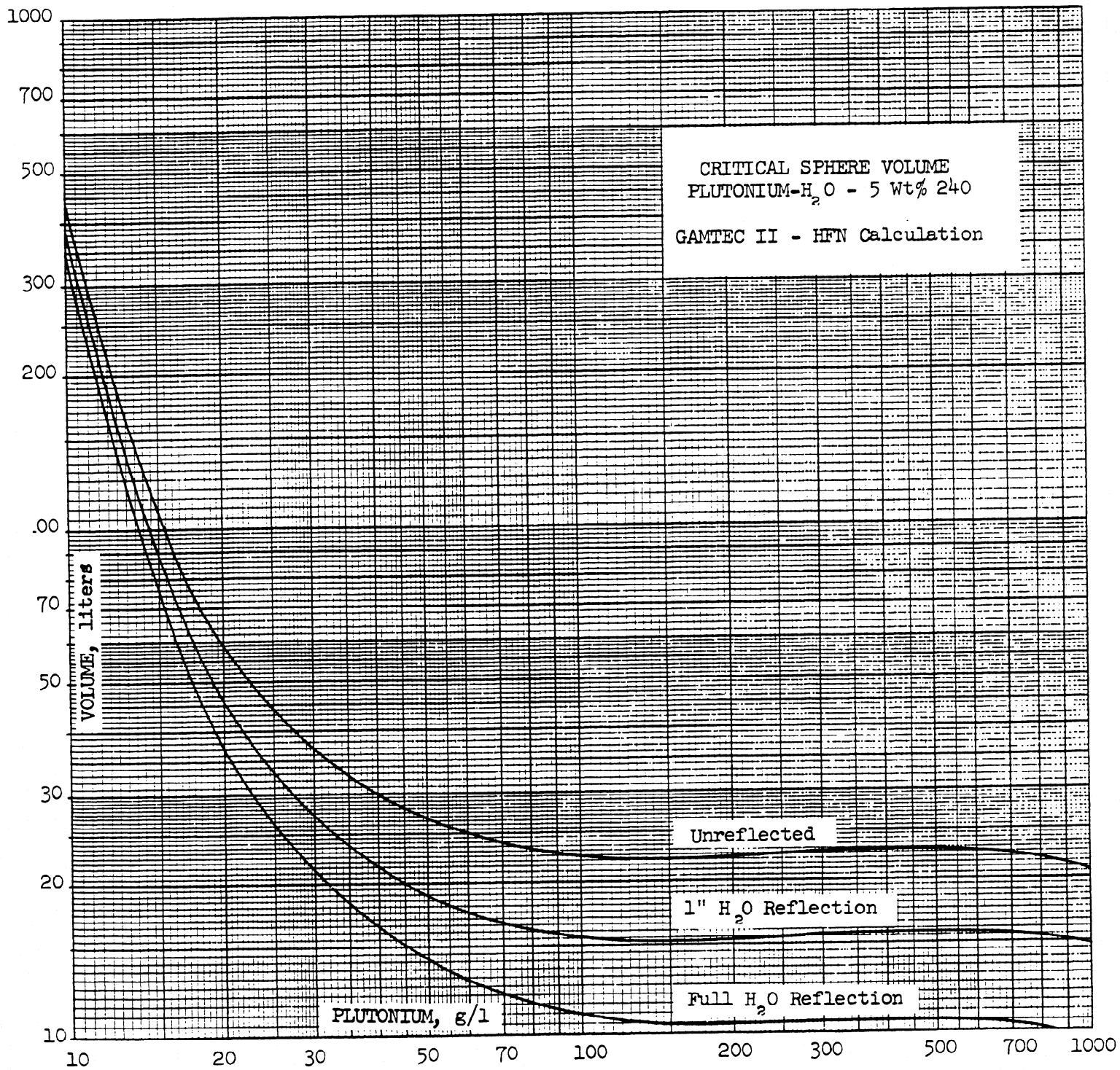


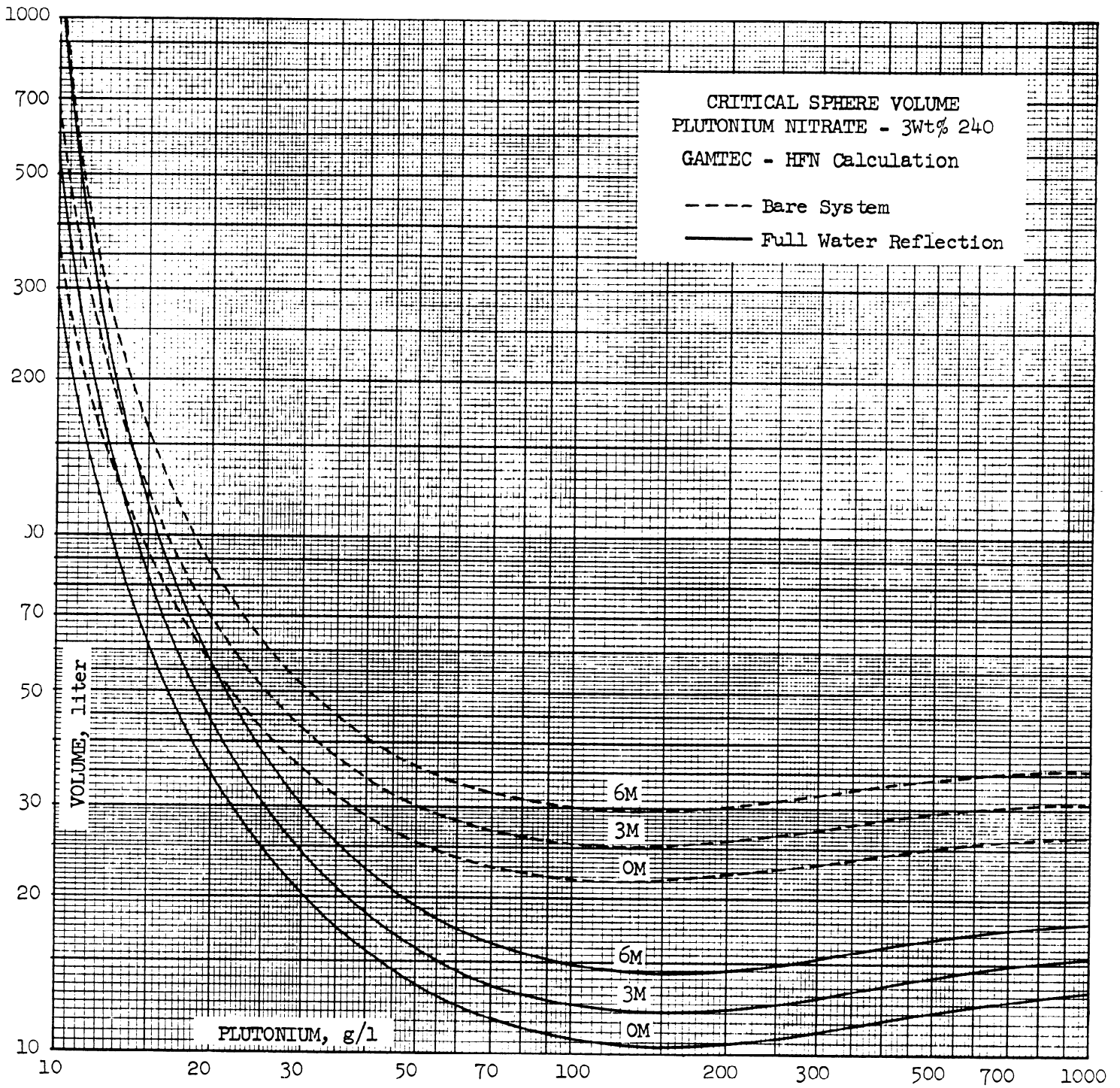


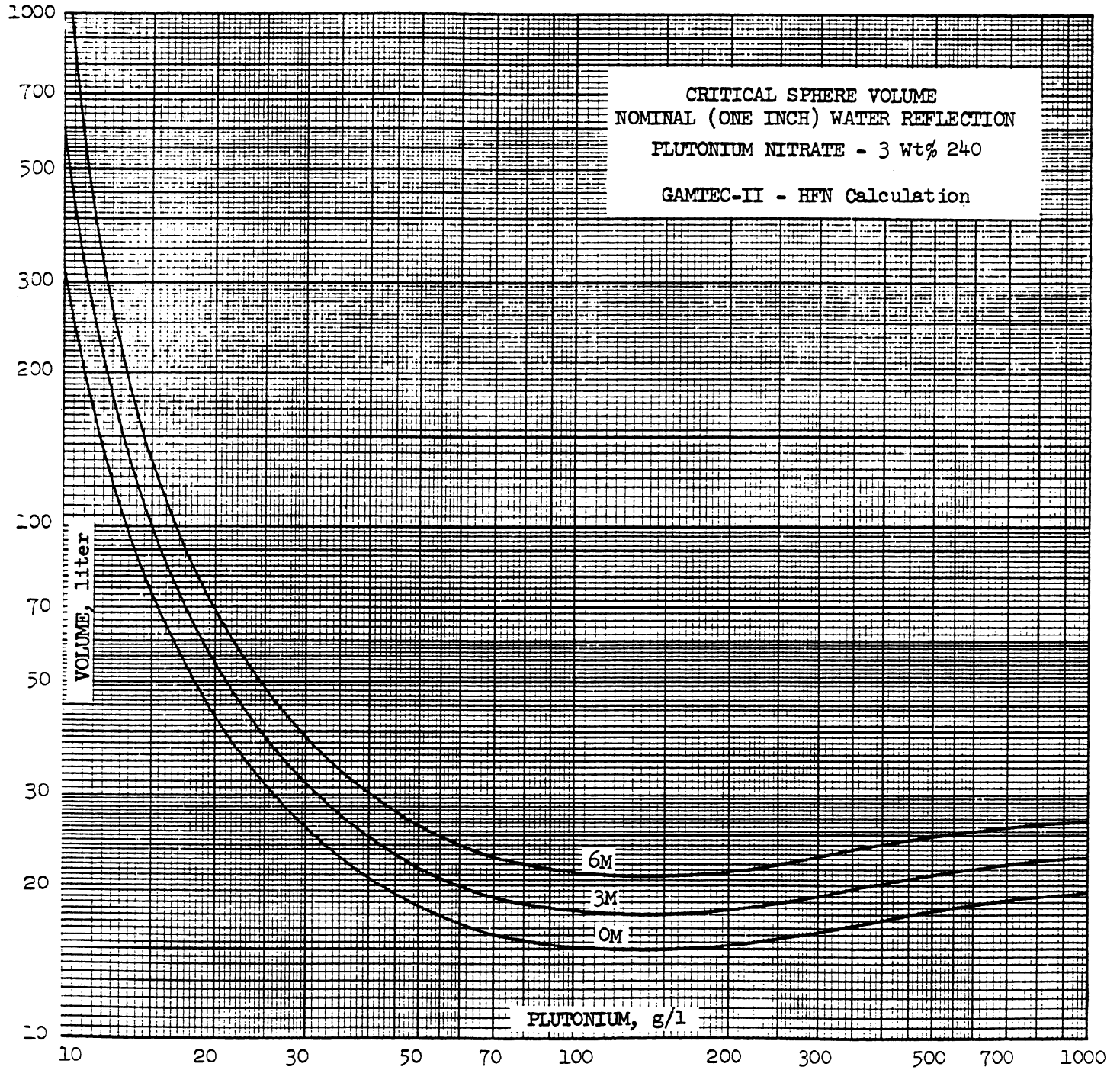




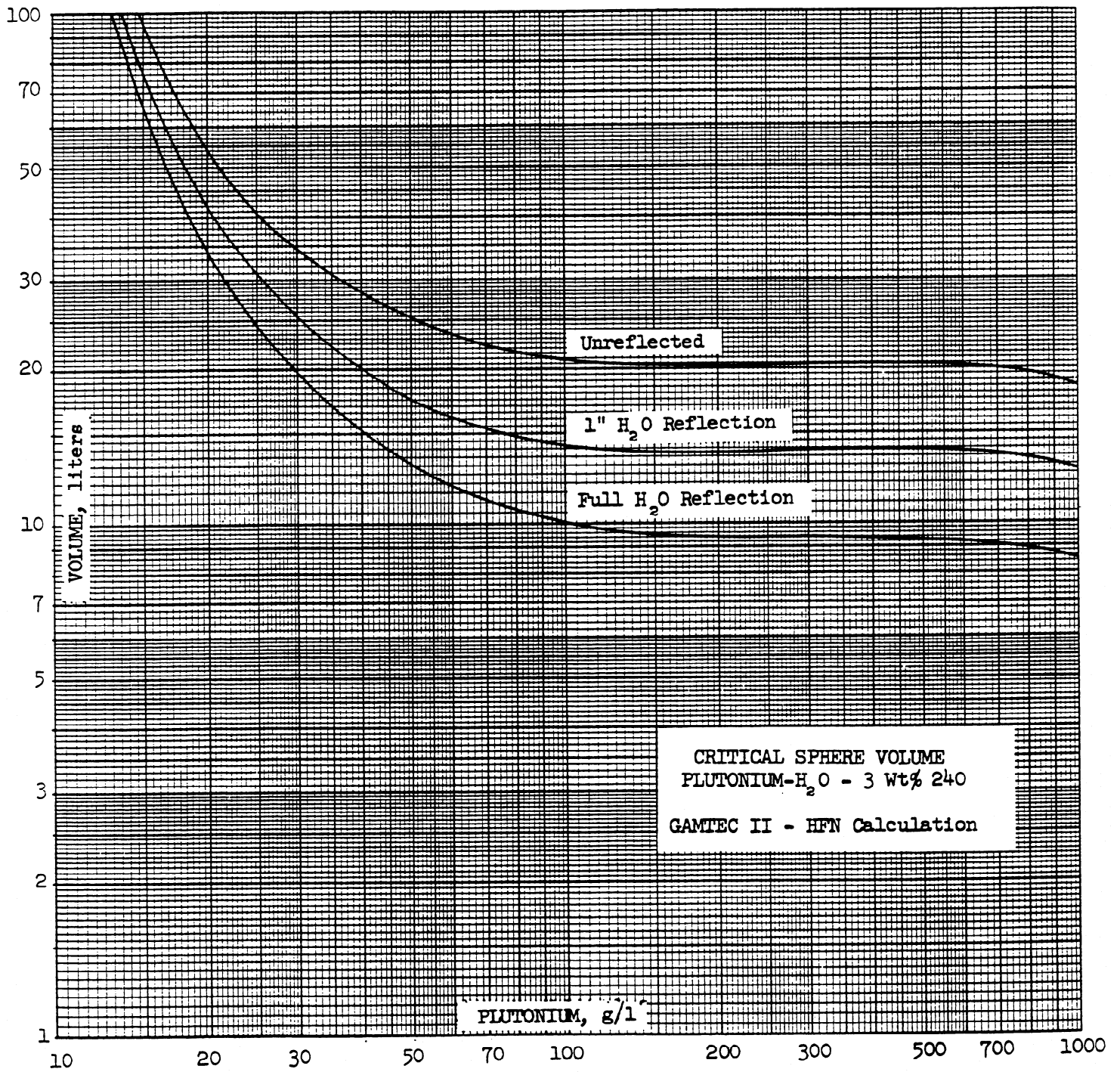


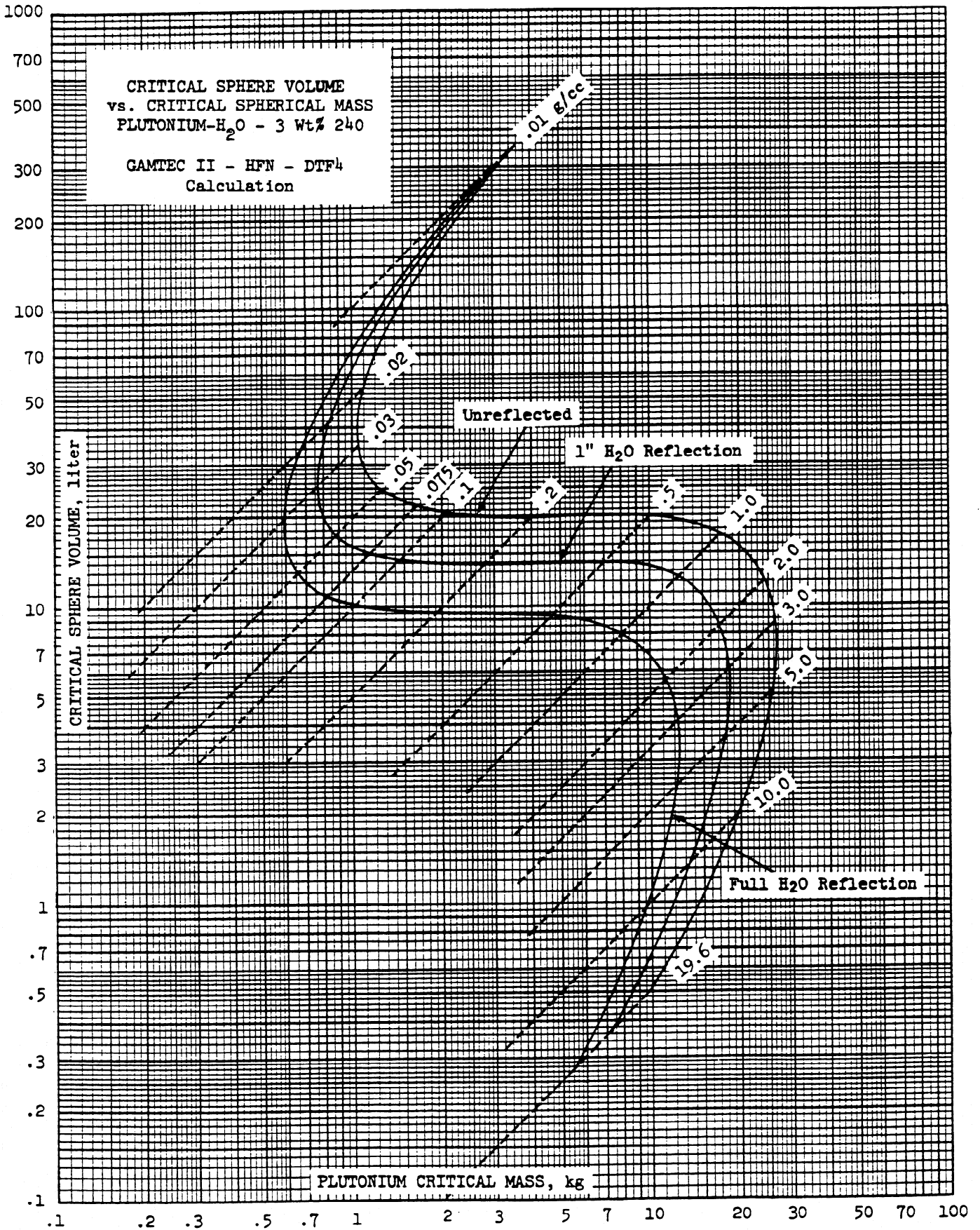


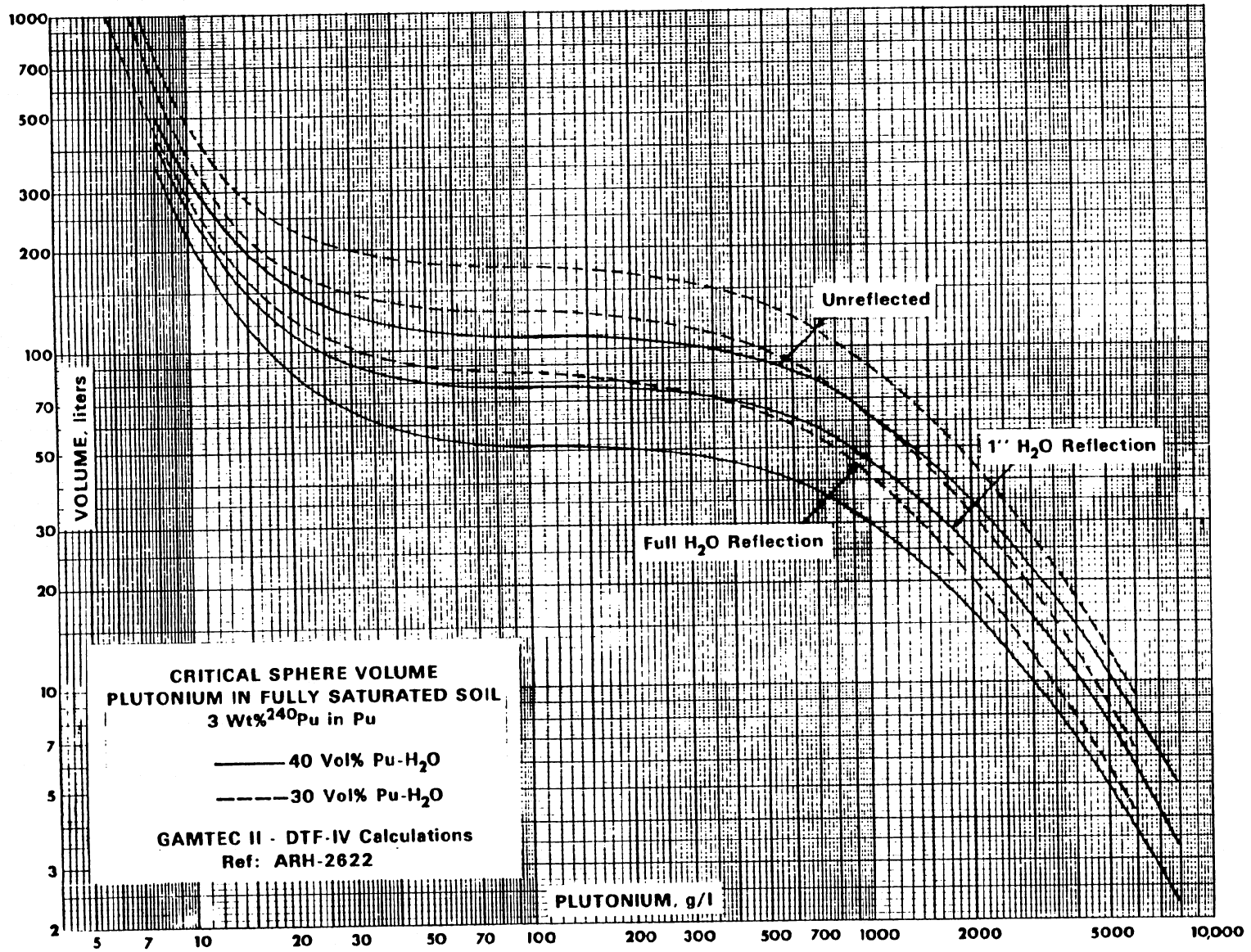






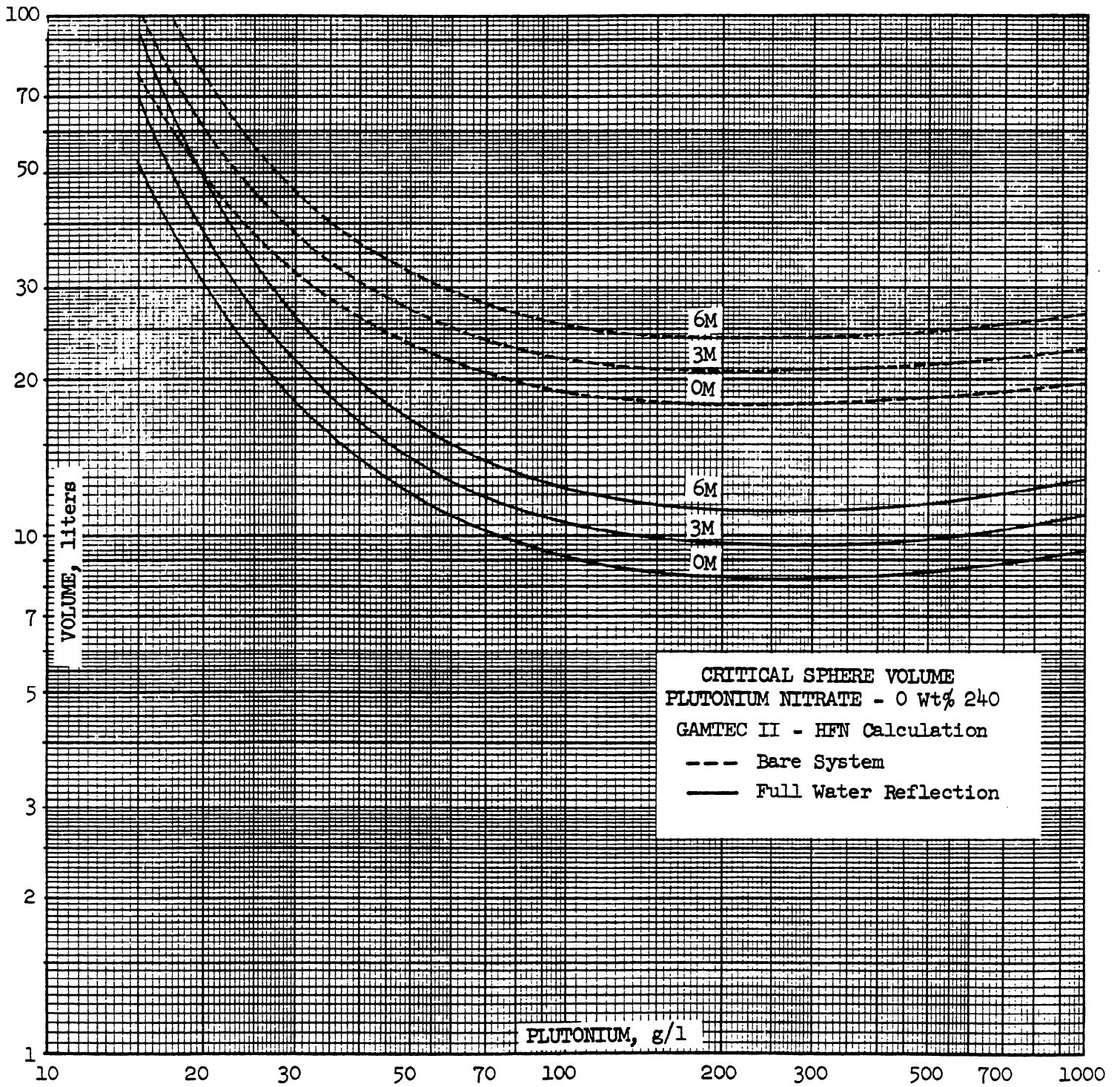


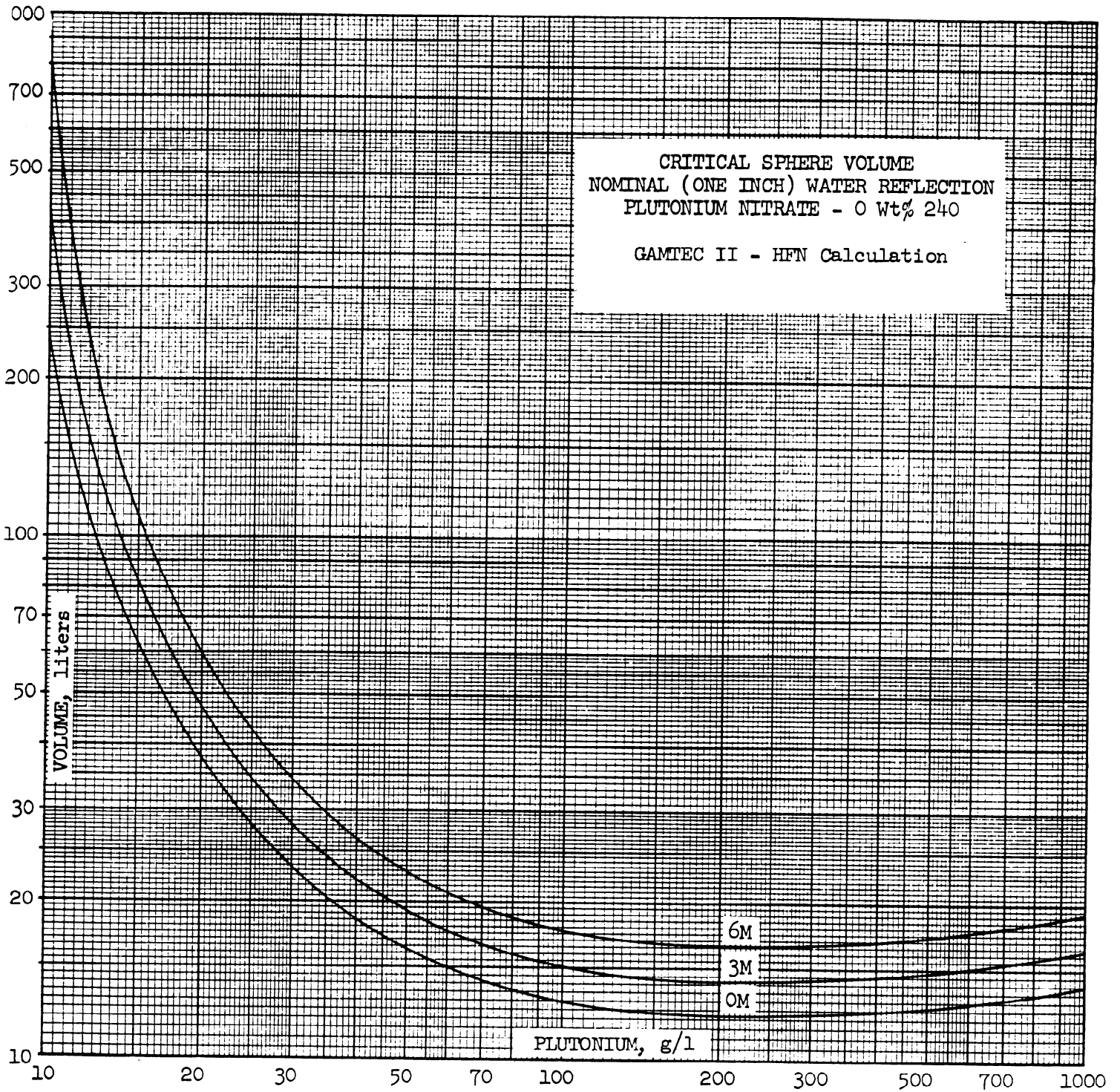


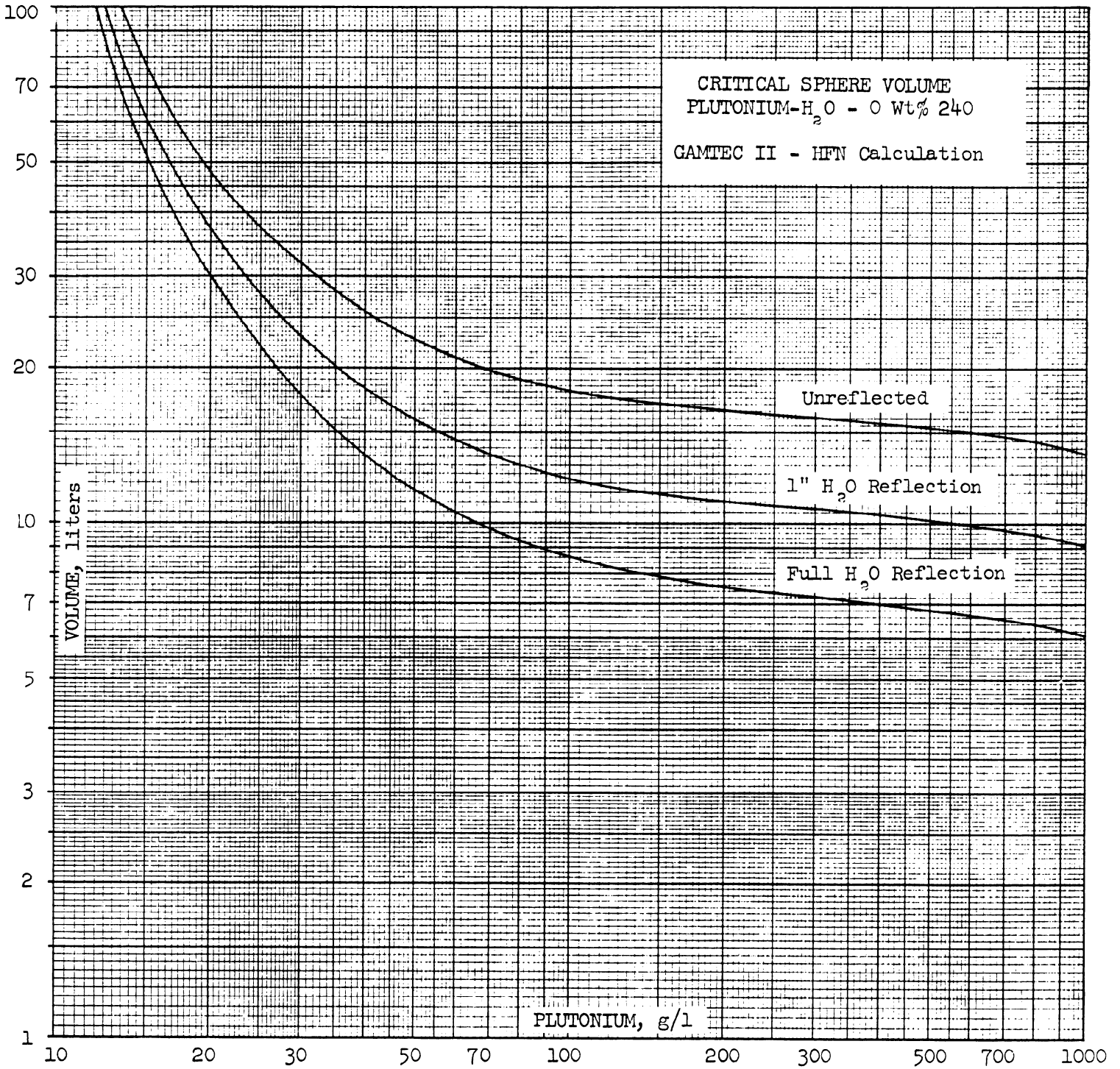


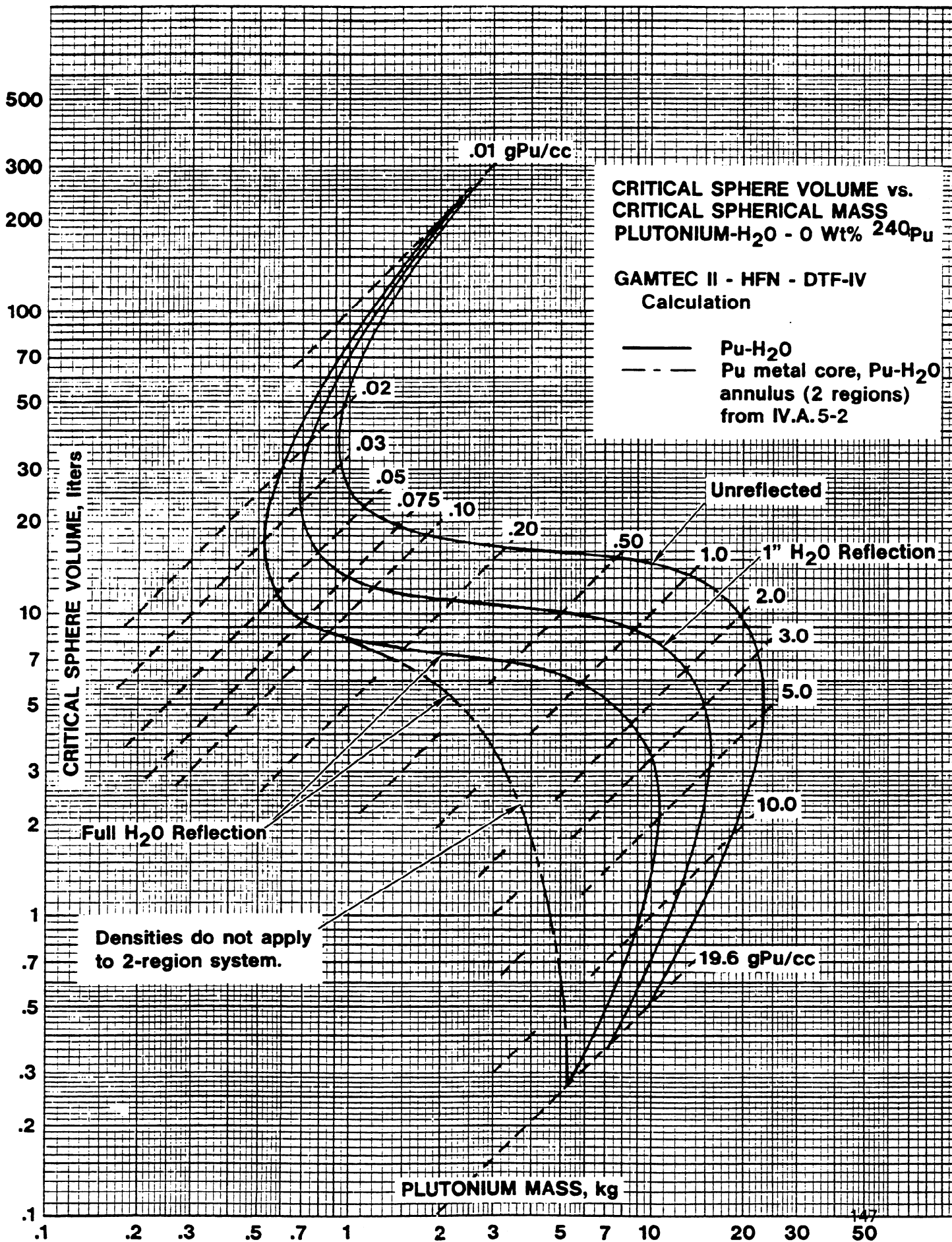
III.A.9(97)-5

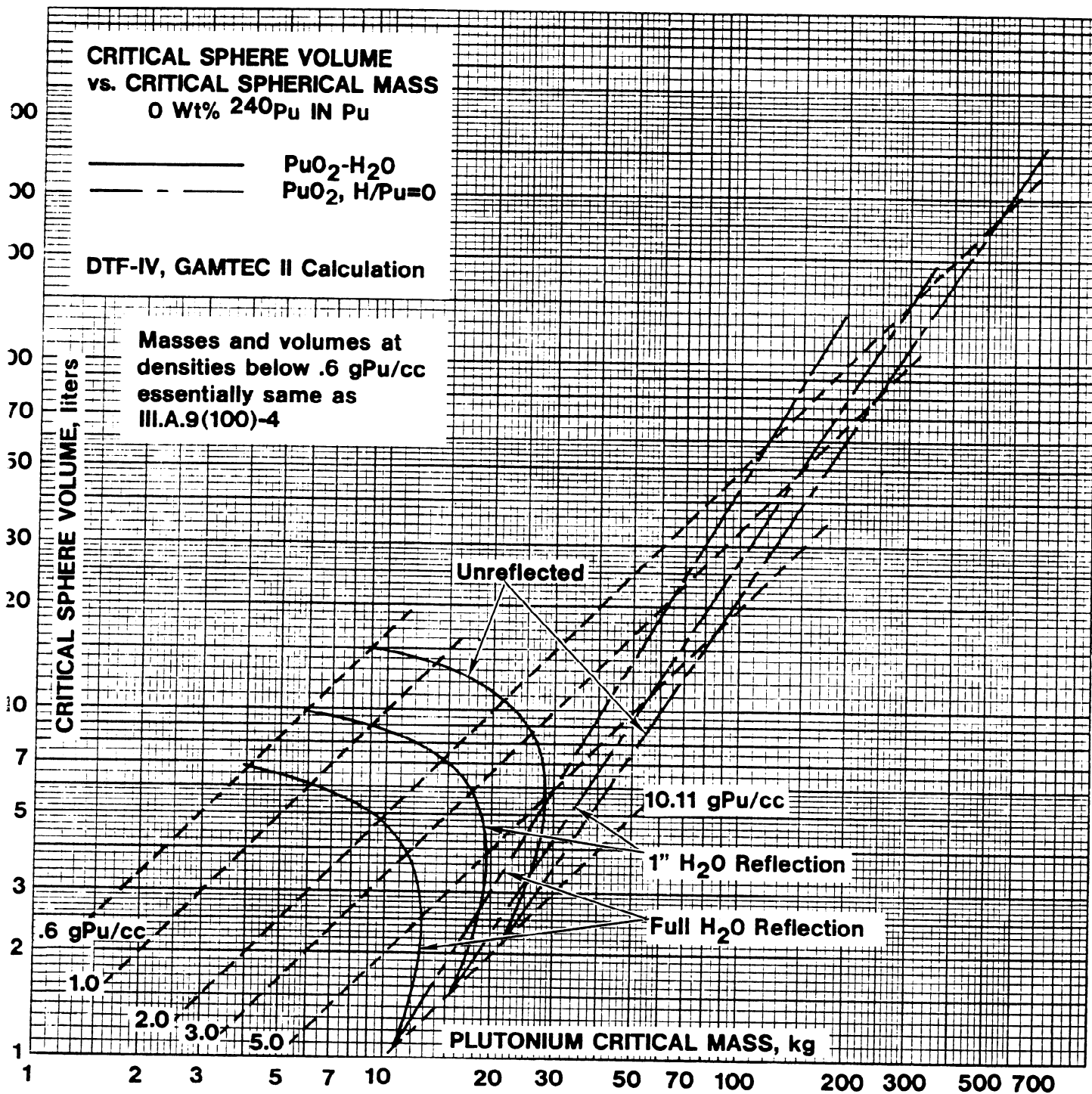
ARH-600



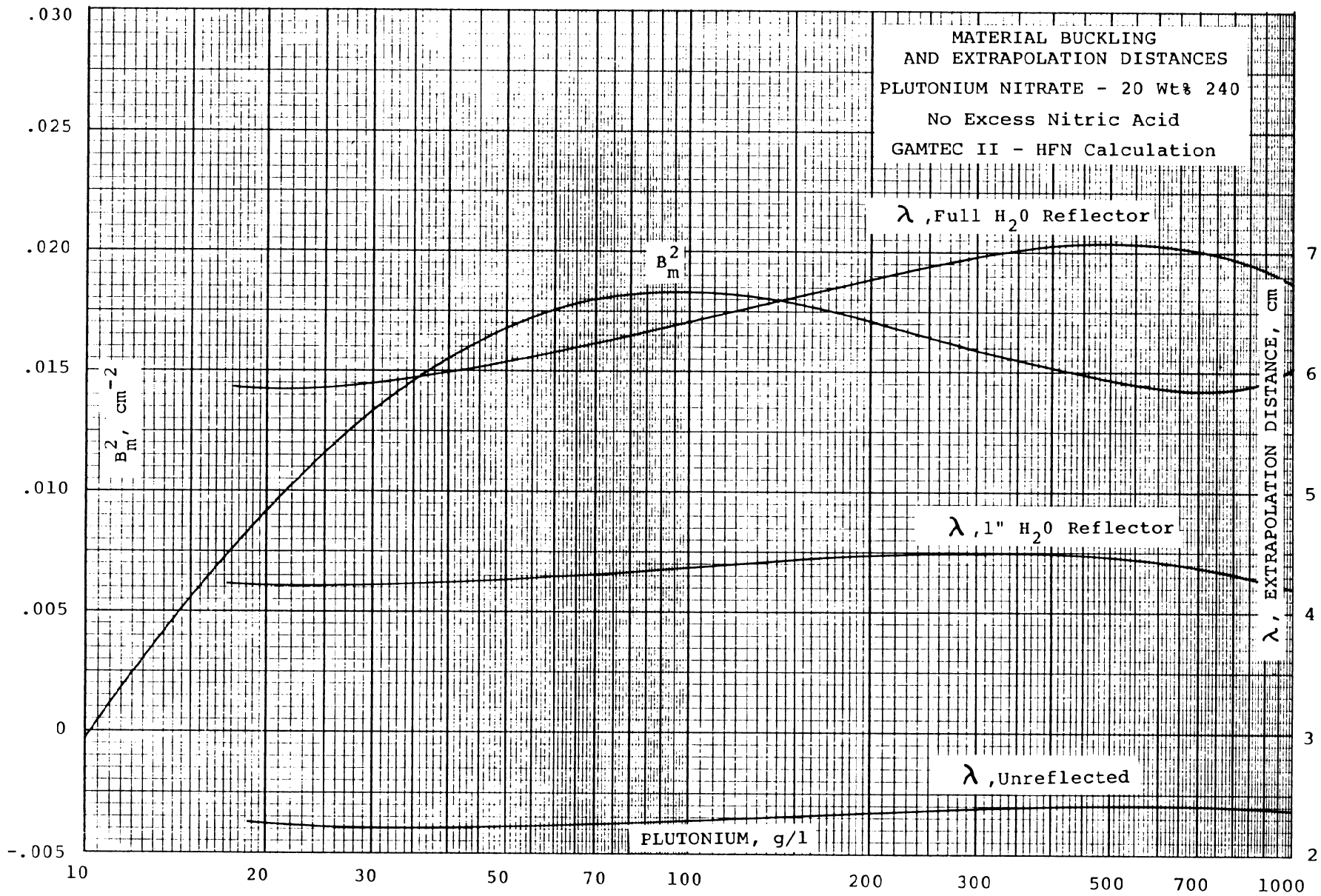


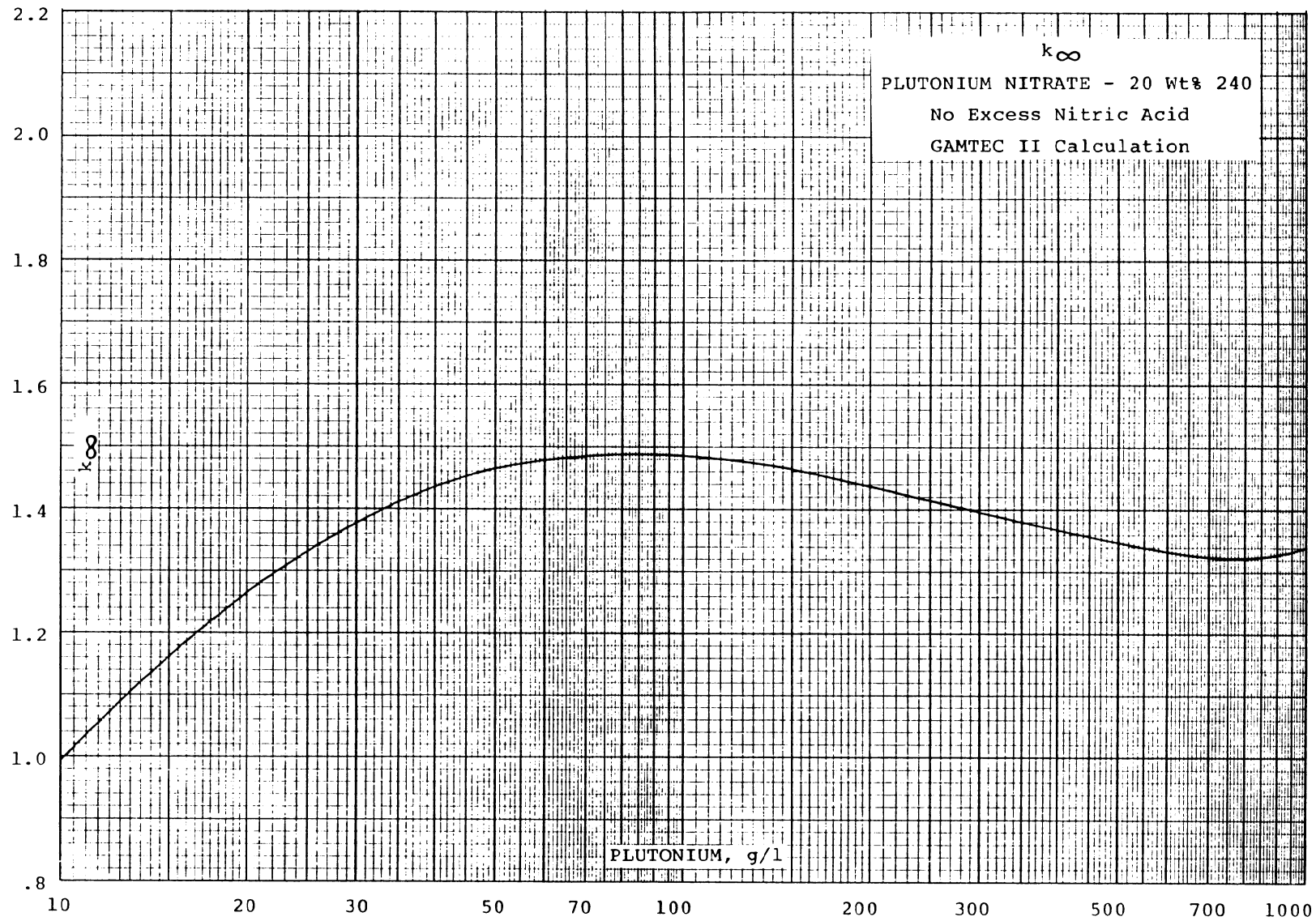




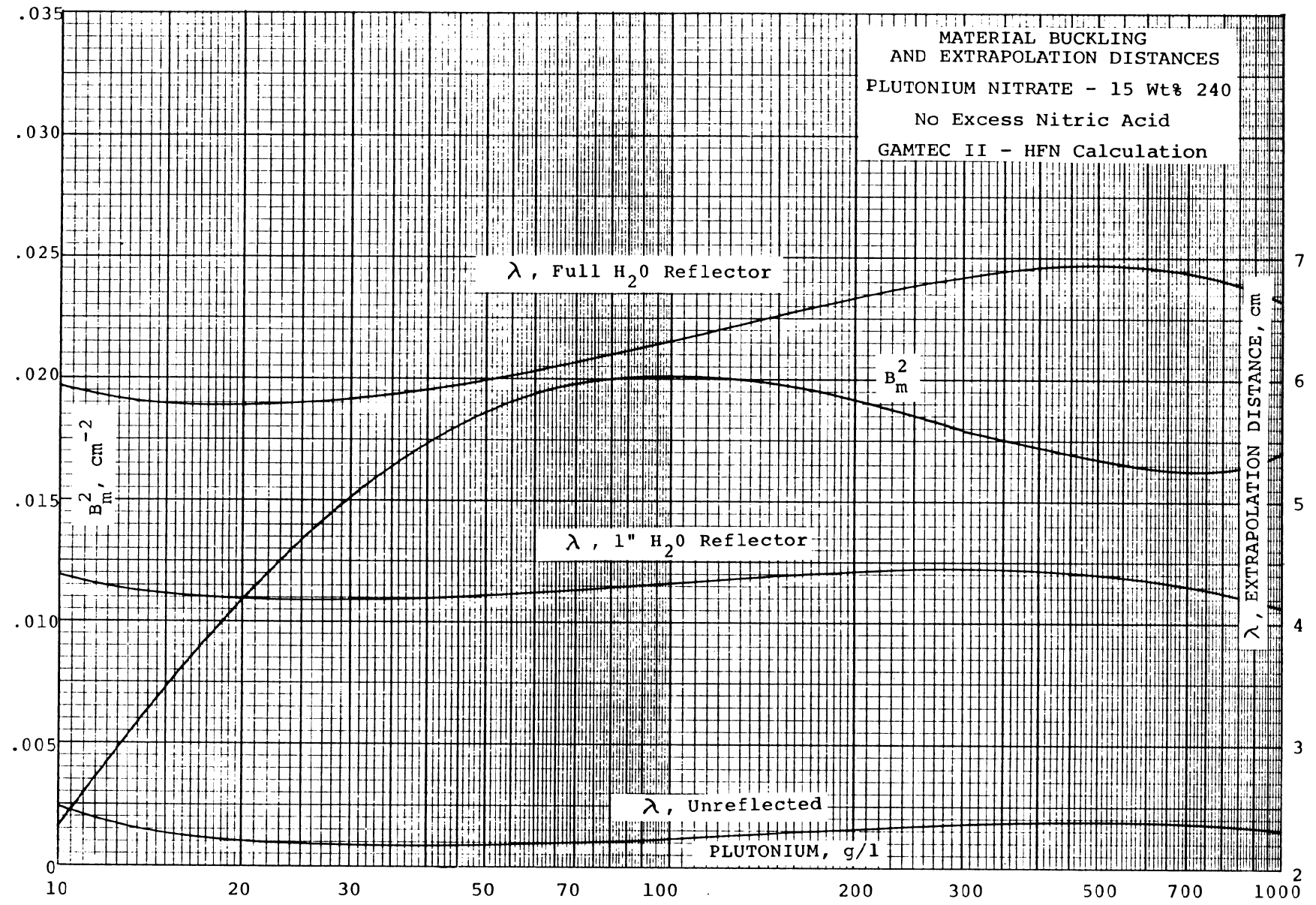


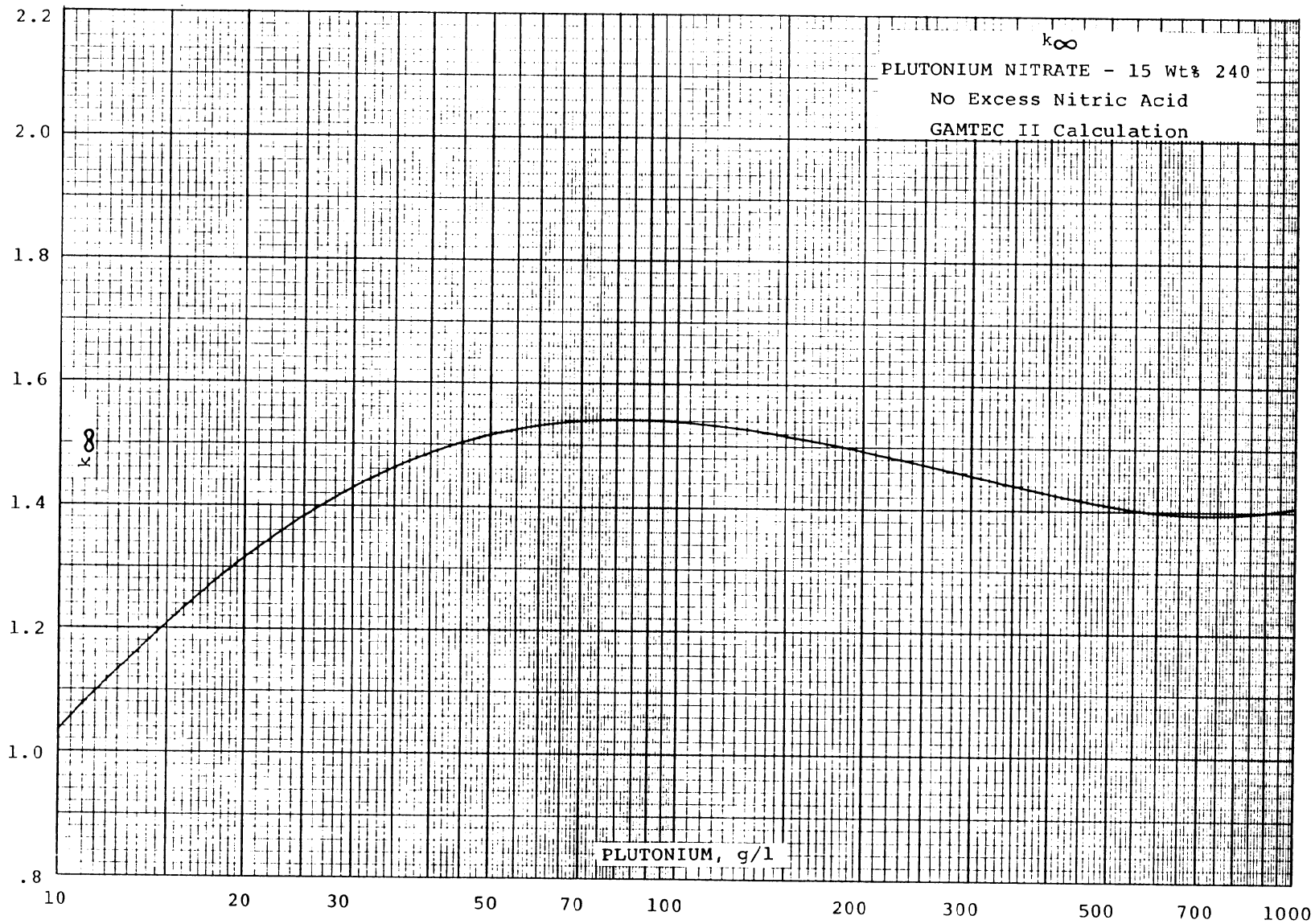


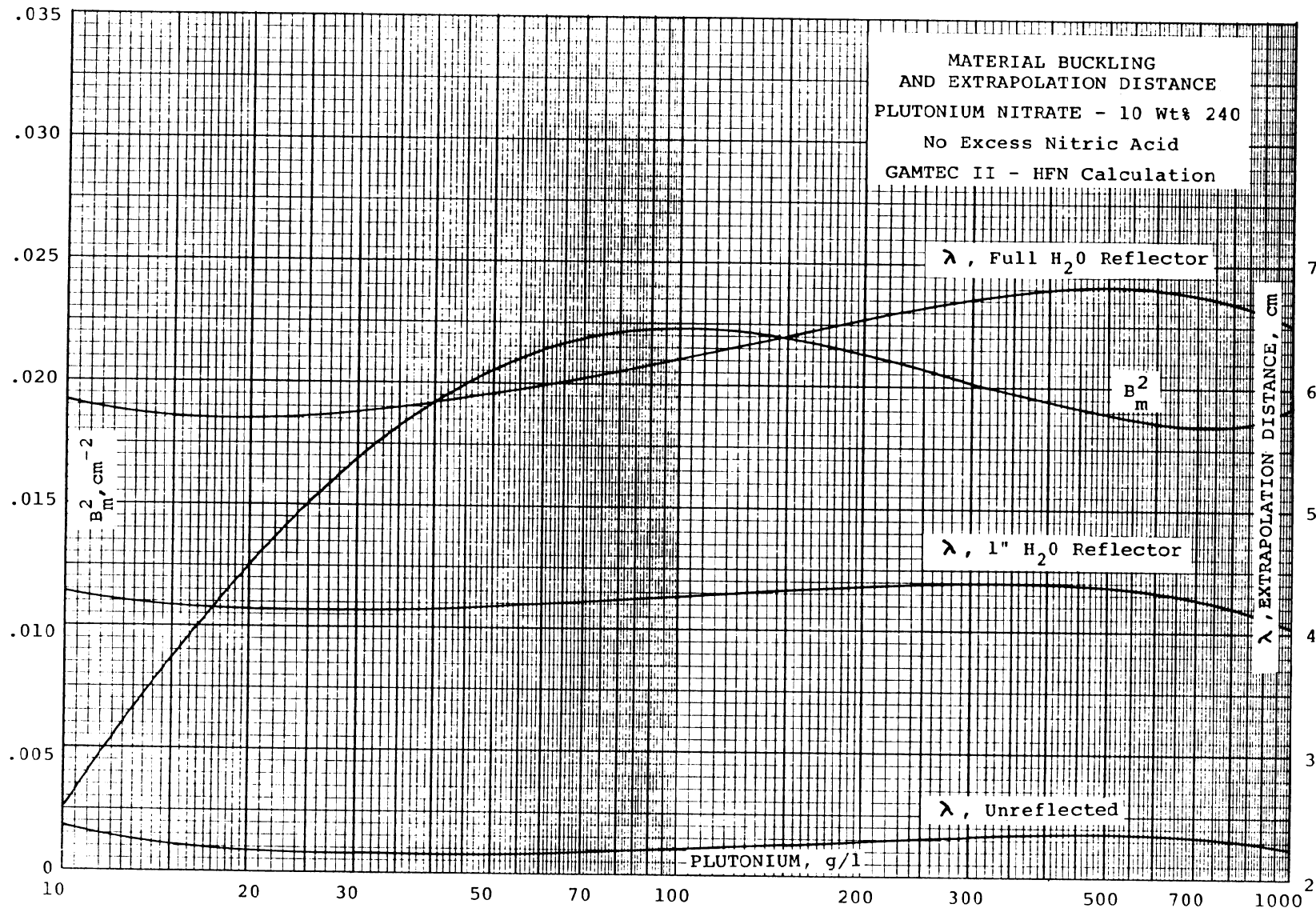




MATERIAL BUCKLING  
 AND EXTRAPOLATION DISTANCES  
 PLUTONIUM NITRATE - 15 Wt% 240  
 No Excess Nitric Acid  
 GAMTEC II - HFN Calculation

