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APPLICATION OF INTERACTION CRITERIA TO HETEROGENEOUS SYSTEMS

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UNION CARBIDE NUCLEAR COMPANY
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APPLICATION OF INTERACTION CRITERIA TO HETEROGENEOUS SYSTEMS

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ABSTRACT

Recent experimental criticality data with homogeneous and heterogeneous systems of interacting containers were used in evaluating an interaction principle advanced at the Oak Ridge Gaseous Diffusion Plant for the safe storage and handling of dissimilar containers of fissionable materials. The experimental data, which included slab and cylindrical geometries, U-235 assays of [redacted] 93.2%, and H/U-235 atomic ratios from 0 to 330, and which extend below the useful range of a two-group theory previously used to evaluate interaction experiments, indicate (a) the principle is valid over the wide range of criticality parameters considered, and (b) a homogeneous system of interacting containers is, in general, more highly reactive than any corresponding heterogeneous one. An analysis was also made of the safety of cylindrical storage units where criticality control is based upon mass rather than upon geometric limitations. Calculations using a two-group interaction theory indicate that, for containers meeting ORGDP safe interaction criteria, either uniform dilution or concentration of the fuel from an optimum H/U-235 ratio of about 600 will result in a smaller container separation being required.

APPLICATION OF INTERACTION CRITERIA TO HETEROGENEOUS SYSTEMS

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APPLICATION OF INTERACTION CRITERIA TO HETEROGENEOUS SYSTEMS

Introduction

The self-consistent set of interaction criteria* developed at the ORGDP[1] for use in specifying the spacing of containers of enriched uranium are in such form that they may be applied to a wide variety of systems, provided the multiplication factor, k, of each unit of the system and the "average" solid angle, Ω, of interaction between the various units of the system are determinable. From a practical standpoint, these conditions are comparatively easily met with homogeneous systems of individually subcritical identical units but their application to a heterogeneous system is somewhat complicated; for example, the "average" solid angle of interaction between 2 units of dissimilar dimensions is usually not simply determinable, especially if the separation distances are approximately the same as the dimensions of the interacting units or smaller.

In a production facility, it is perhaps obvious that there will be many cases where spacing of heterogeneous units will be required and that there will even be cases, such as those posed by miscellaneous shipments of fissionable materials, when the spacing must be appropriate to take care of the interaction even though the actual units of one of the interacting systems will be unknown. Thus, in this report, the use of a simple principle of interaction as stated by Henry which may be generally applicable in specifying safe spacings is described, and its validity checked, insofar as possible, by available experimental data.

In addition, the general interaction theory previously developed has been applied to some of the recent experimental data[2,3] involving various heterogeneous systems of slabs and cylinders in an attempt not only to determine its accuracy when used with these specific systems but also to evaluate any trend which would indicate that it would give very non-conservative results for any types of systems; in particular, the use of this theory, where applicable, has been combined with the general interaction principle to determine if the basic interaction criteria previously developed can be applied to systems which are heterogeneous with respect to U-235 assay, moderation, and geometry. The results have been checked by the method originally used[4] with the comparatively large number of available interaction experiments involving systems of identical units to verify these basic interaction criteria.

Conclusions

Based on the results with heterogeneous systems as described in this report, as well as those with homogeneous systems as previously reported, it appears that the following conclusions may be safely drawn in determining safe

---

* These will be identified in this report as the basic interaction criteria.

conditions for separating individually safe units of fissionable materials provided the materials used do not differ from those which may be normally anticipated at the ORGDP:[5]

1. Two containers which are dissimilar or which contain dissimilar quantities of fissionable materials will be safe if they are separated by a distance which is not less than the average of the corresponding distances by which each would be safe if separated from a container which is identical to itself. This also applies to separate systems, each comprising several individual units.

2. In general, a homogeneous system is more reactive than any corresponding heterogeneous one. Although the possibility cannot be ruled out that a heterogeneous system which is more reactive than a corresponding homogeneous one may actually exist, it appears that such a system would be a very unusual one with the homogeneous-heterogeneous reactivity difference being very small.

3. The interaction criteria[1] previously developed on the basis of theoretical interpretation of experimental data[2,3] with homogeneous systems are also directly applicable to systems which are heterogeneous with respect