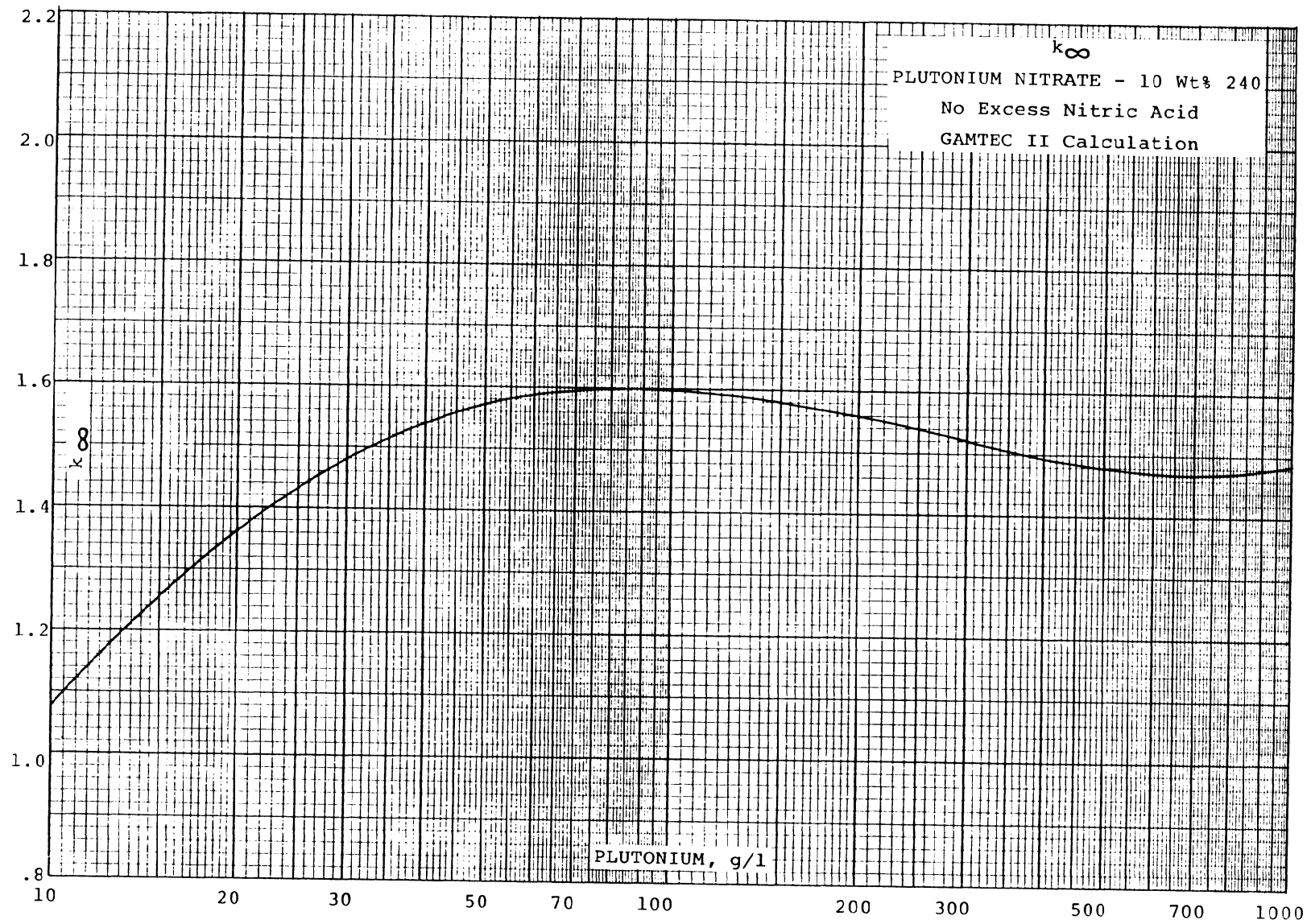


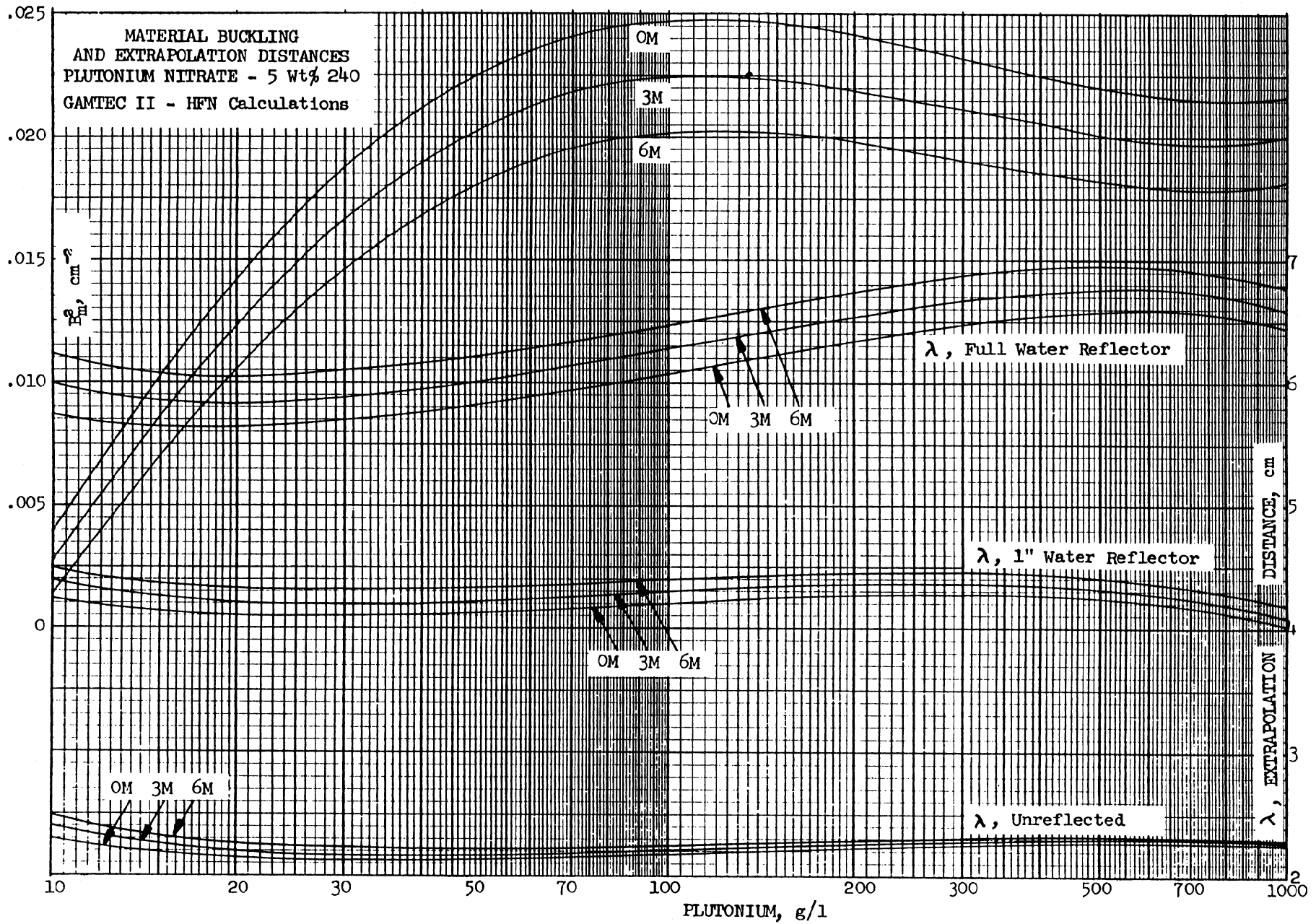




III.A.10(90)-1

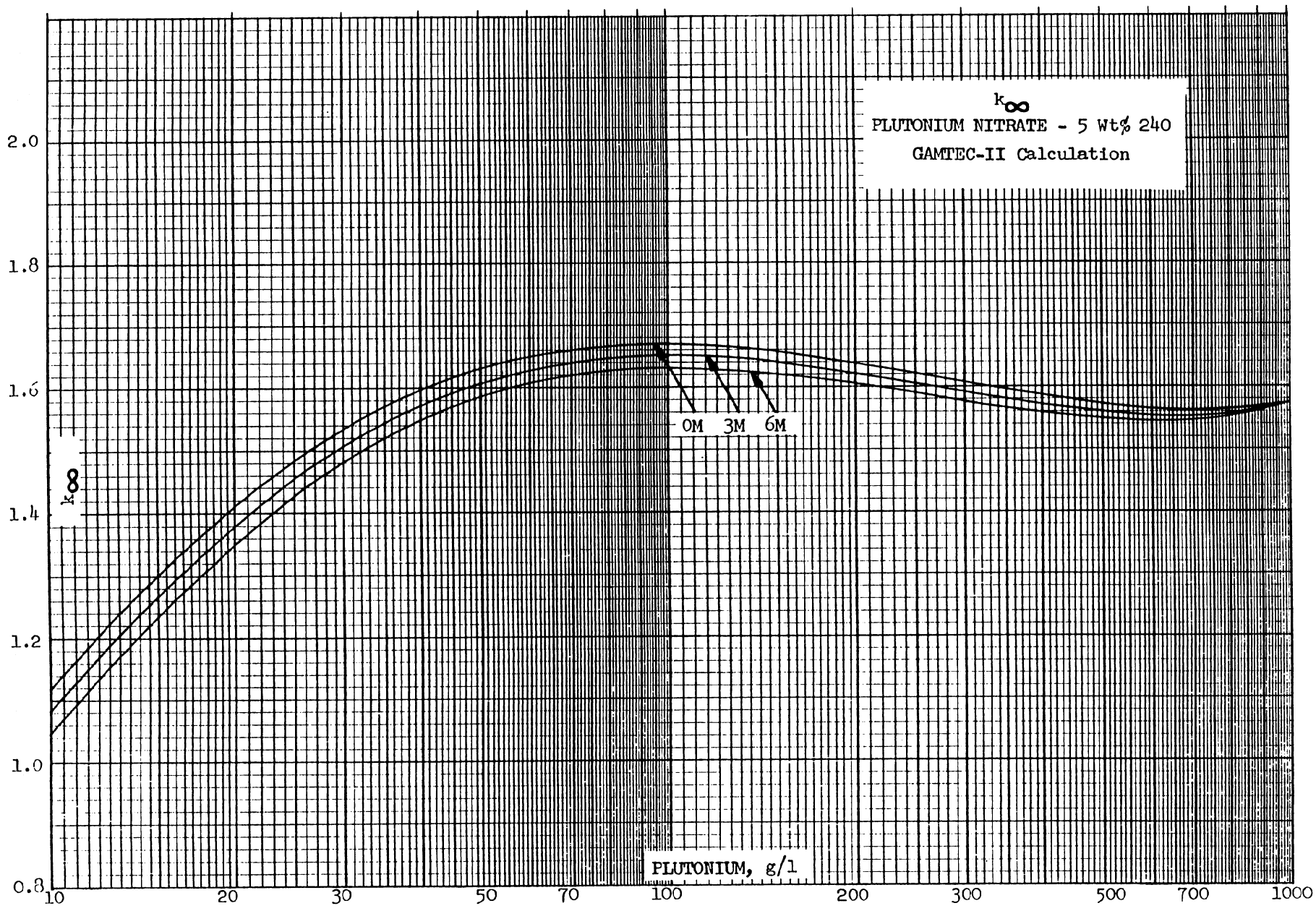
ARR-600





III.A.10.95-1

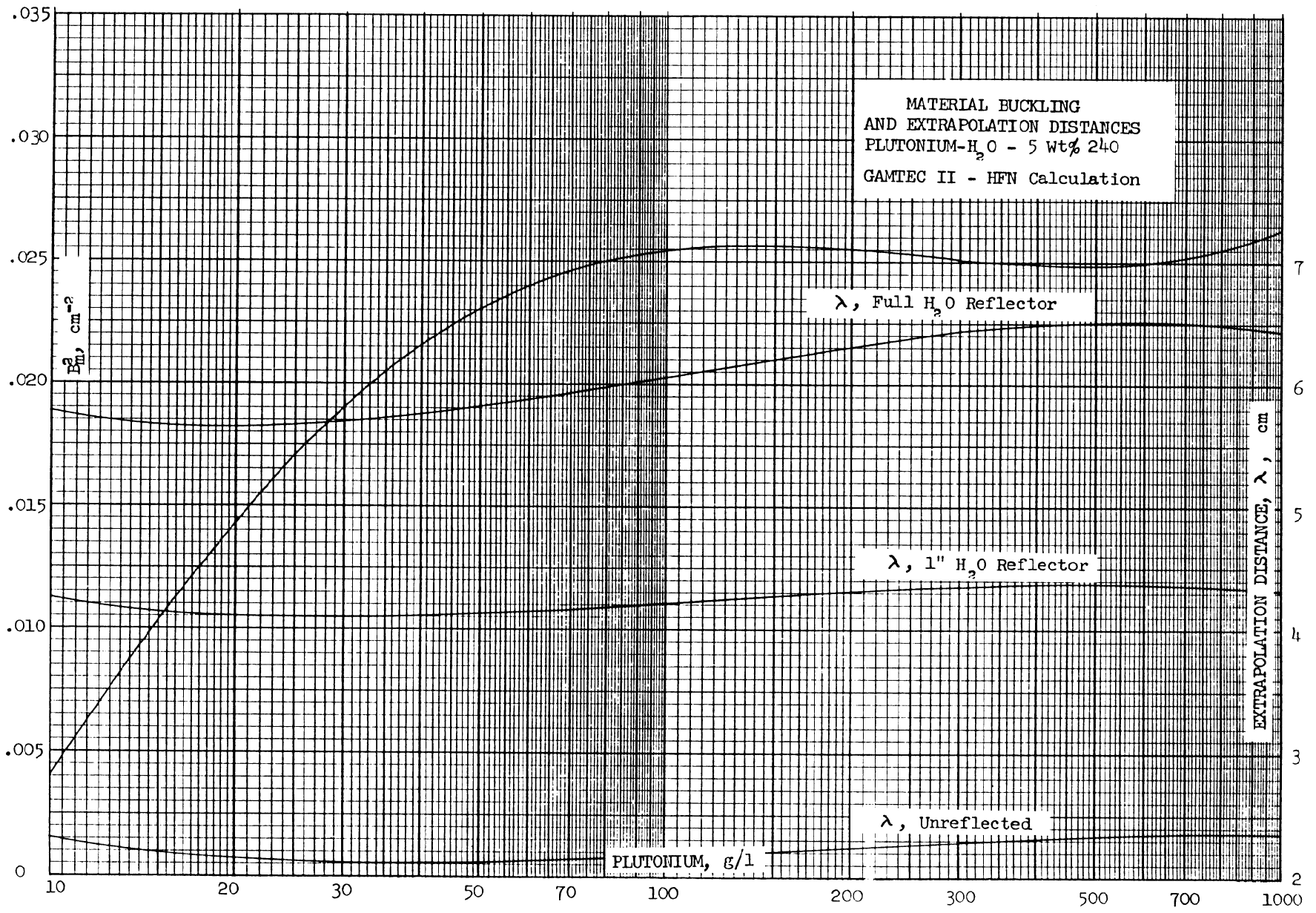
ARR-600



III.A.10.95-2

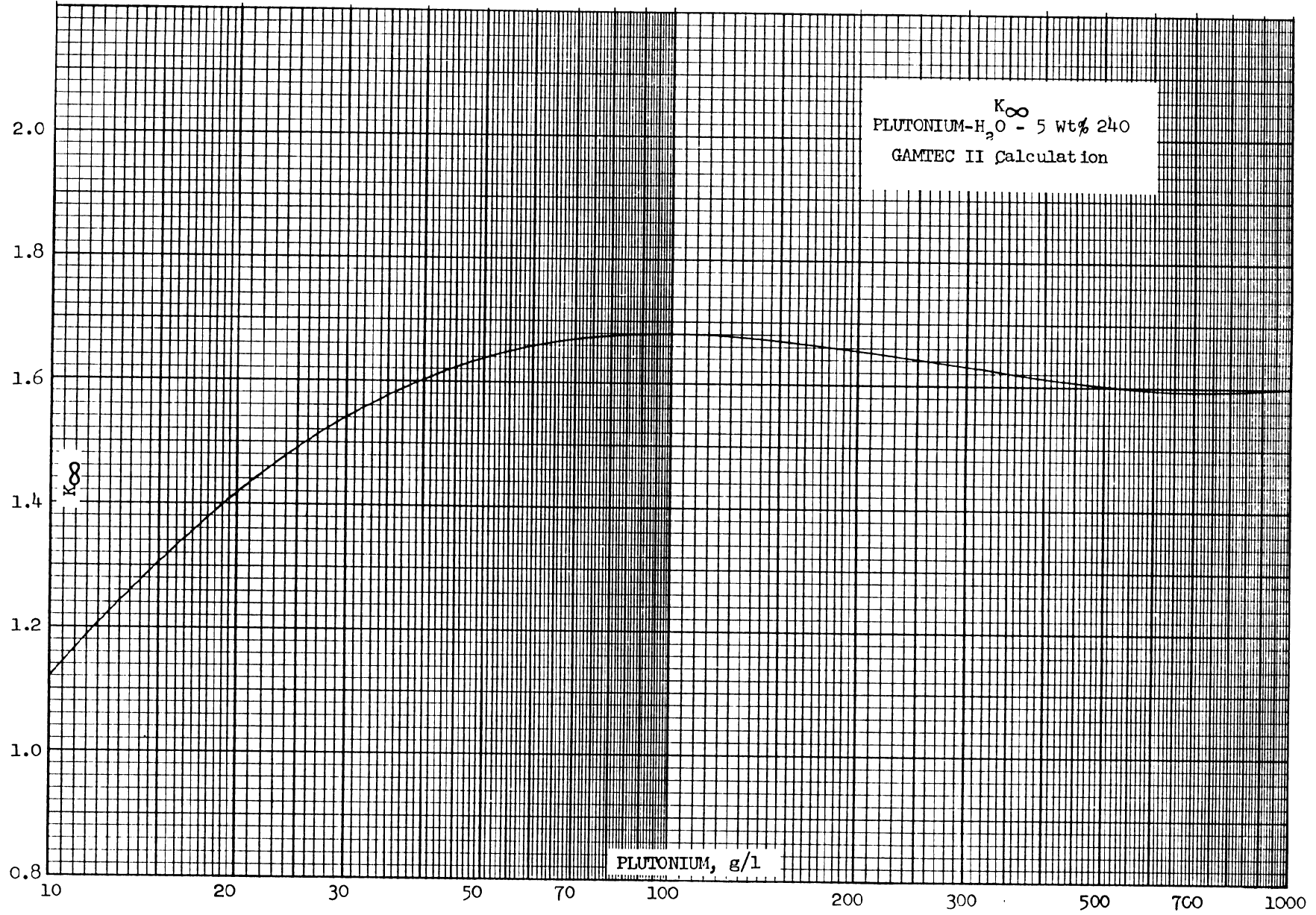
ARR-600





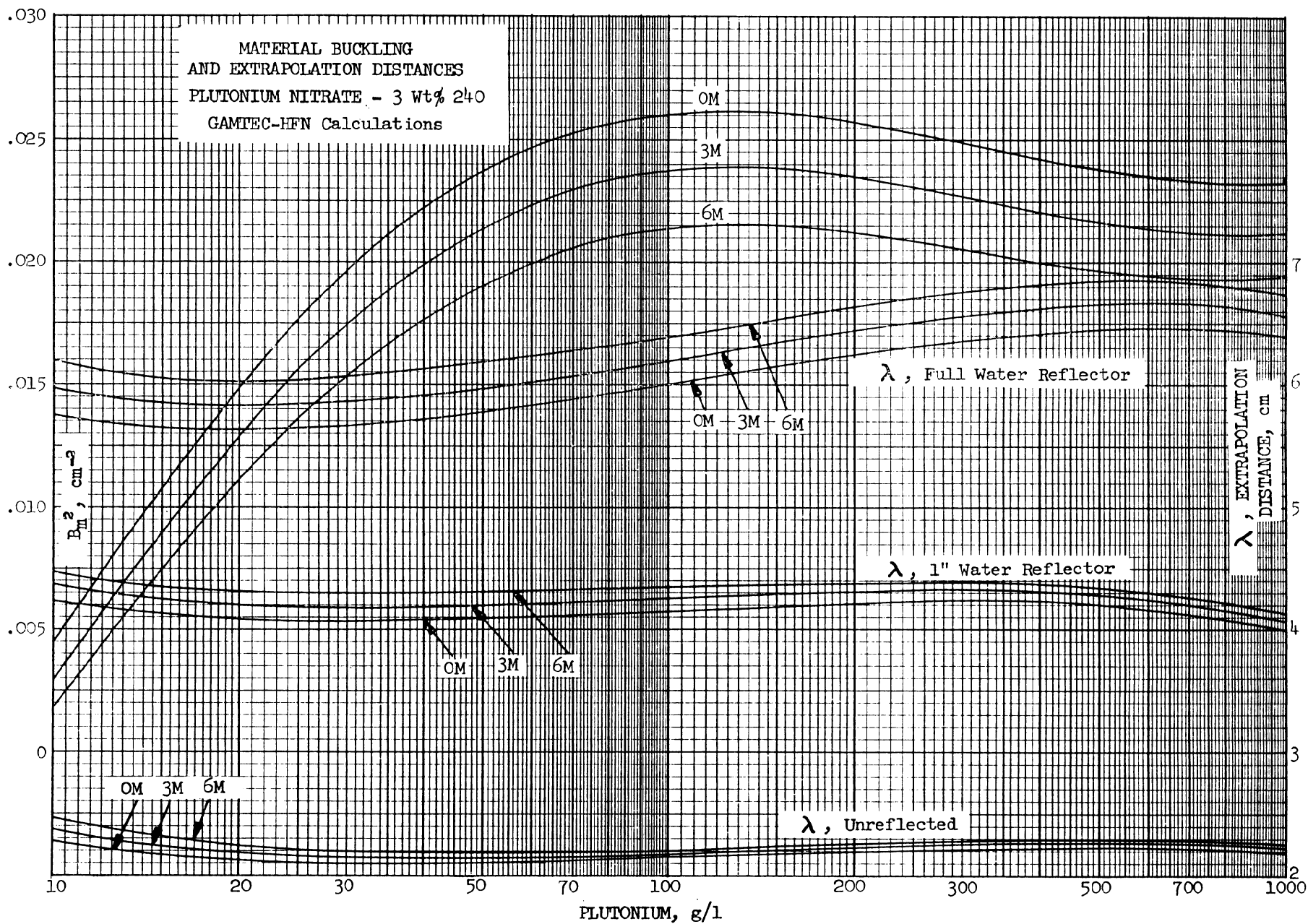
III.A.10.95-3

ARR-500

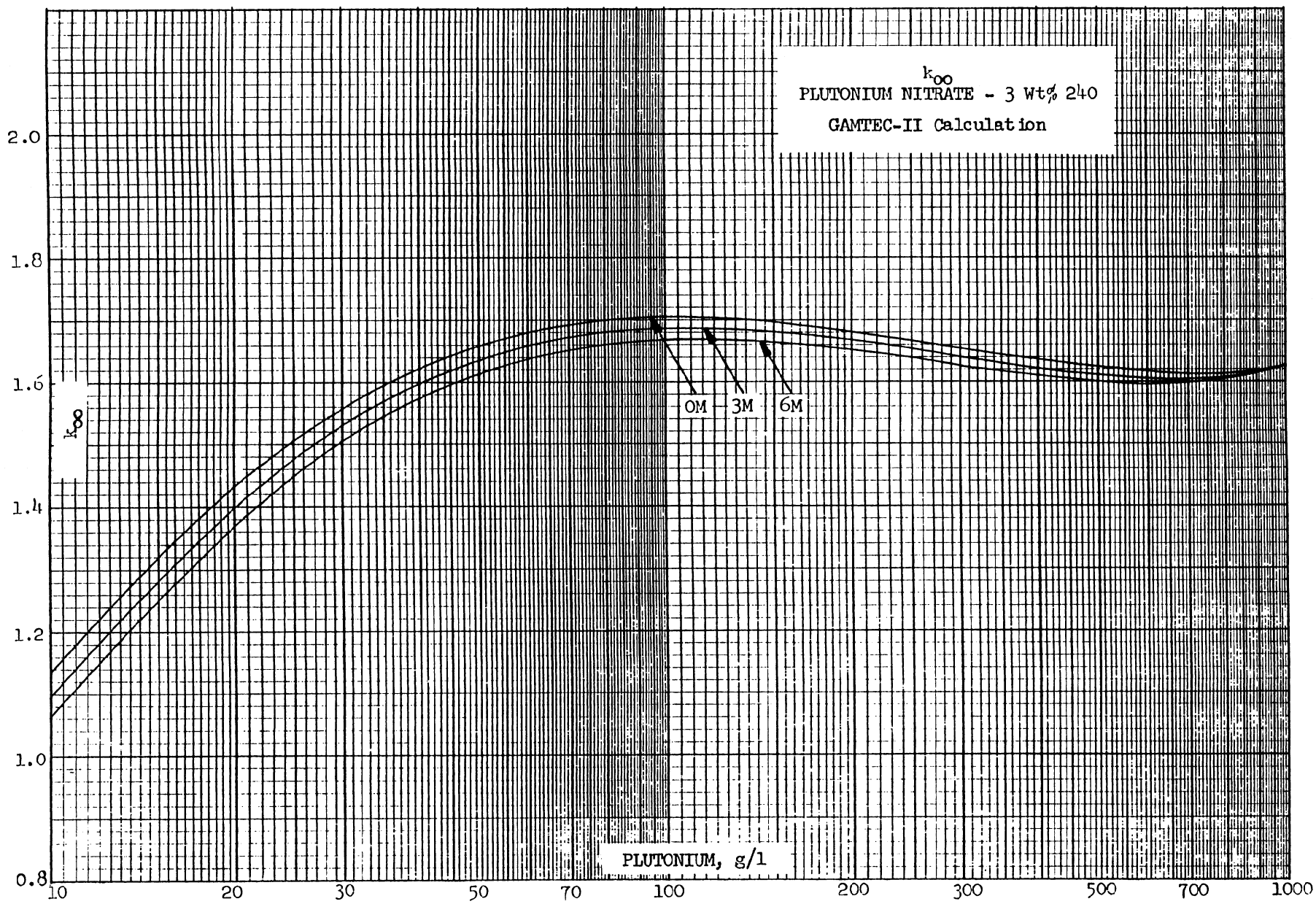


III.A.10.95-4

ARH-600

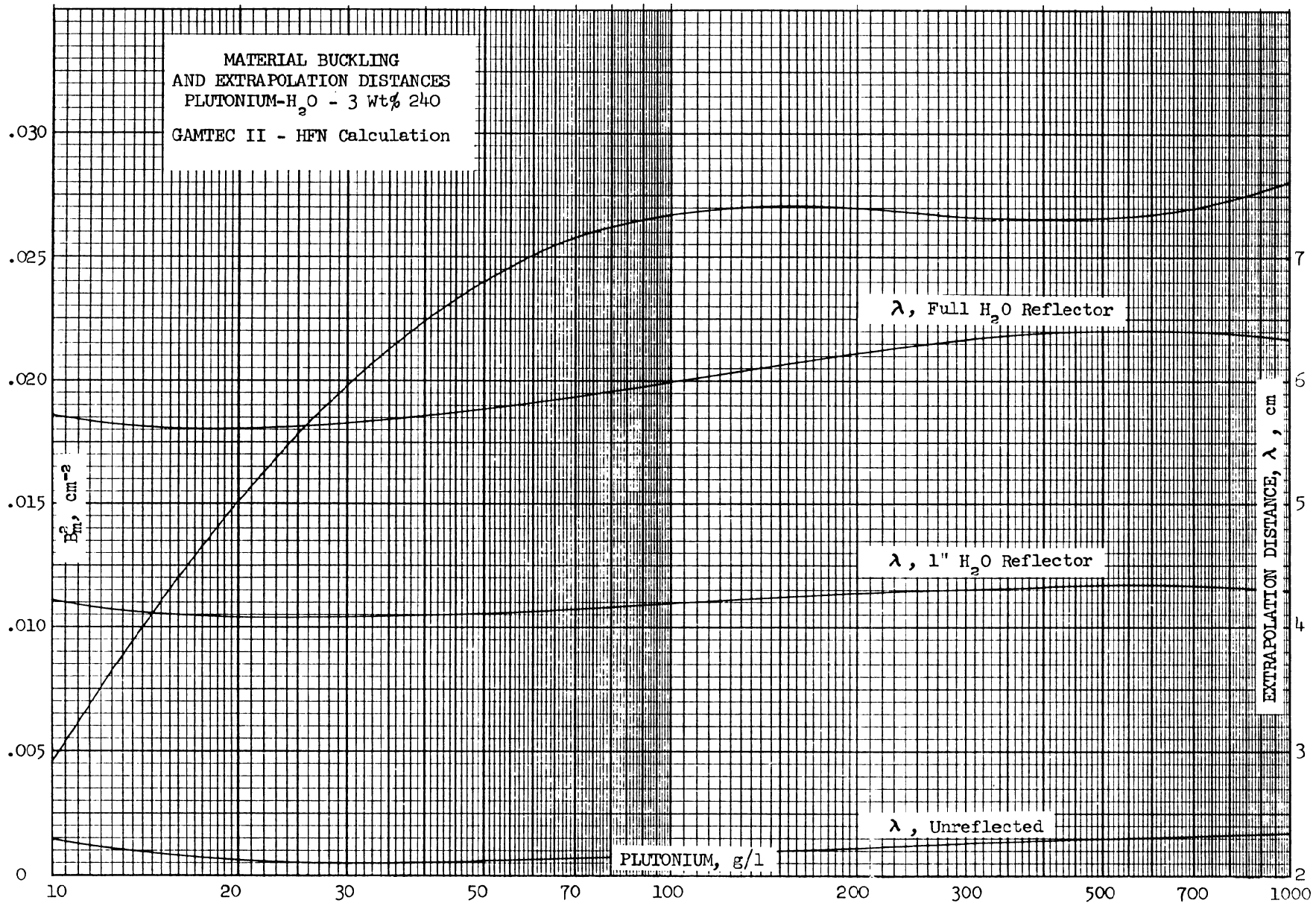


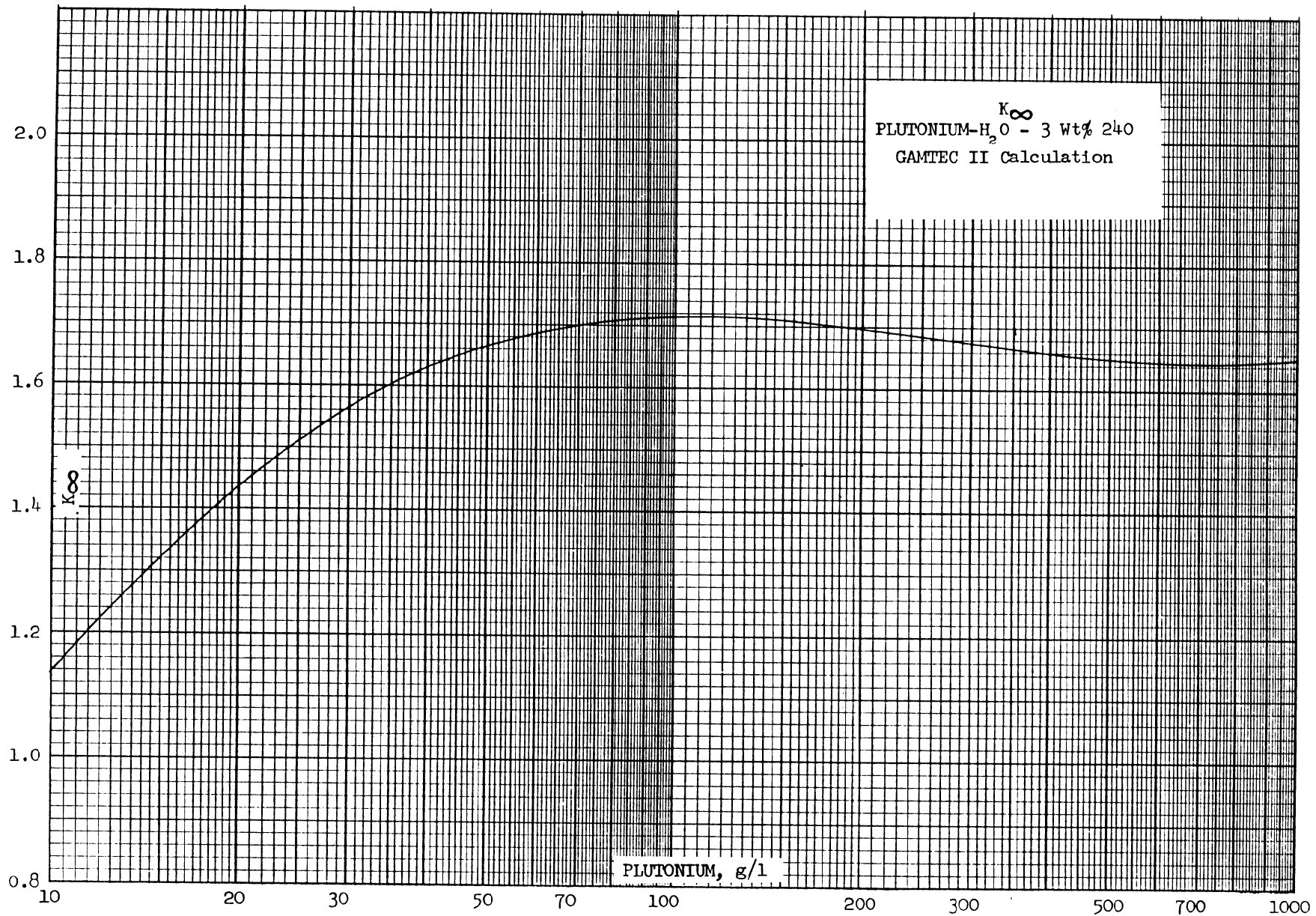
Revised 4/7/72



III.A.10 (97)-2

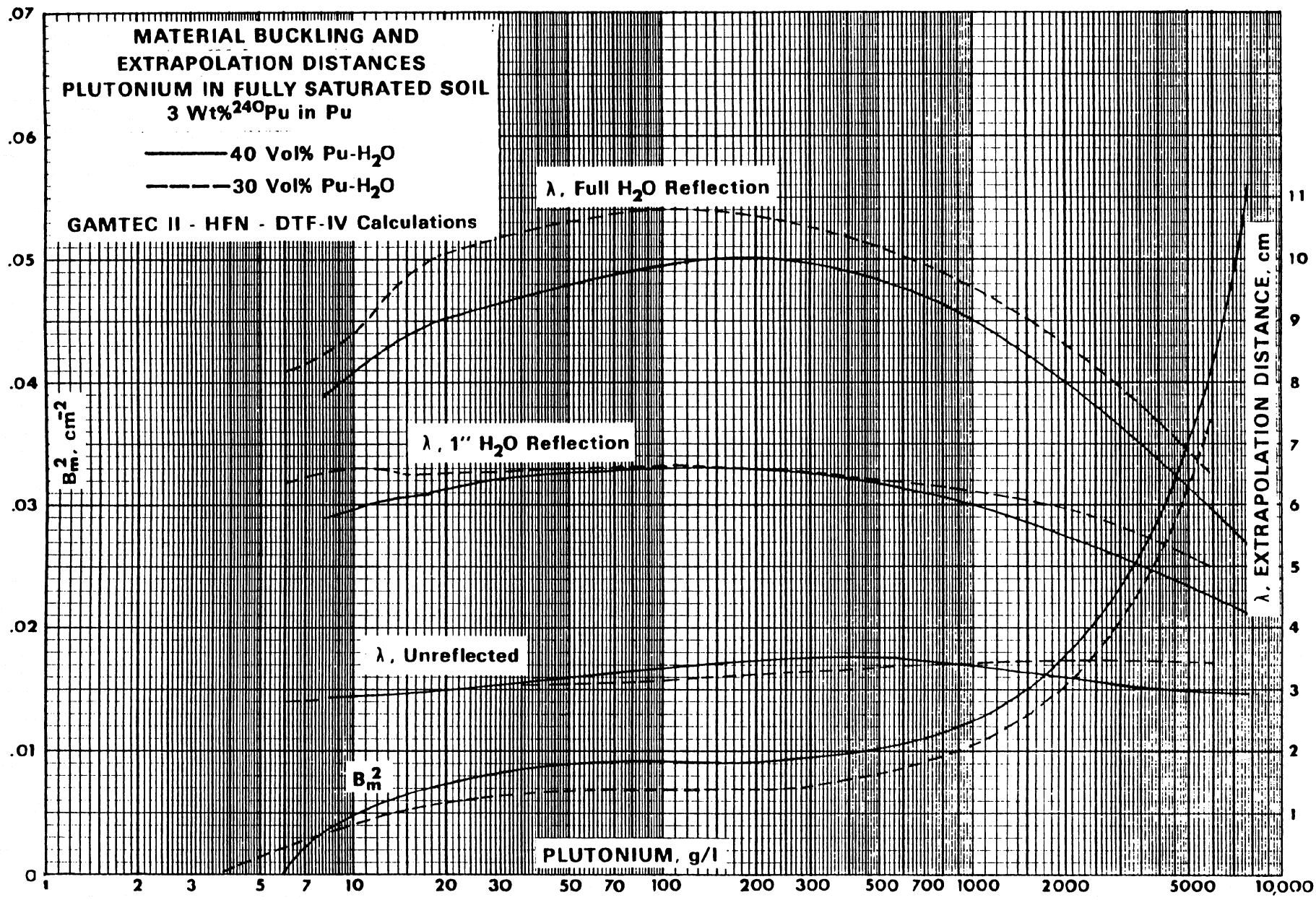
ARR-500

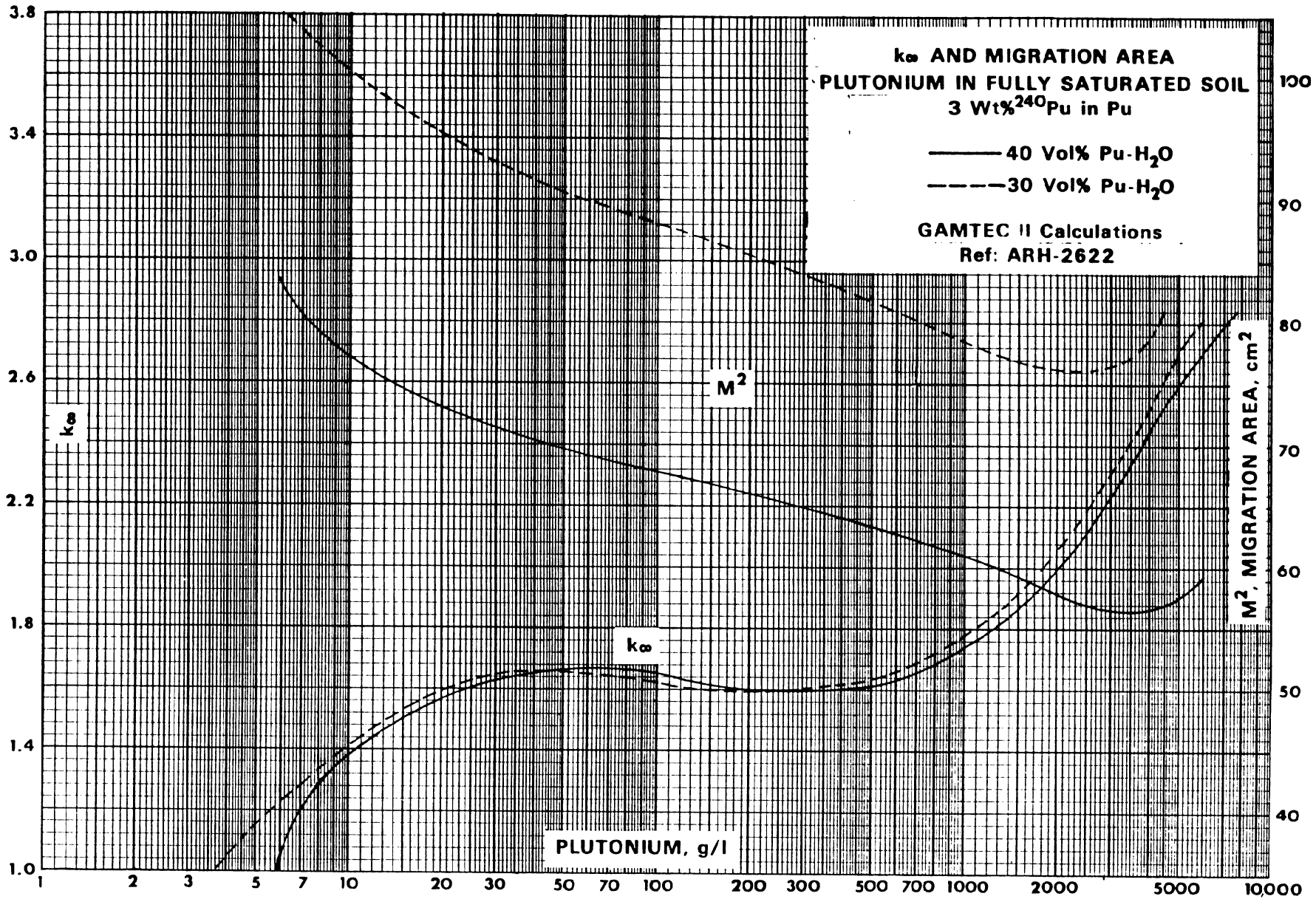




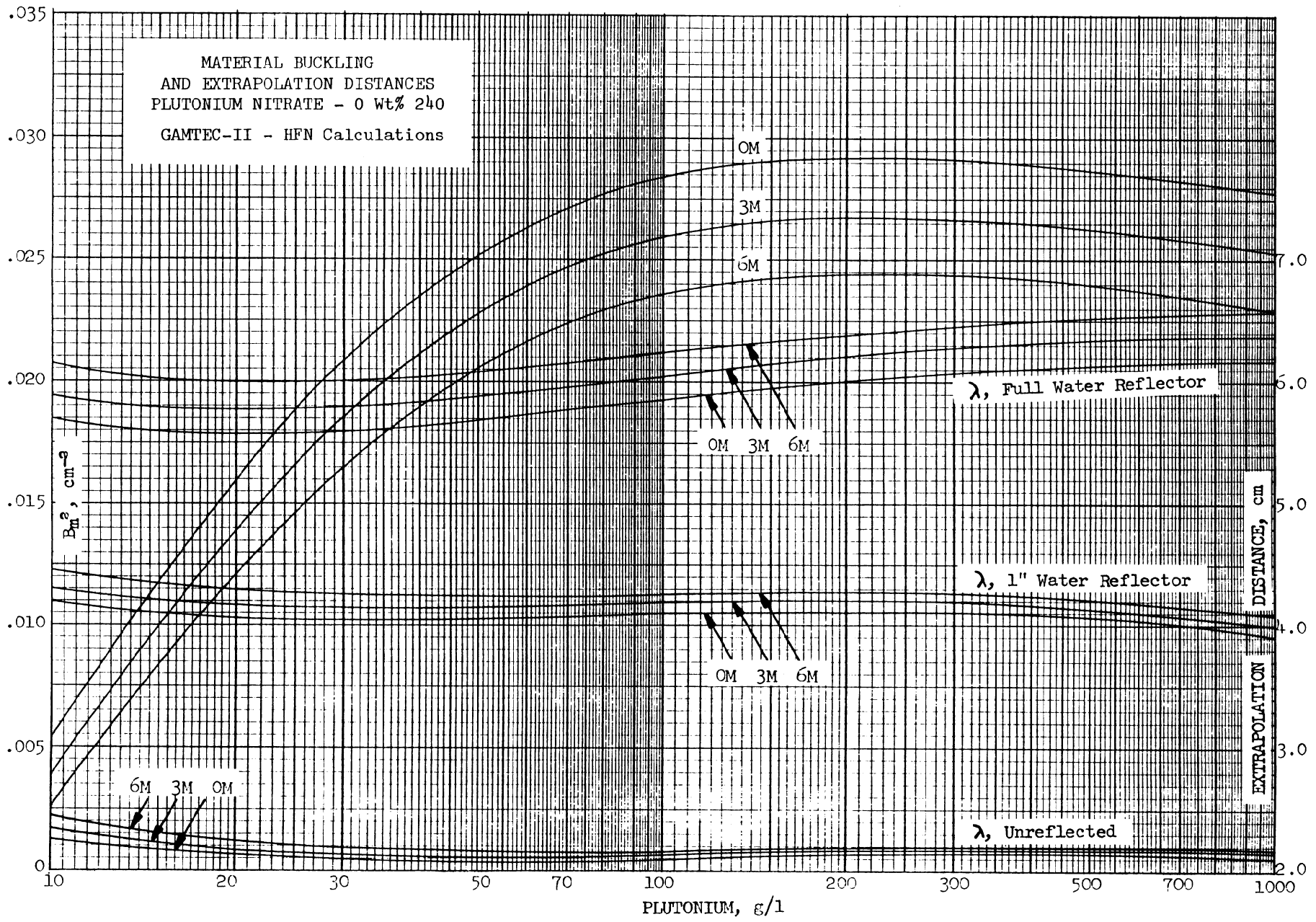
III.A.10.97-4

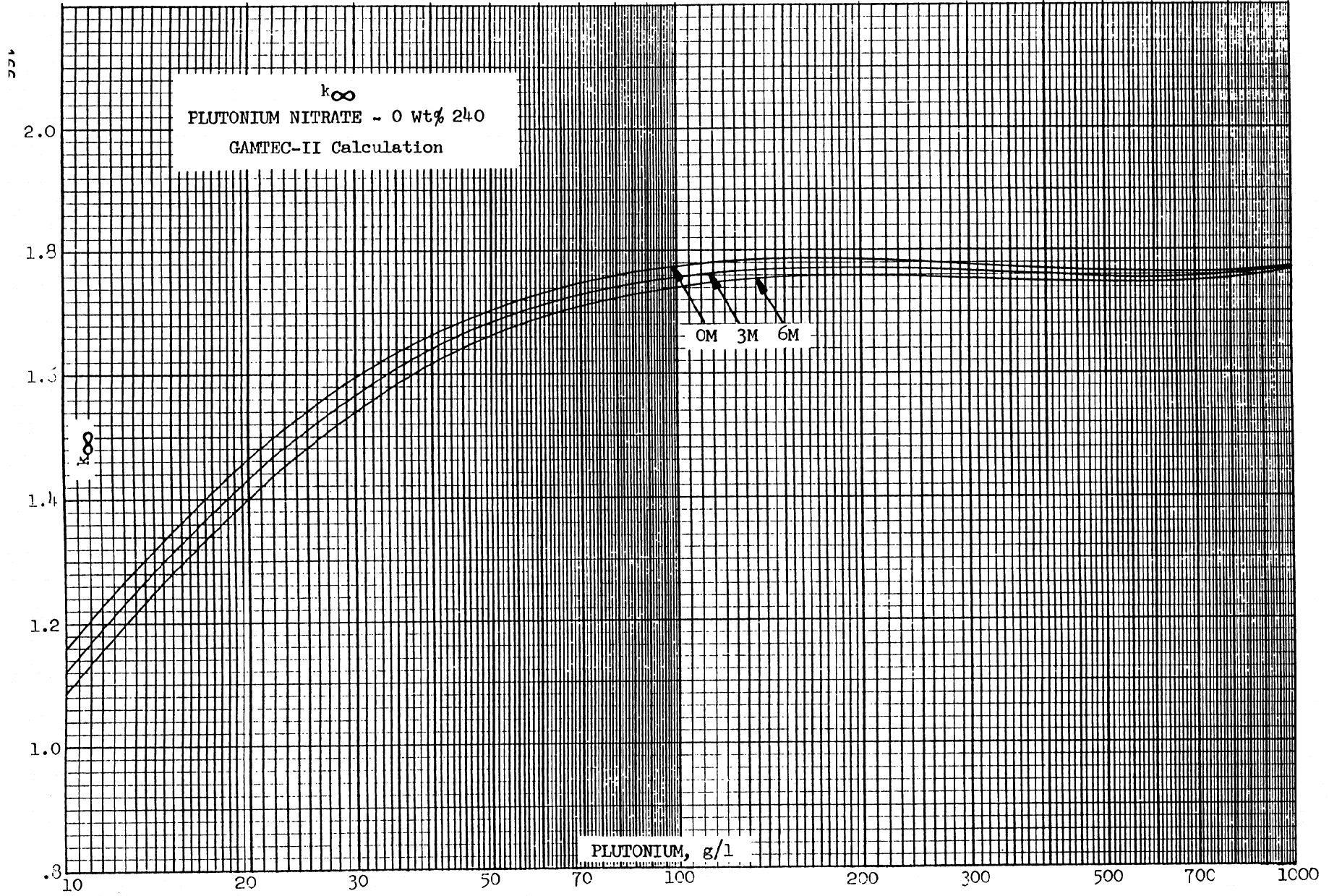
ARR-600

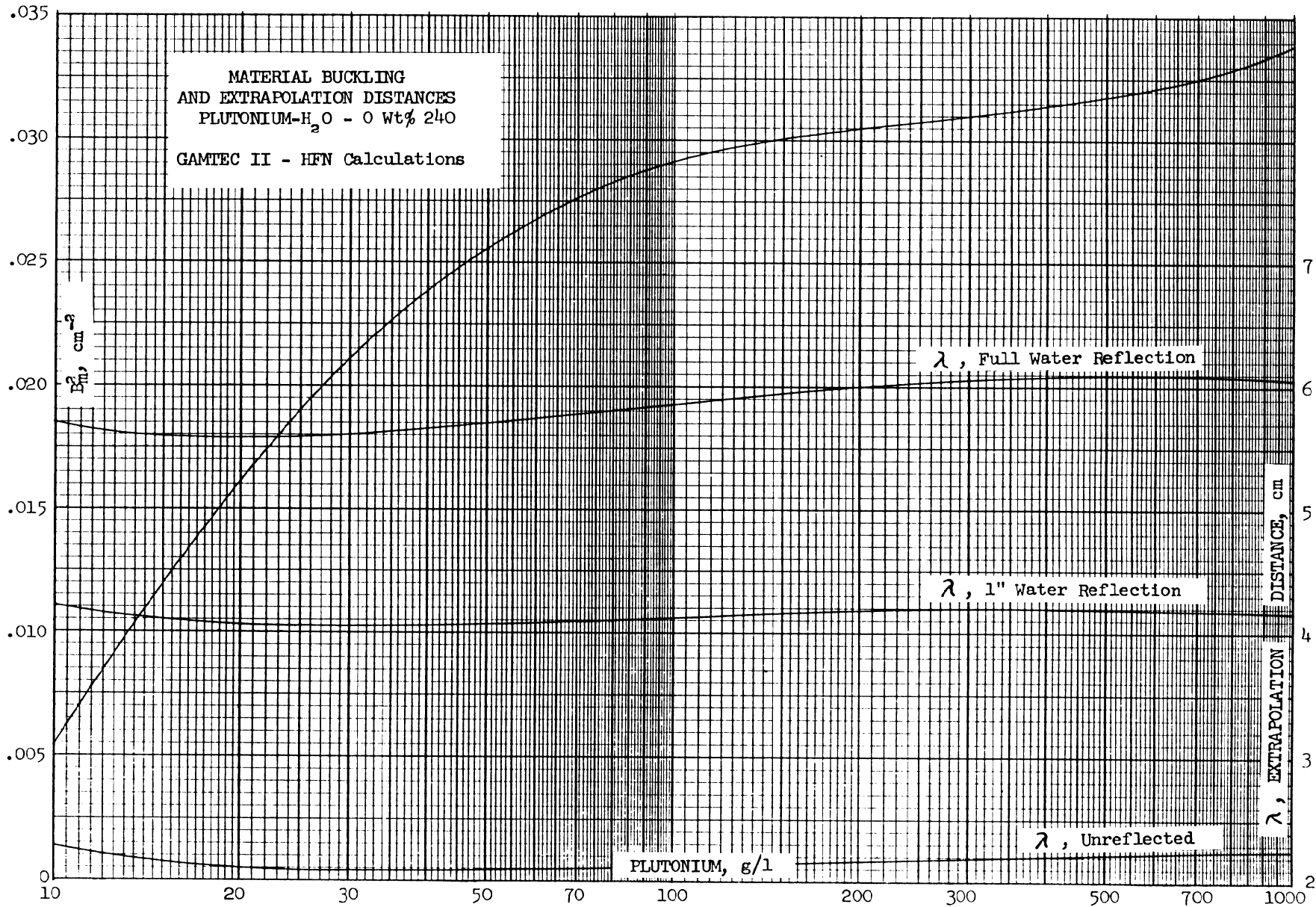






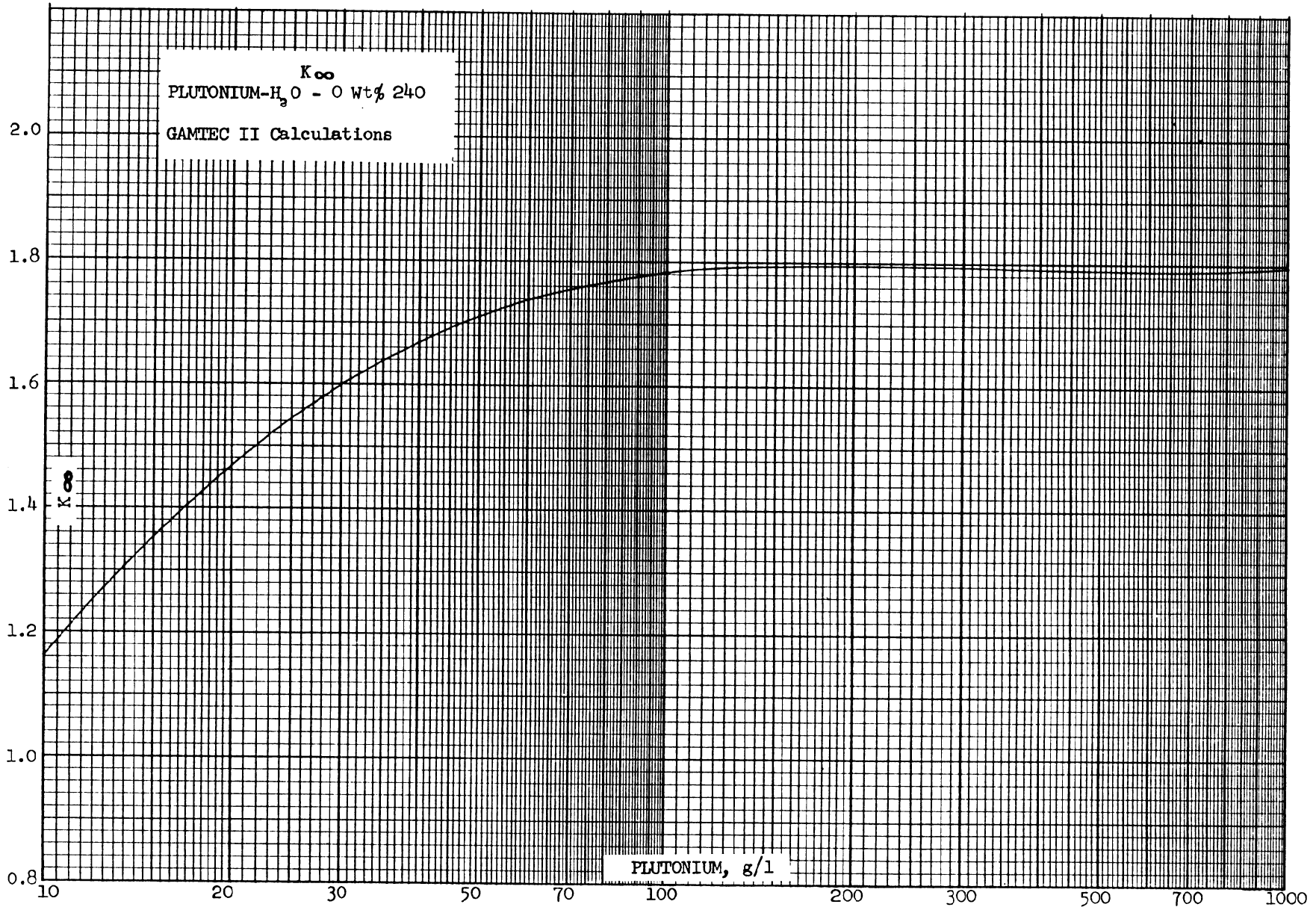






III.A.10.100-3

ARH-600



III.A.10.100.4

ARH-600

## III. HOMOGENEOUS DATA

## B. URANIUM-235 SYSTEMS

1. Correlation Between Calculation and Experiment
2. H/U versus Uranium g/l Relationship
3. Critical Sphere Dimensions

Earlier graphs within these divisions have the percentage by weight of the major fissile isotope (U-235) as the fourth identification number (e.g., III.B.3.97-2 would signify the second graph showing data for uranium containing 97 weight percent U-235). Because the use of fractional percentages made the page number difficult to read, later graph identification has been changed to set off the weight percent by parentheses, III.B.3(97)-2, in the interest of clarity.

4. Critical Cylinder Dimensions
5. Critical Slab Dimensions
6. Critical Mass - Sphere
7. Critical Mass per Unit Height - Cylinder
8. Critical Mass per Unit Area - Slab
9. Critical Volume
10. Material Bucklings and Infinite Multiplication Factor

BASIC URANIUM-235 CRITICAL PARAMETERS

These basic values are taken from references which would normally be used as bases for standards. ARH-600 values compare favorably.

<u>METAL</u>	<u>Full Reflection*</u>	<u>Bare** (3)</u>
Minimum critical spherical mass, Kg $^{235}\text{U}$ 18.82 g/cm <sup>3</sup>	21.85 (1)	
Minimum critical spherical mass, Kg $^{235}\text{U}$ (93.5) 18.8 g/cm <sup>3</sup>	22.8 (2)	47.
Infinite cylinder diameter, inches, $^{235}\text{U}$ 18.82 g/cm <sup>3</sup>	3.0 (1)	4.5
Infinite slab thickness, inches, $^{235}\text{U}$ 18.82 g/cm <sup>3</sup>	0.586 (1)	2.2
Minimum spherical volume, liters, $^{235}\text{U}$ 18.82 g/cm <sup>3</sup>	1.16 (1)	2.7
<u>HOMOGENEOUS SOLUTIONS (4)</u>		
Minimum critical mass, g $^{235}\text{U}$	820	1400
Infinite cylinder diameter, inches	5.63	8.5
Infinite slab thickness, inches	1.93	4.5
Minimum spherical volume, liters	6.1	14.0
Minimum areal concentration g/ft <sup>2</sup>	390	~520
Minimum critical aqueous concentration, g/l $^{235}\text{U}$	11.8	
Minimum enrichment for criticality, Wt% $^{235}\text{U}$ (5)	1.034 ± 0.010	
Minimum enrichment for criticality for UNH solutions, Wt% $^{235}\text{U}$ (6)	2.104 ± 0.010	

\* Reflector is water unless otherwise specified.

\*\* "Bare" solutions have 1/16-inch stainless steel reflector.

(1) W. H. Roach and D. R. Smith. "Estimates of Maximum Subcritical Dimensions of Single Fissile Metal Units", ORNL-CDC-3, October, 1967, (reflected metal systems).

(2) G. A. Graves and H. C. Paxton. "Critical Masses of Oralloid Assemblies", Nucleonics 15, No. 6, 90, June, 1957, (bare metal systems).

- (3) H. C. Paxton, et al. "Critical Dimensions of Systems Containing  $^{235}\text{U}$ ,  $^{239}\text{Pu}$  and  $^{233}\text{U}$ ", TID-7028, June, 1964, (for all "bare" systems unless otherwise noted; solutions are U(93.2)-H<sub>2</sub>O with correction for H/U relationships of actual solutions).
- (4) J. W. Webster. "Calculated Neutron Multiplication Factors of Uniform Aqueous Solutions of  $^{233}\text{U}$  and  $^{235}\text{U}$ ", ORNL-CDC-2, October, 1967, (for reflected U(100)O<sub>2</sub>F<sub>2</sub> systems unless noted otherwise).
- (5) H. E. Handler. "Measurement of Multiplication Constant of Slightly Enriched Homogeneous UO<sub>3</sub>-H<sub>2</sub>O Mixture and Minimum Enrichment for Criticality", USAEC Report, HW-70310, August, 1961.
- (6) S. R. Bierman and G. M. Hess. "Minimum Critical  $^{235}\text{U}$  Enrichment of Homogeneous Hydrogenous Uranyl Nitrate", ORNL-CDC-5, June, 1968.

### III.B.1 Correlations Between Calculations and Experiment

The data for 3 weight percent uranium trioxide and 93.2 weight percent uranyl nitrate in this section was obtained by the GAMTEC II (reference 1) and HFN (reference 2) codes. The GAMTEC II code was used to produce 18 neutron energy group cross-section sets that, in turn, were used in the HFN one-dimensional diffusion theory code to produce critical sizes, extrapolation distances and material bucklings. Unless otherwise indicated, the material bucklings for the other enrichments and the  $k_{\infty}$  and migration areas were obtained from the GAMTEC II code alone. GAMTEC II utilizes a special averaging technique to calculate two-group constants, one broad fast group and one thermal group. From these two group constants the code calculates the material buckling and  $k_{\infty}$ .

These parameters for low enriched uranium and the correlation of the GAMTEC II code to experimental data have been reported previously (reference 3).

The migration areas provided by the GAMTEC II code are high compared with those calculated using HFN material bucklings and GAMTEC  $k_{\infty}$ . When using the GAMTEC migration areas and material buckling, a  $k_{eff}$  within one percent of that calculated using HFN migration areas and material bucklings will result. Therefore, these GAMTEC 2-group parameters are included until the more accurate GAMTEC-HFN calculations for desired enrichments are justified.

The calculated effective multiplication constant of critical experiments obtained from GAMTEC II - DIF IV (reference 4) (18 groups) are also shown in this section. These results are included to show the calculational accuracy of the DIF IV code using multigroup constants of uranium provided by GAMTEC II.

In some cases, comparison is made with data from the criticality handbook issued by the United Kingdom Atomic Energy Authority<sup>(5)</sup> and is referenced as AHSB(U.K.) or U.K.

- 
- (1) L. L. Carter, C. R. Richey, C. E. Hughey, "GAMTEC II," BNWL-52, 1965.
  - (2) J. R. Lillie, "Computer Code HFN," HW-71545, 1961.
  - (3) K. R. Ridgway, "Calculated Critical Parameters of Low Enriched Uranium," ISO-174 and ISO-SA-4, 1966.
  - (4) K. D. Lathrop, "A Fortran IV Program for Solving the Multigroup Transport Equation with Anisotropic Scattering," LA-3376, 1965.
  - (5) J. H. Chalmers, et al, "Handbook of Criticality Data, Vol. 1," AHSB(S) Handbook 1, (1st Revision), 1967.



GAMTEC II - HFN and DTF IV calculations of critical experiments are listed below:

	K-Effective	
	<u>GAMTEC-HFN</u>	<u>GAMTEC-DTF</u>
<u>ORNL-TM-1195 U(4.98)O<sub>2</sub>F<sub>2</sub> 901 g U/1</u>		
15.39" I.D. Cylinder 40.04" high	0.989	0.996
<u>ORNL-2968 U(4.89)<sub>3</sub>O<sub>8</sub> In Sterotex 47.9 g U-235/1</u>		
Bare 24" x 24" x 18.8"	0.995	0.993
Full H <sub>2</sub> O Reflection 20" x 20" x 13.1"	0.988	0.987
<u>ORNL-1926 U(93.2)O<sub>2</sub>F<sub>2</sub></u>		
20" x 20" x 2.75" Full Reflection, 347.7 g U-235/1	0.9951	
6" I.D. Aluminum Cylinder 35.43" high, Full Reflection, 830.9 g U-235/1		1.0080
10" I.D. Aluminum Cylinder 5.17" high, Full Reflection, 830.9 g U-235/1		0.9773
10" I.D. Aluminum Cylinder 15.17" high, Bare, 830.9 g U-235/1		1.0028
<u>ORNL-3973 U(4.98)O<sub>2</sub>F<sub>2</sub> 910.18 g U/1, Bare</u>		
19.99 I.D. stainless steel (.020") sphere		1.0041
15.5" I.D. stainless steel (.031") bare		1.0042
<u>ORNL-2367 U(93.2)O<sub>2</sub>F<sub>2</sub> 331.4 g U-235/1, 10" O.D. Aluminum (4/16") Annular Tank, Full Reflection on Outside Except Top</u>		
4" I.D. filled with H <sub>2</sub> O 9.37" high		0.9973
4" I.D. with air 10.87" high		1.0491
4" I.D. 20 mil Cd sheet & air 12.56" high		1.0300
4" I.D. 20 mil Cd sheet & H <sub>2</sub> O 17.87" high		0.9754

III.B.2 H/U Versus U g/l Relationships

The calculations for the critical parameters for homogeneous uranium systems were taken from the following H/U relationships:

For U-H<sub>2</sub>O and UO<sub>2</sub>-H<sub>2</sub>O solutions:

Both the U-H<sub>2</sub>O and the low enrichment UO<sub>2</sub>-H<sub>2</sub>O relationships were calculated from the general equation on page II.C.3-1. The U-H<sub>2</sub>O relationship is shown graphically on page III.B.2-4. The UO<sub>2</sub>-H<sub>2</sub>O curves are shown on page III.B.2-6.

For UO<sub>3</sub>-H<sub>2</sub>O solutions:

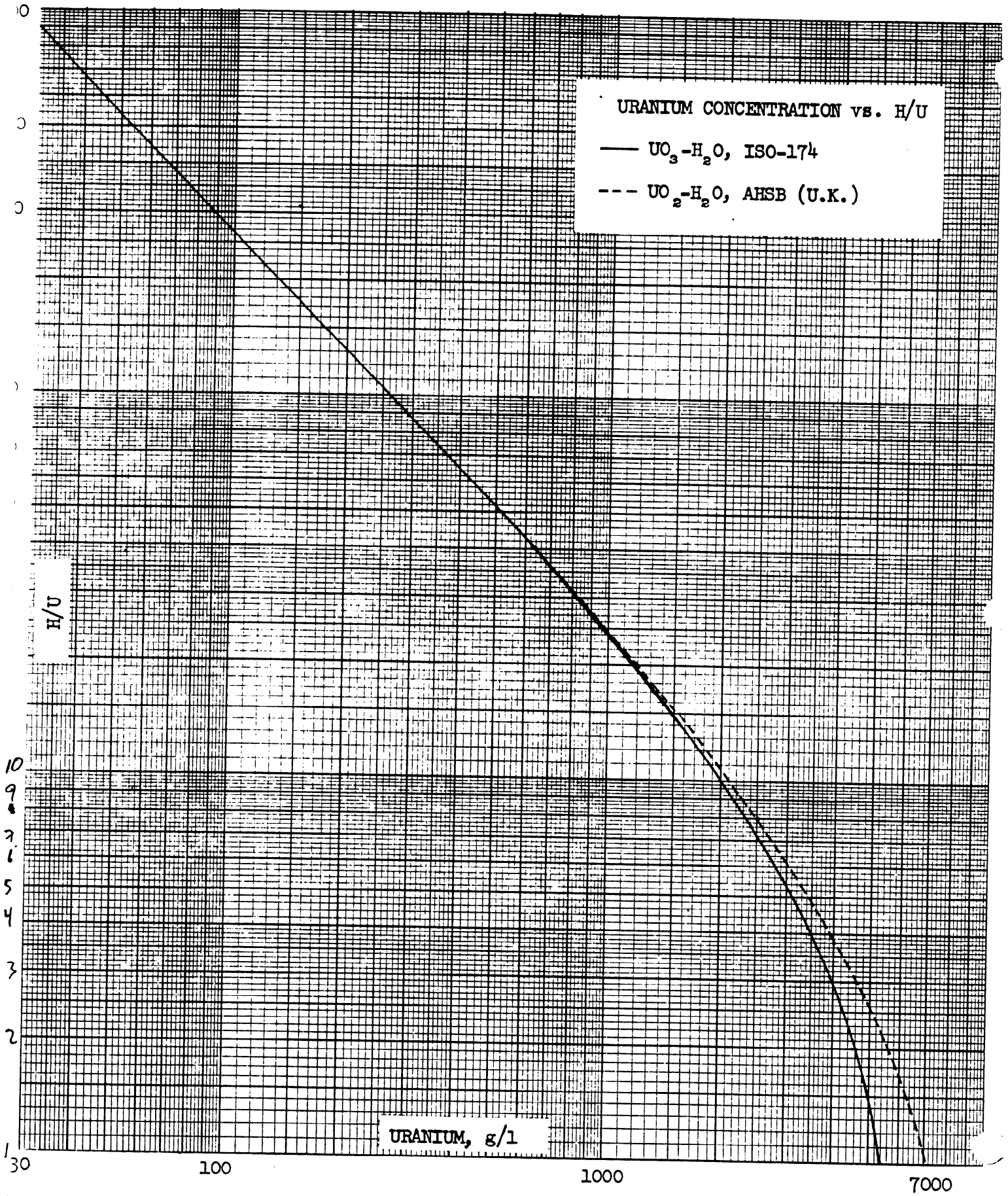
This relationship was taken from the H/U relationship shown on pages III.B.2-2 or III.B.2-3. It takes into account experimental data in the H/U range from 5 to 8.

For uranium nitrate (low enrichment) solutions:

The curve shown on page III.B.2-4 was used. It takes into account denitration at high densities and results in lower H/U values (above about 300 g/l) for a given density than would be calculated by the general equation in section II.D.3. The resulting curves of H/<sup>235</sup>U are shown on page III.B.2-5.

For U(93.5) and U(100) nitrate solutions:

The general equation on page II.C.3-1 was used and therefore no denitration effects were calculated.



URANIUM CONCENTRATION vs. H/U

—  $UO_3-H_2O$ , ISO-174

- - -  $UO_2-H_2O$ , AHSB (U.K.)

H/U

URANIUM, g/l

10

9

8

7

6

5

4

3

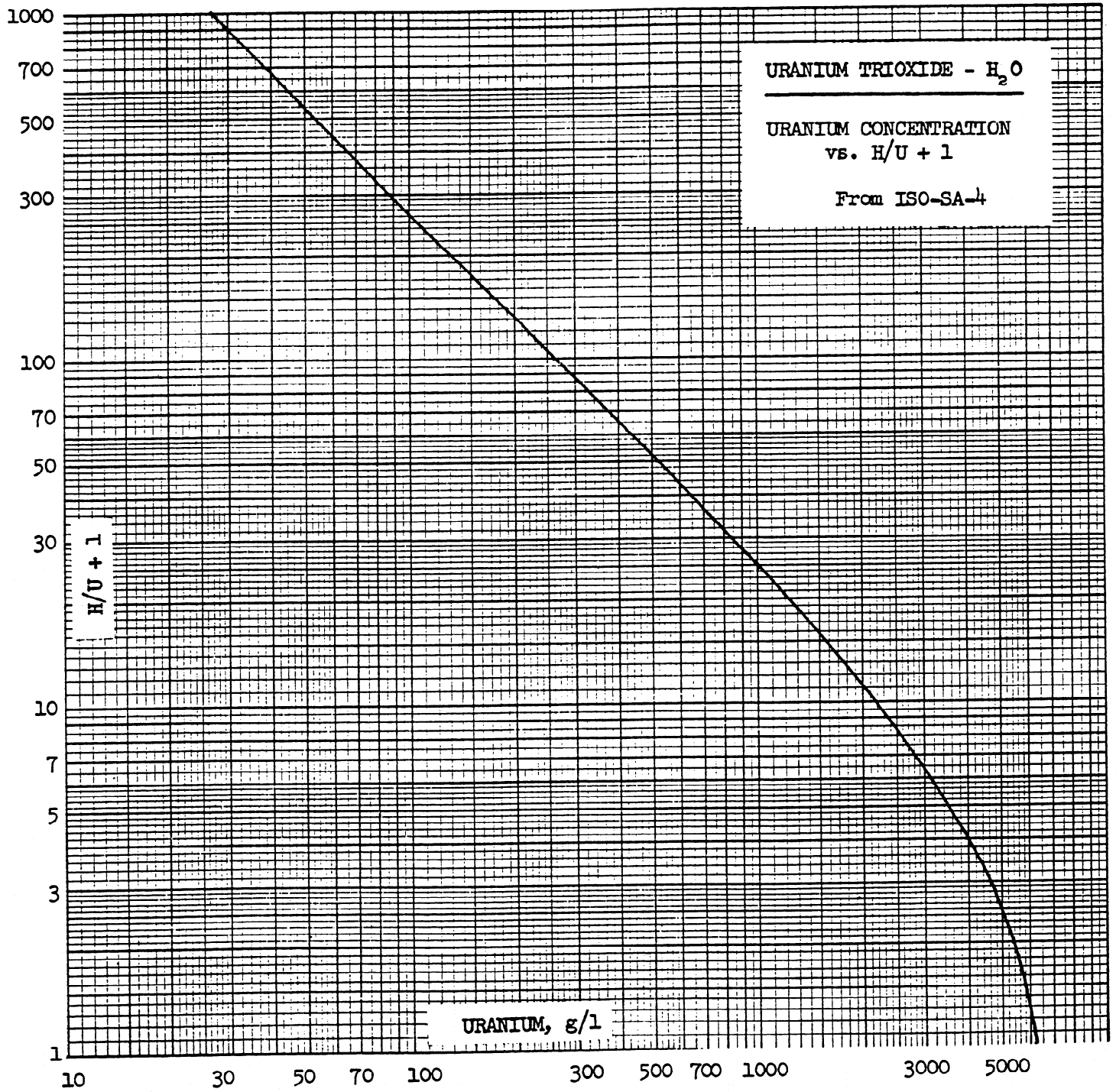
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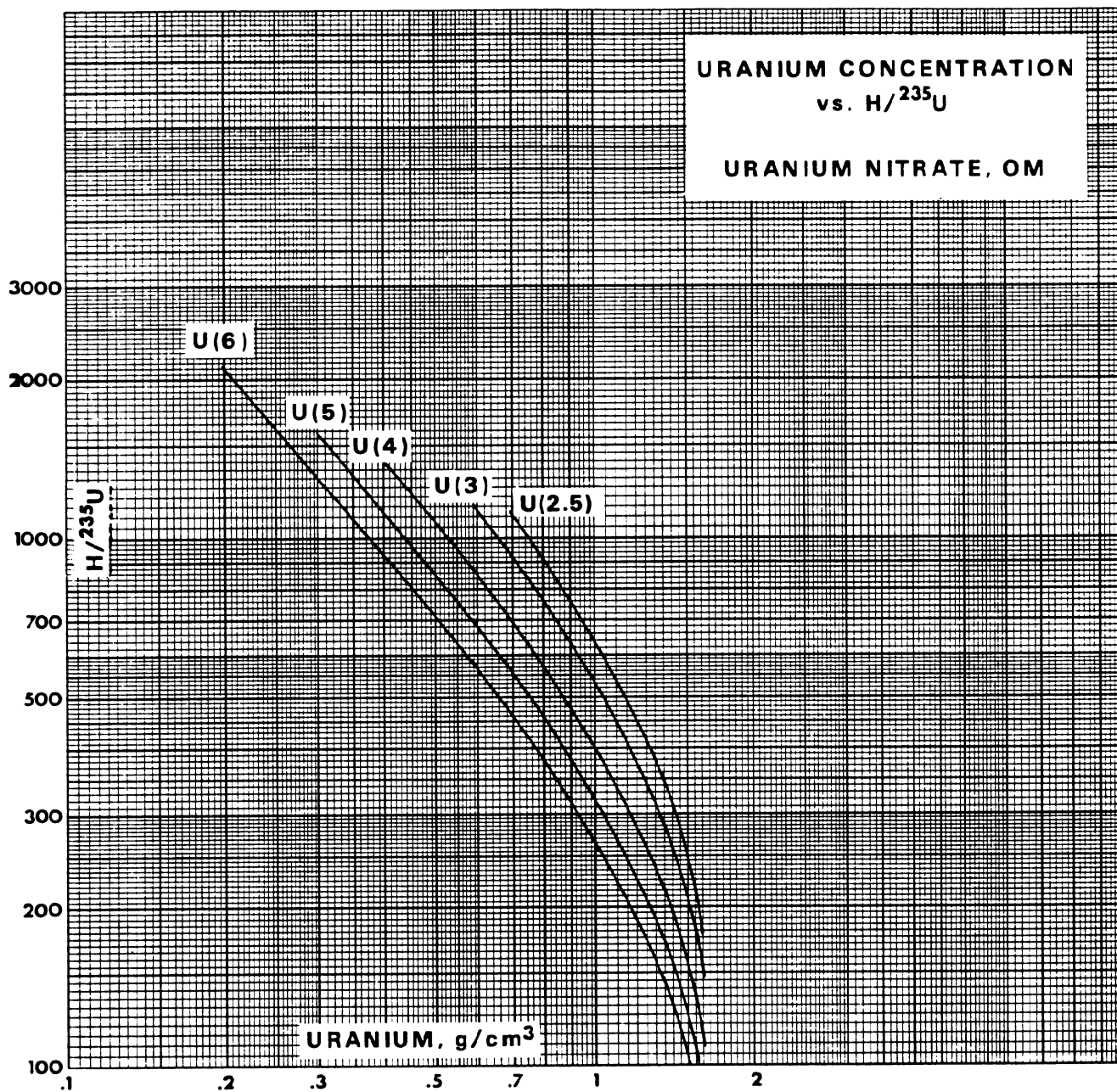
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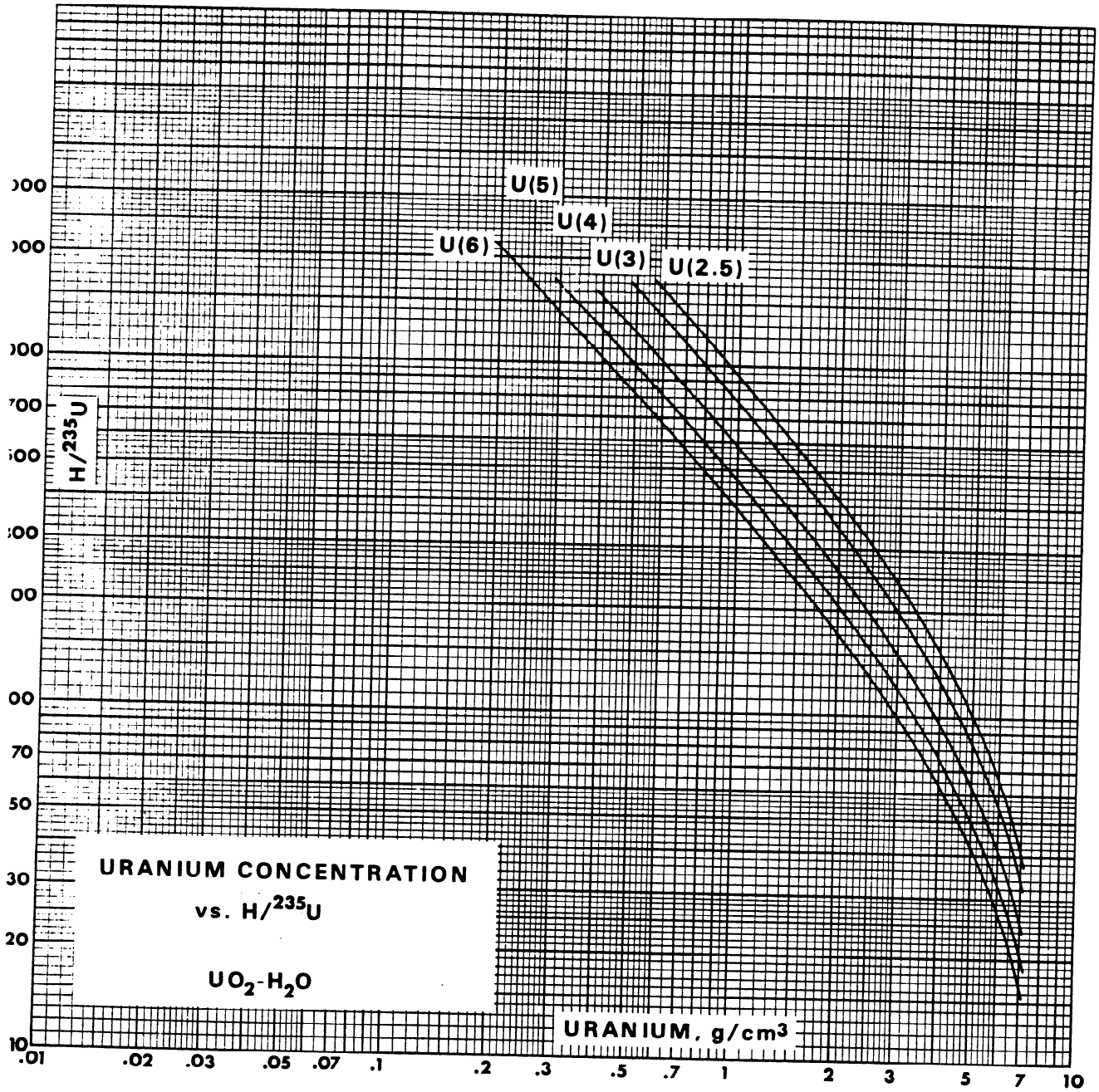
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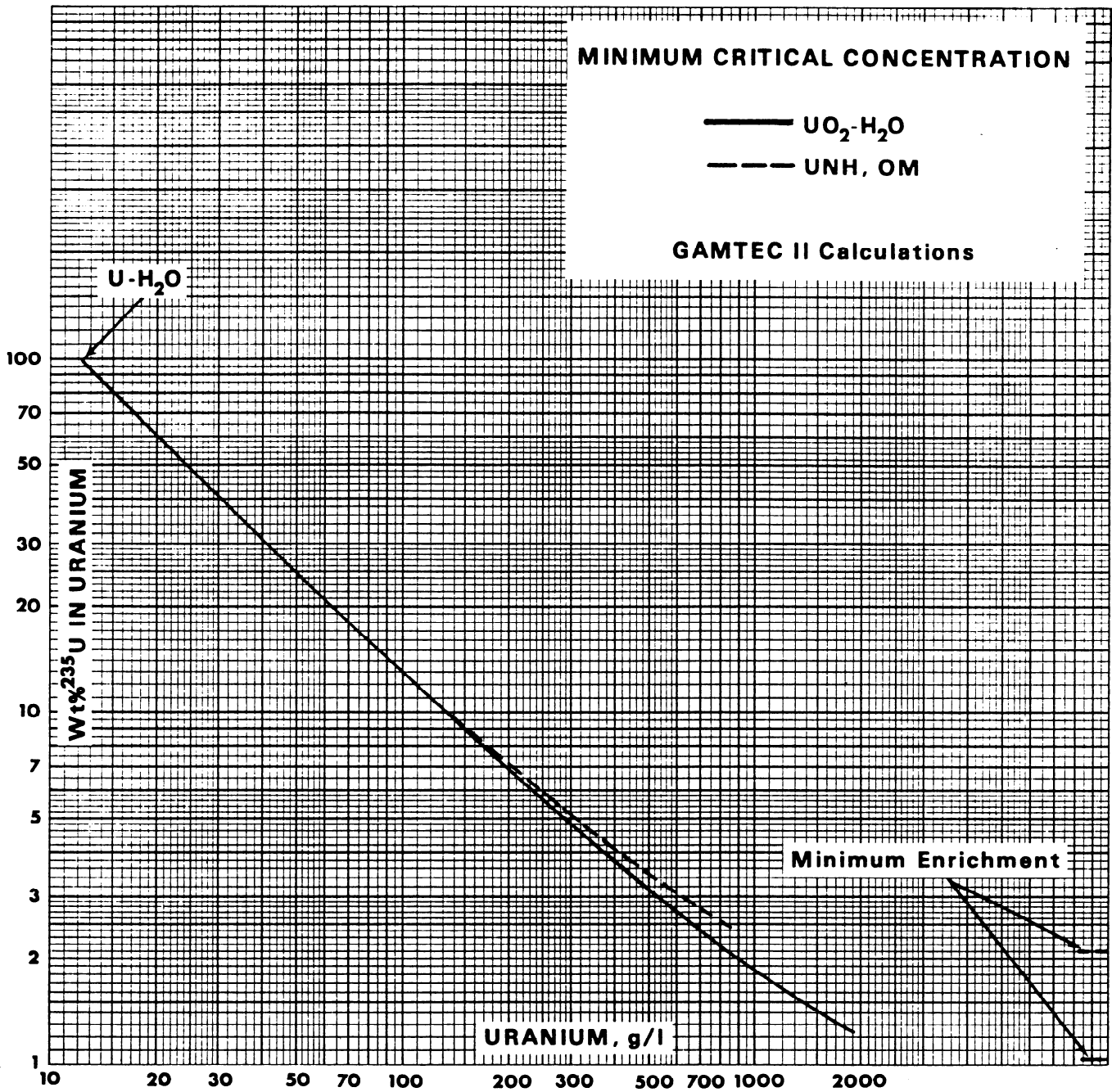
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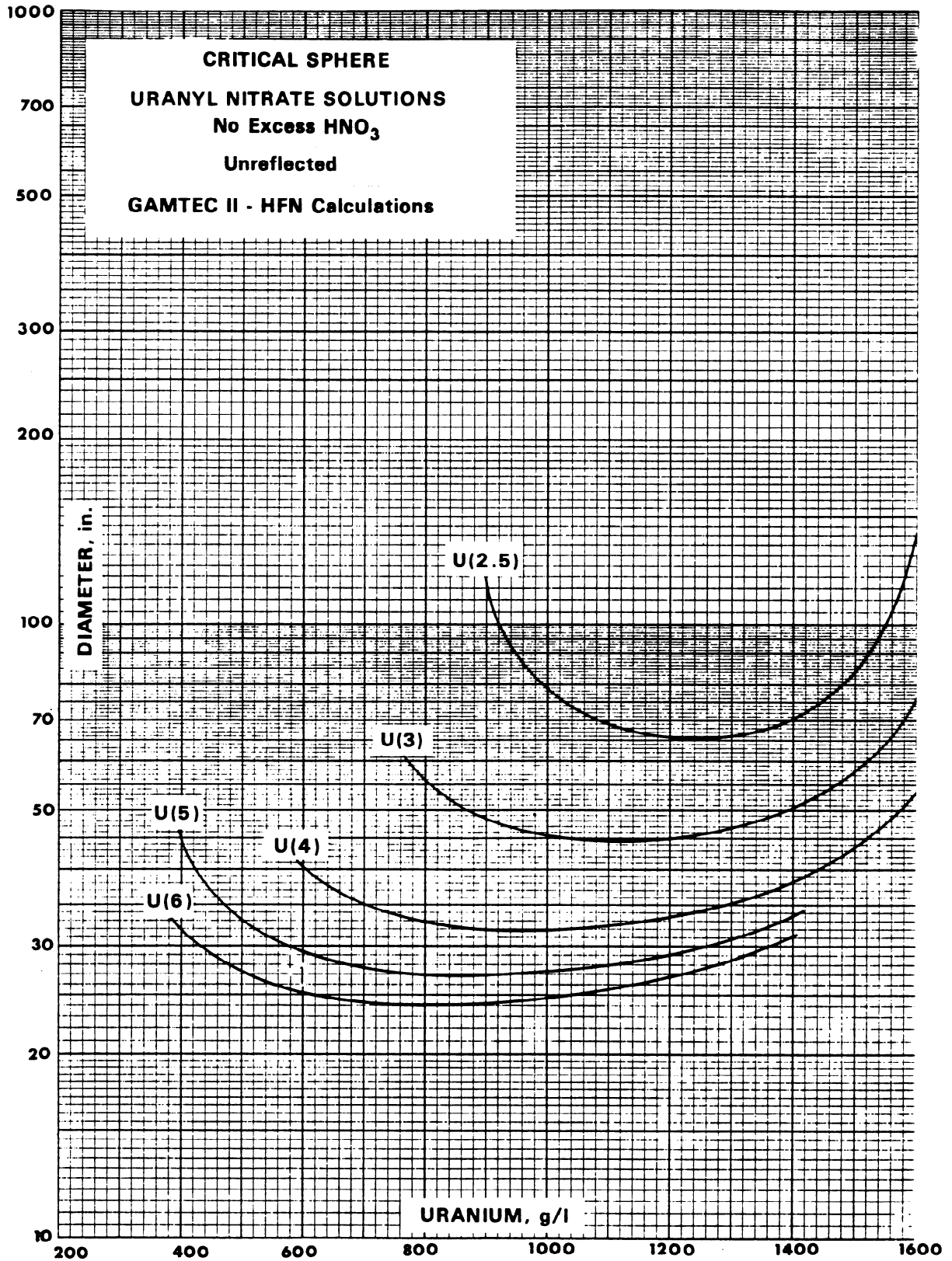
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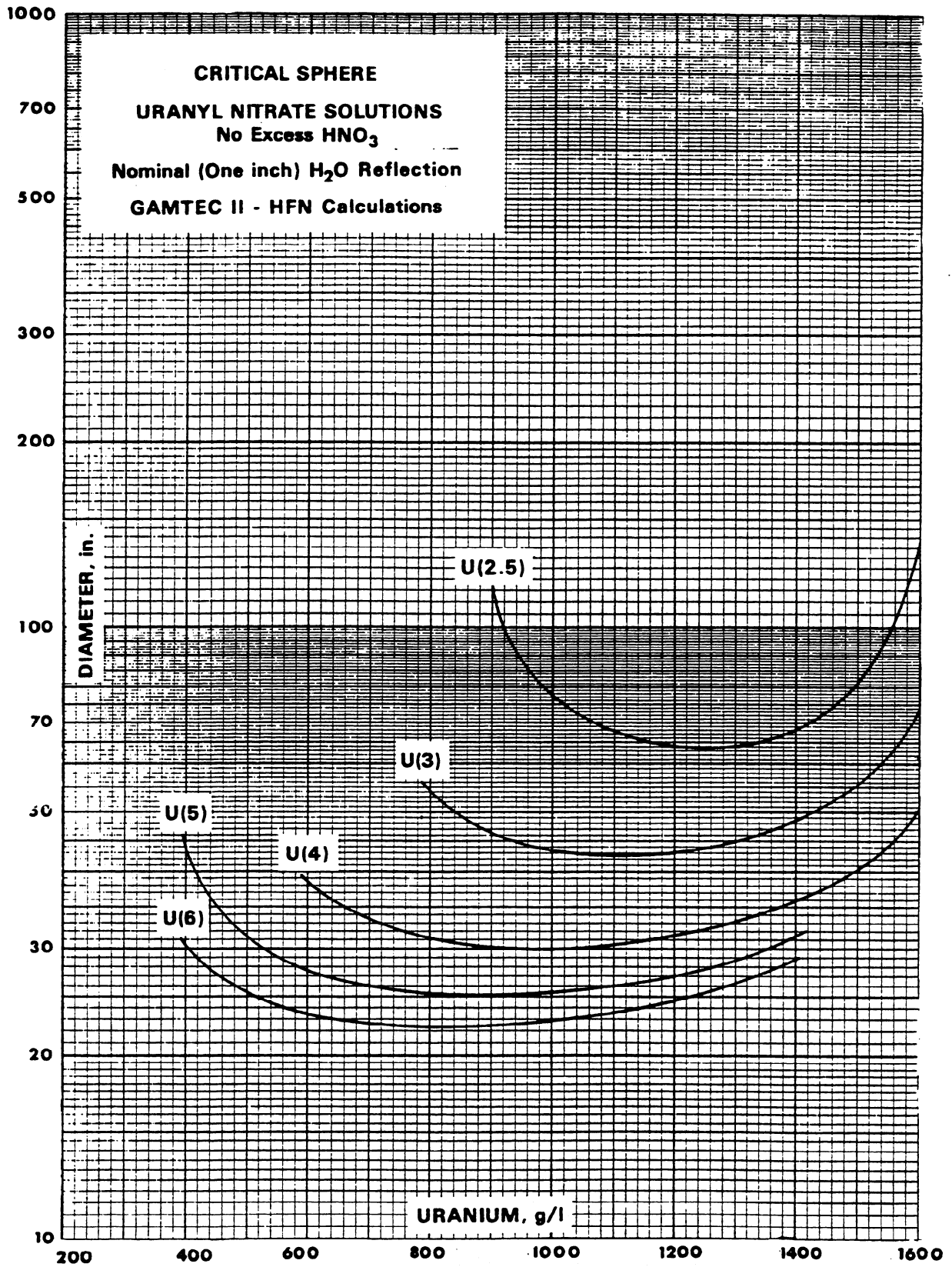


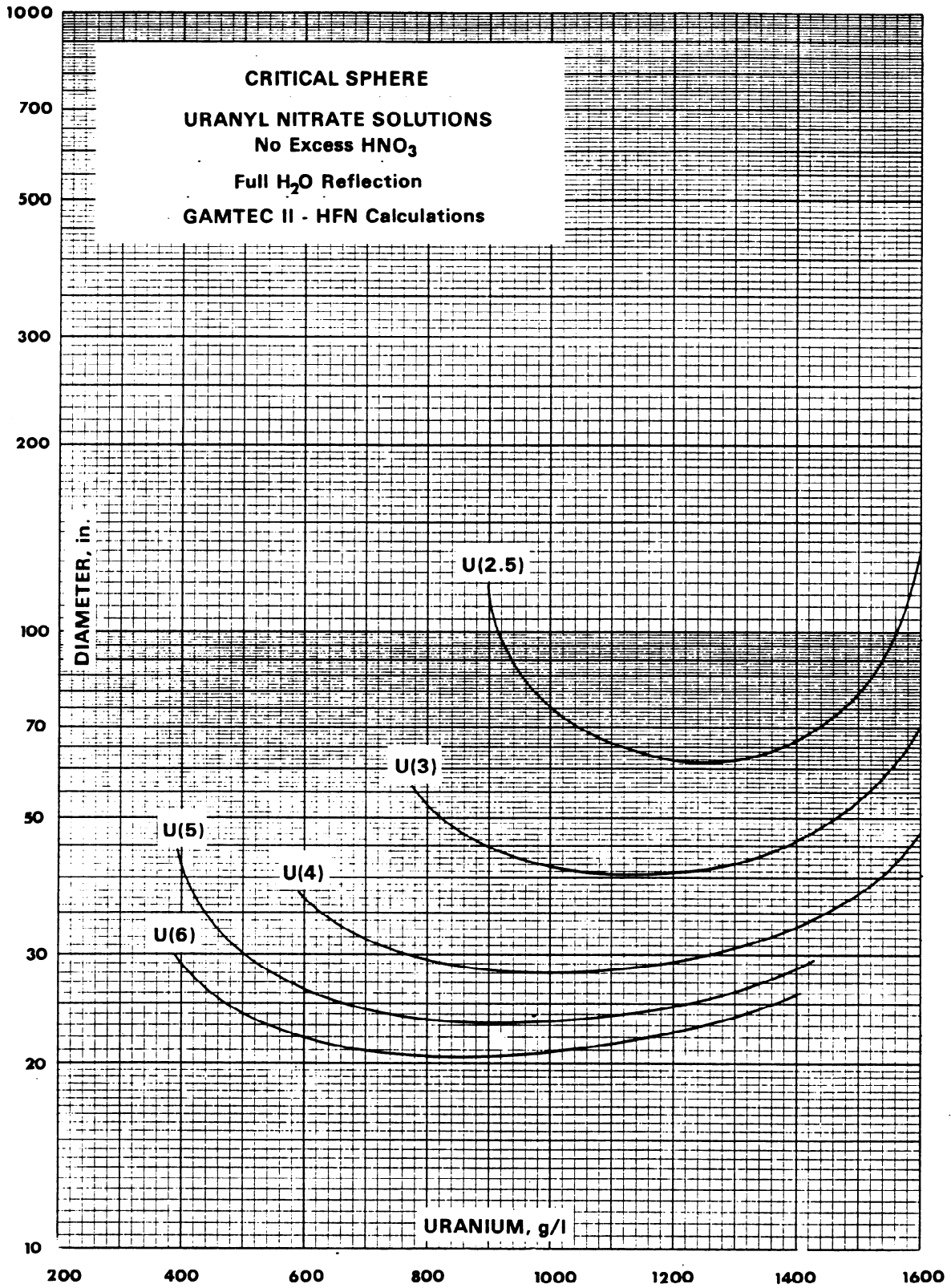


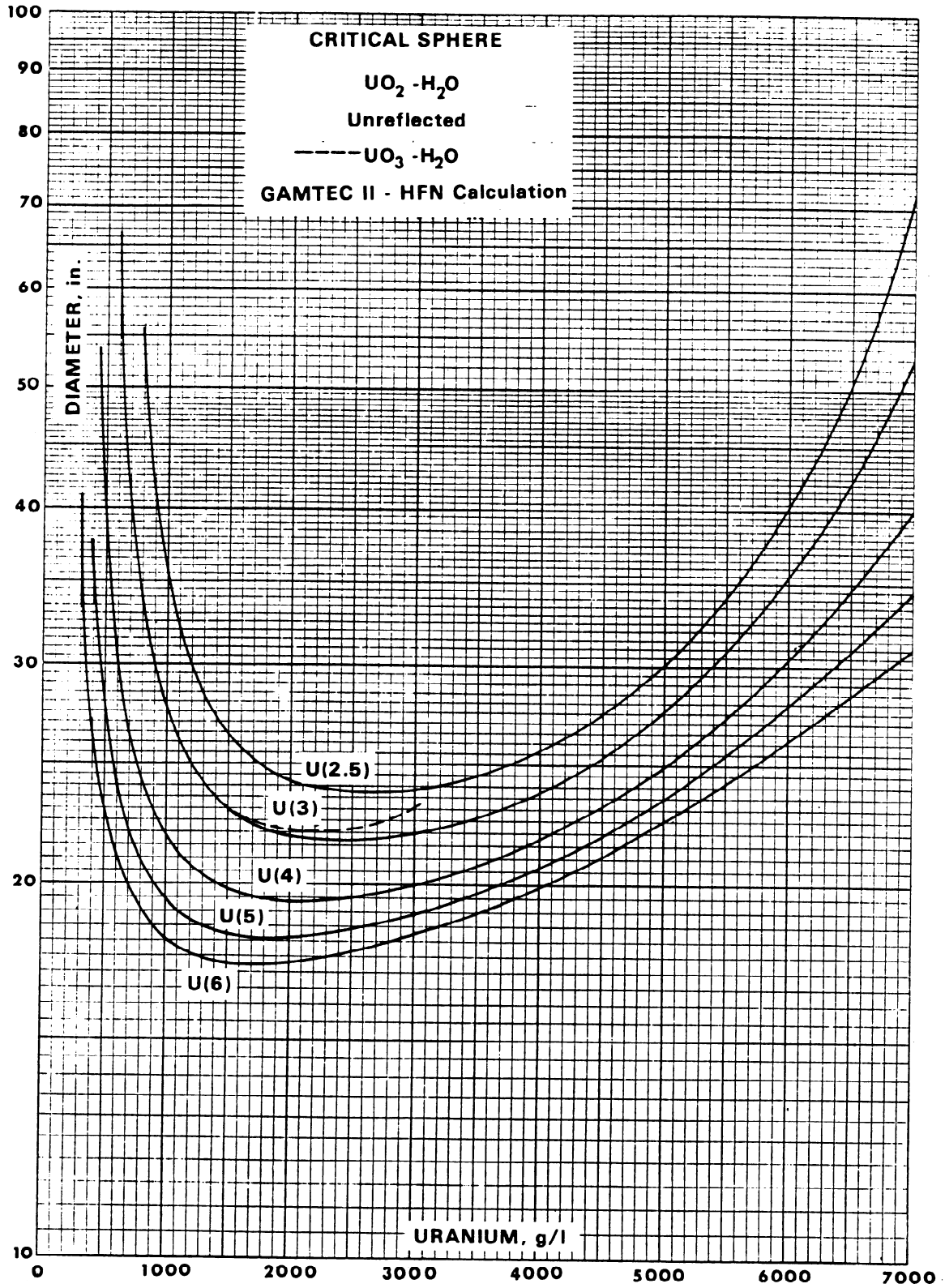


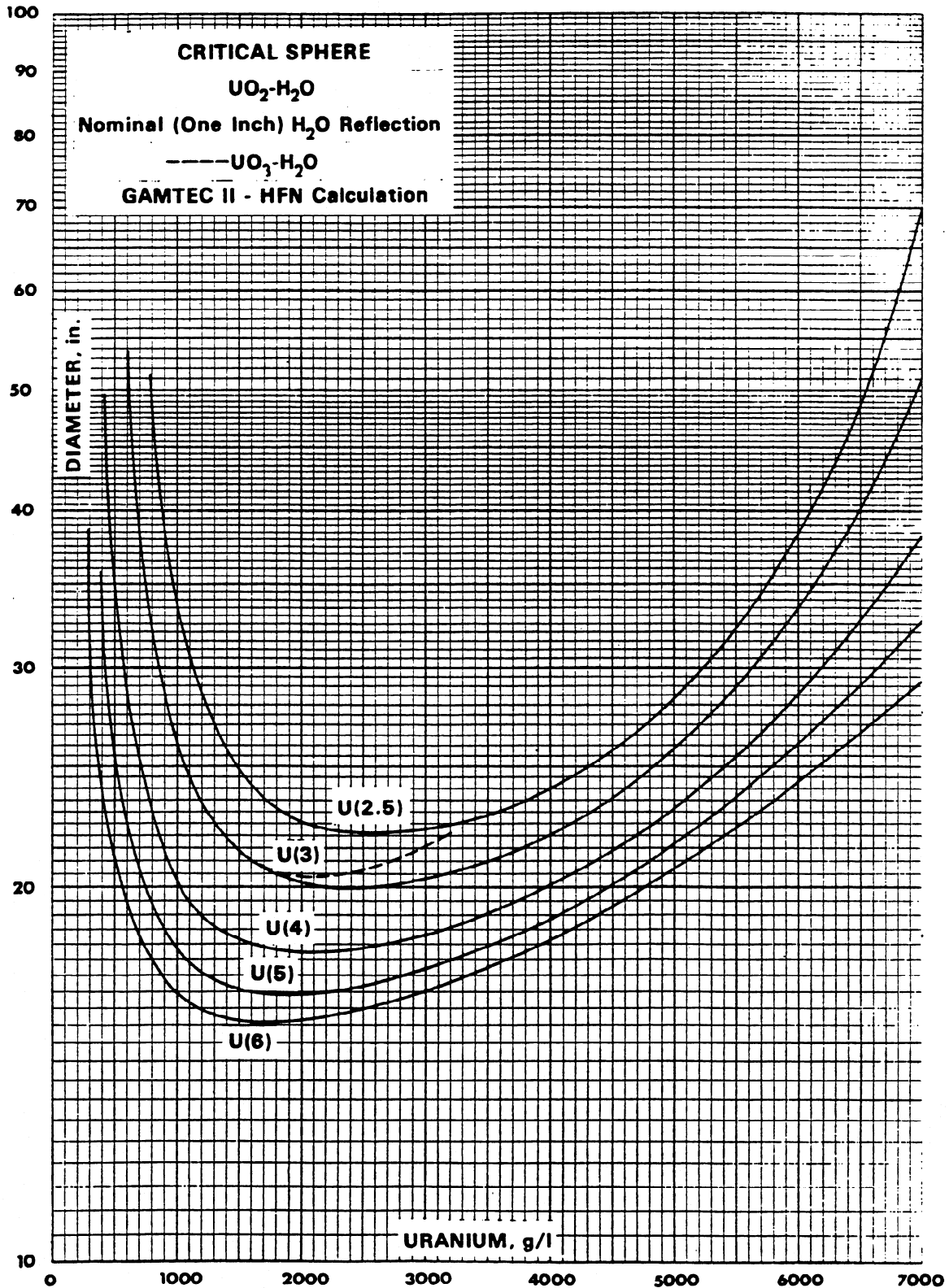


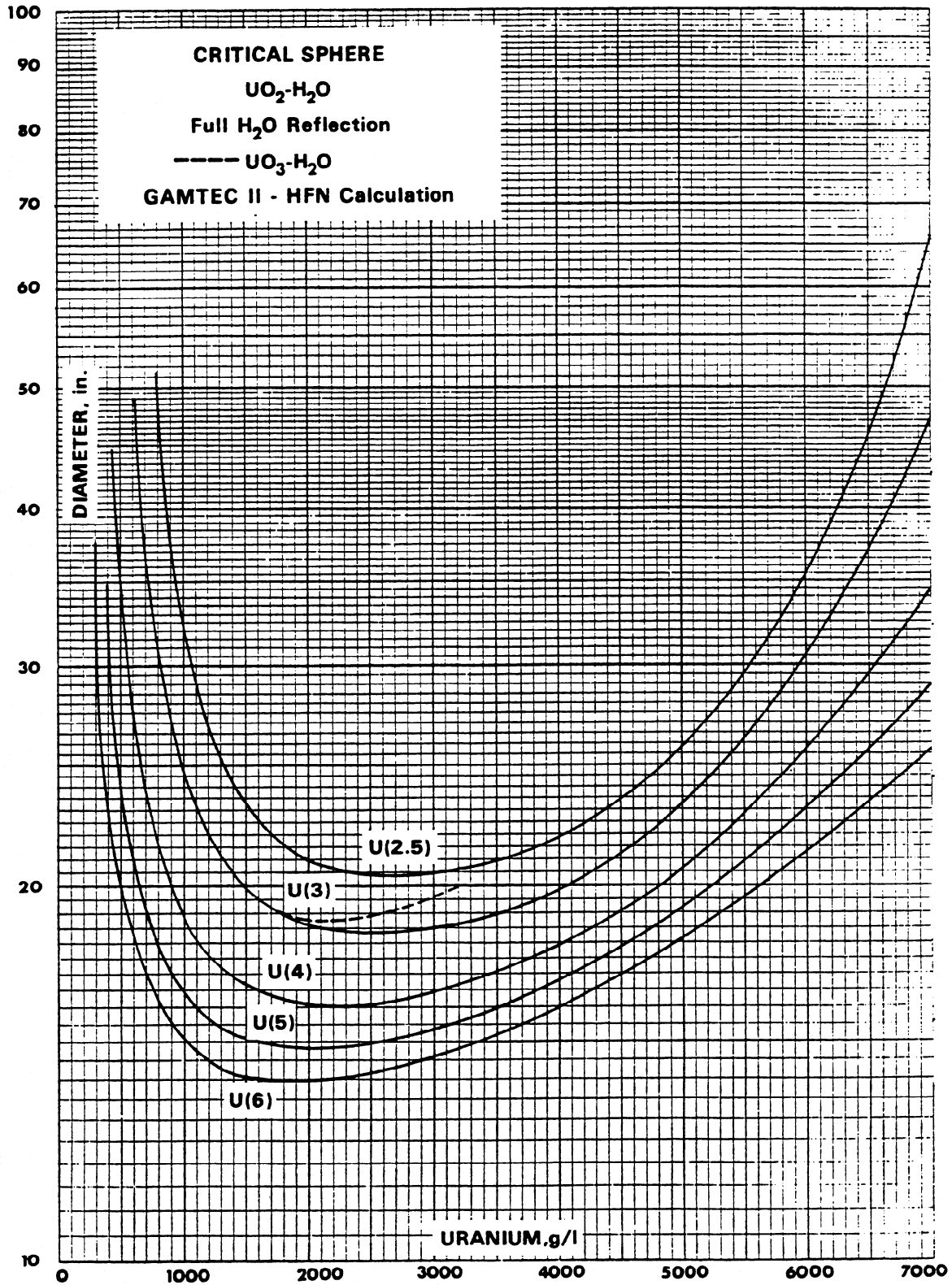


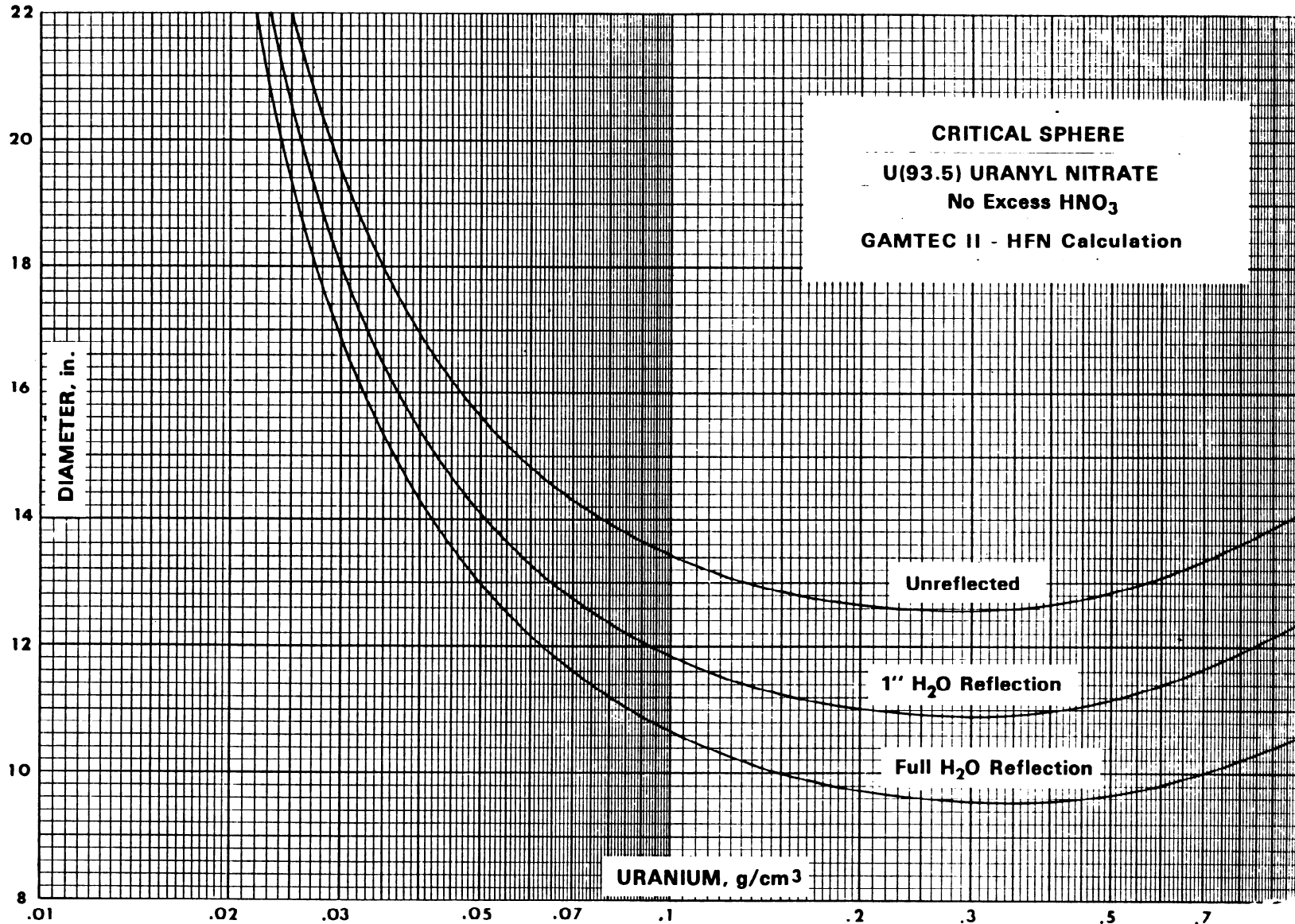






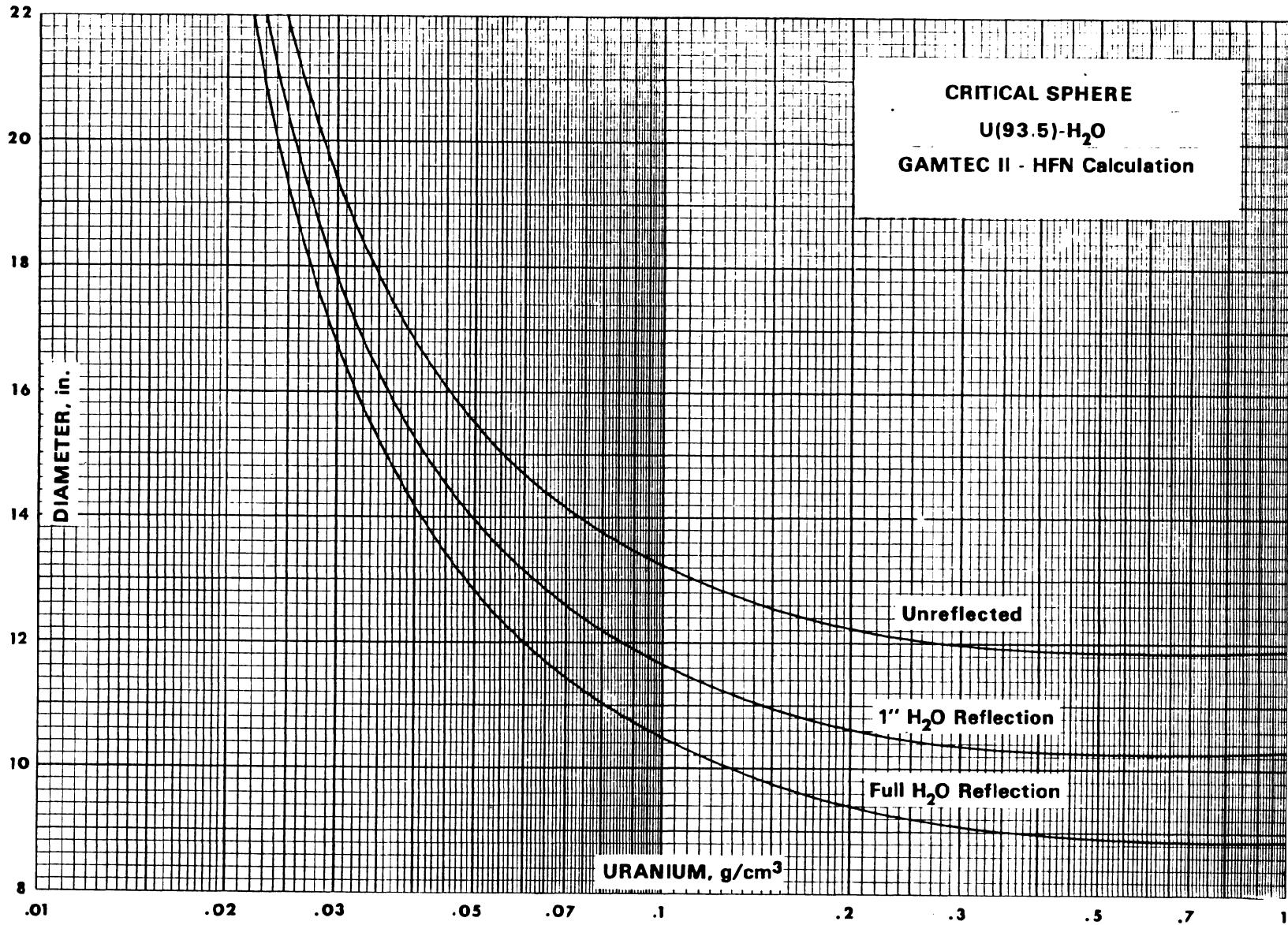






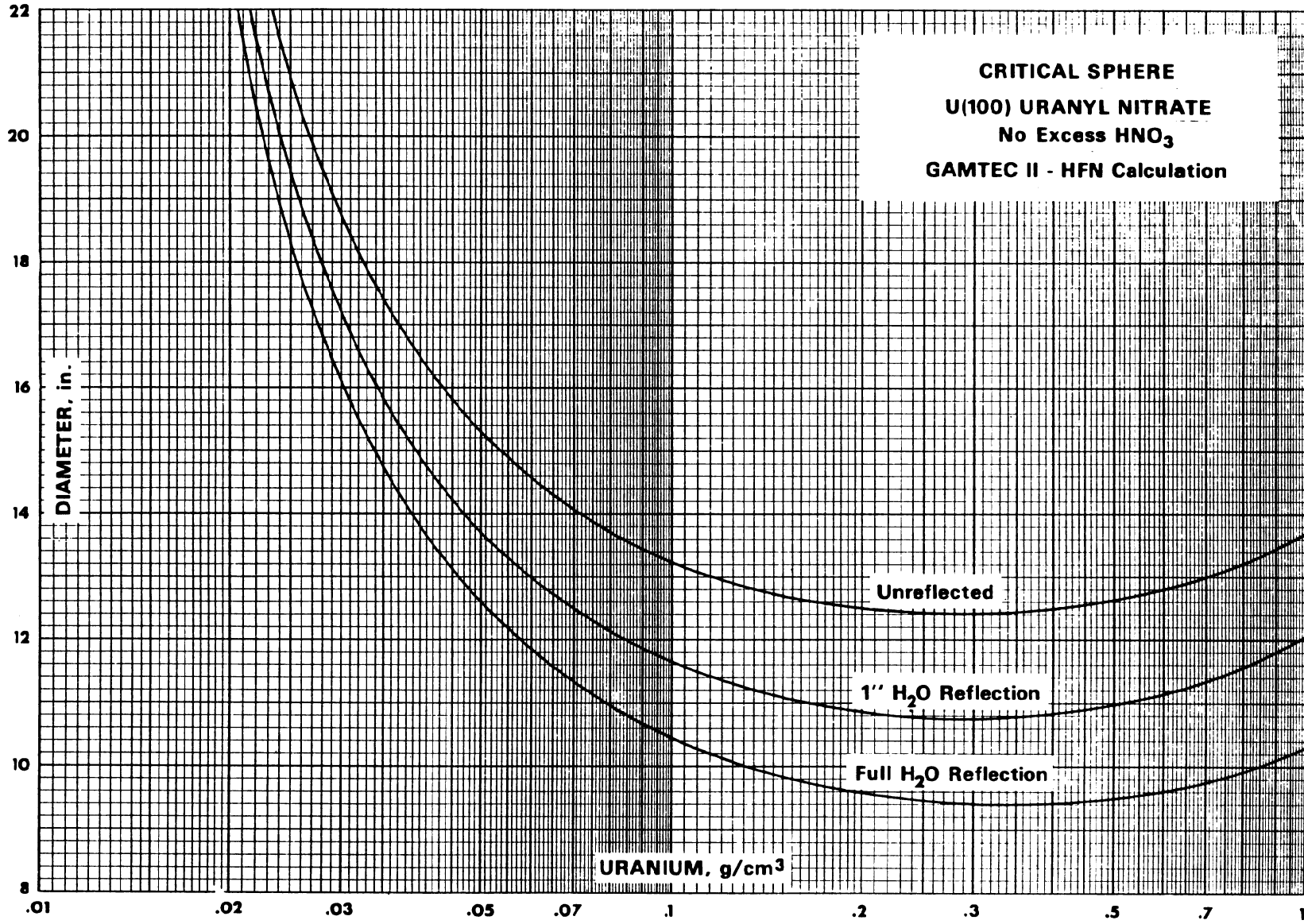
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ARH-600



III.B.3(93.5)-2

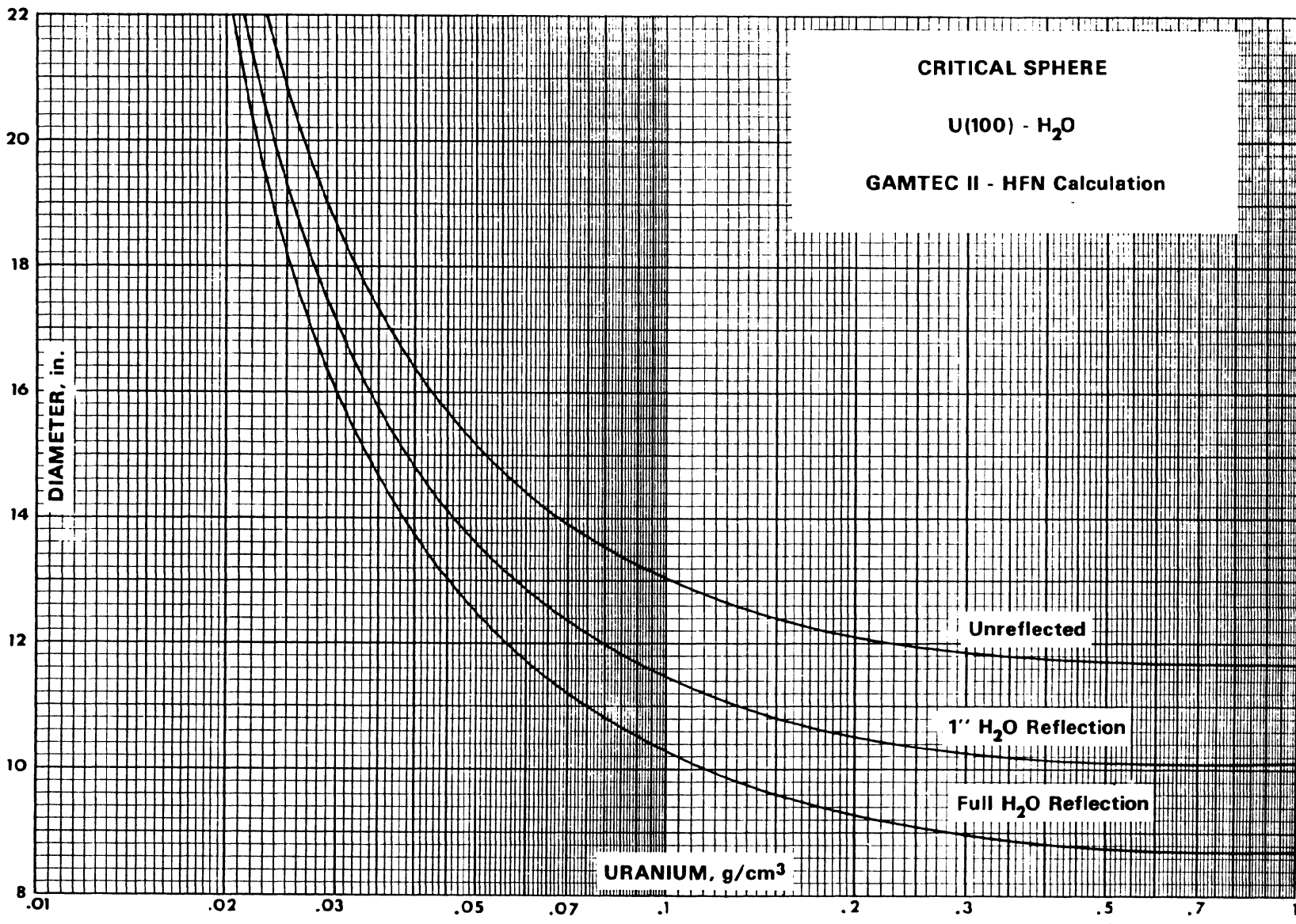
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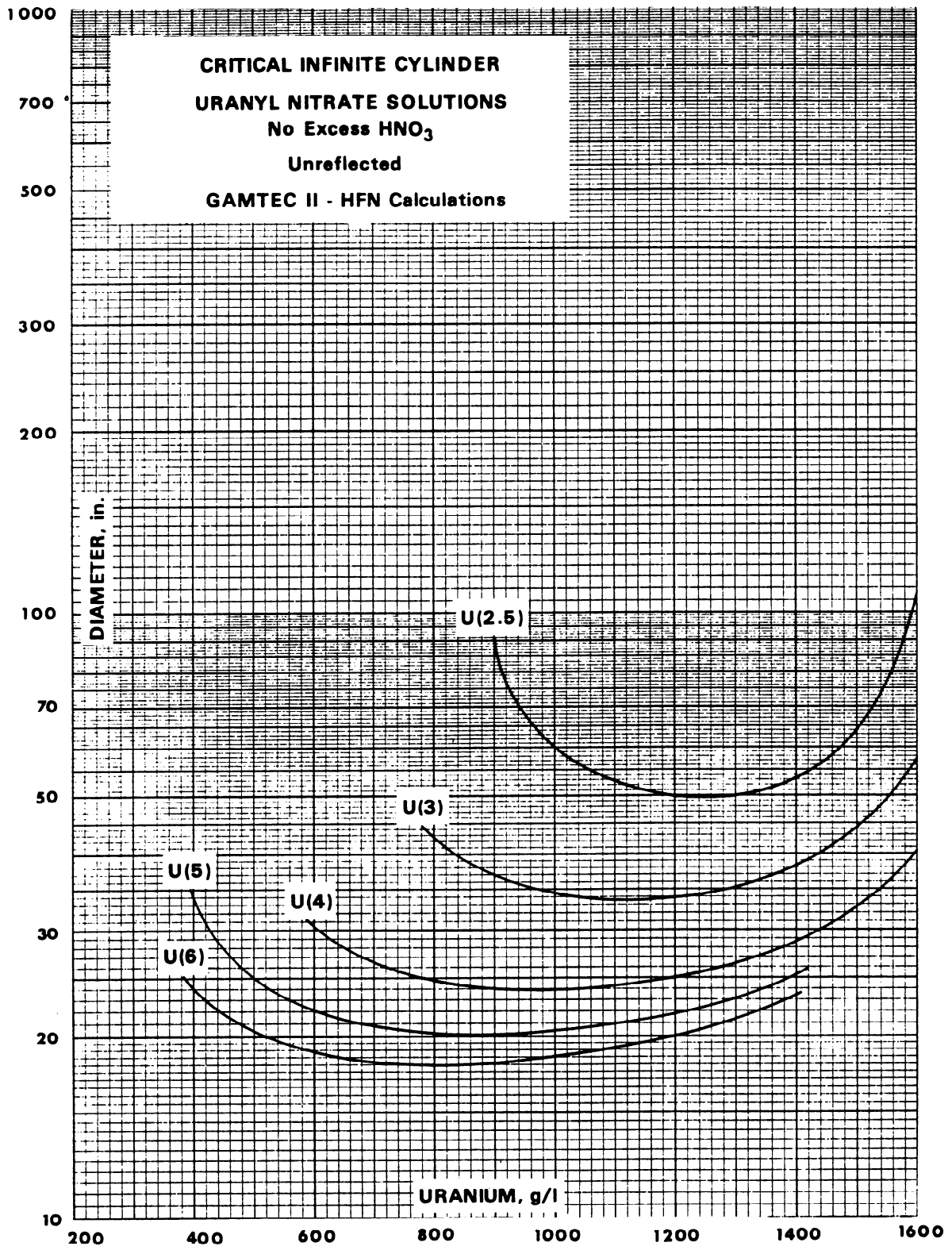
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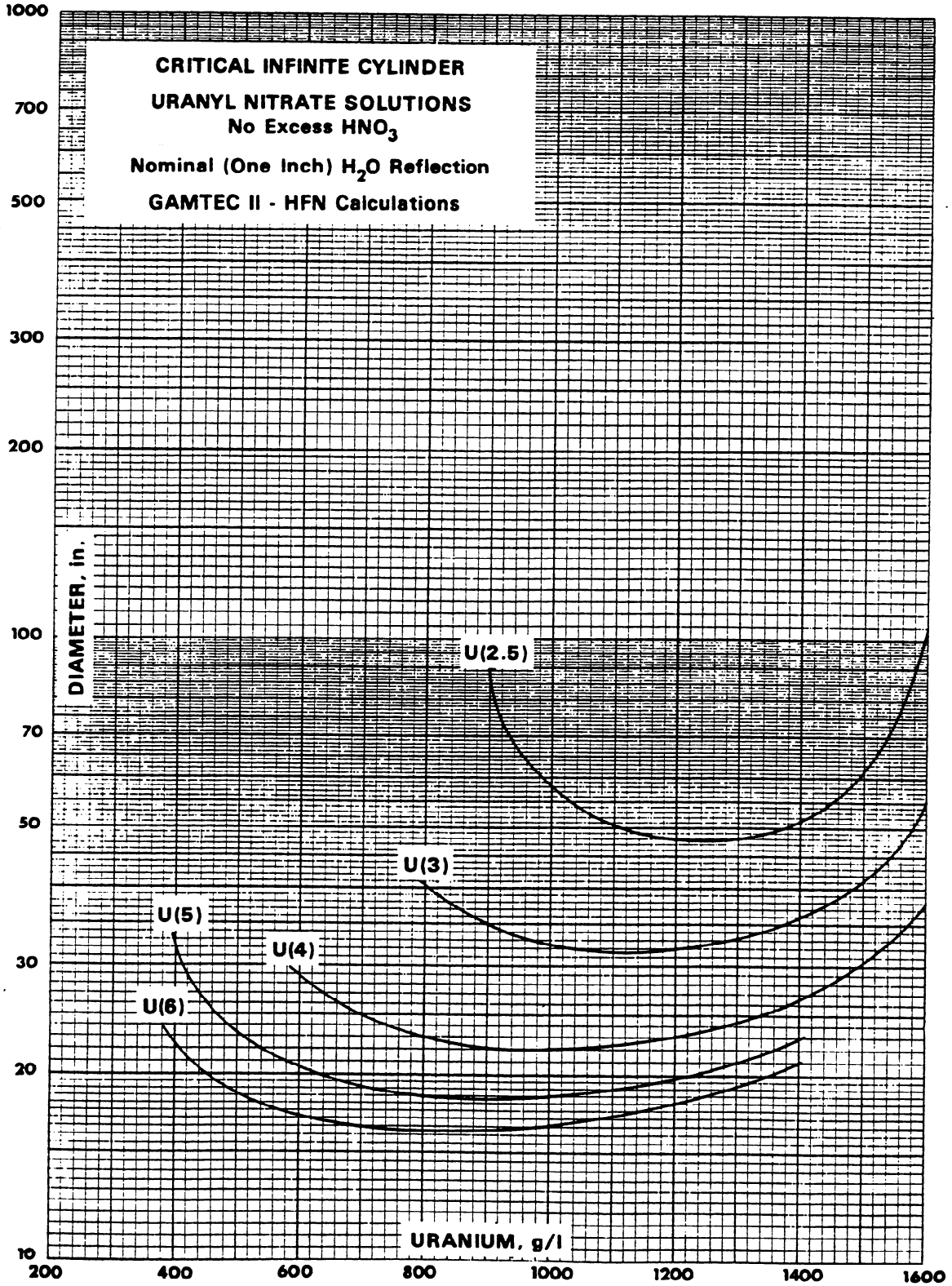


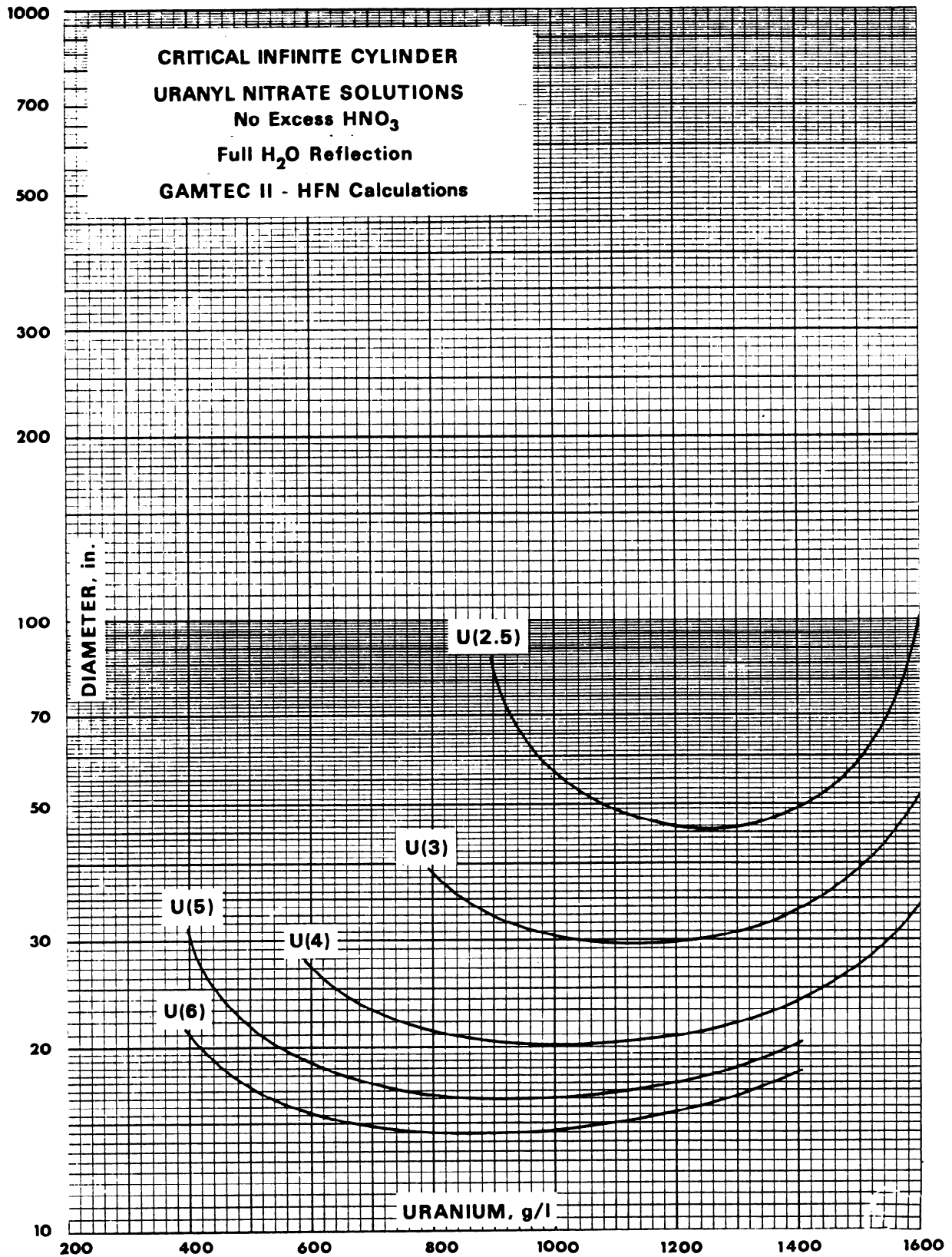


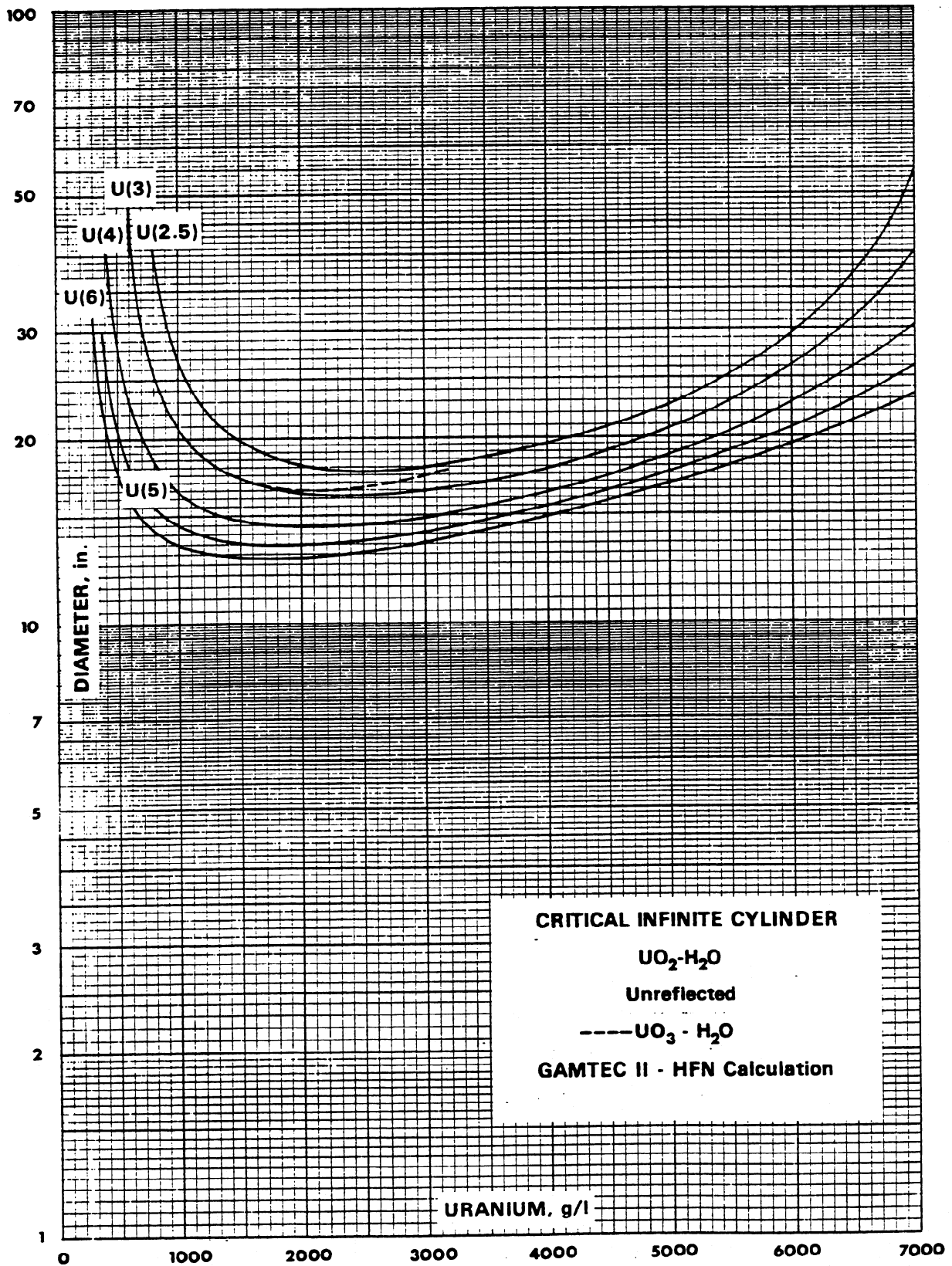
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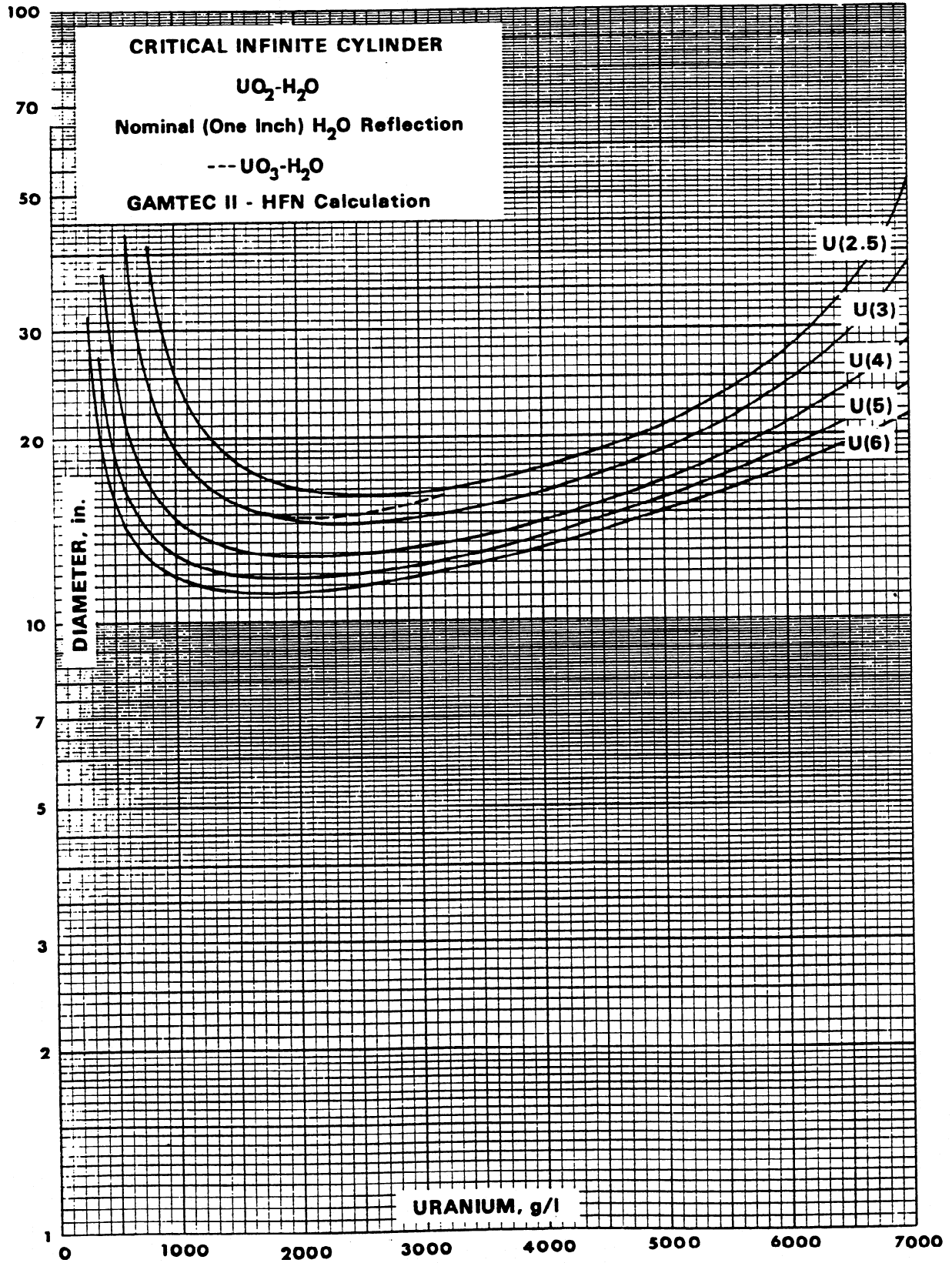
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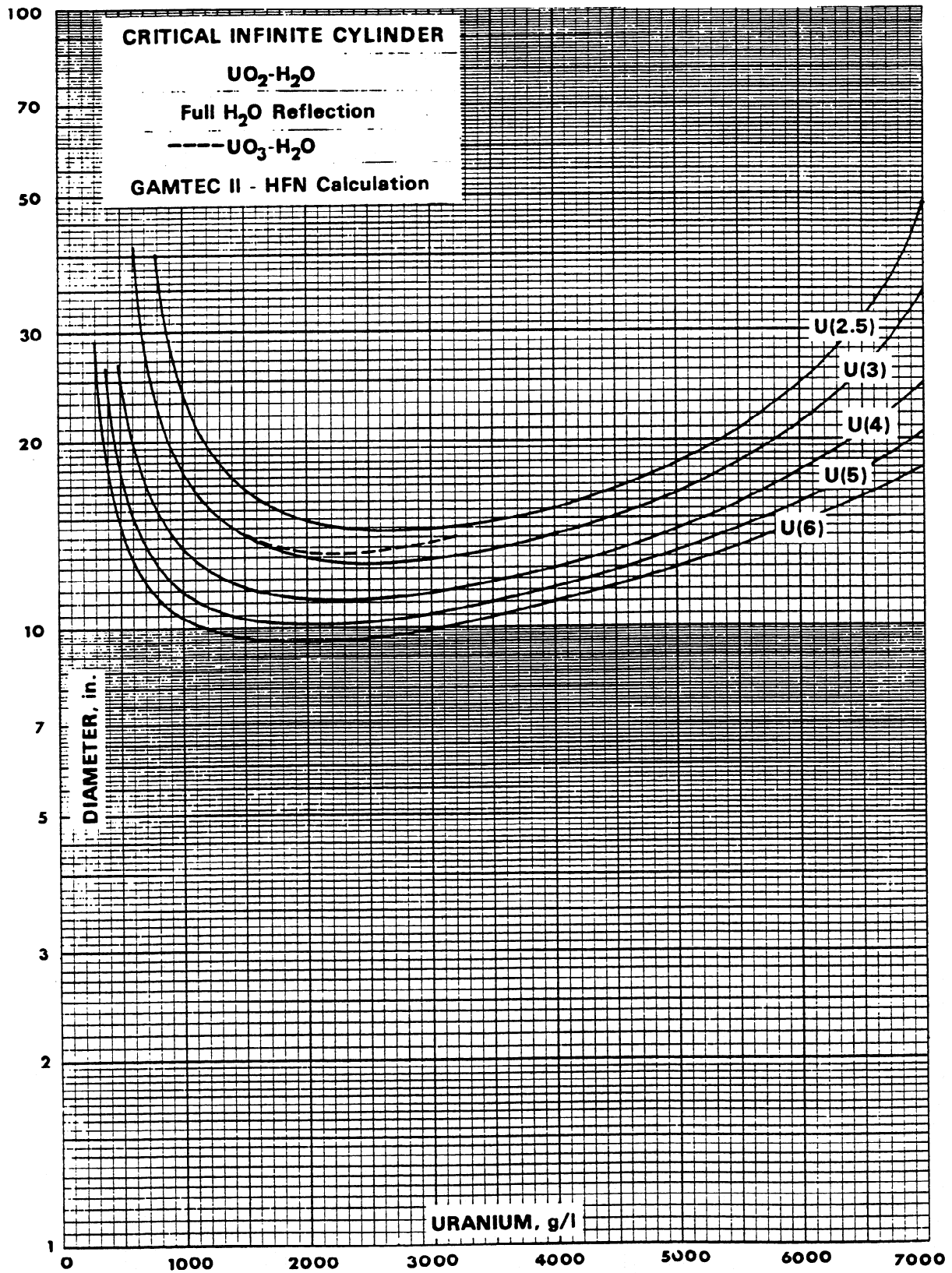


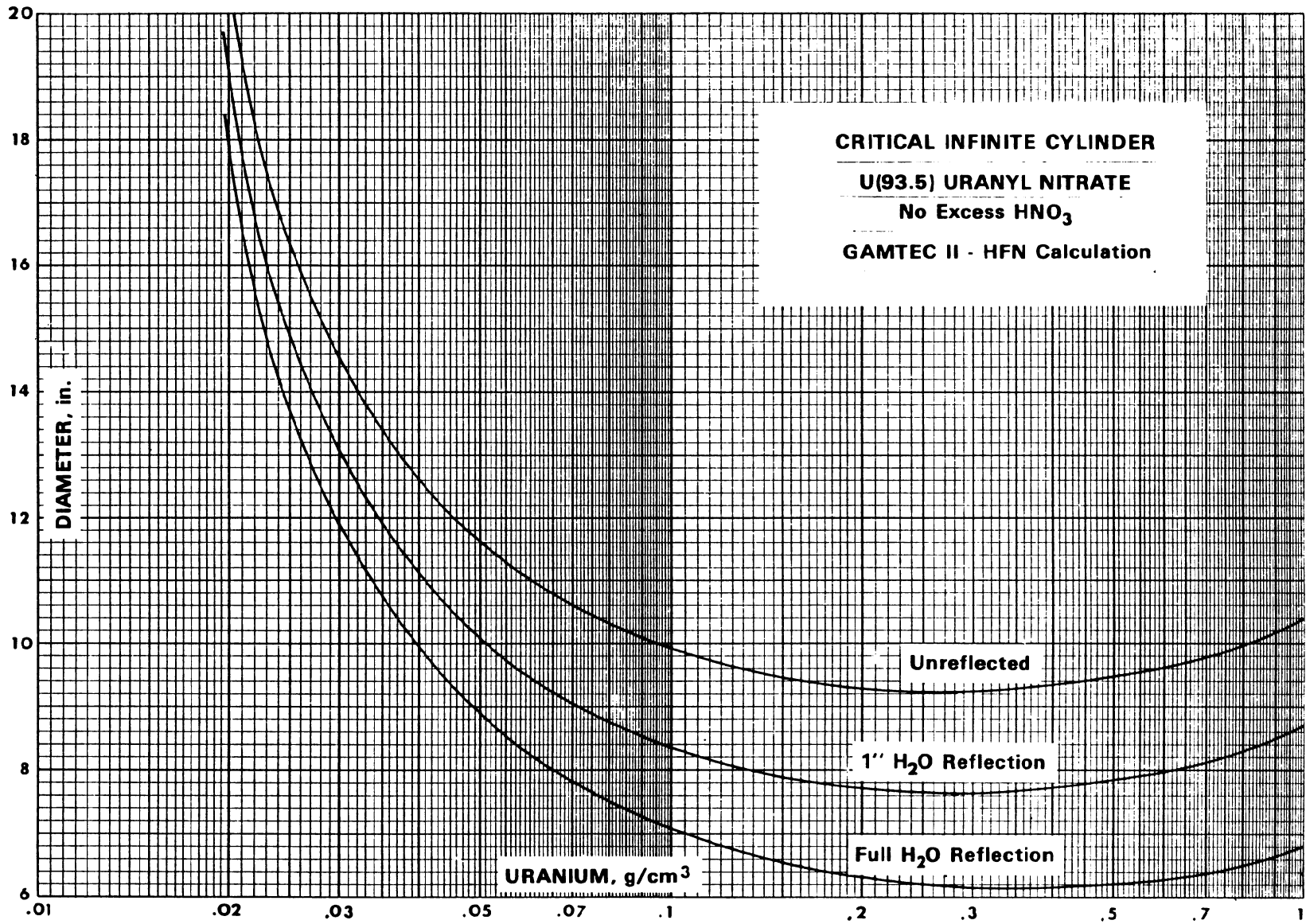








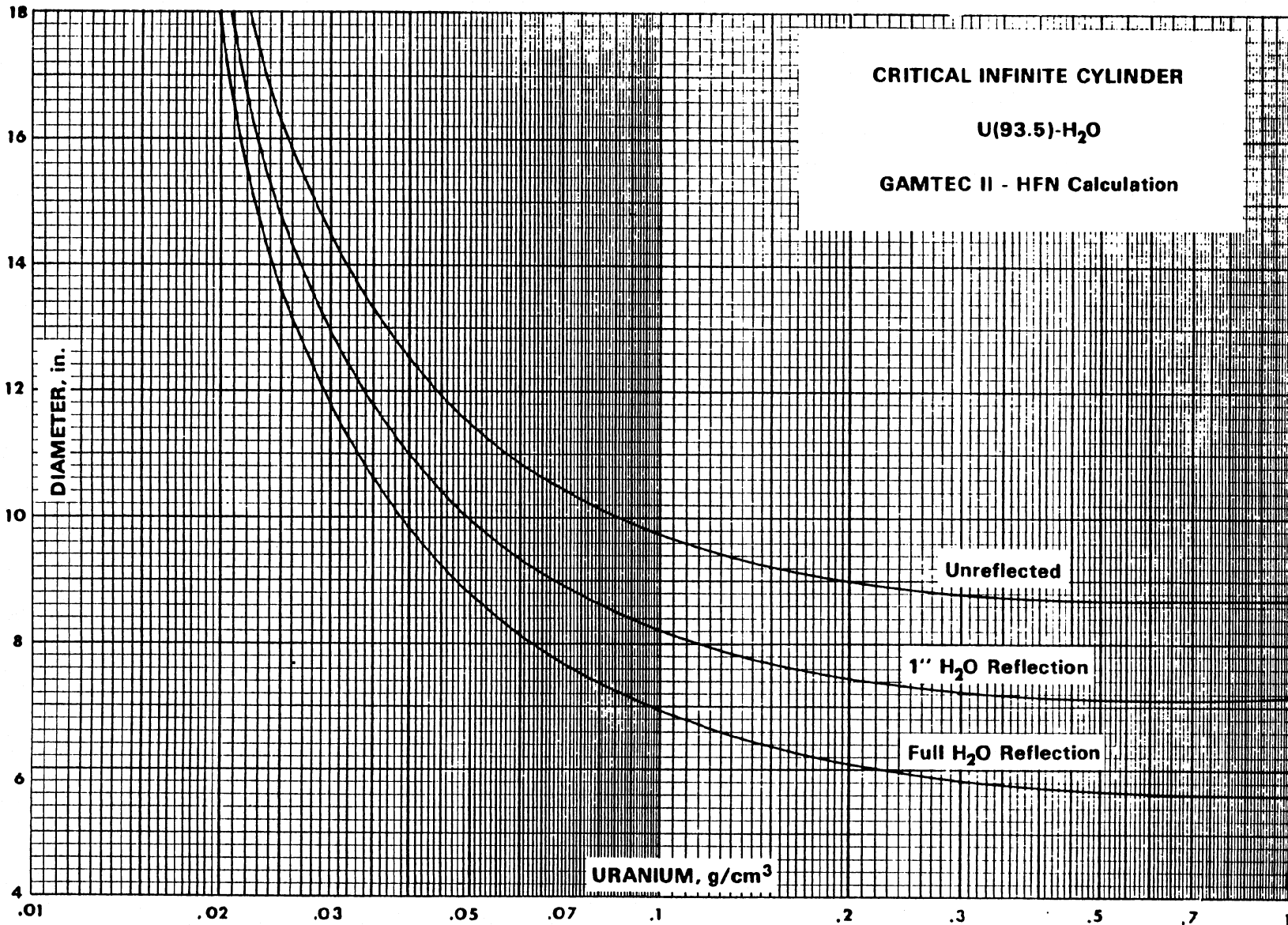


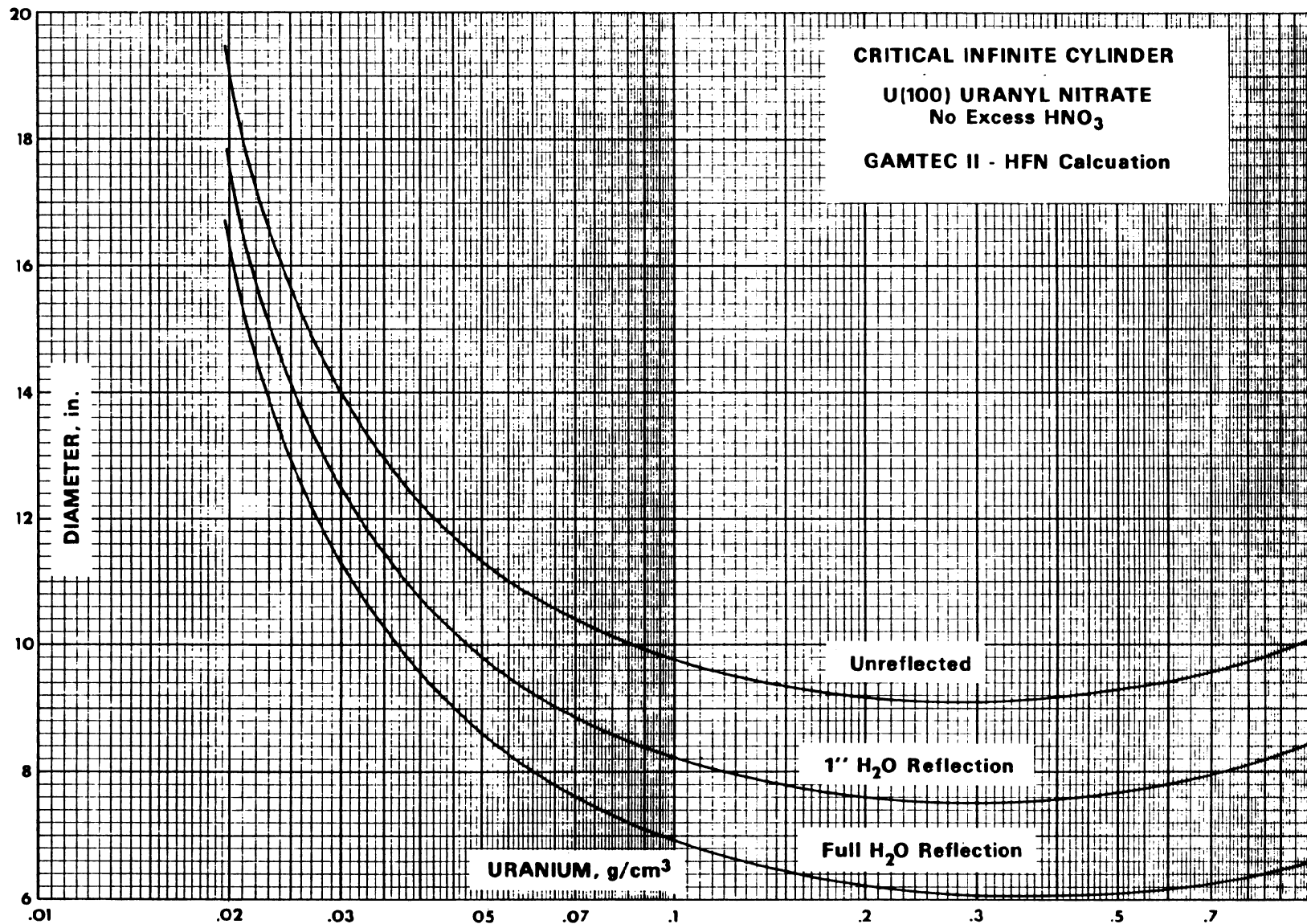


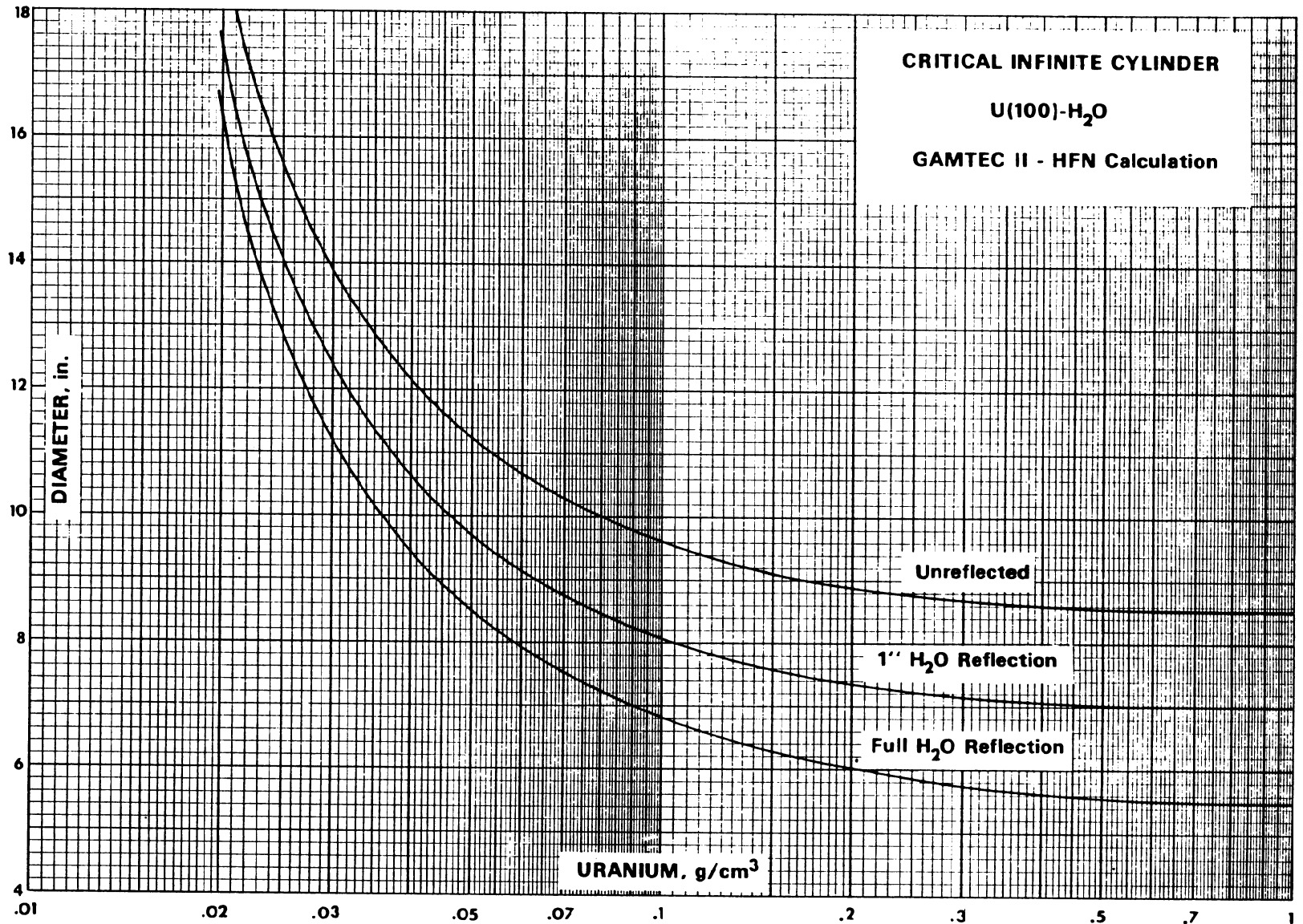
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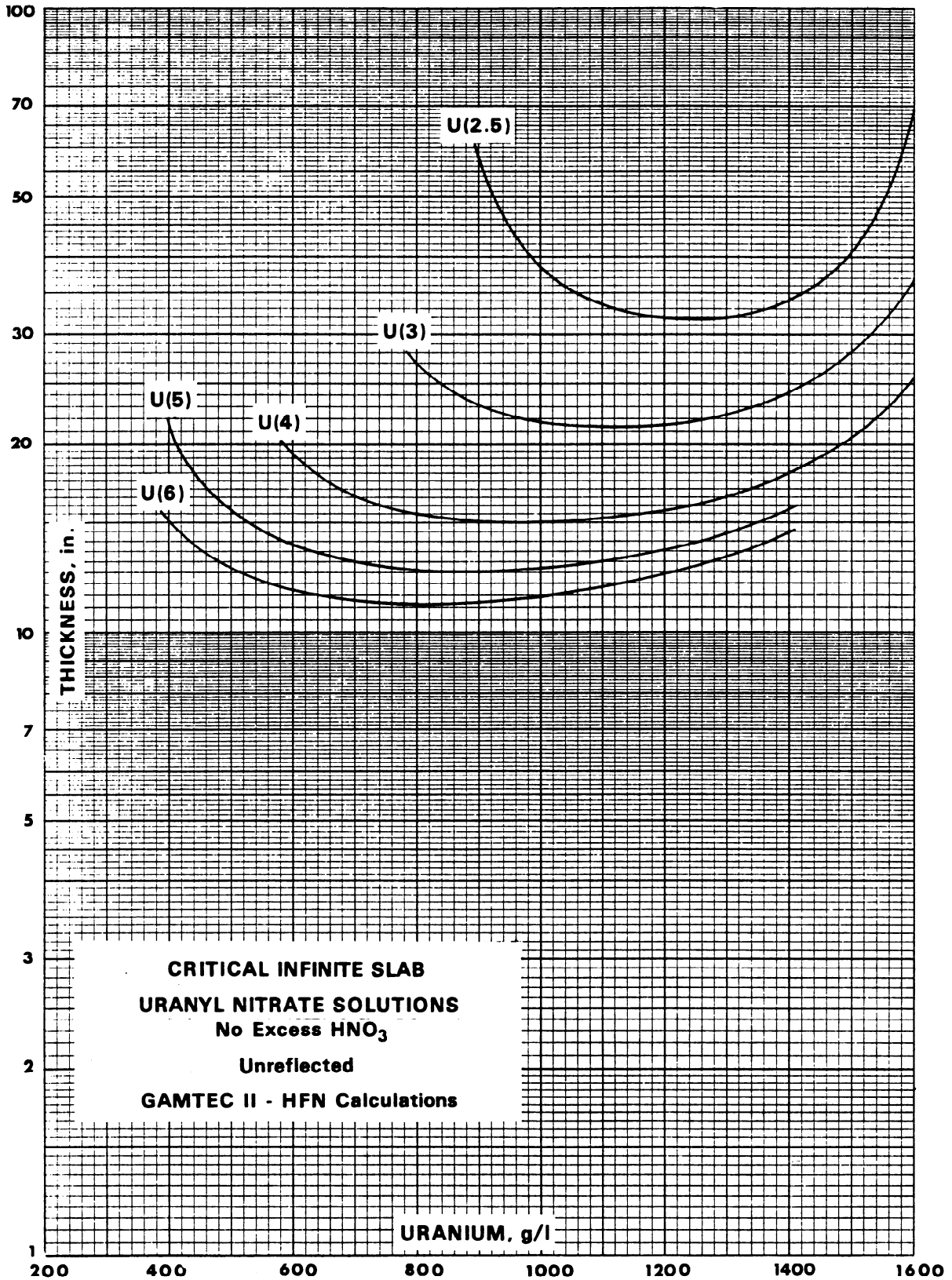


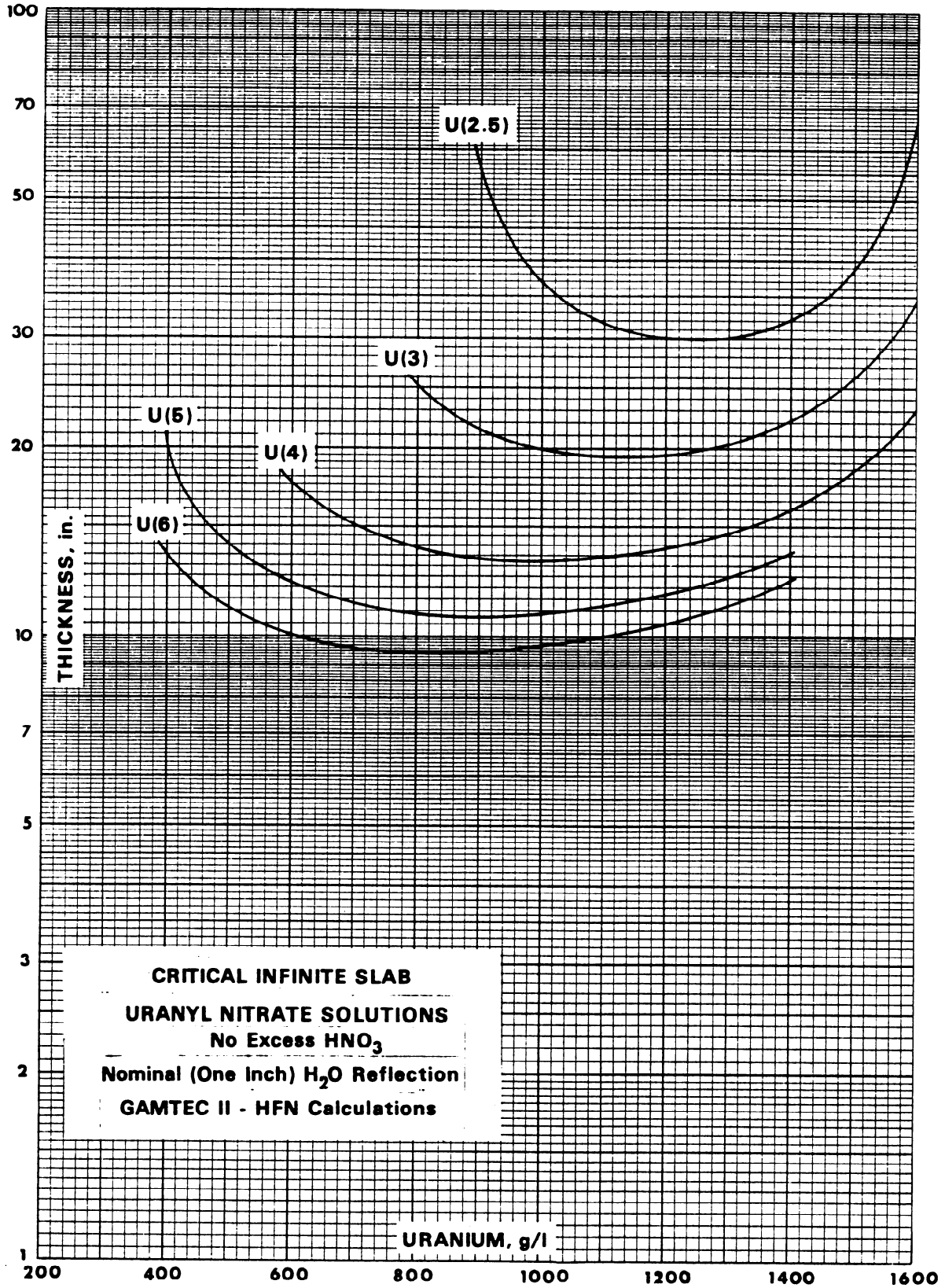


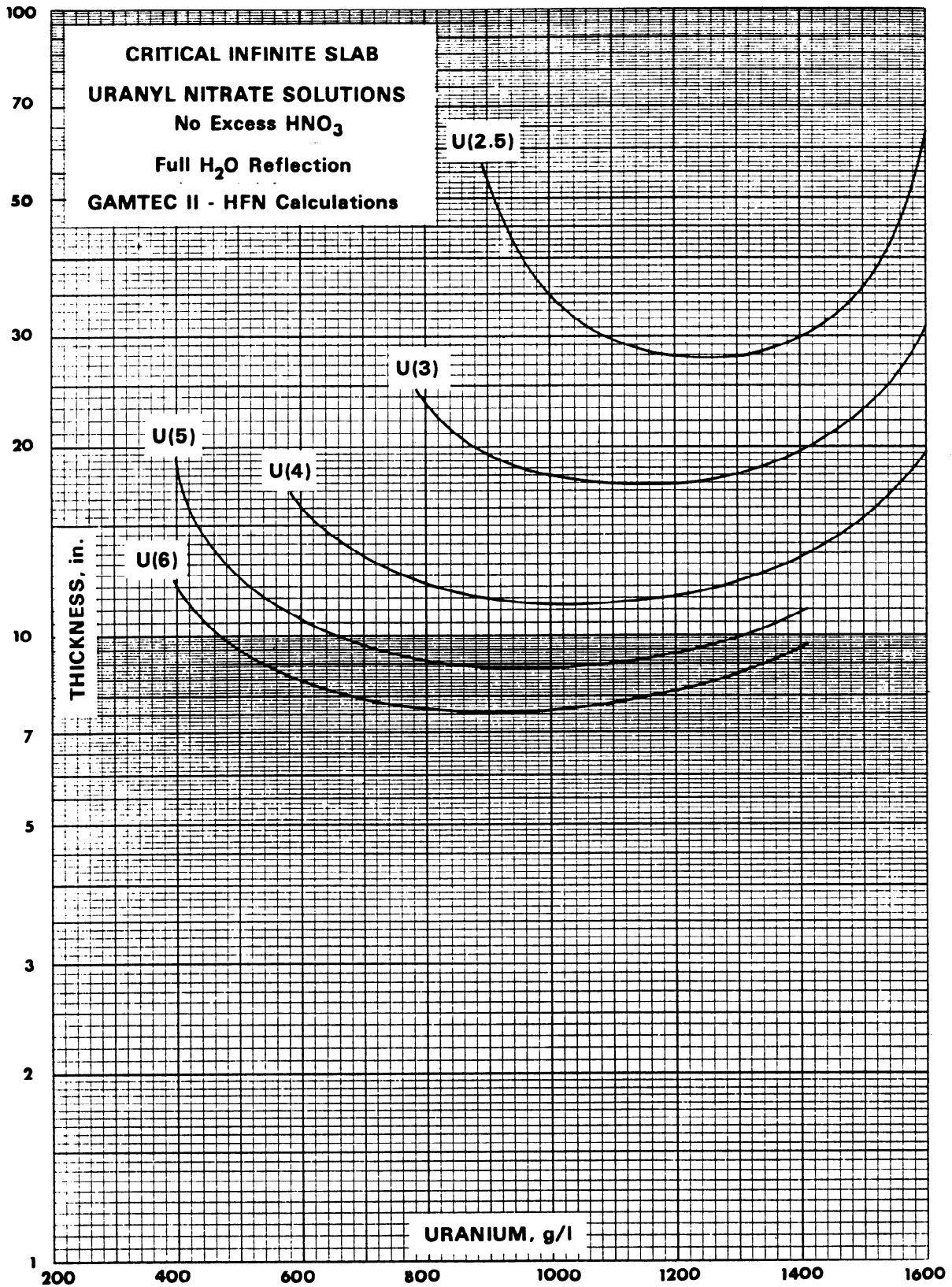


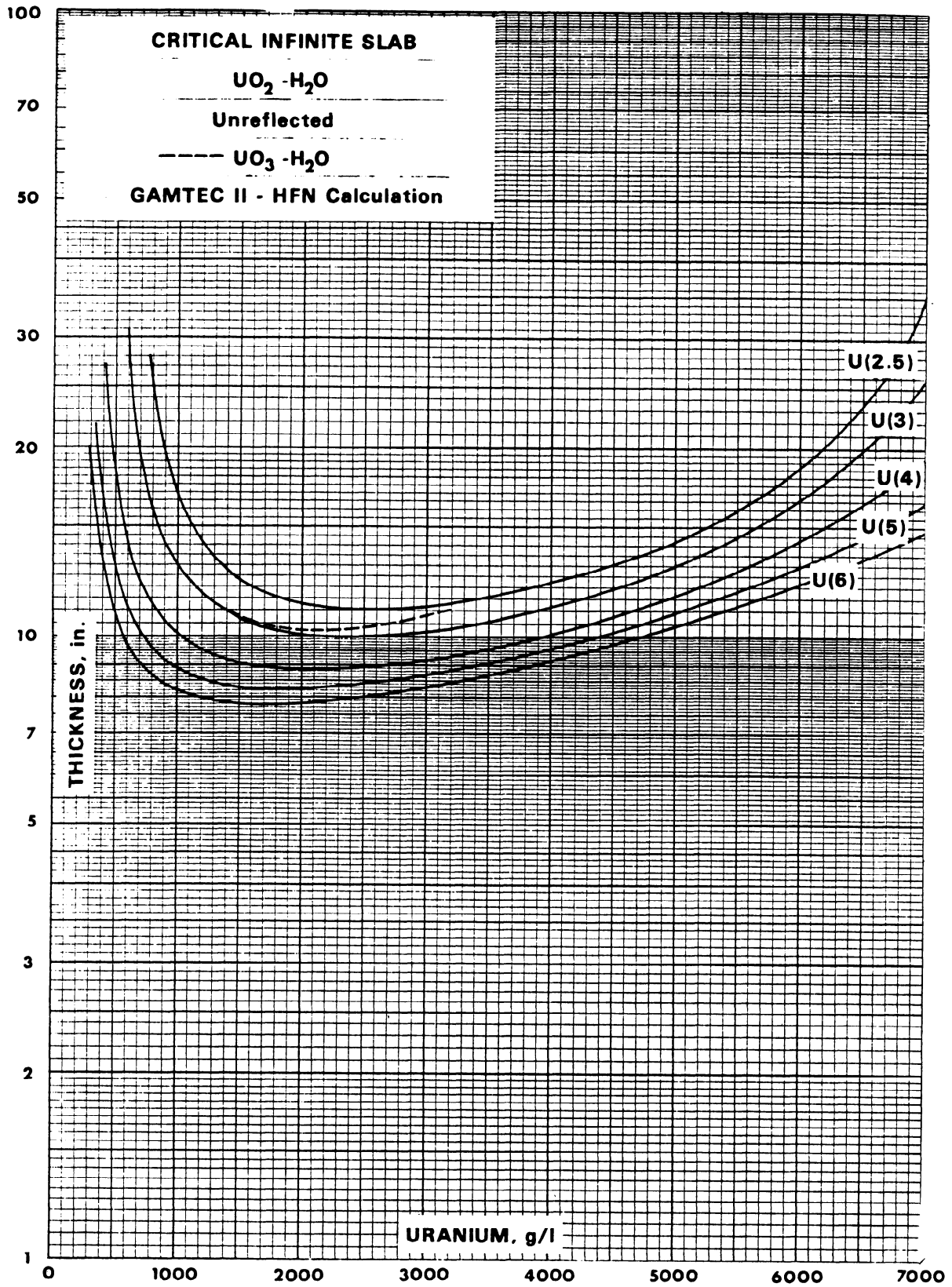
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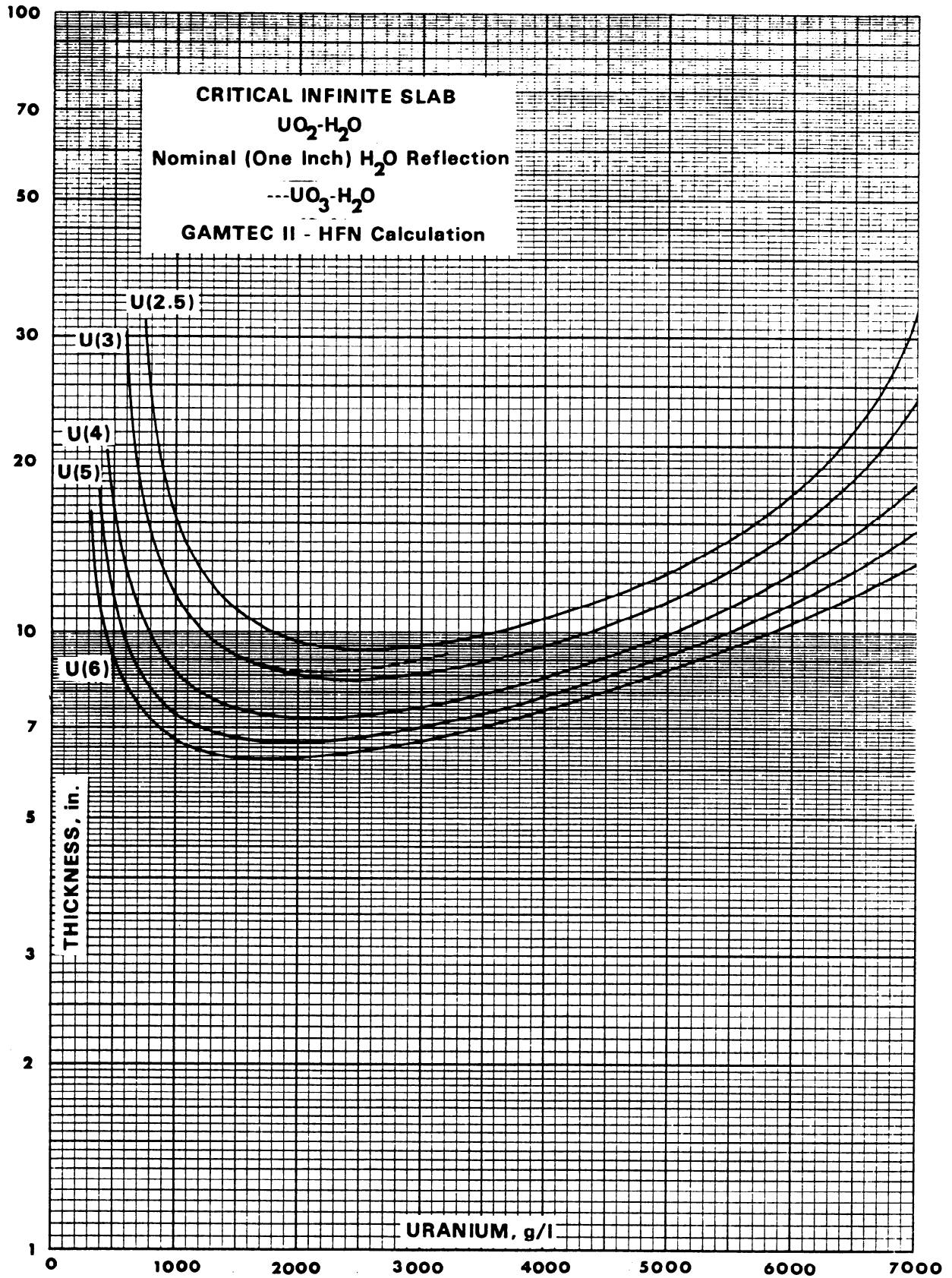
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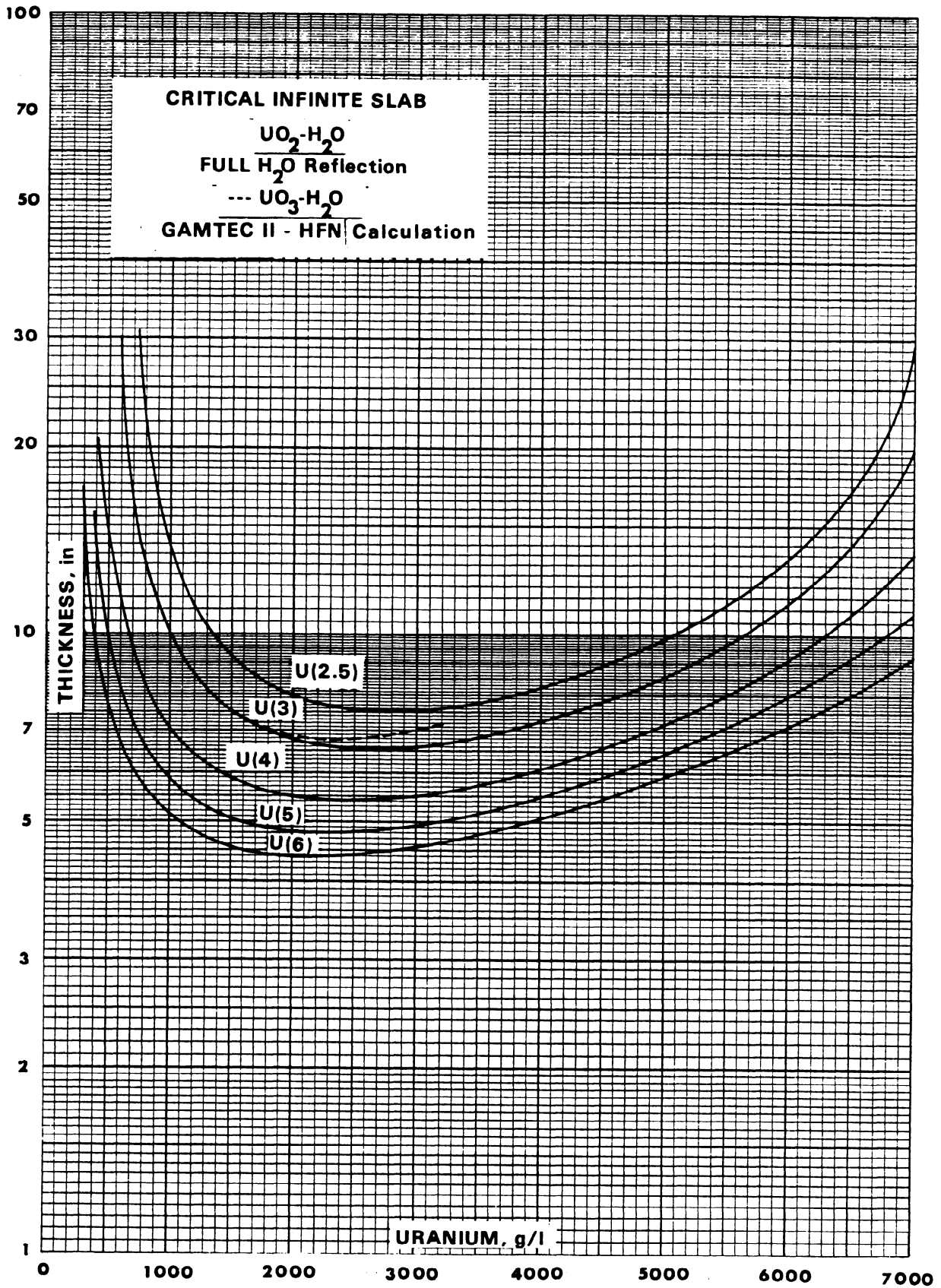


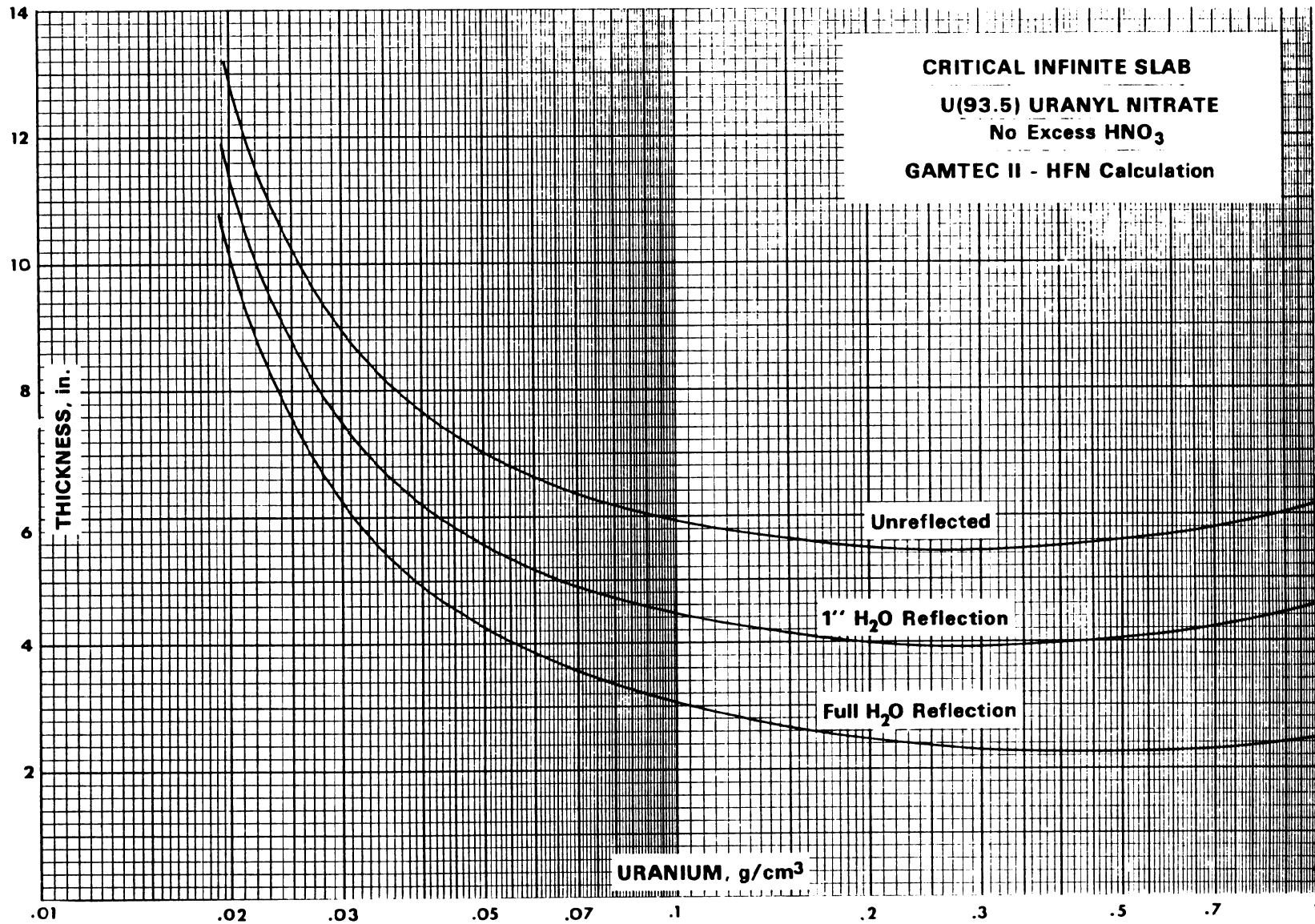






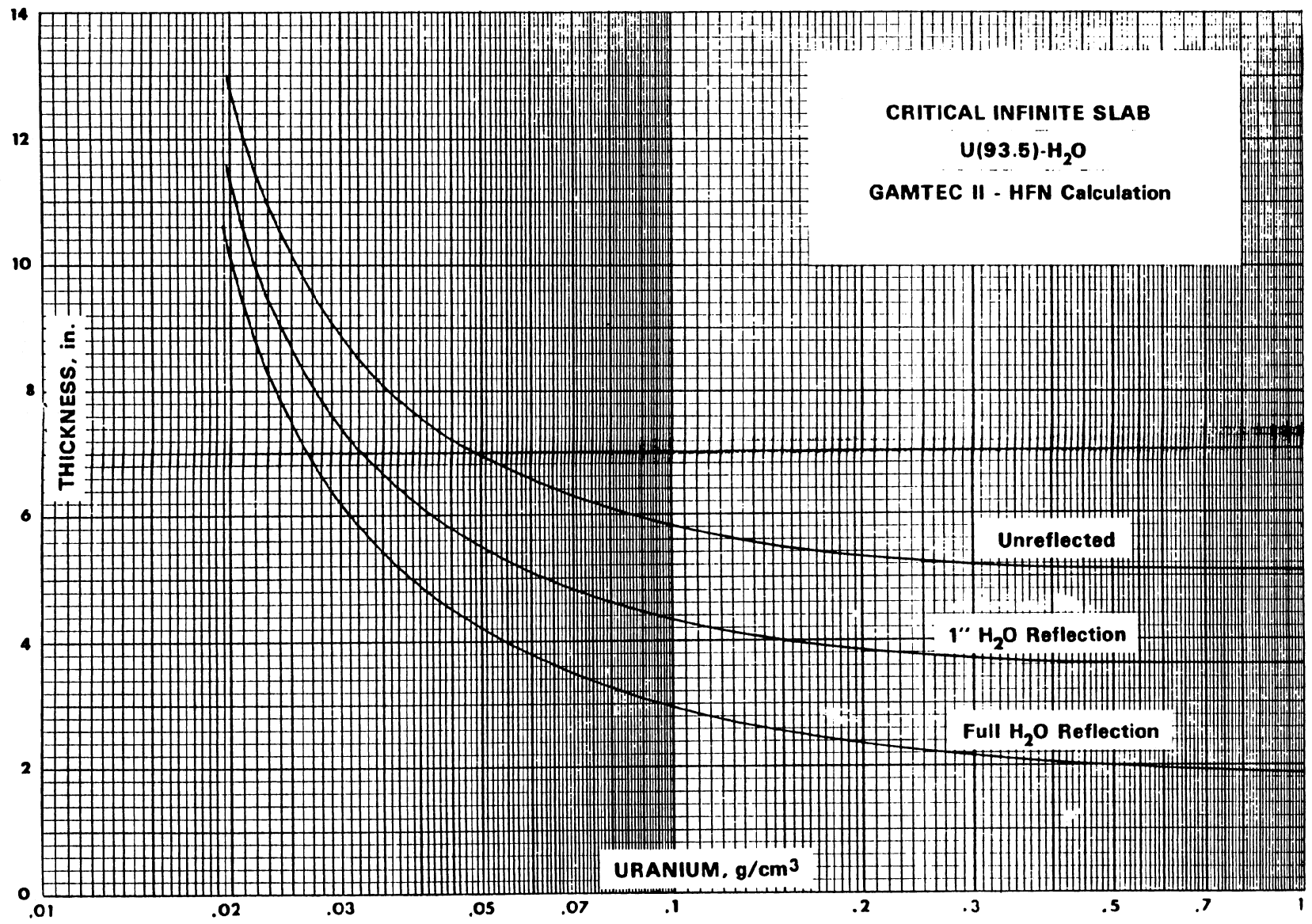






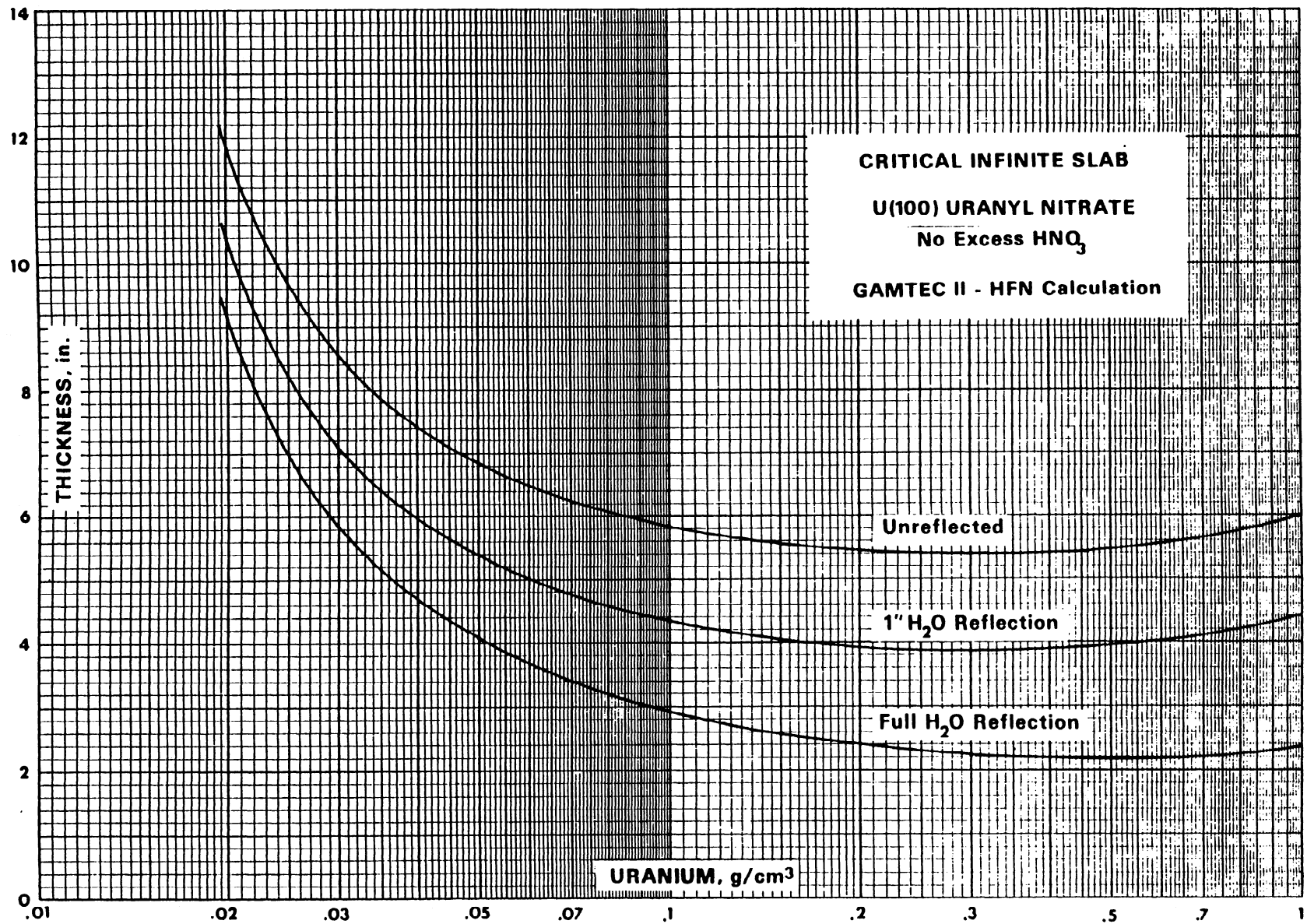
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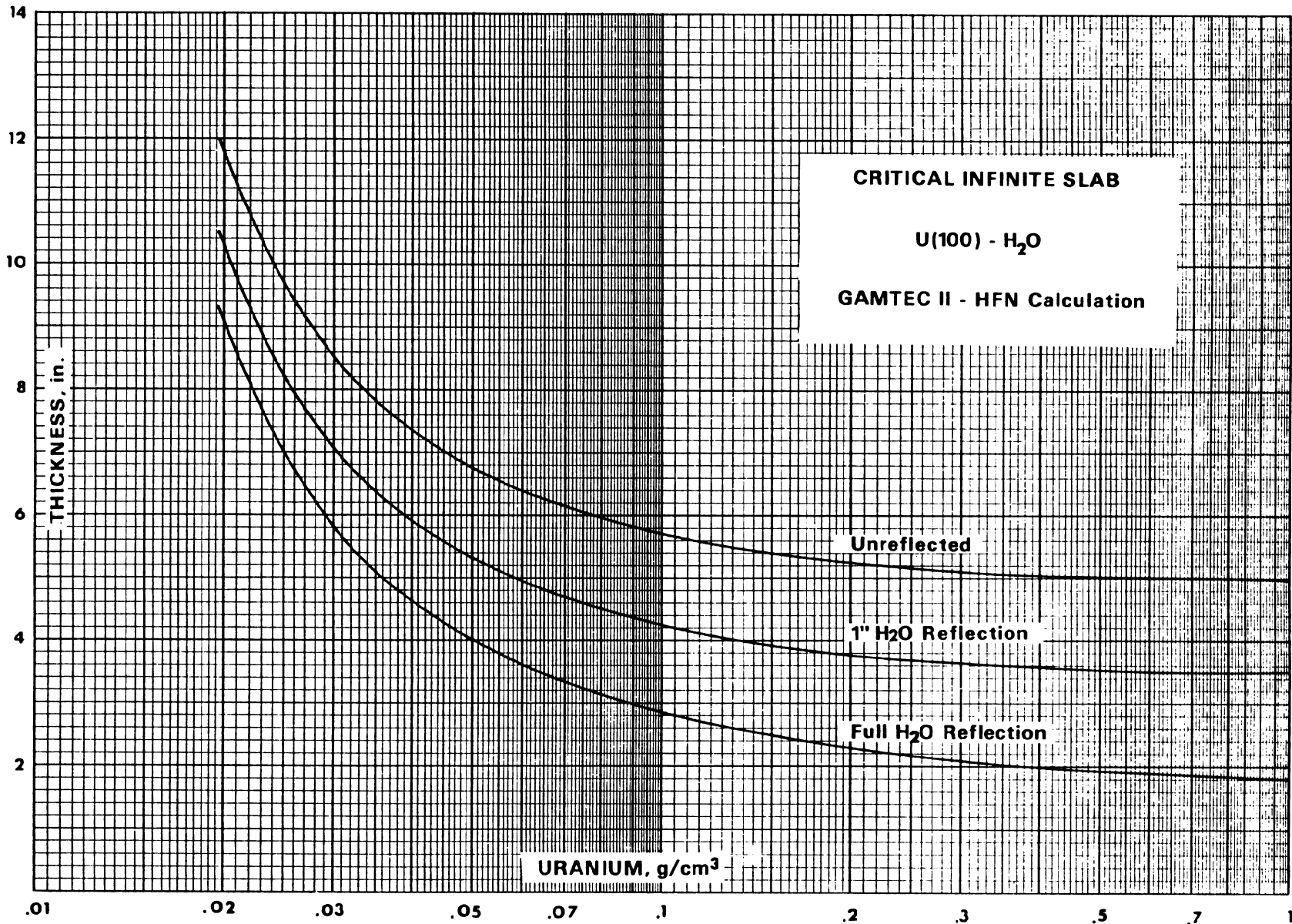
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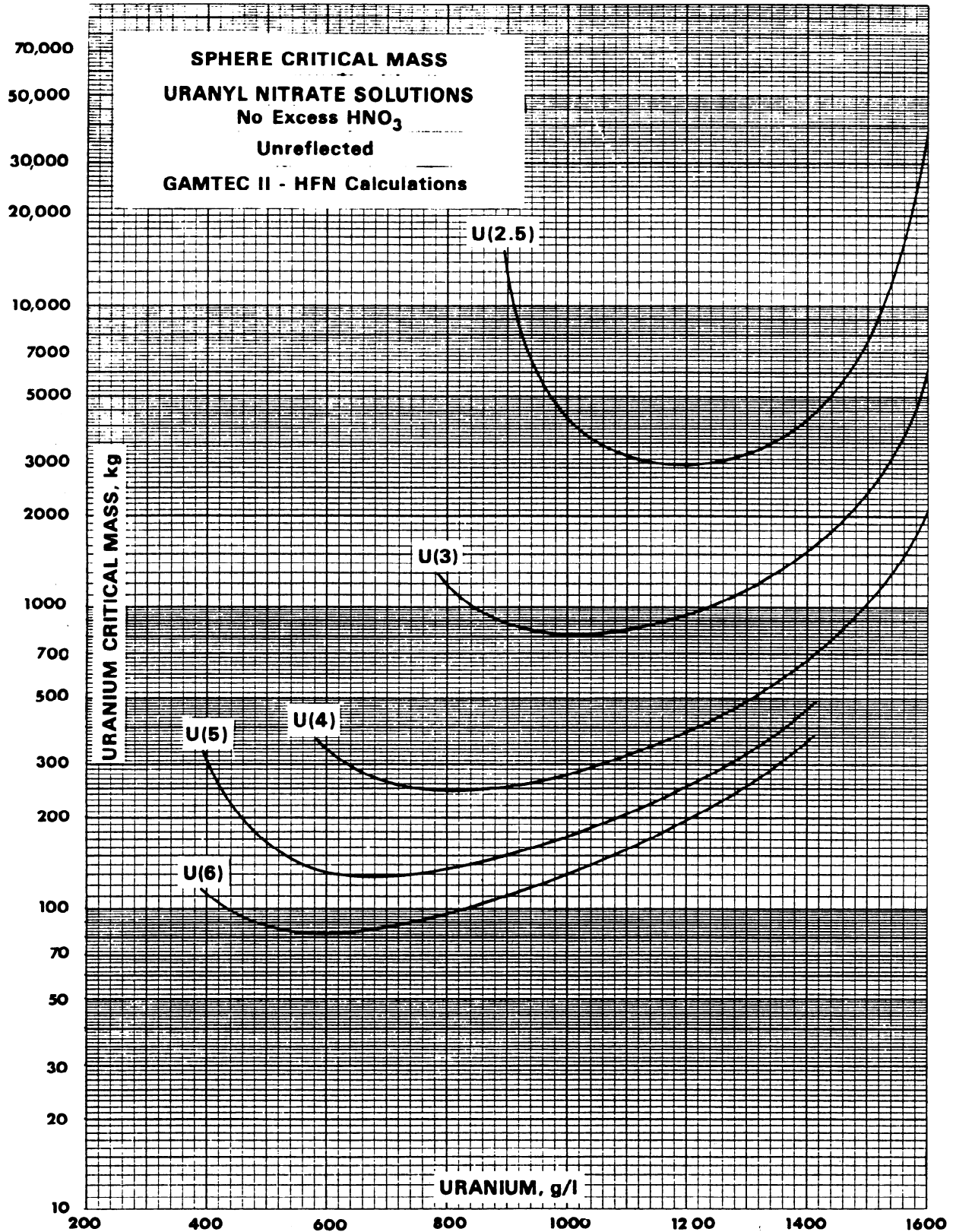


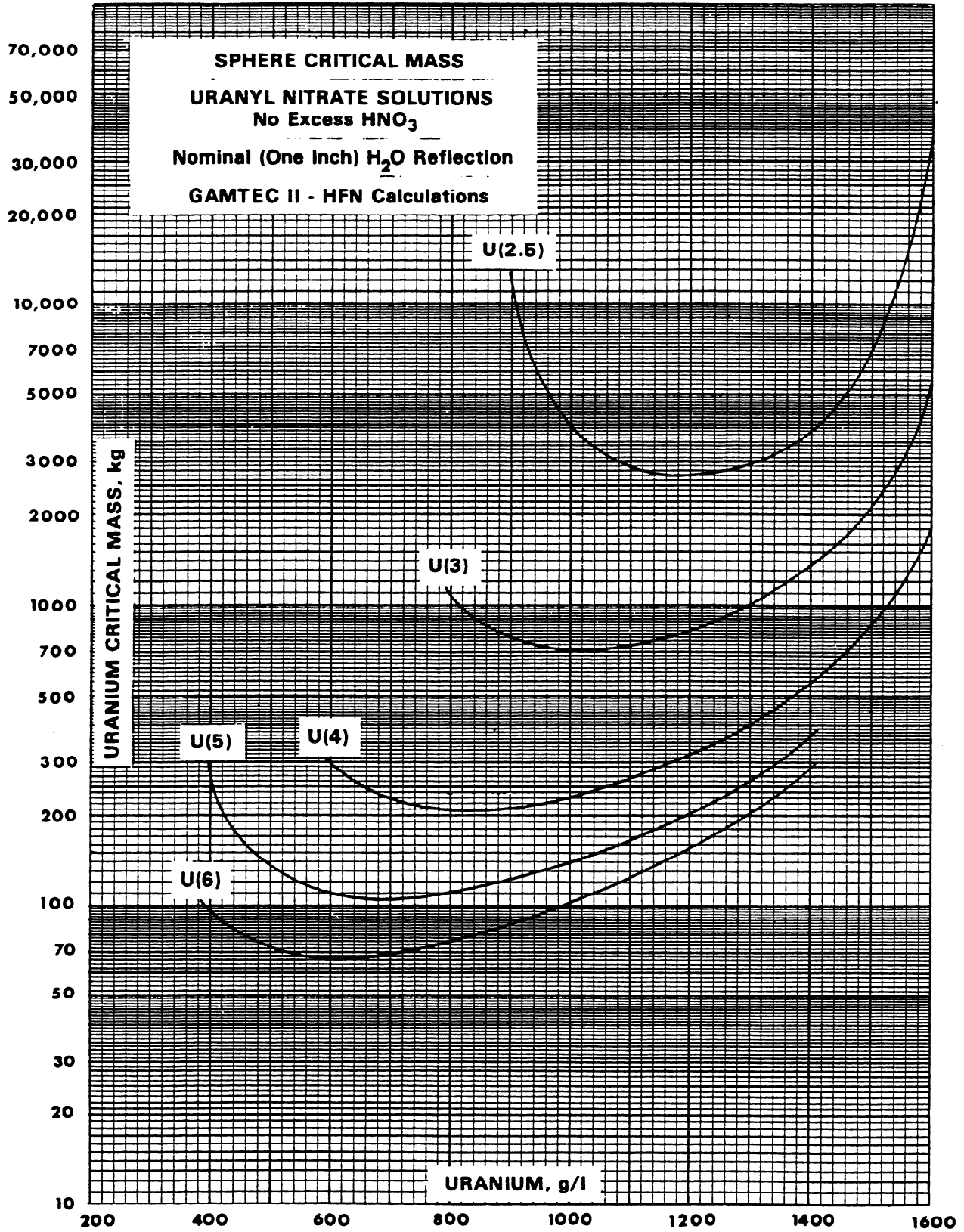
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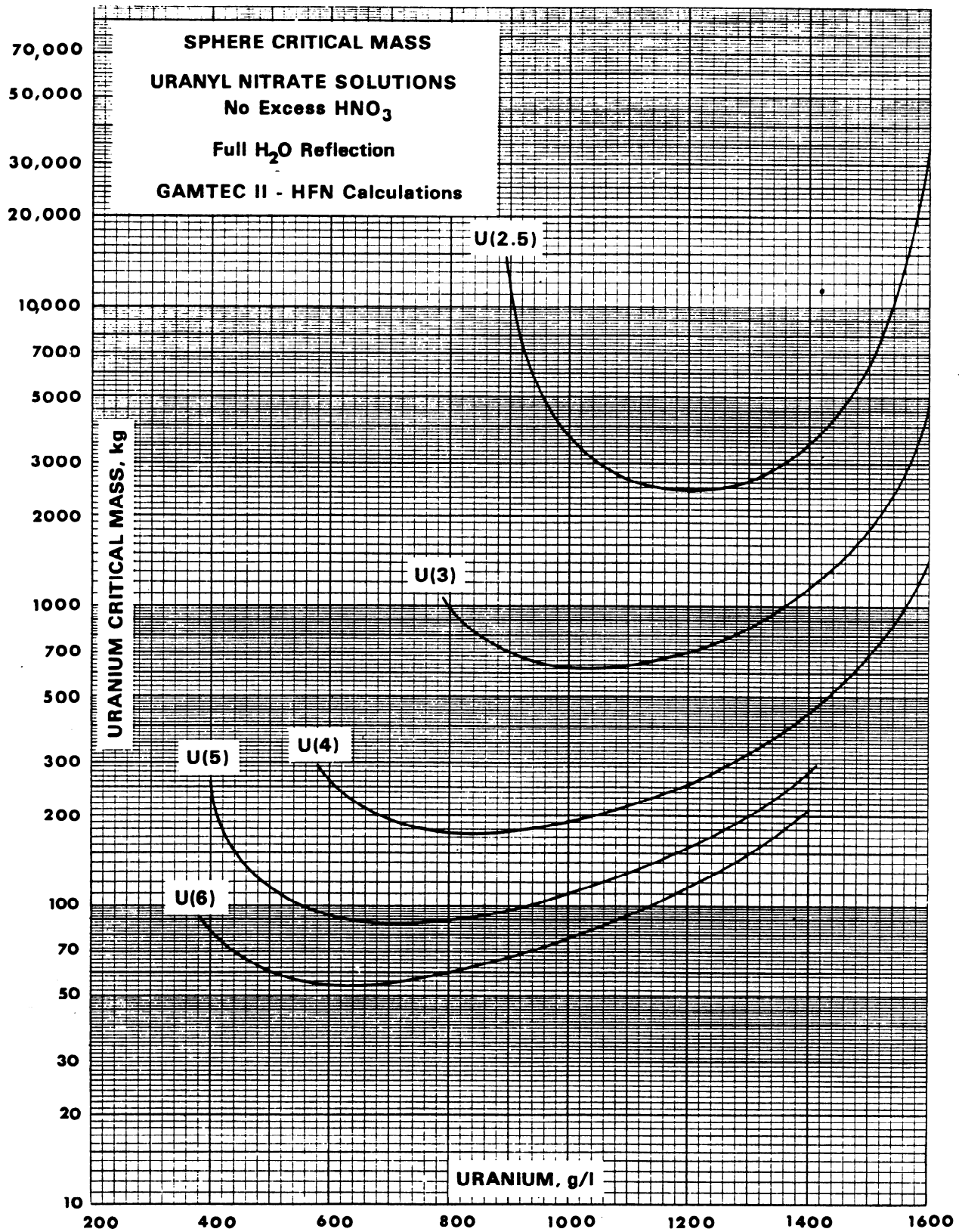
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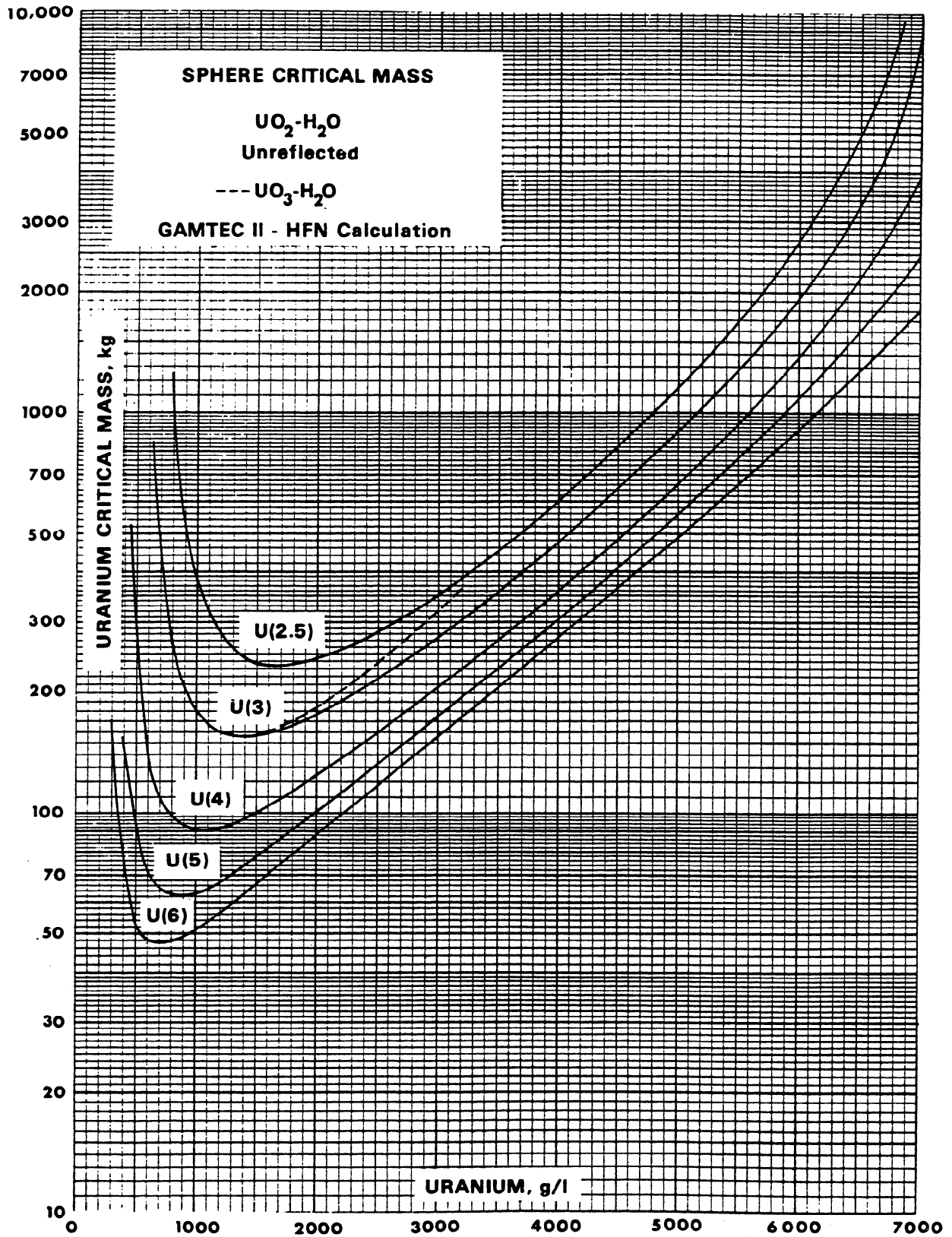


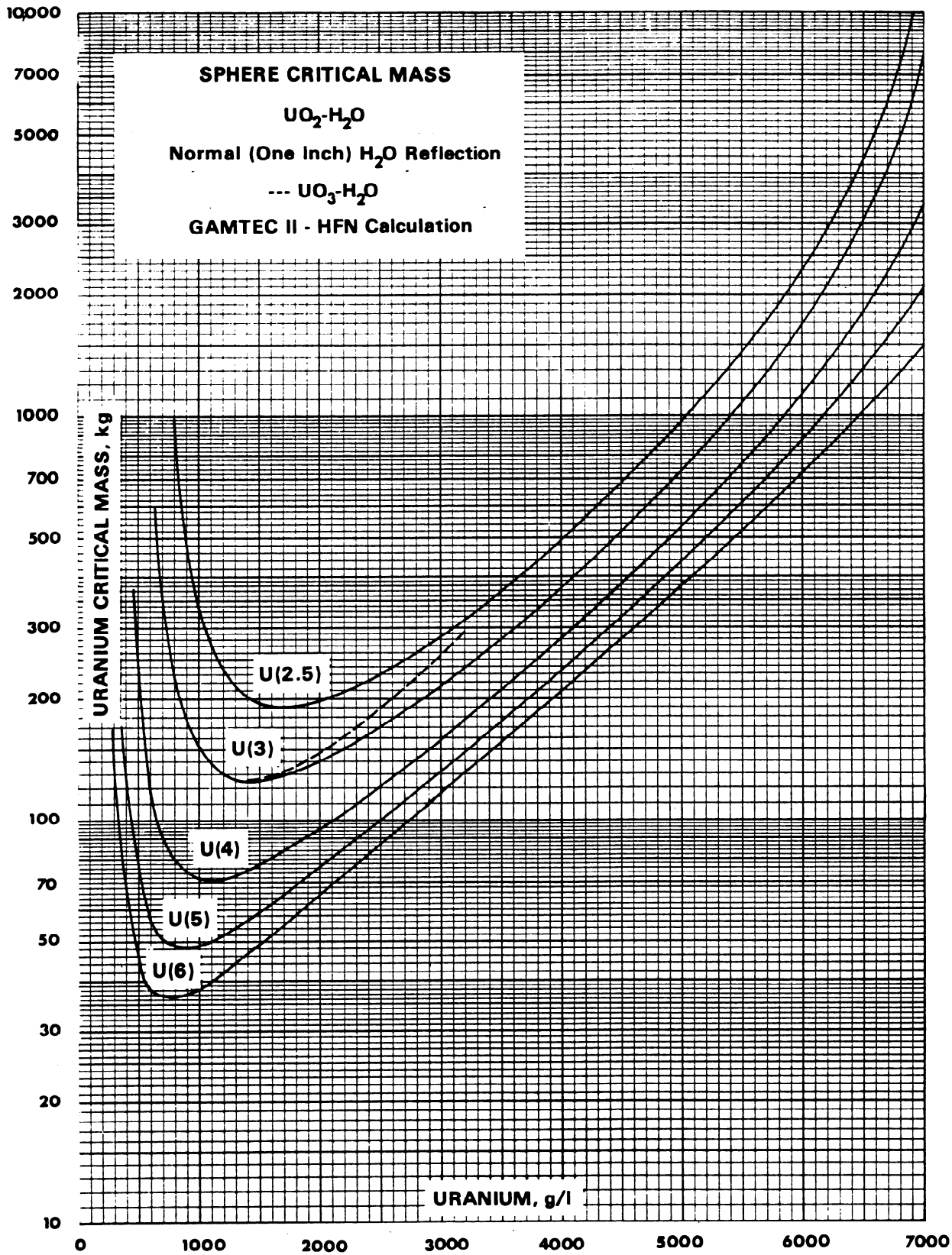


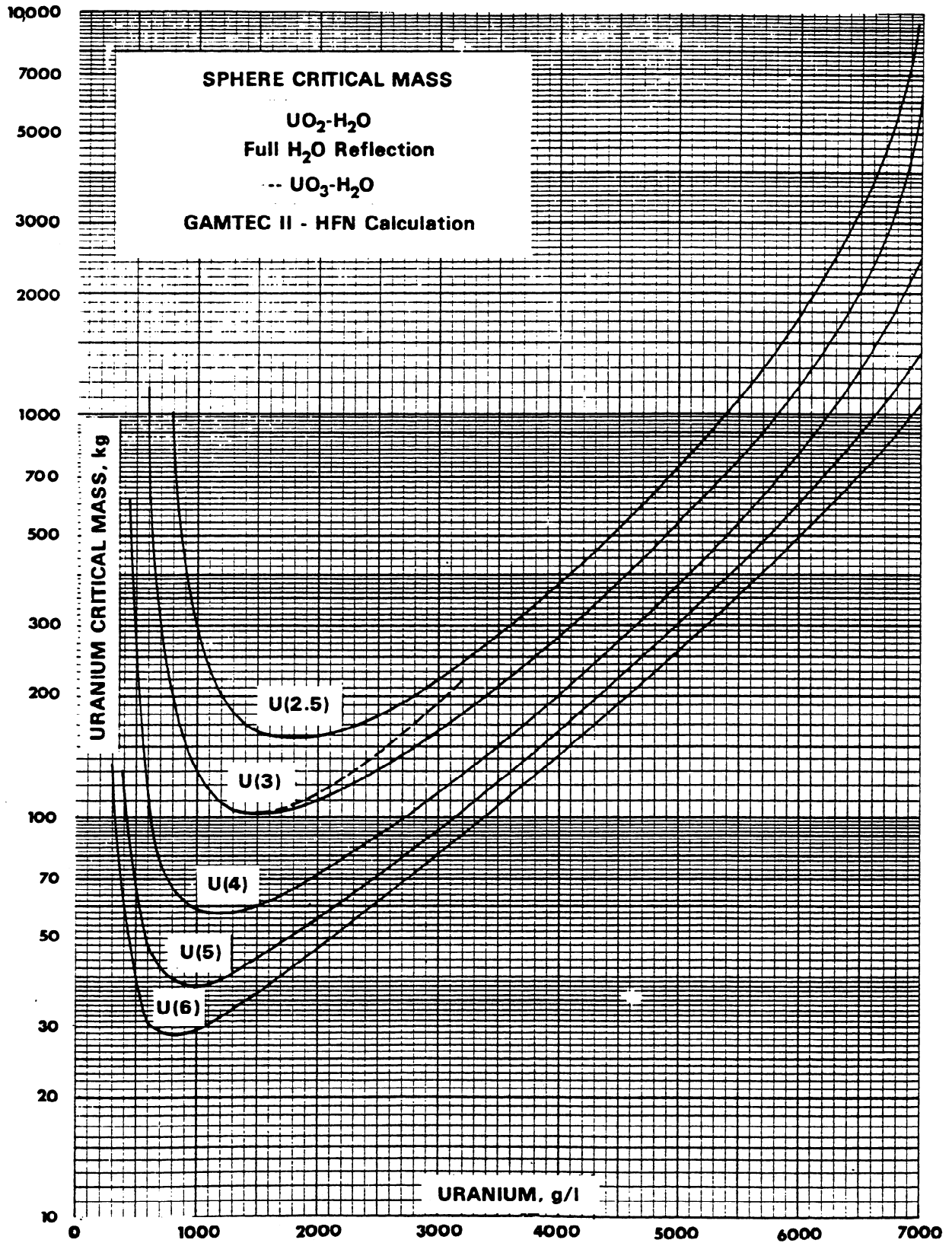


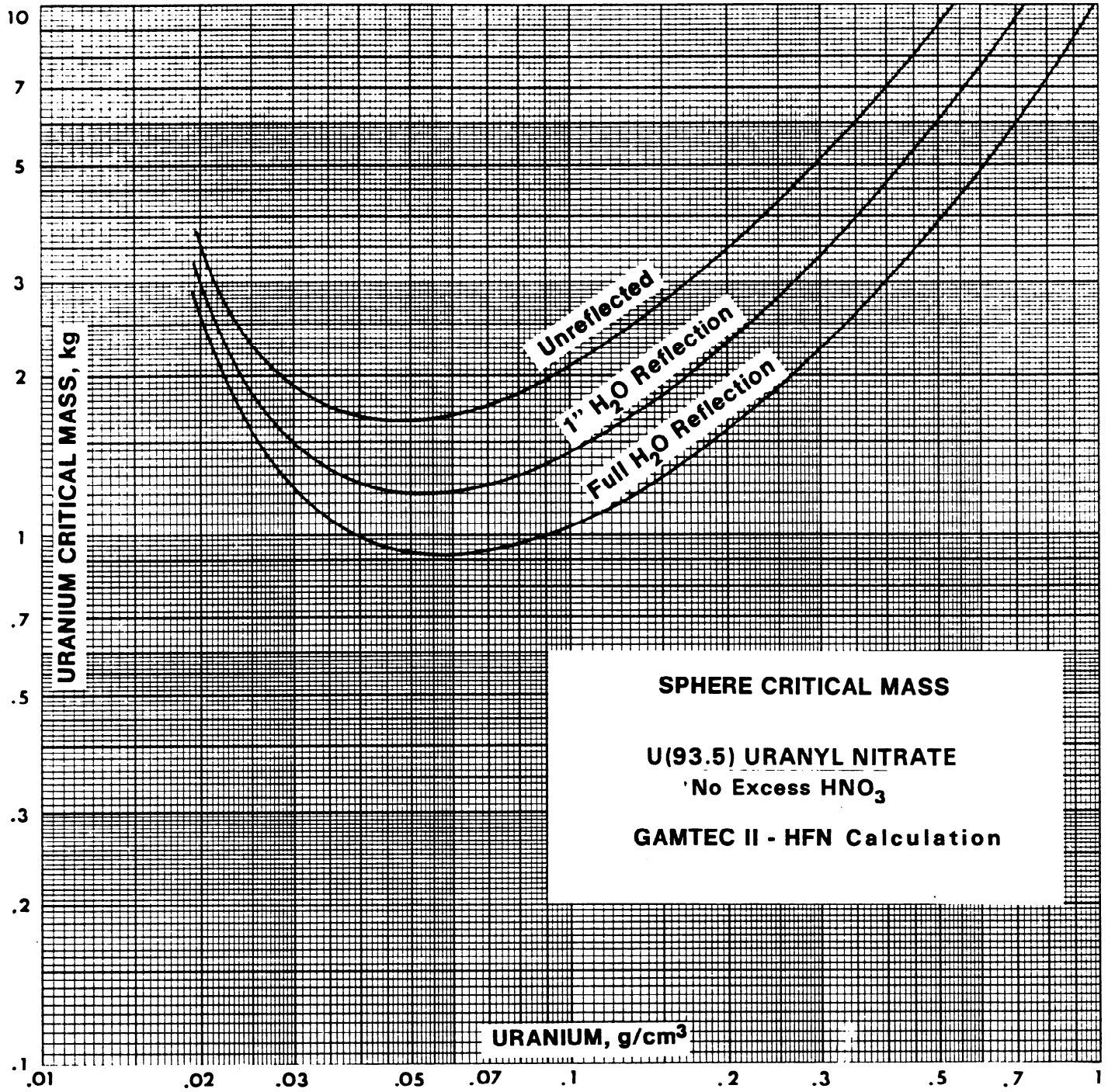


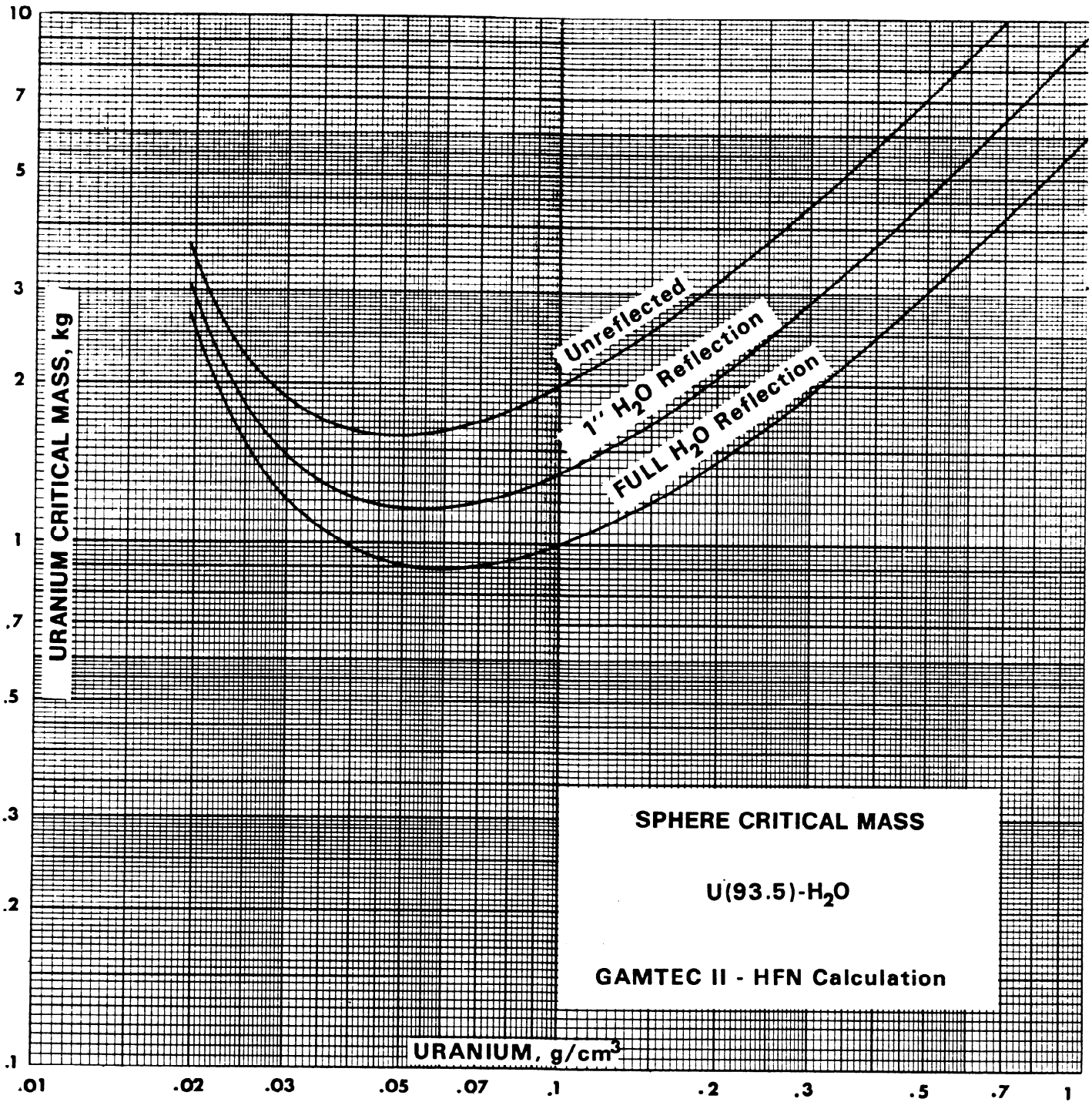


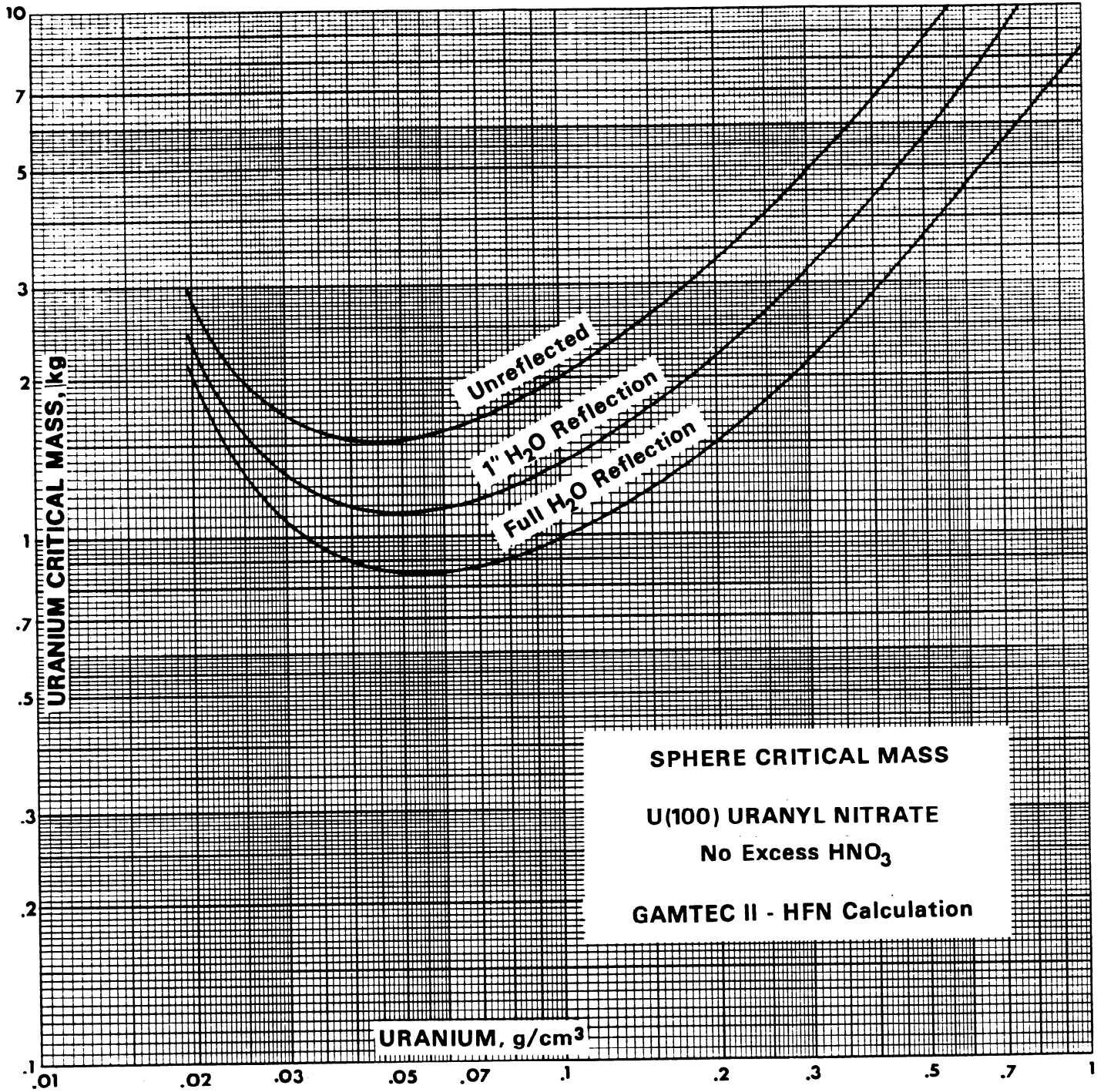


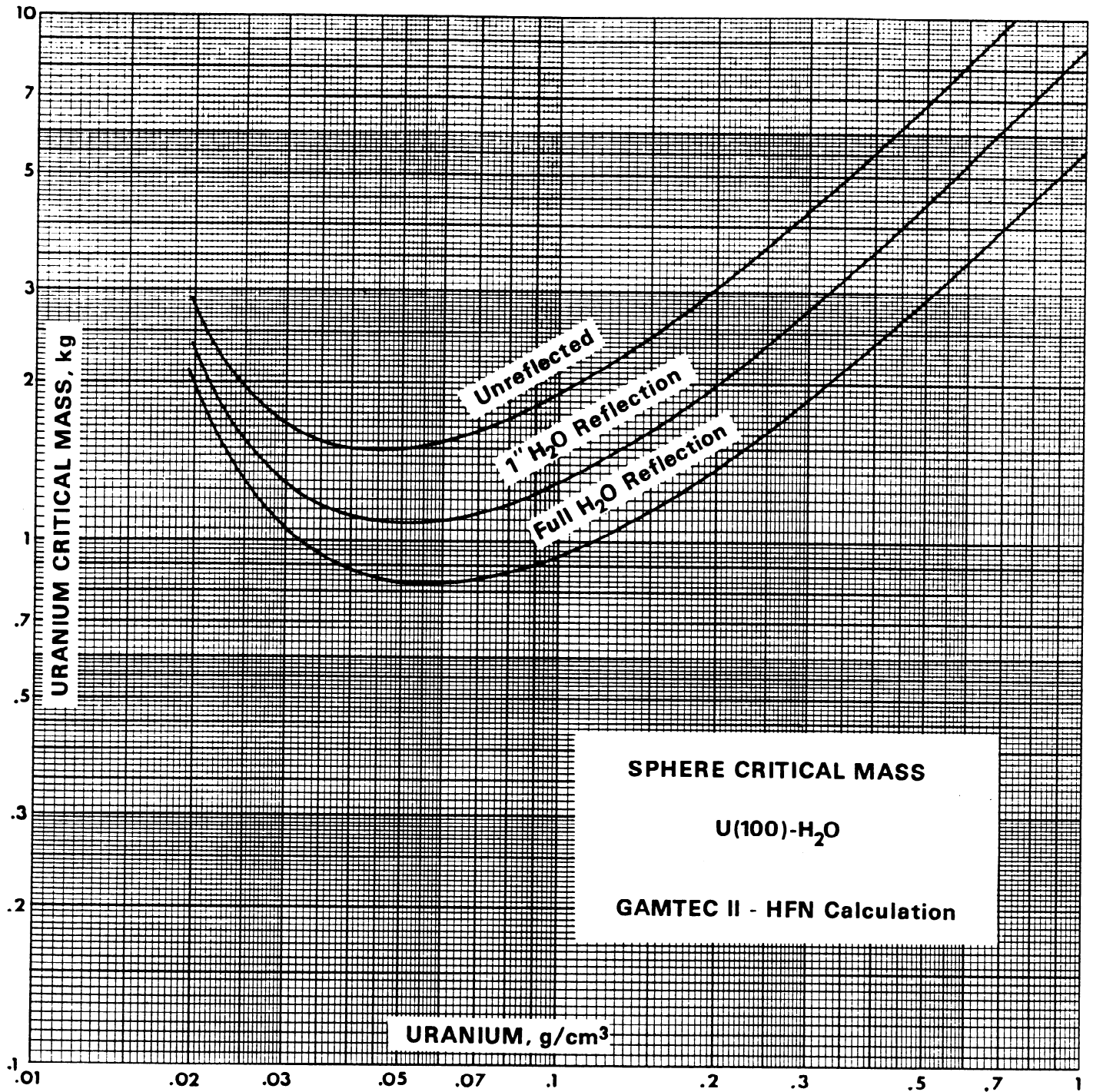


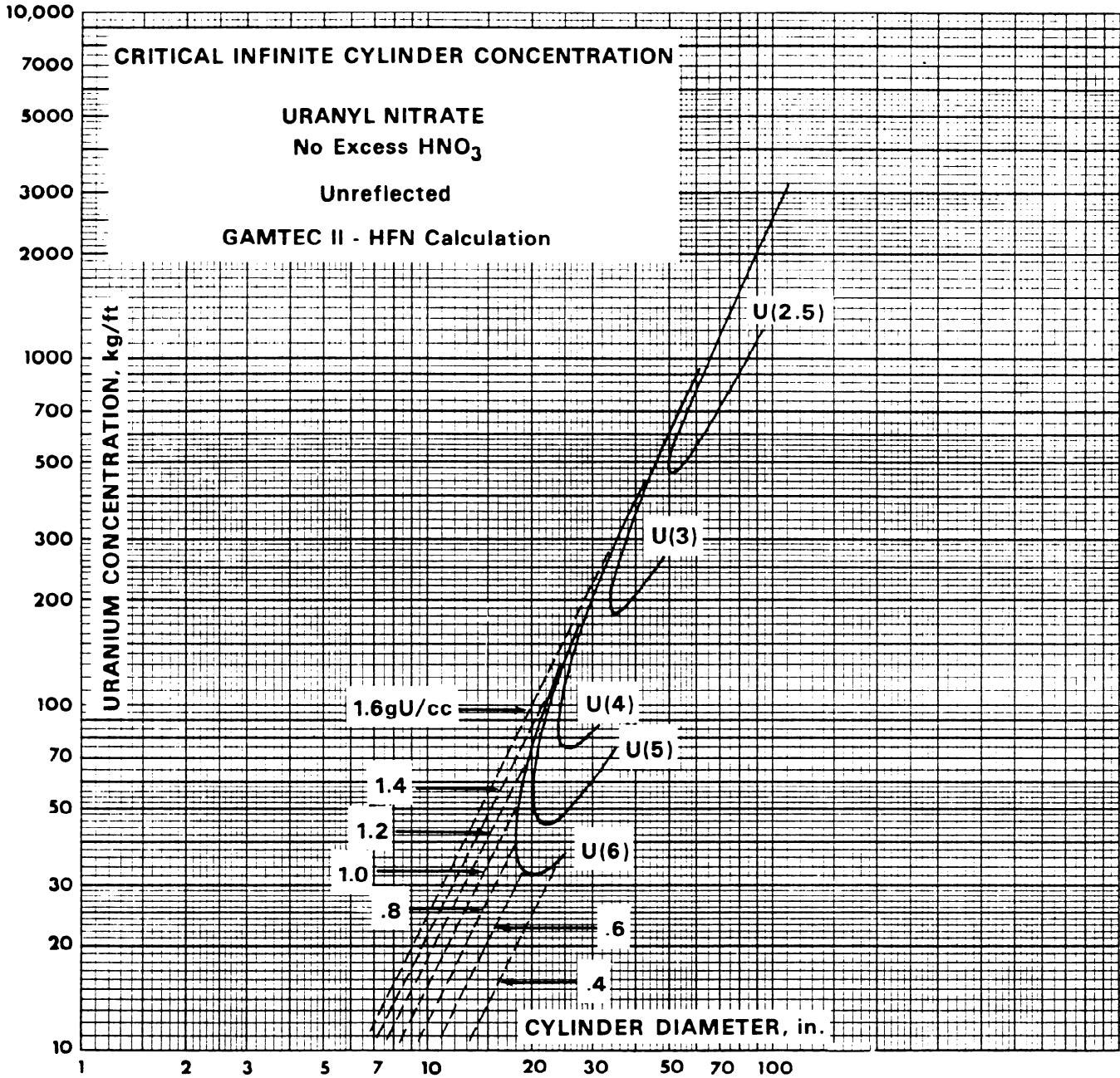




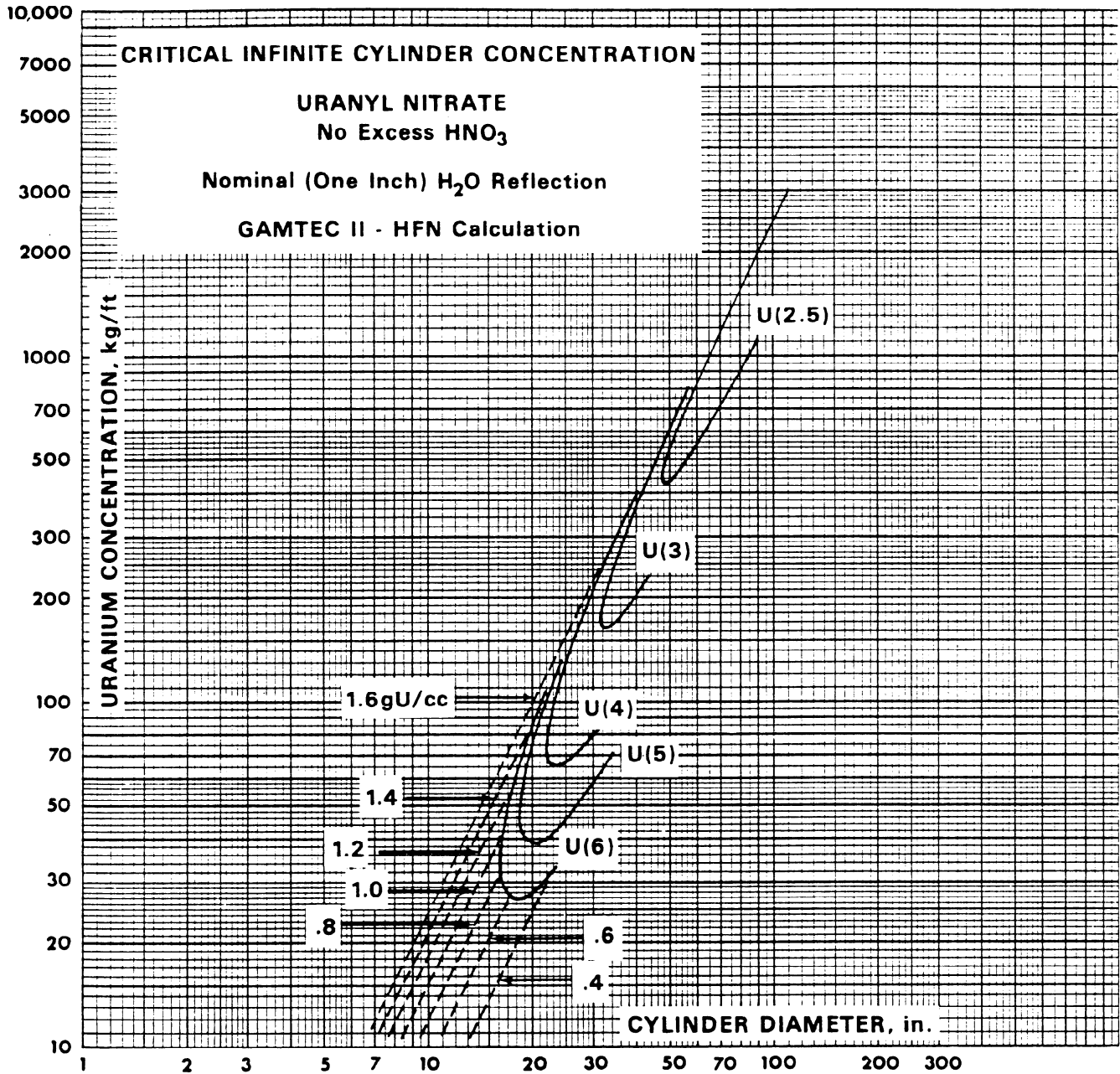


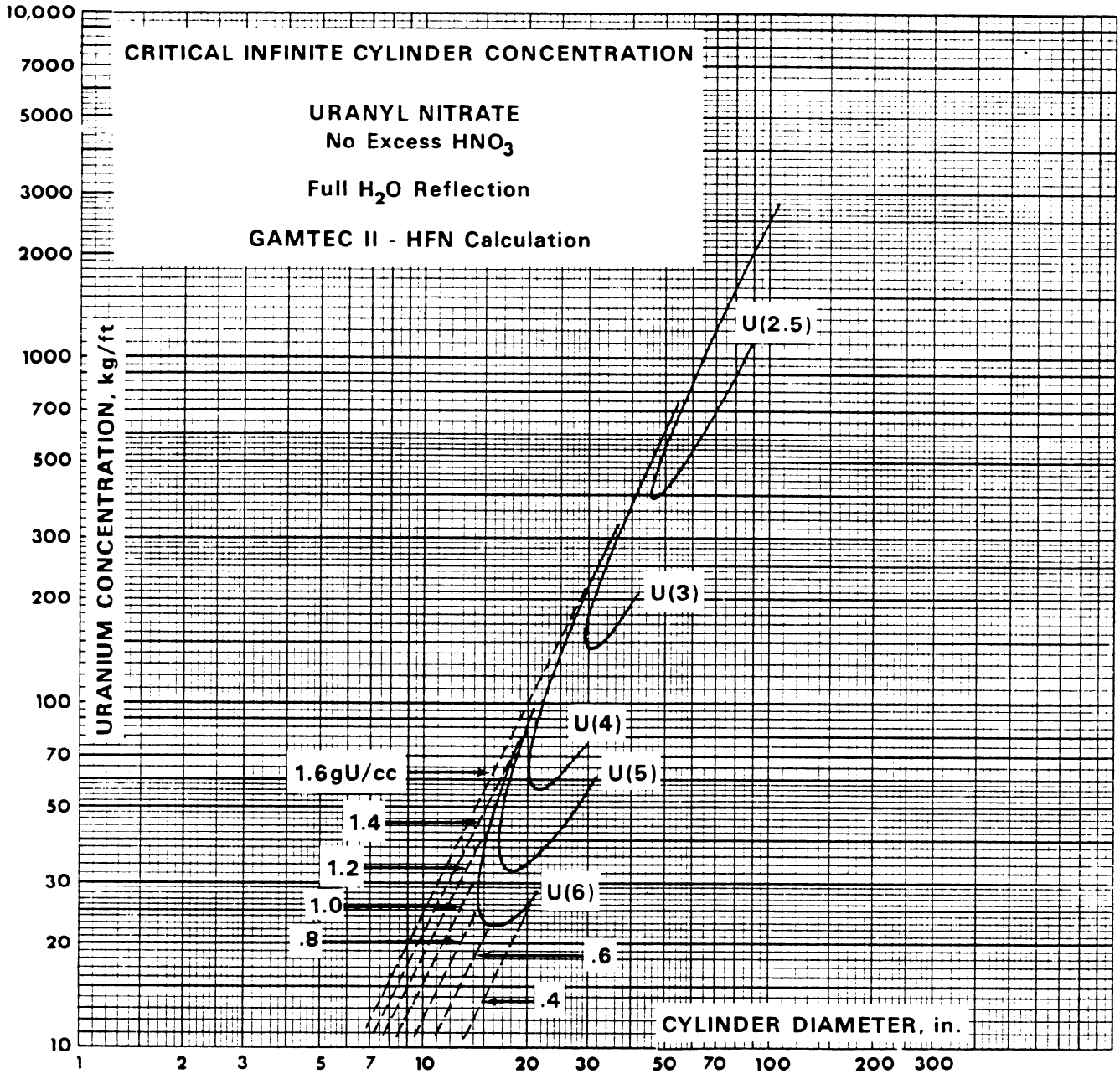


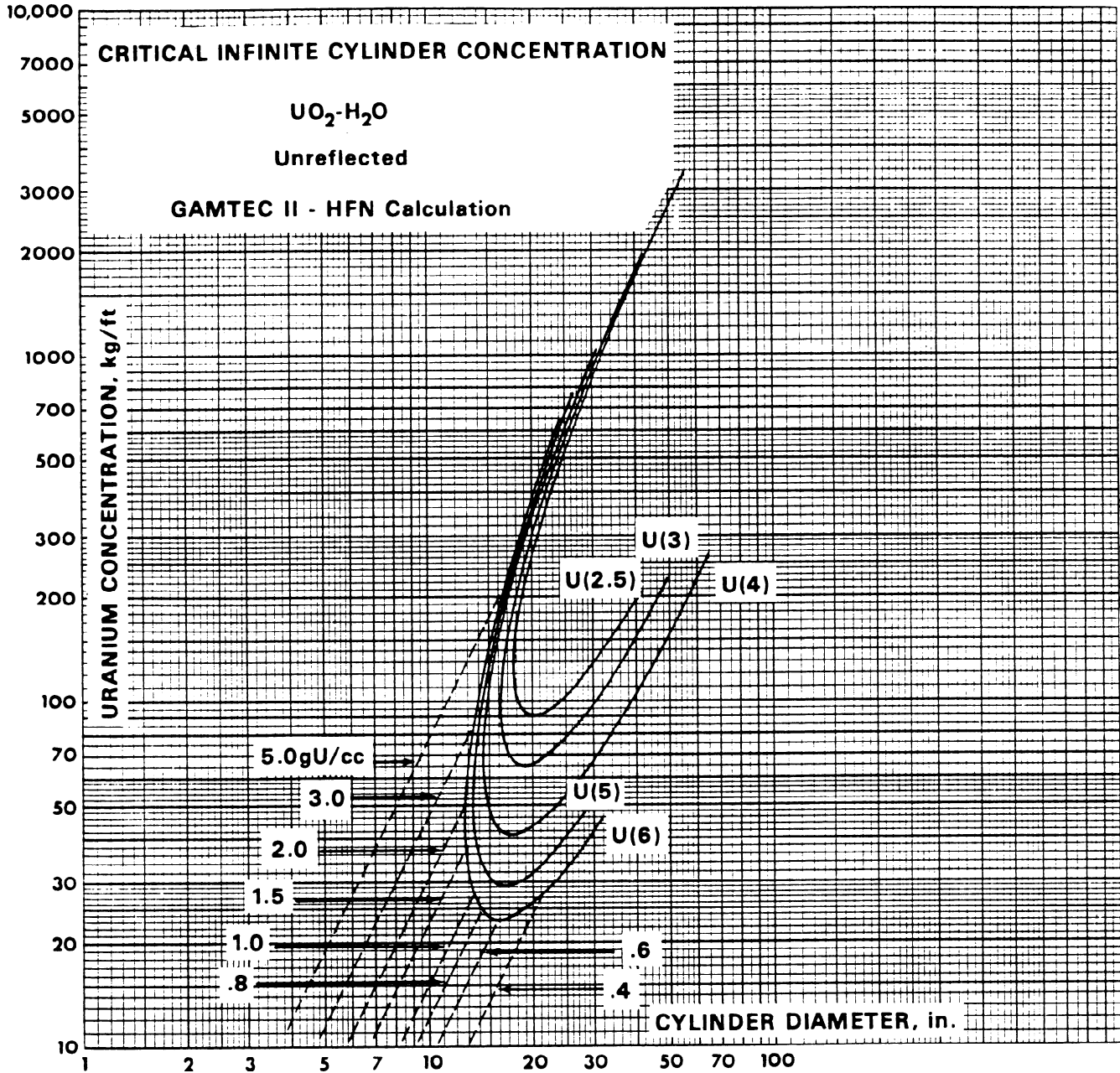


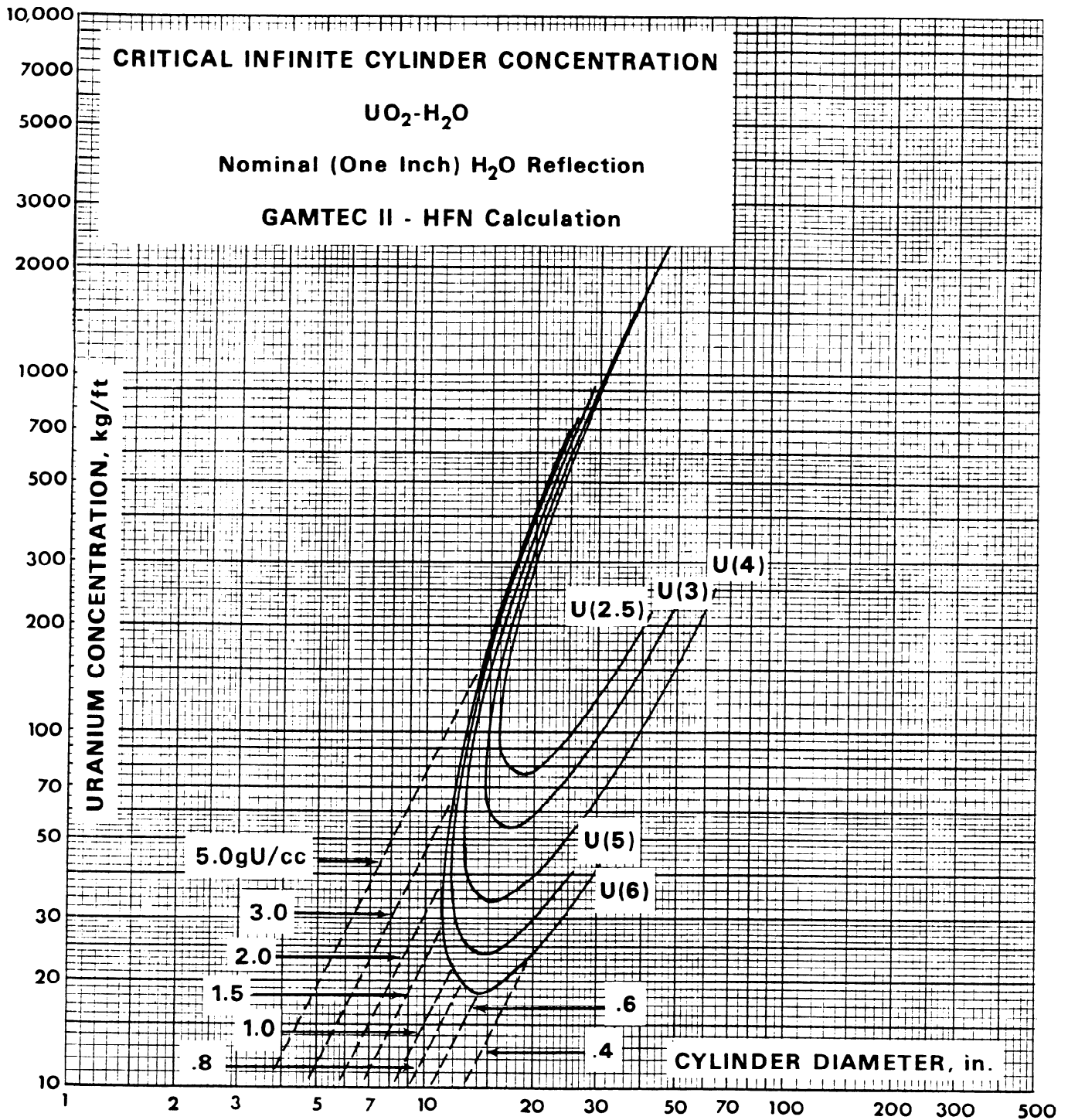




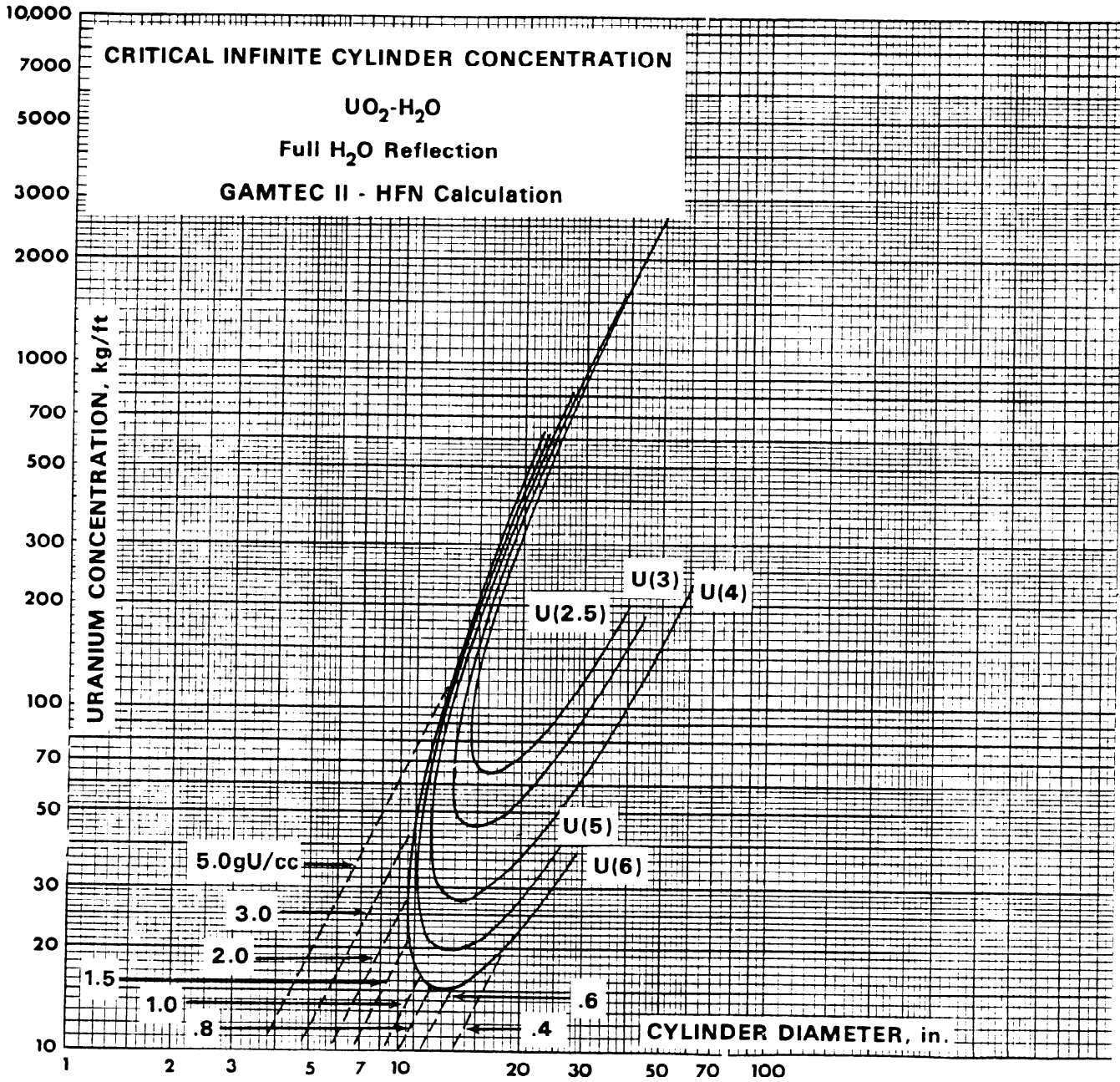




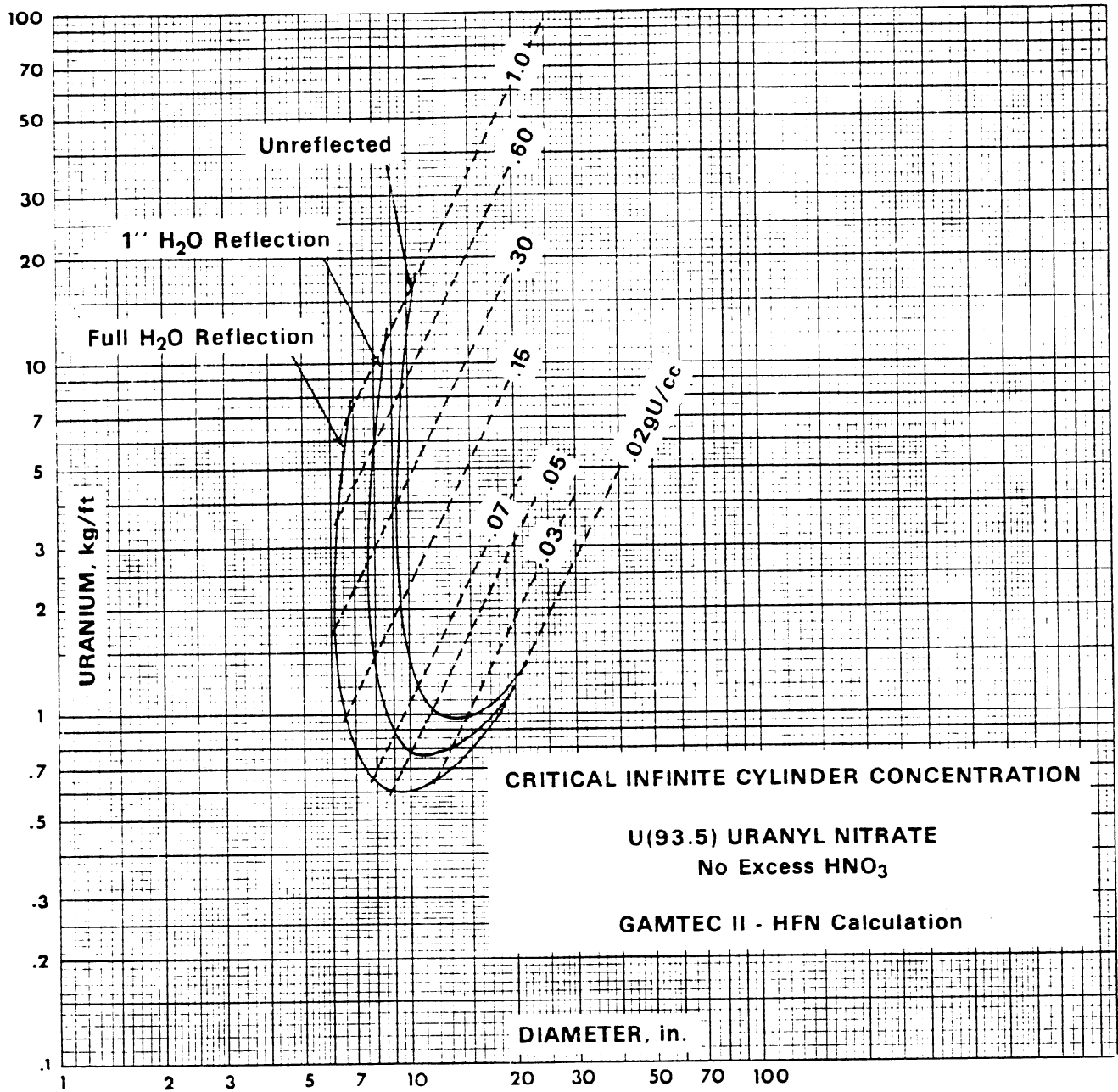




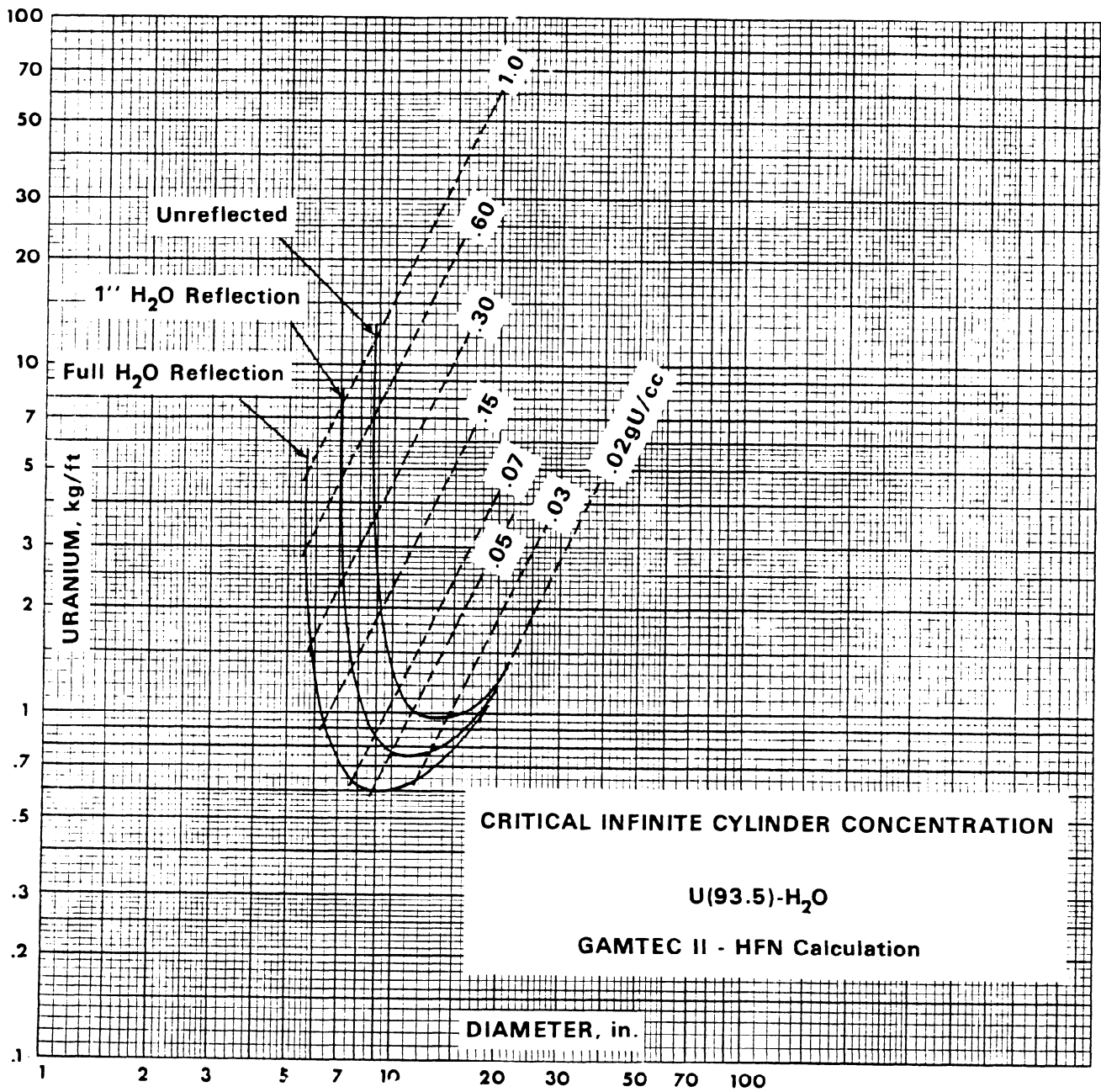
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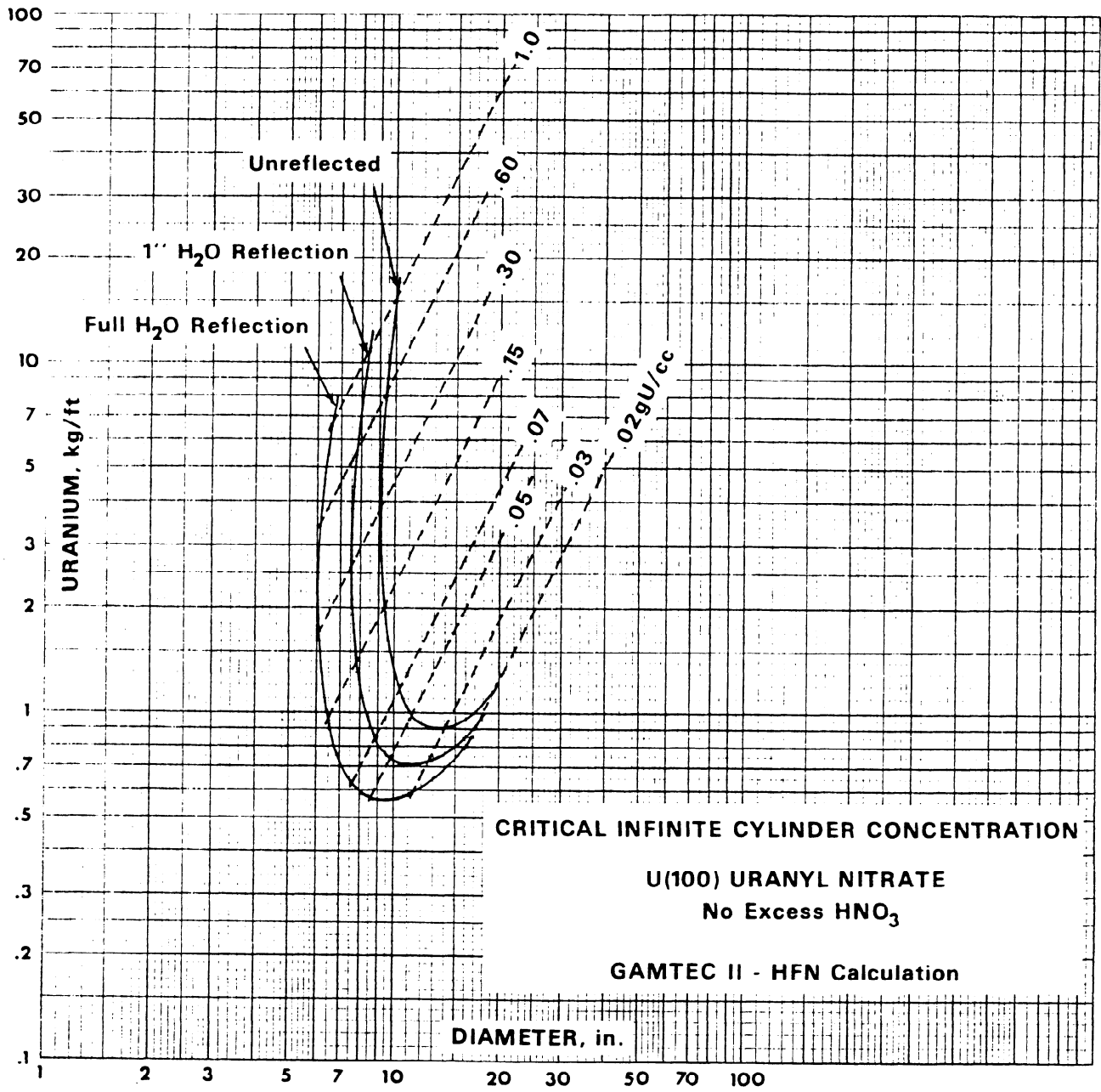


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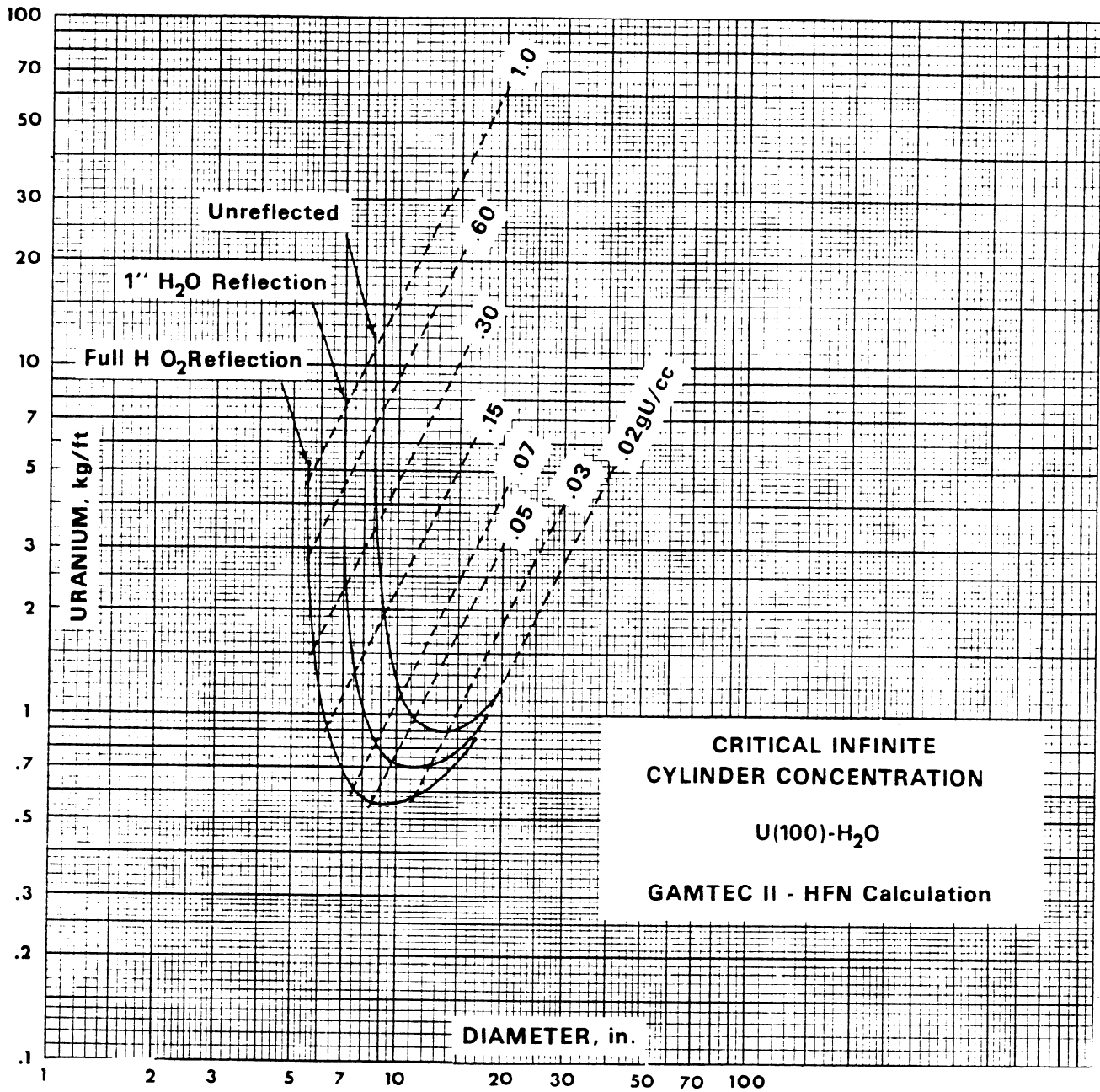


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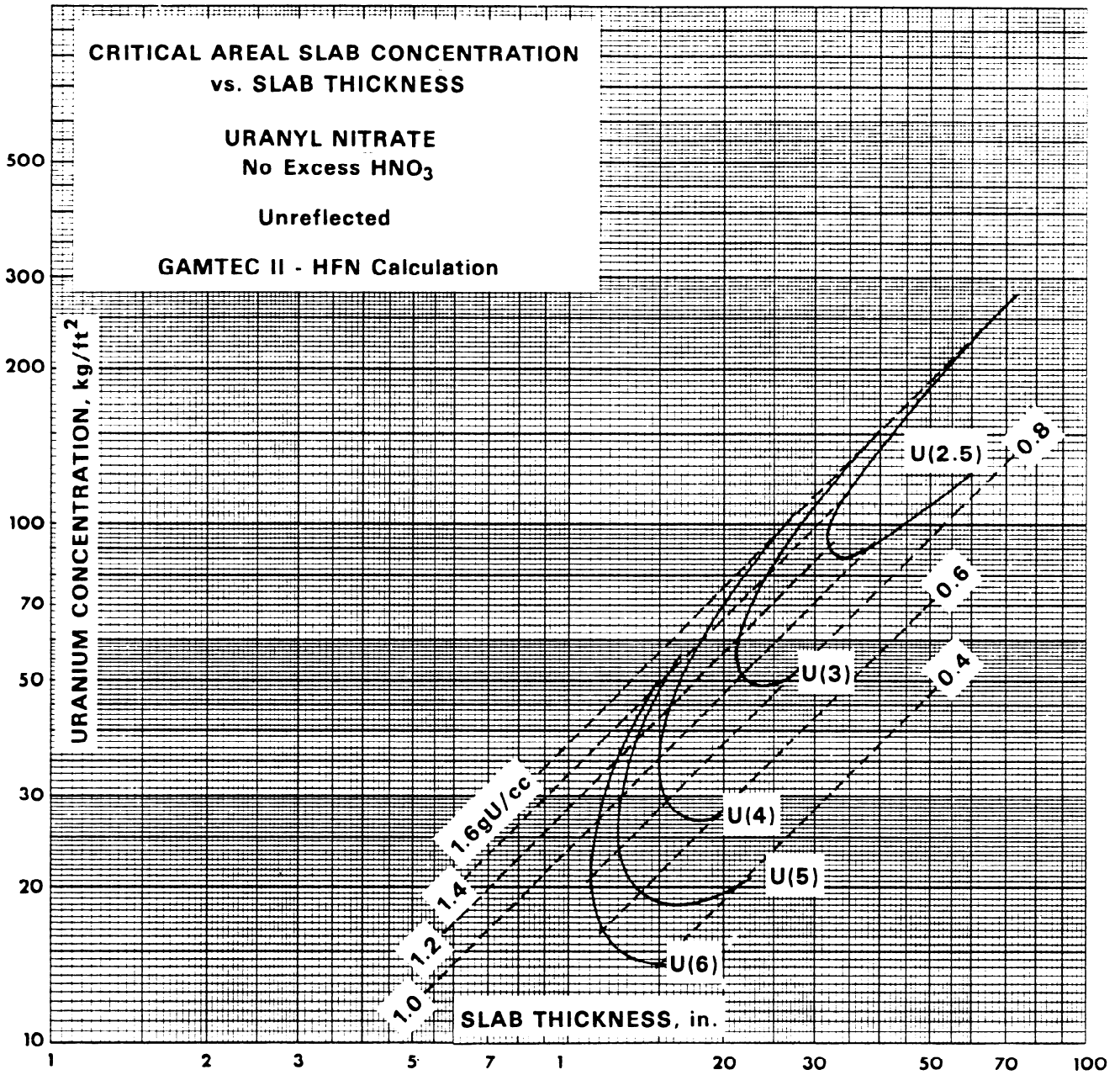


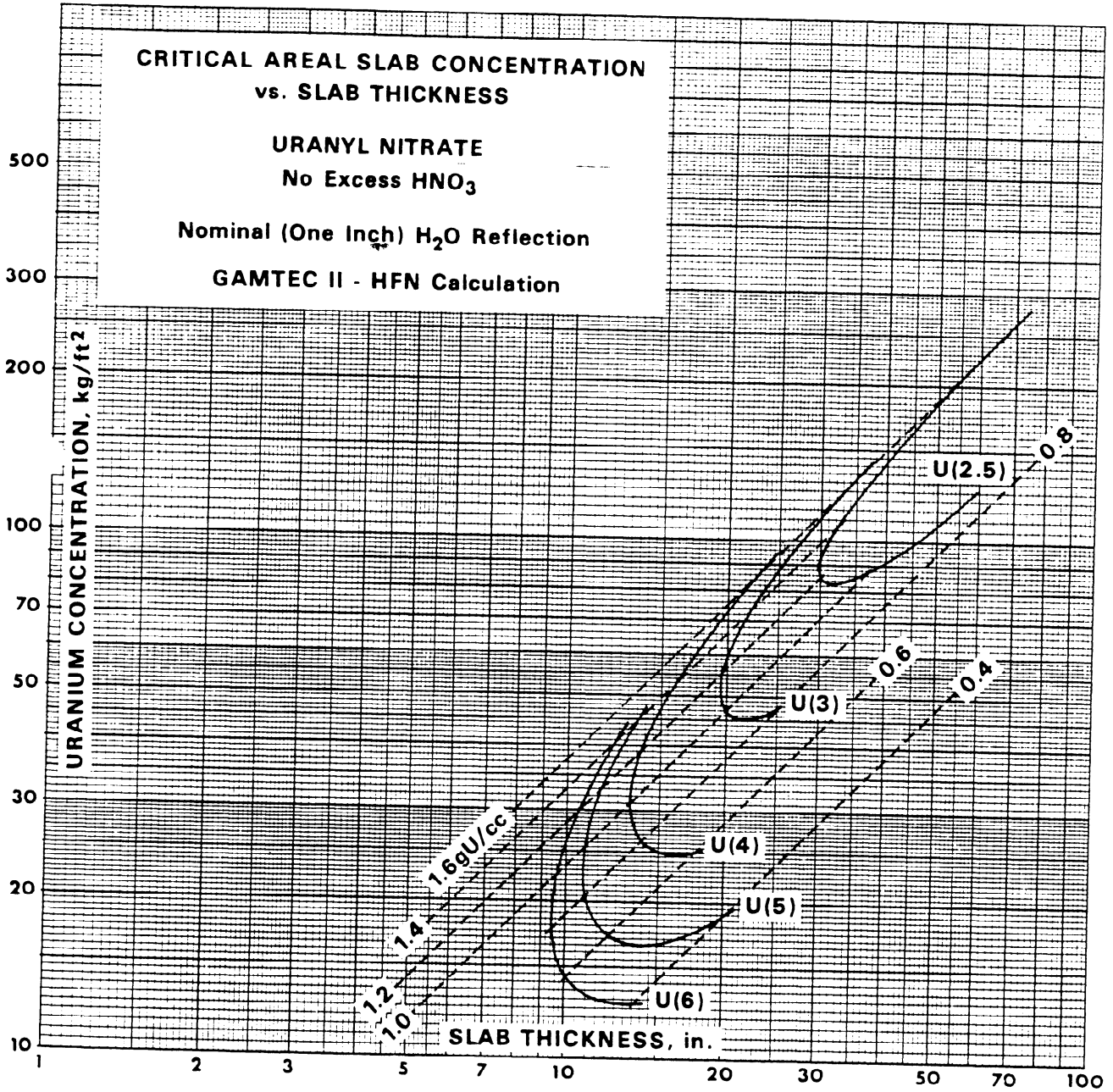


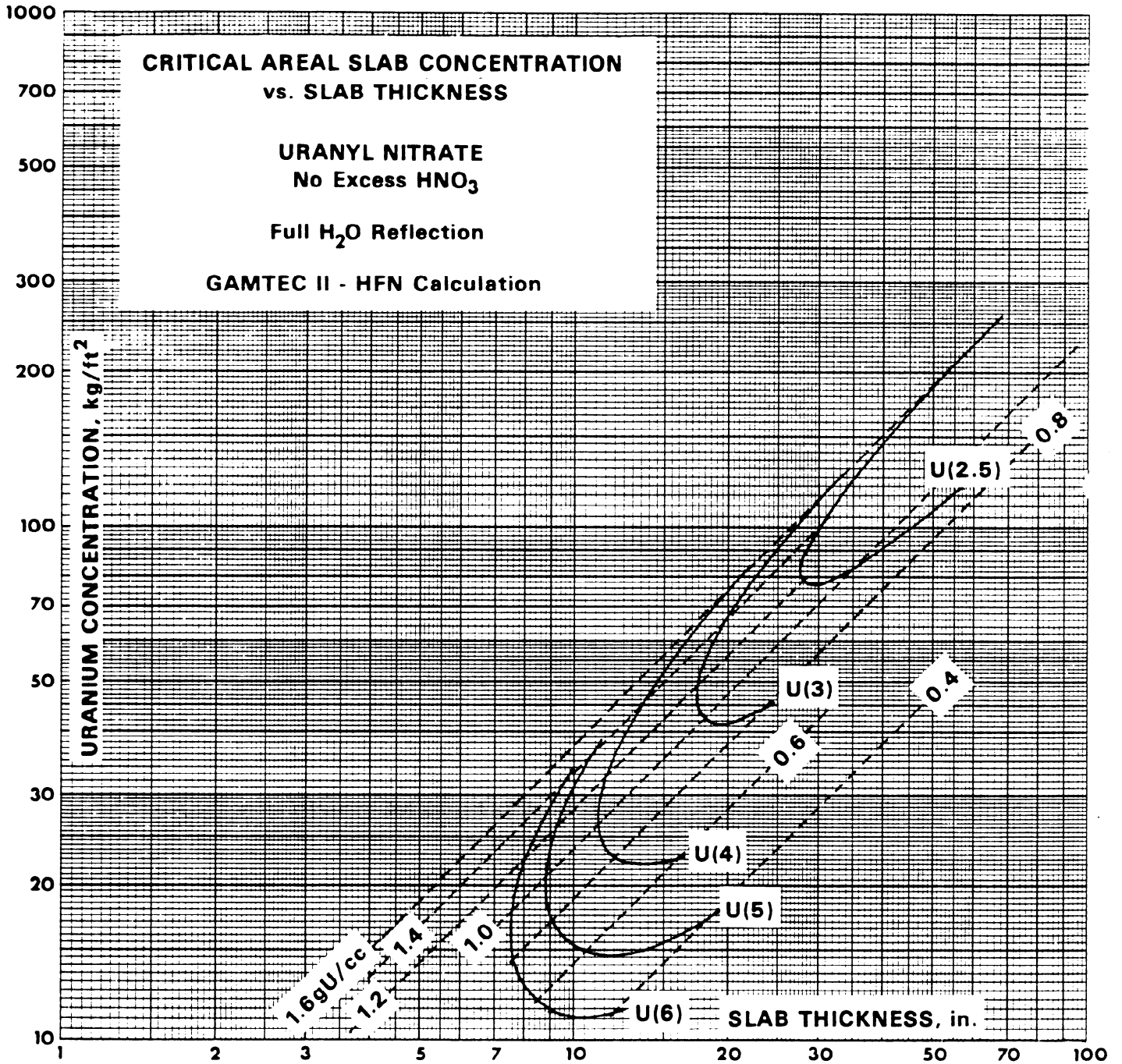


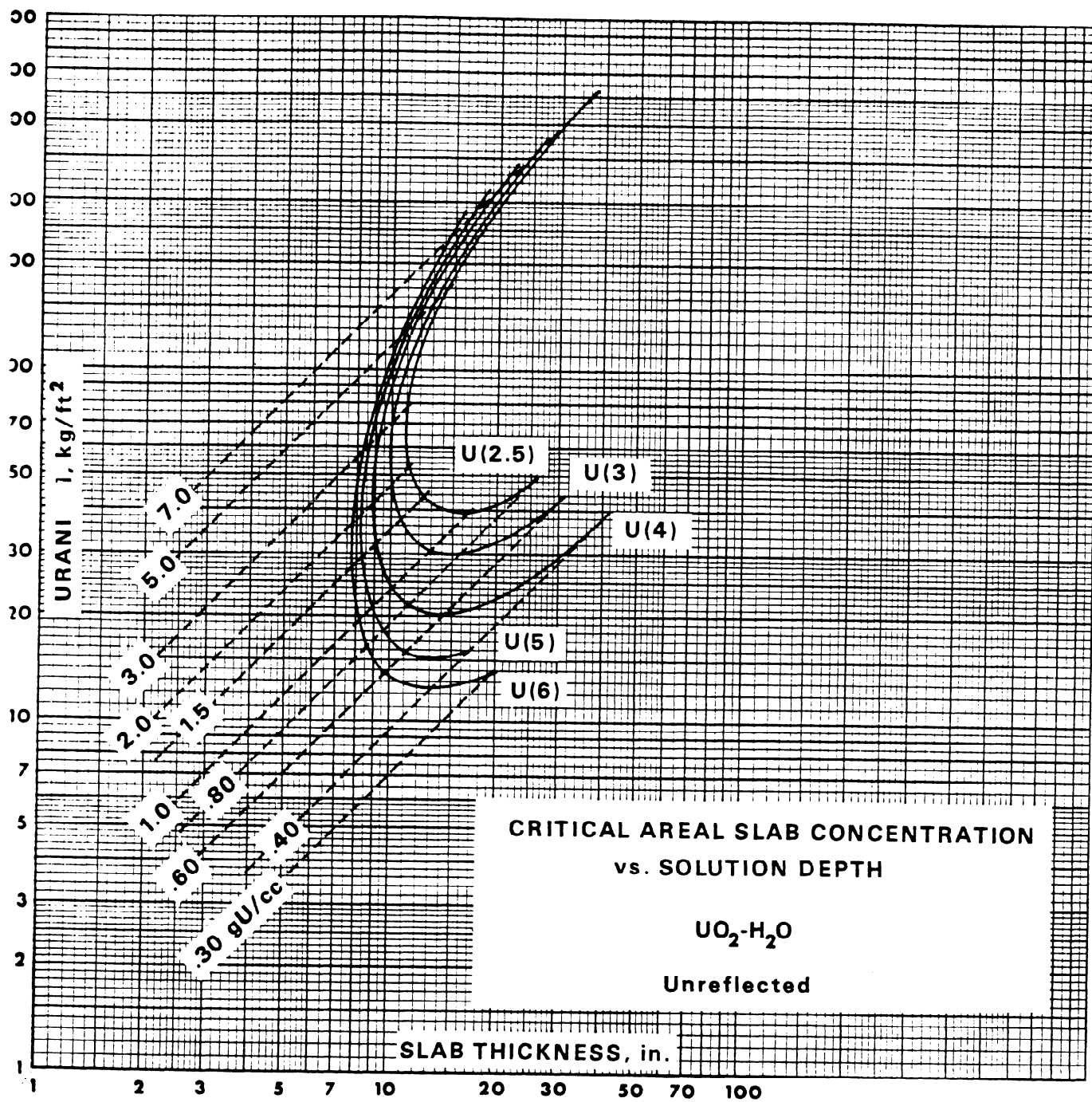


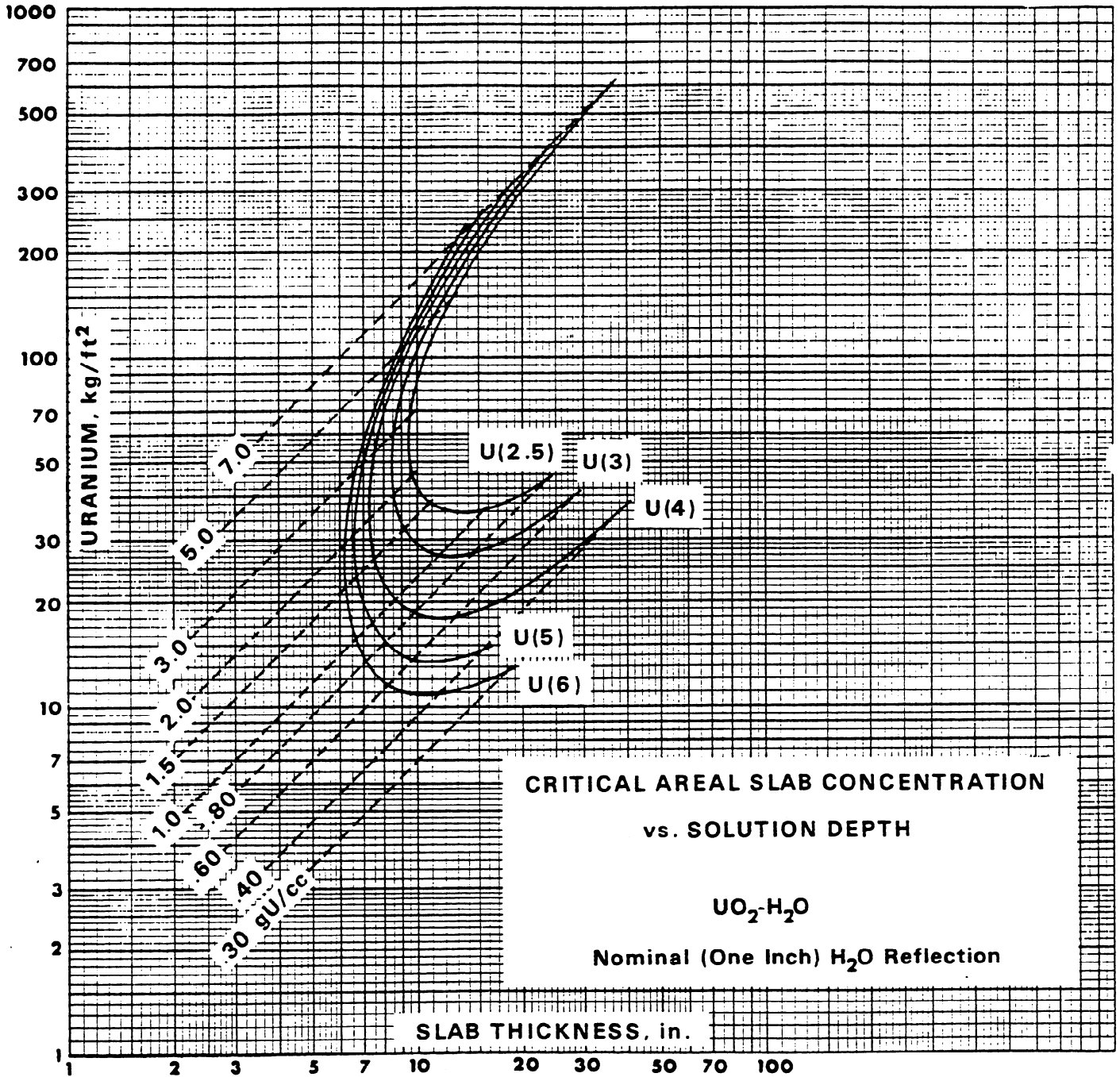
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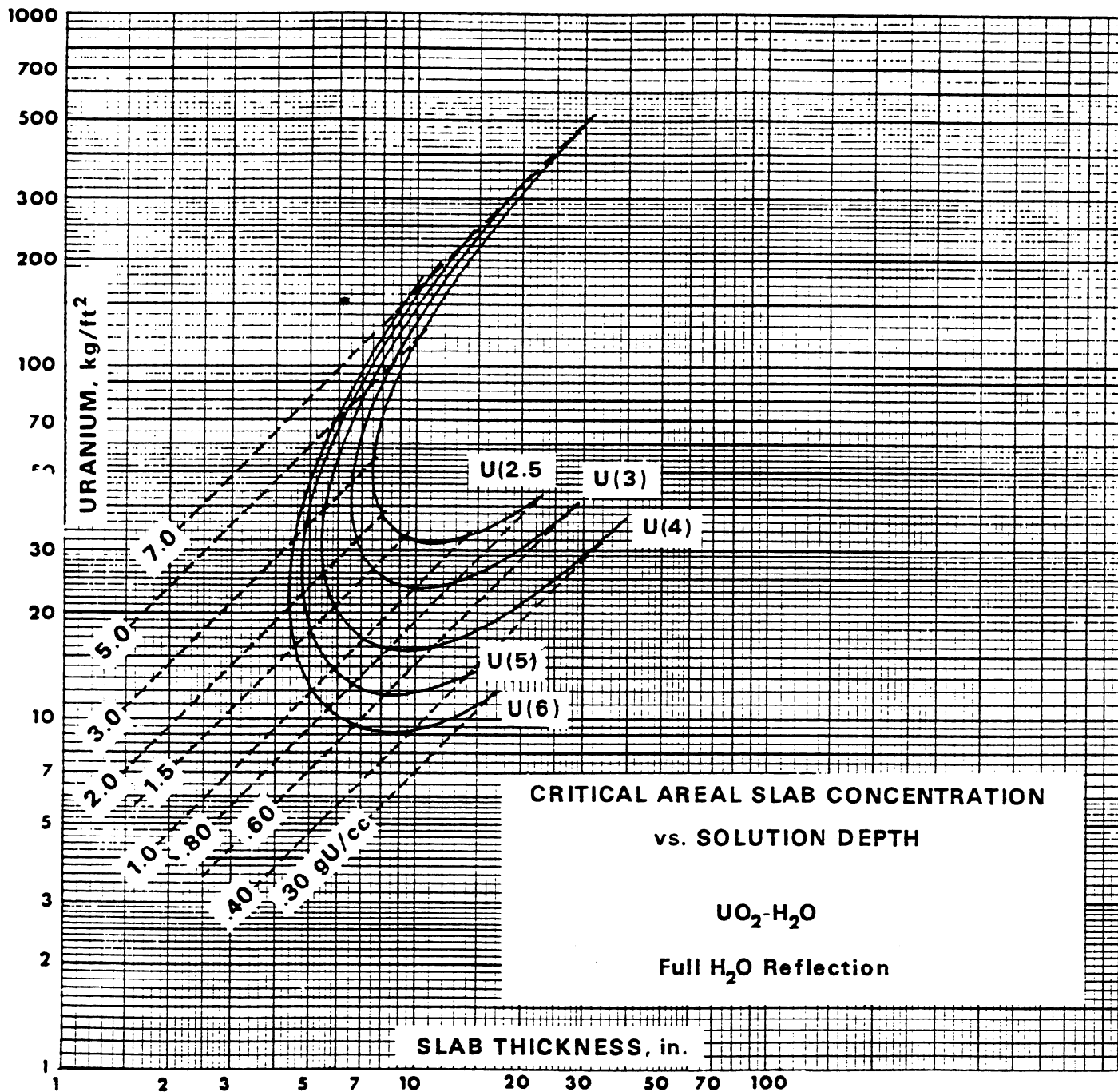


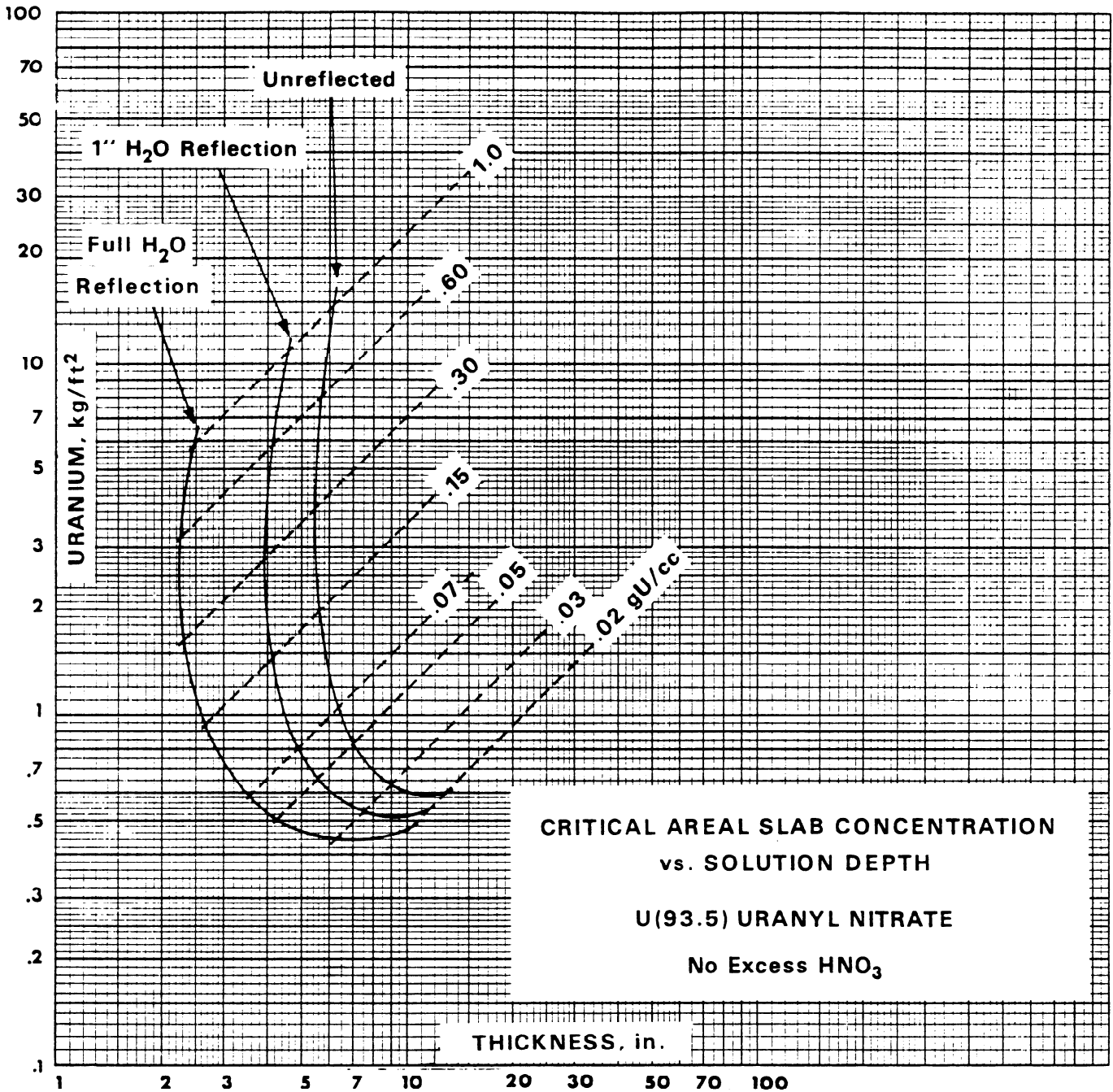




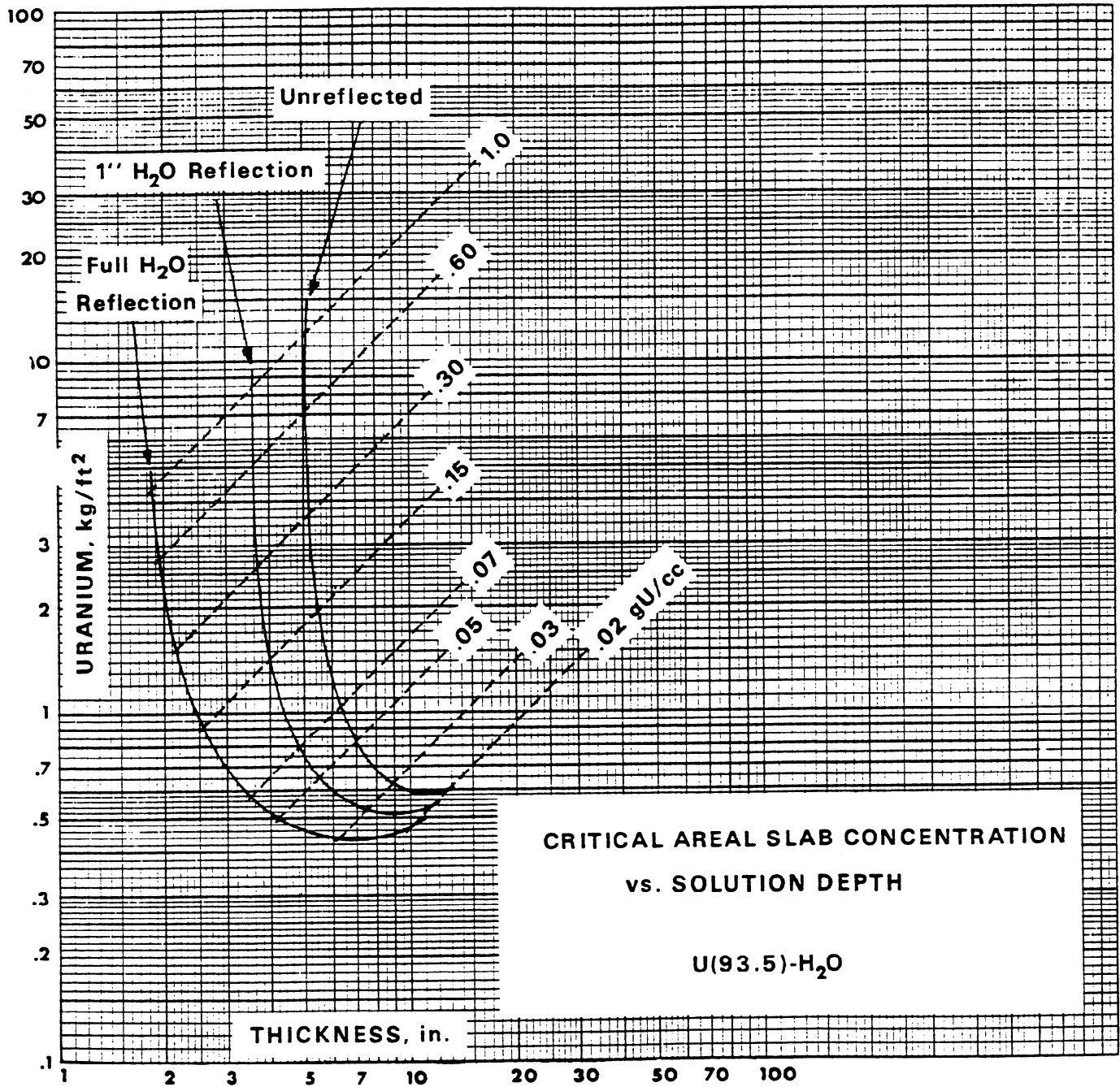


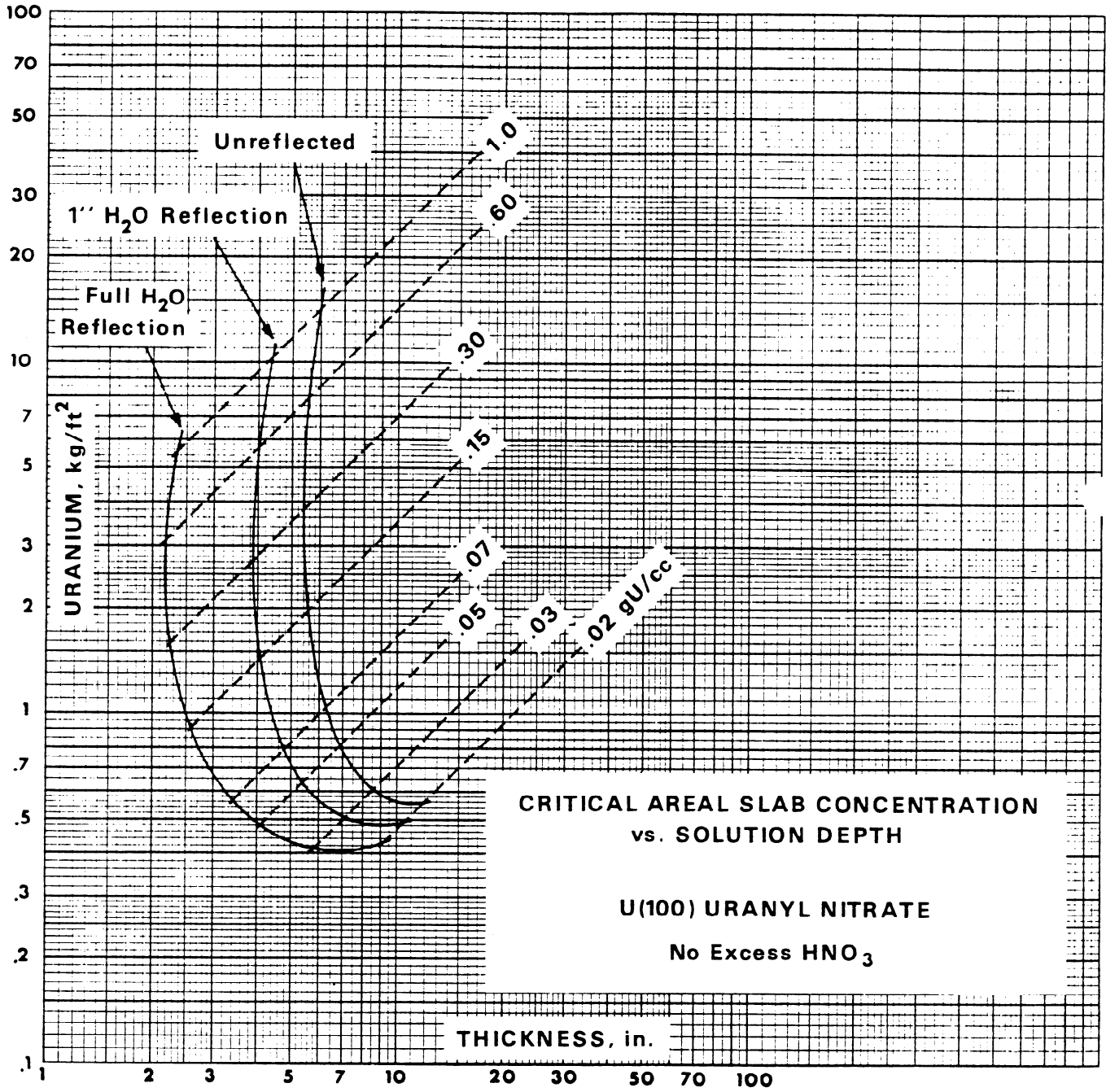


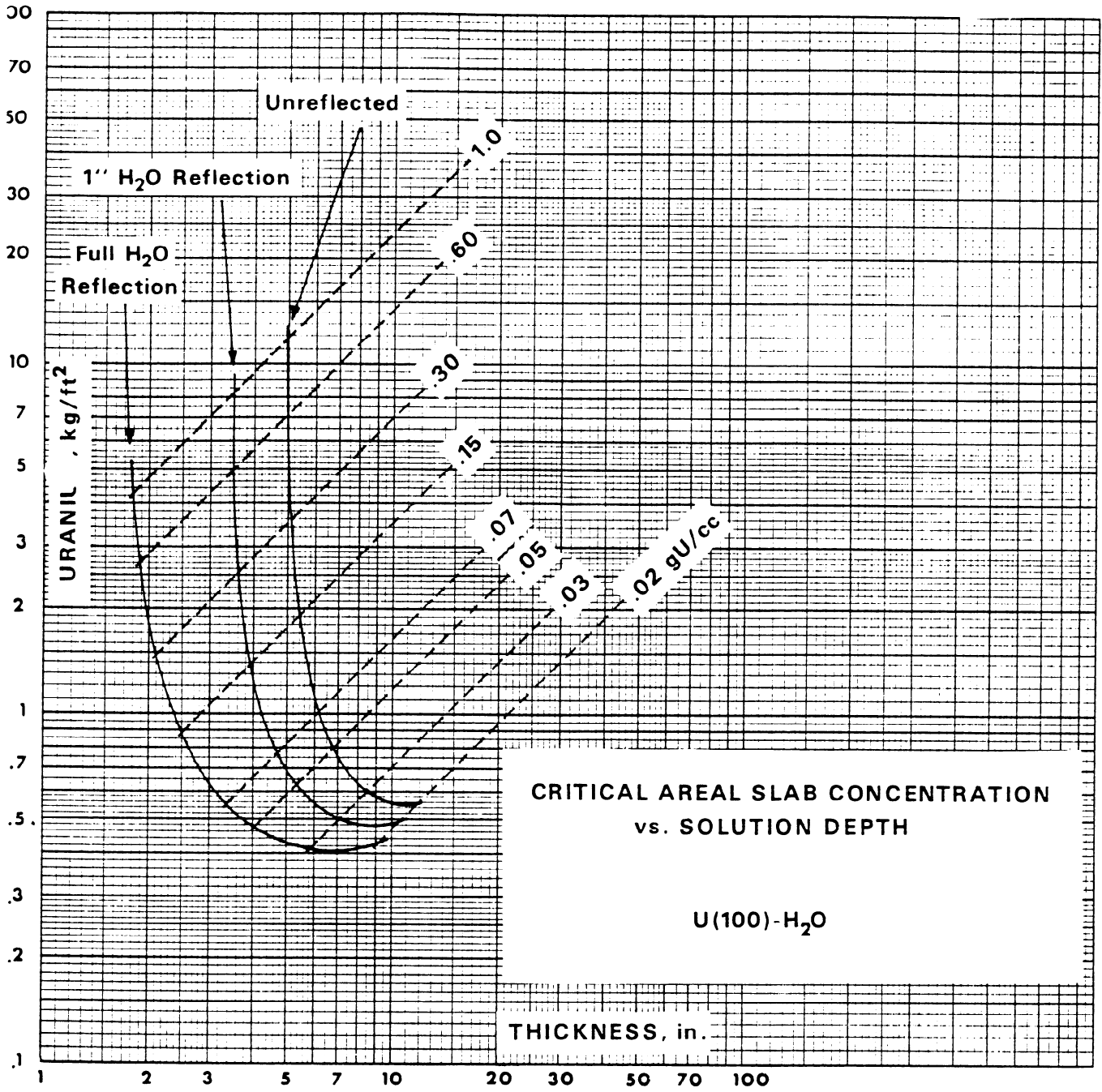


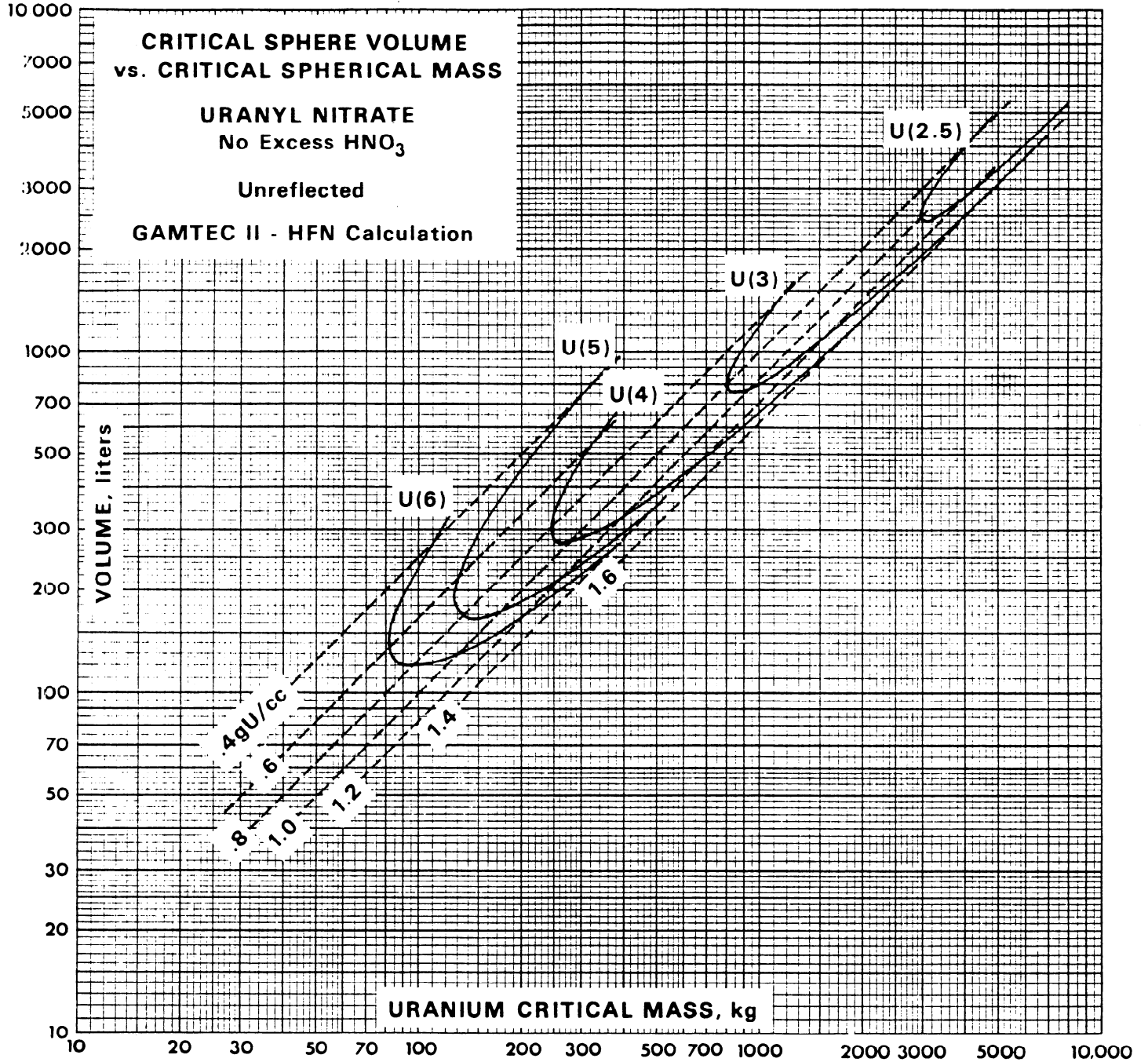


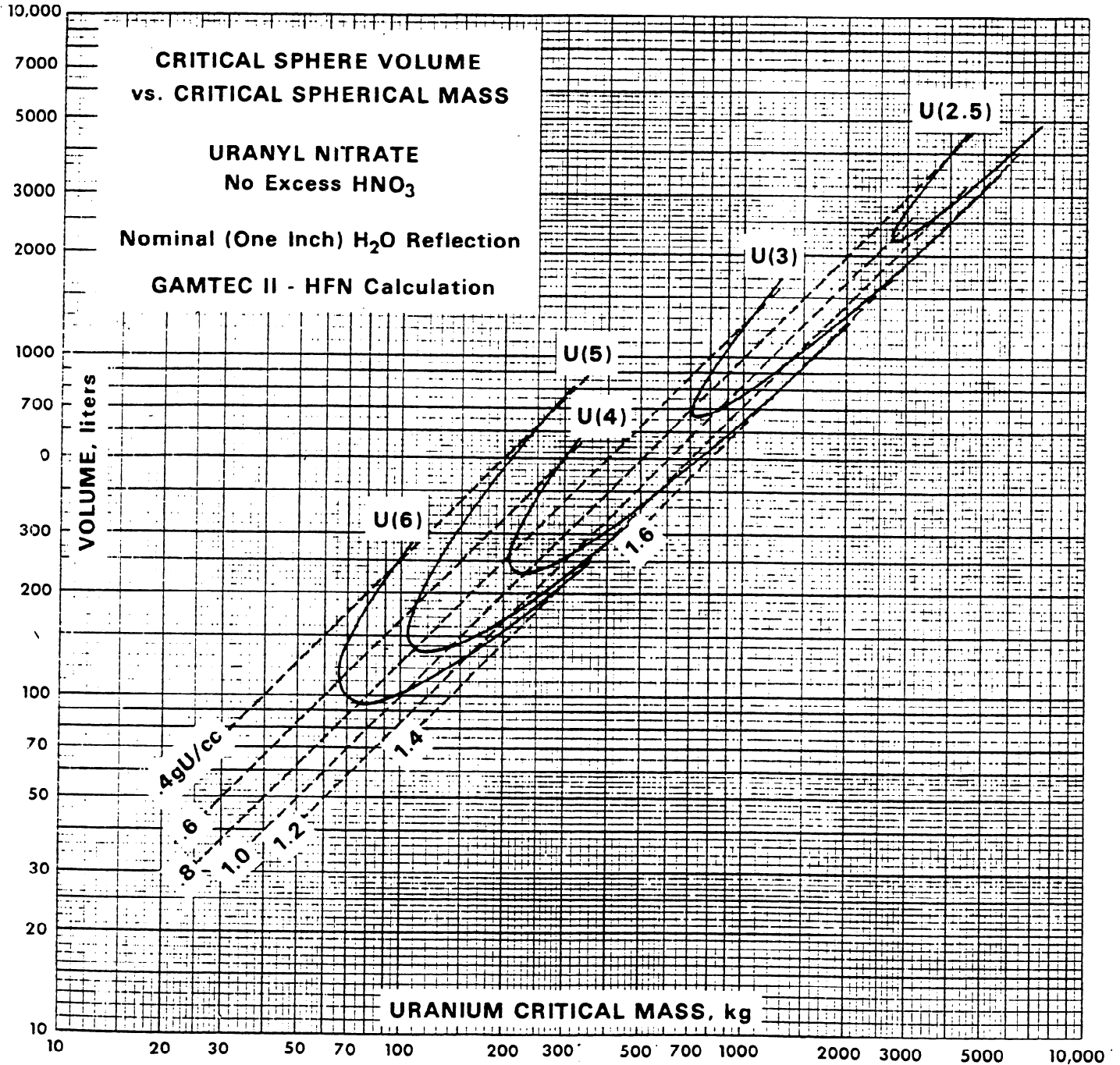




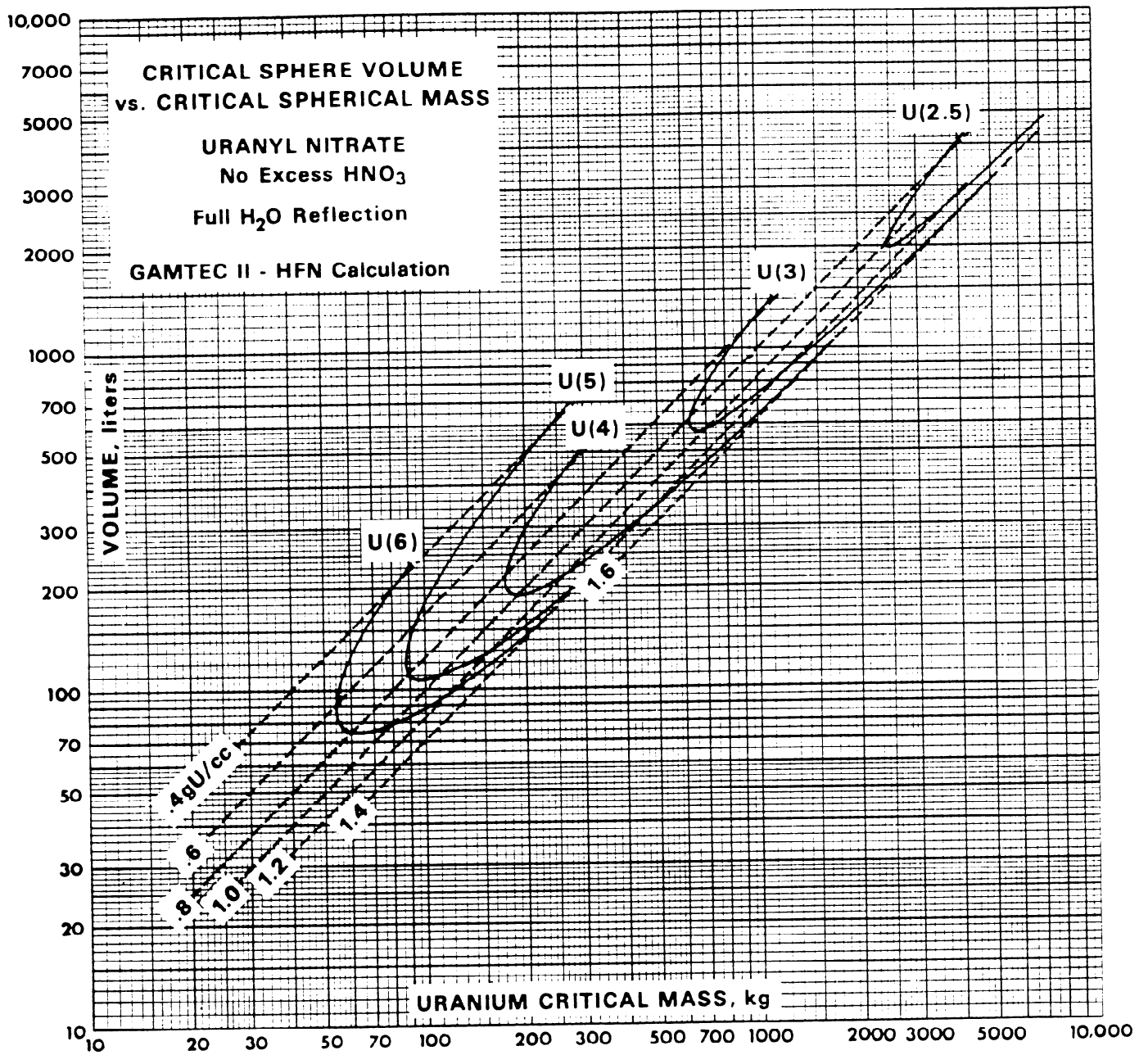


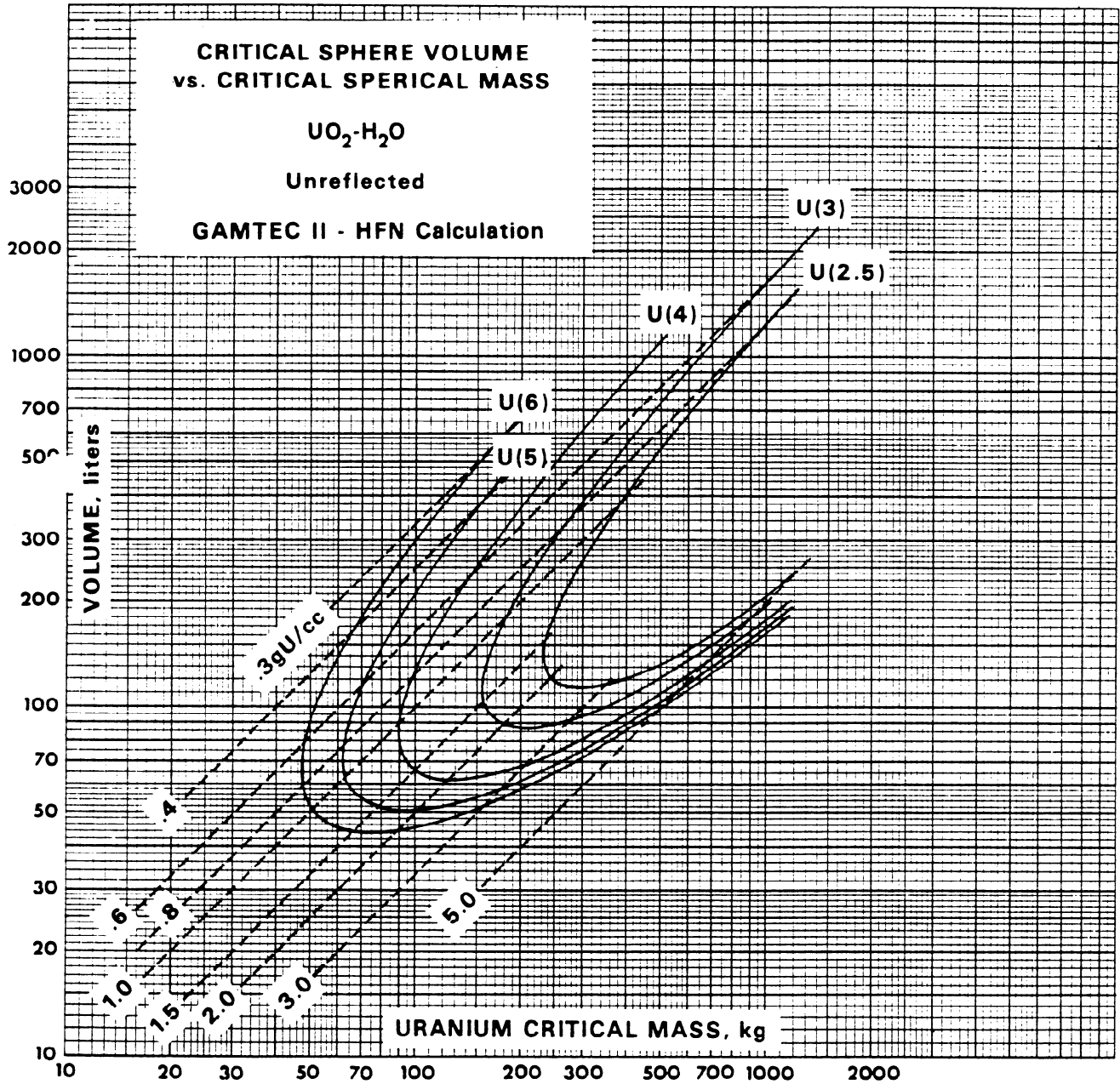


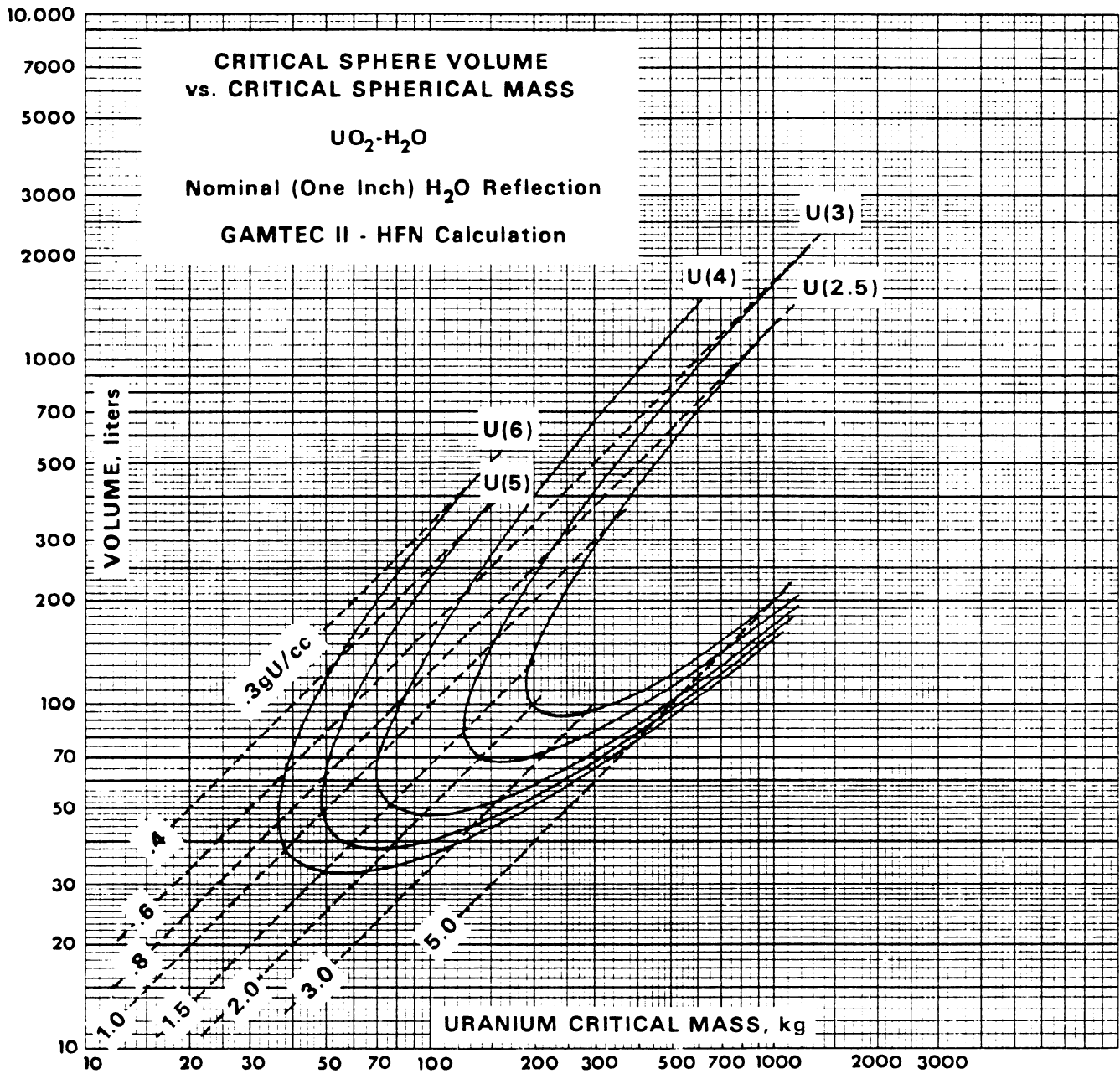




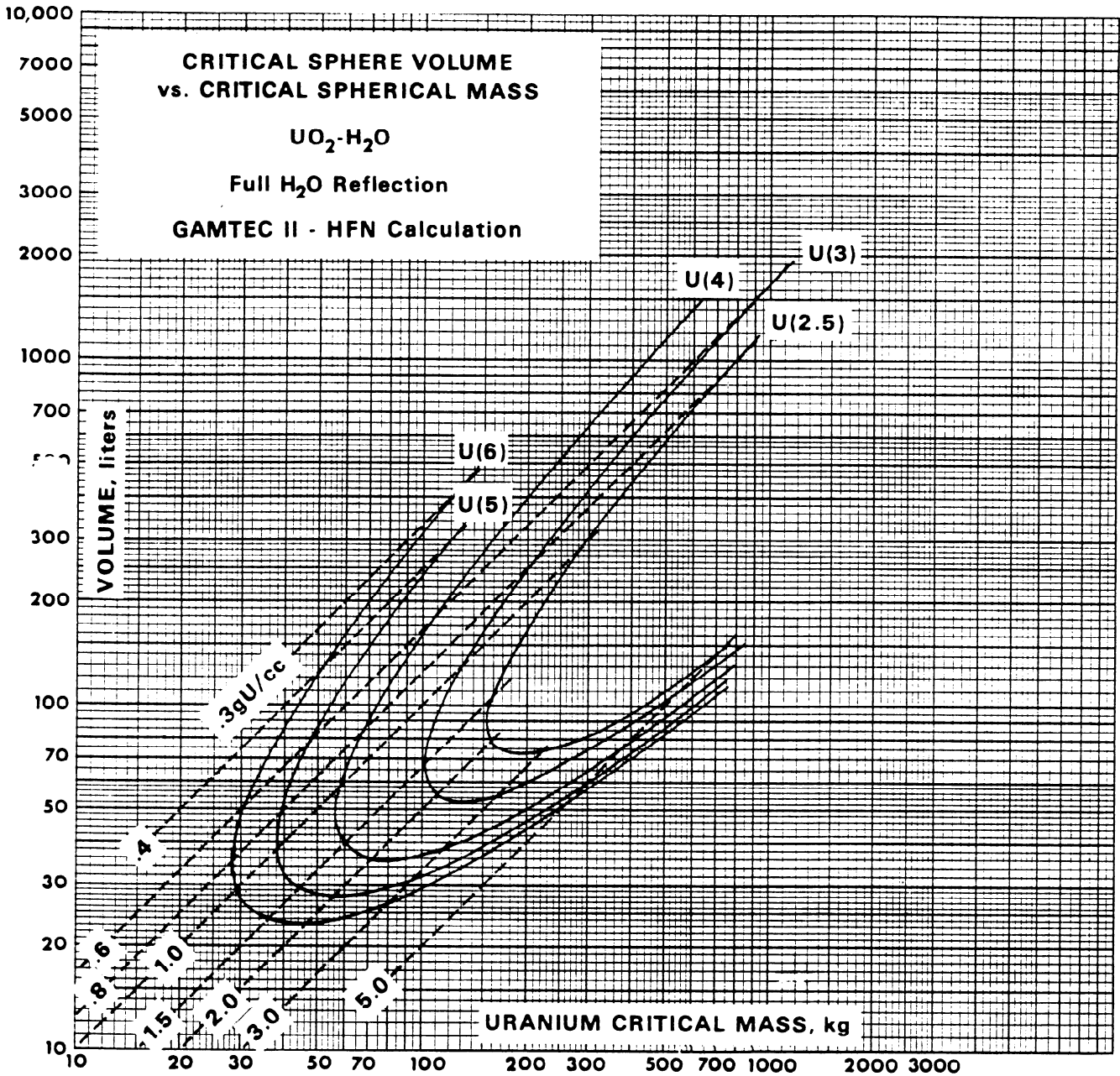
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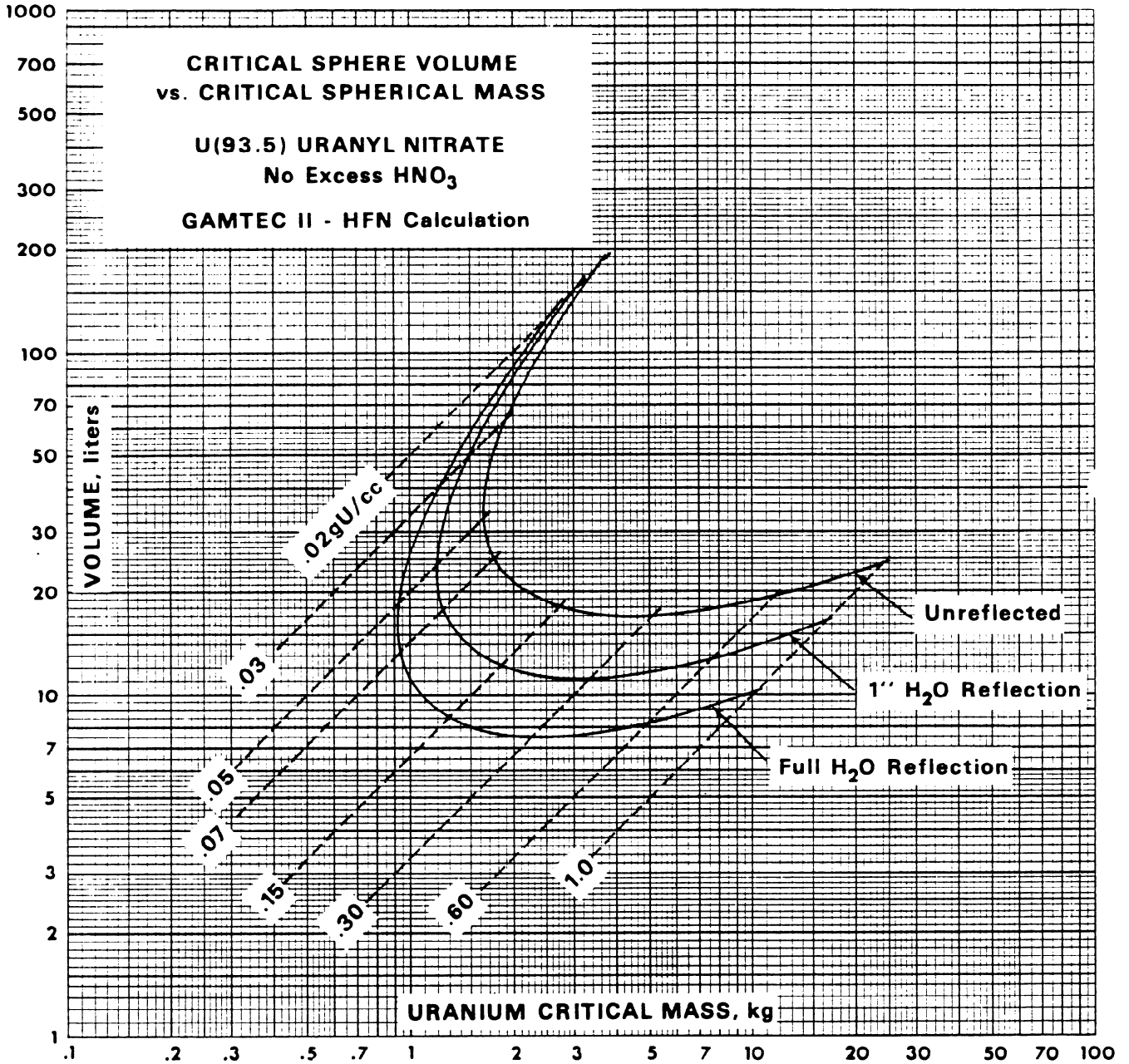


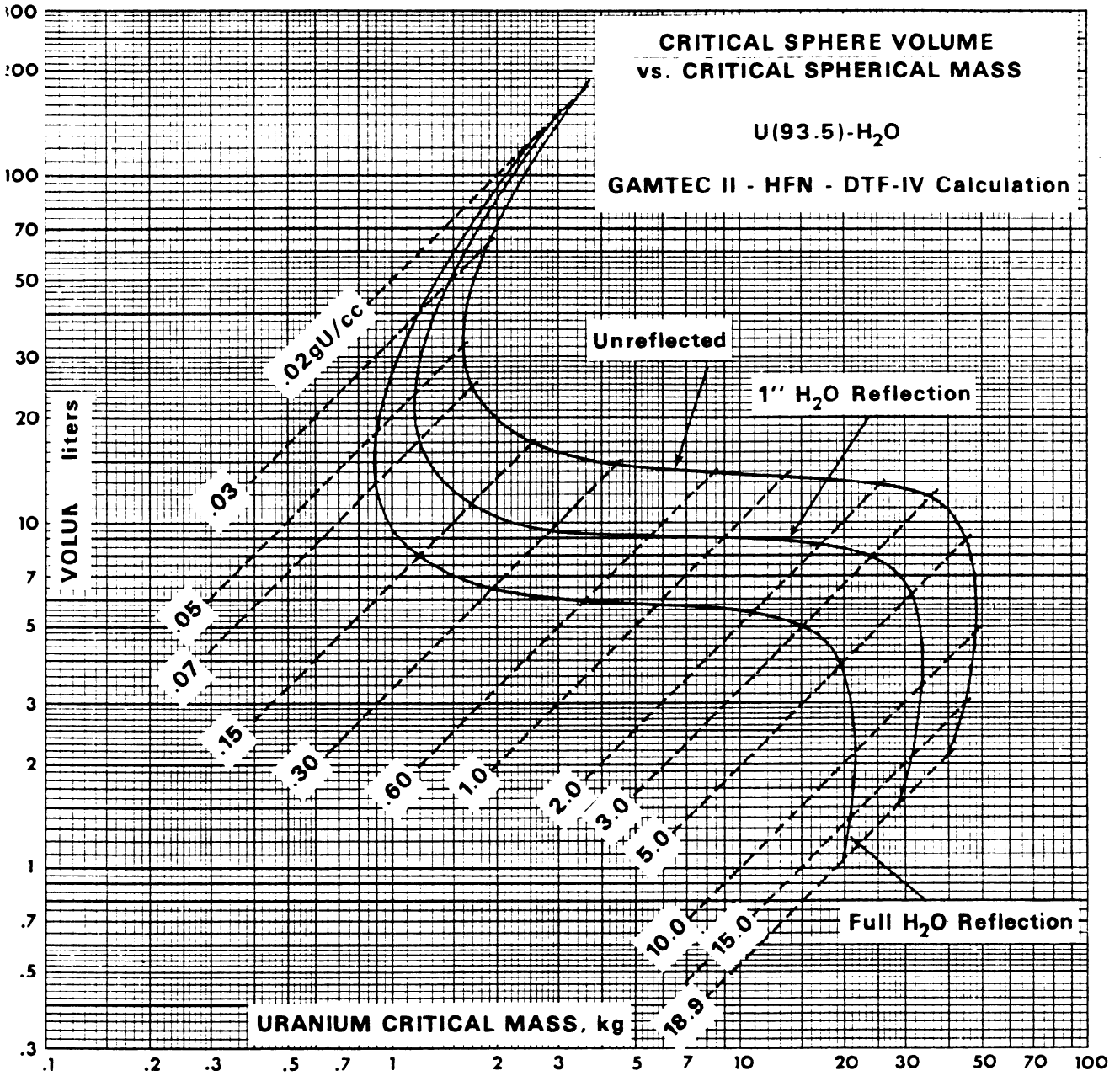


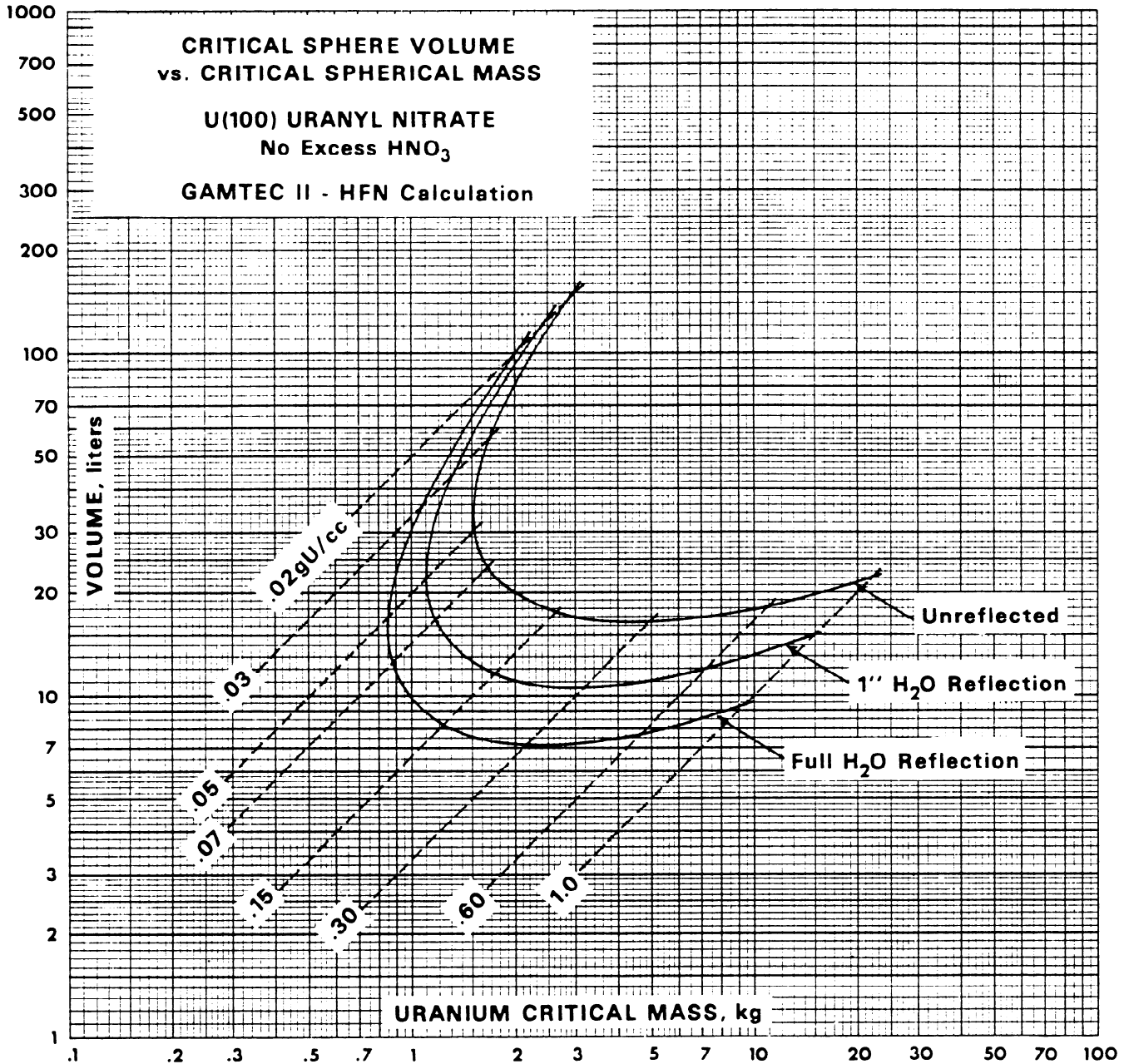


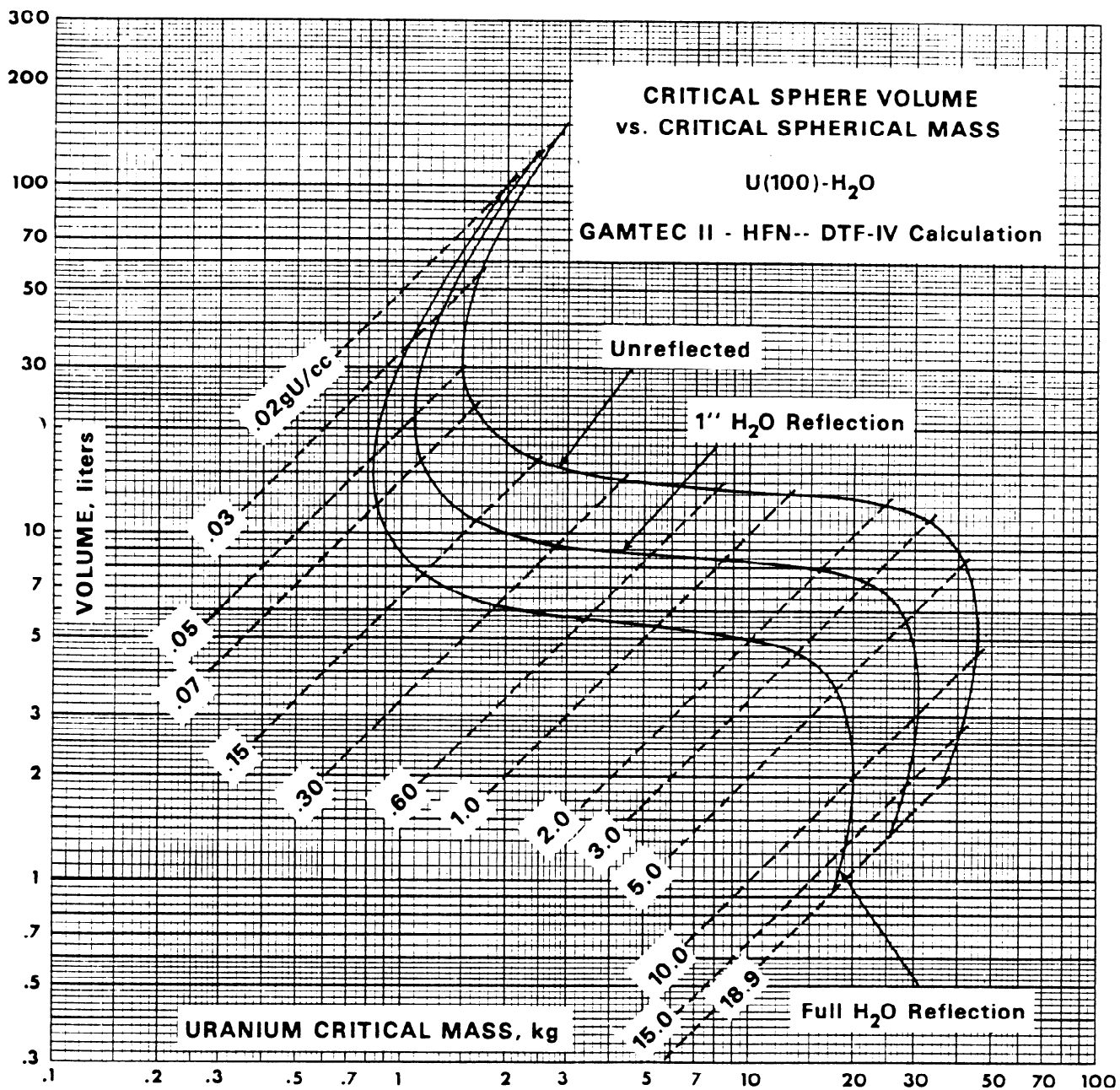


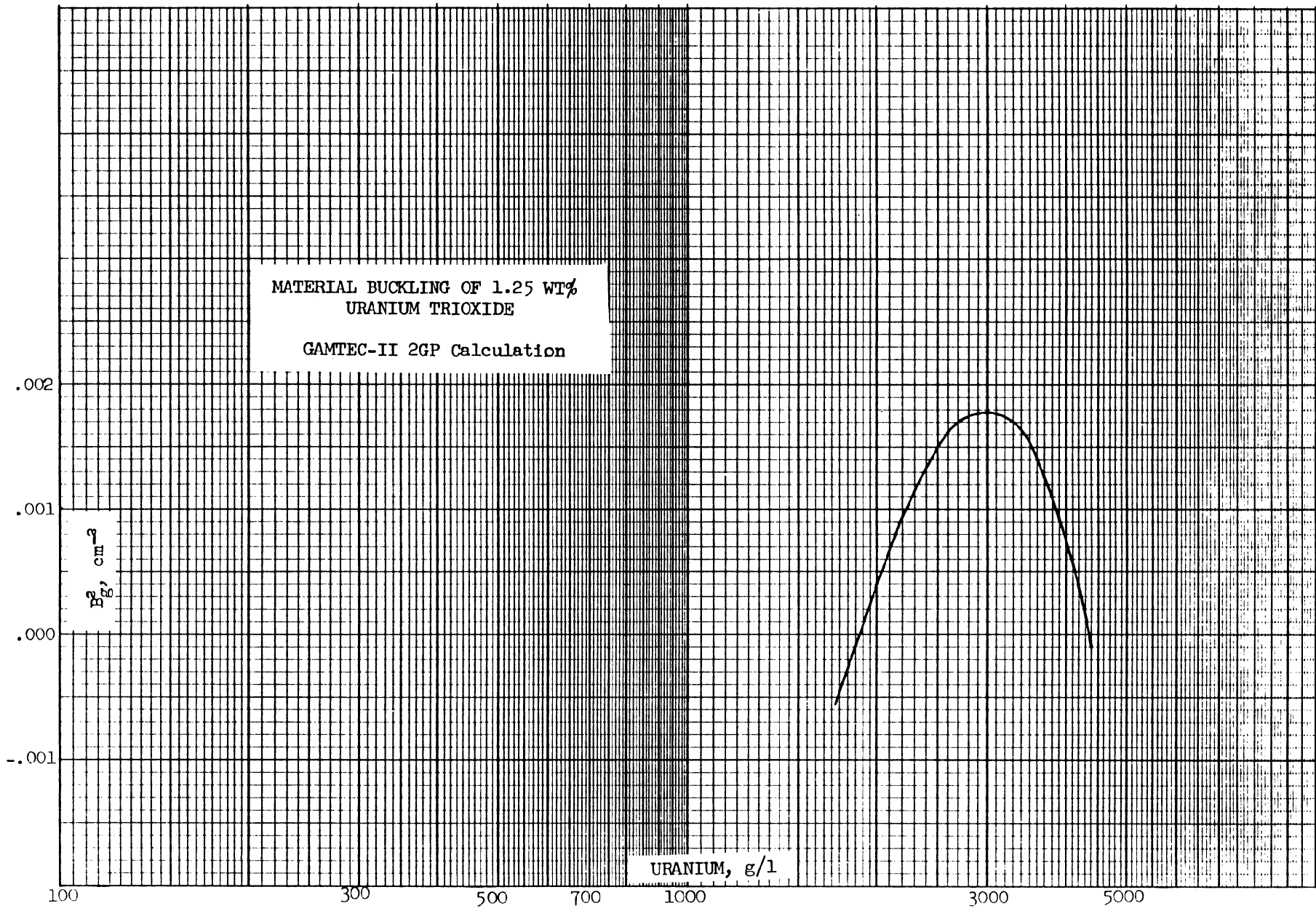




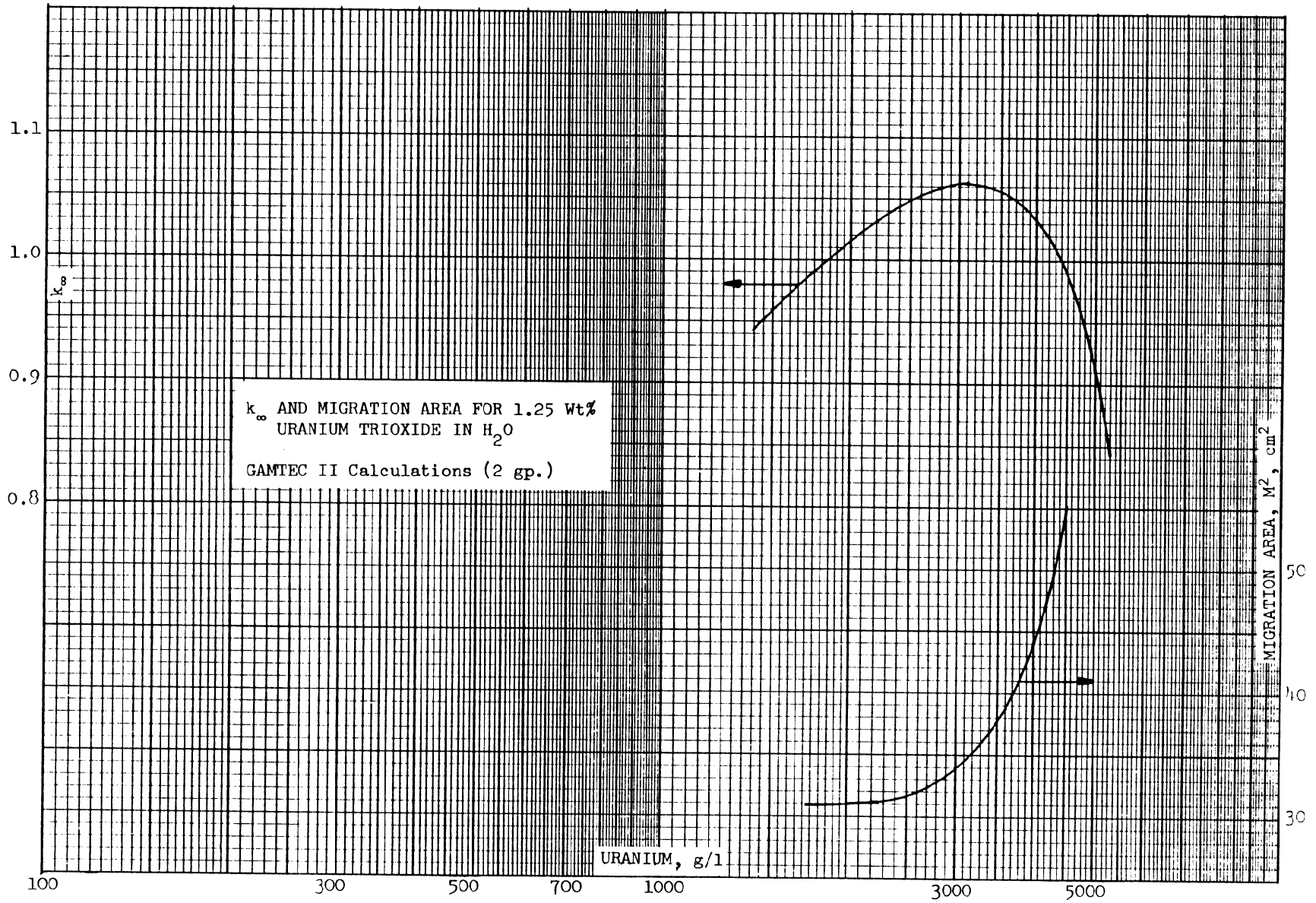






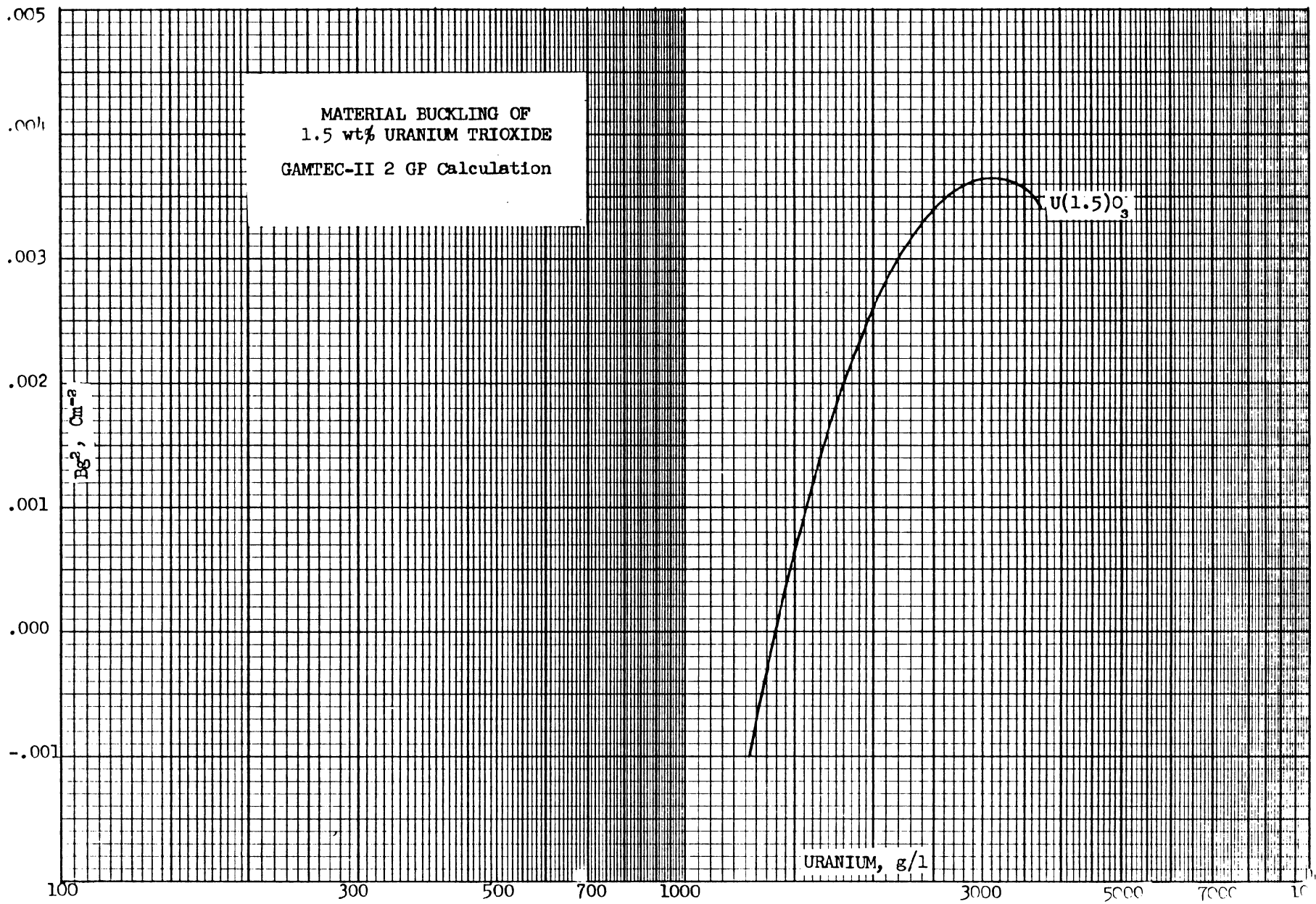


Revised 4/7/72



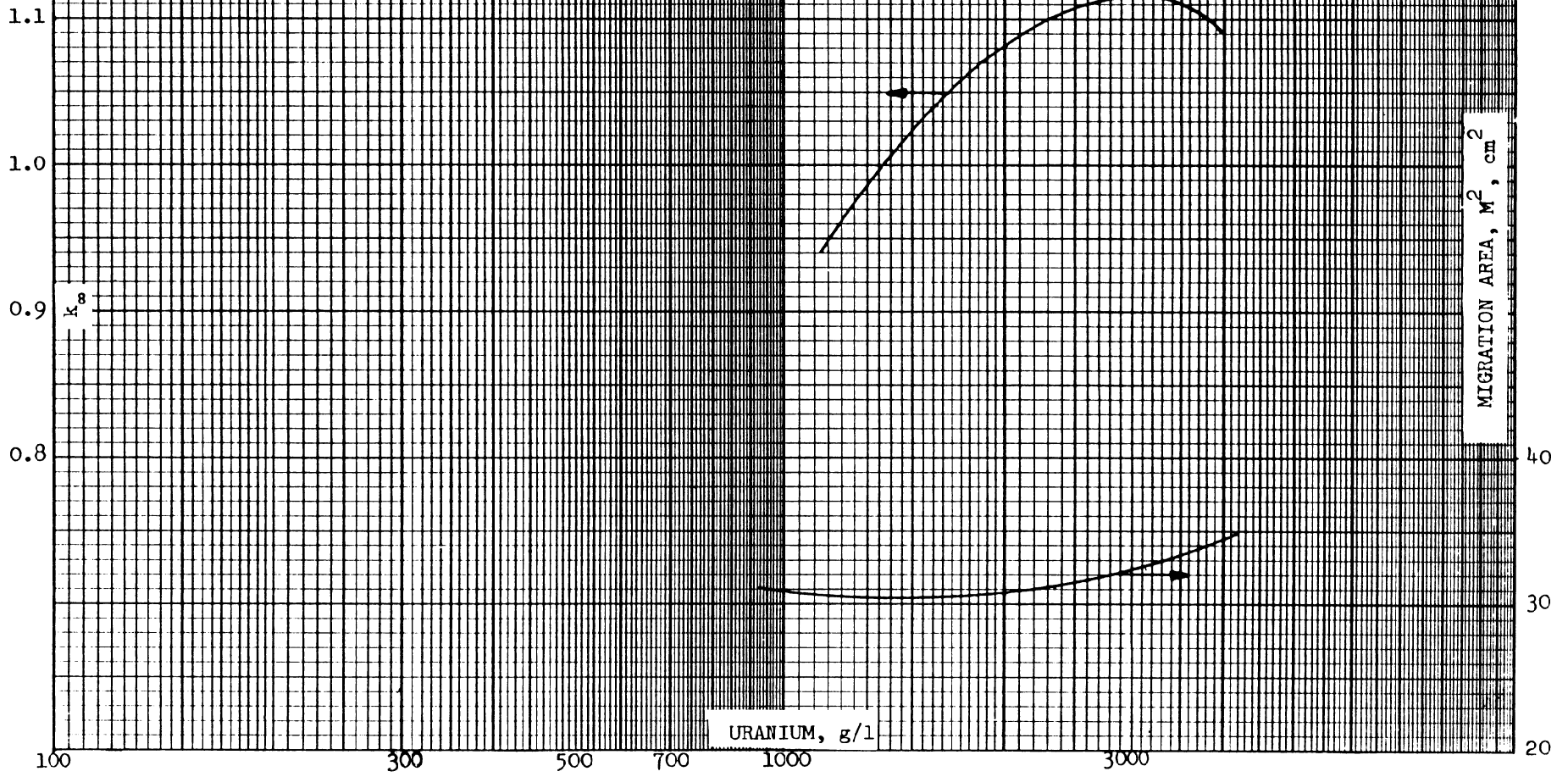
III.B.10(1.25)-2

ARH-600

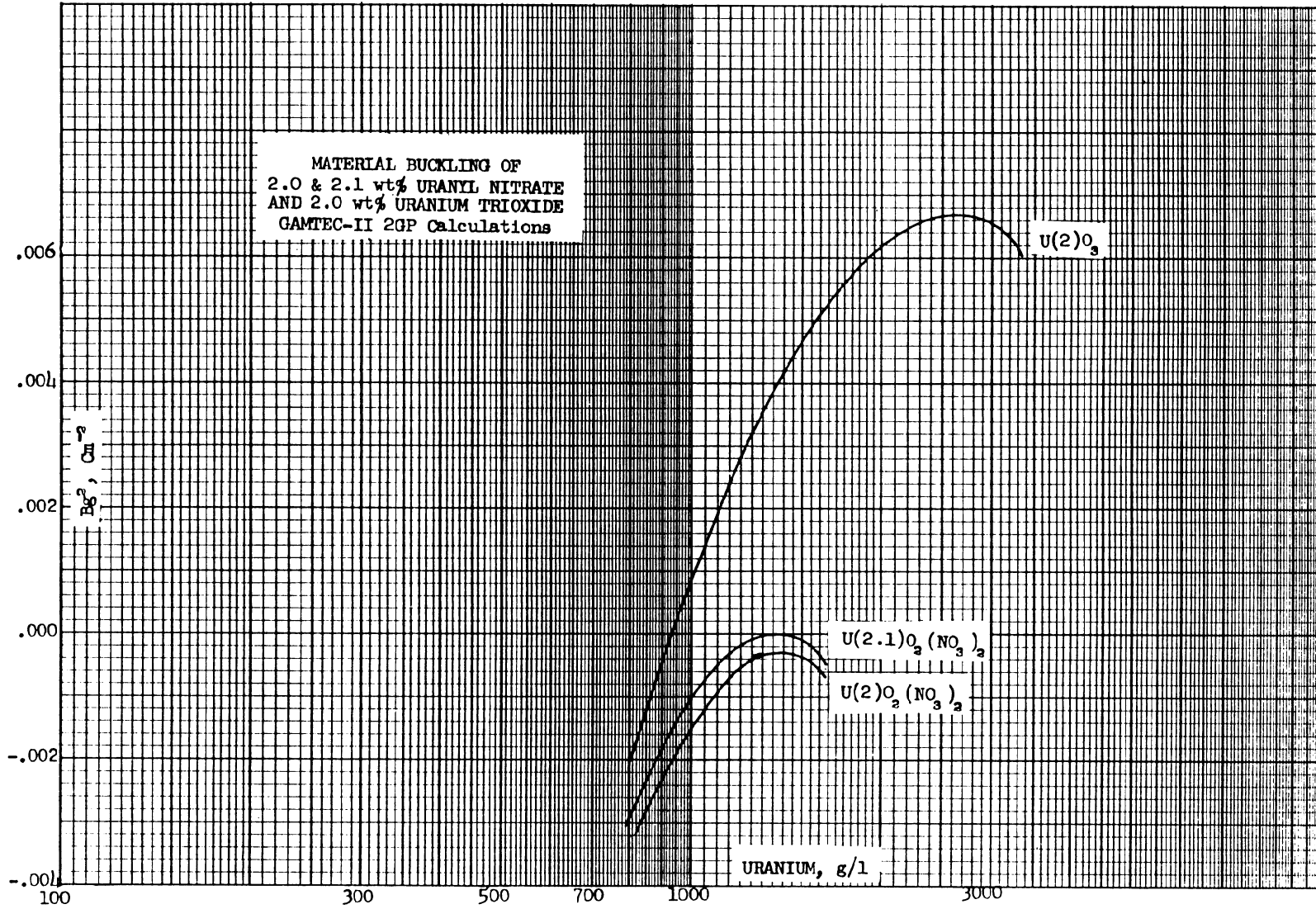




$k_{\infty}$  AND MIGRATION AREA FOR  
1.5 Wt% URANIUM TRIOXIDE IN H<sub>2</sub>O  
GAMTEC II Calculations (2 gp.)



Revised: 10-25-68



III.B.10(2)-1

ARH-600

Revised 4/7/72

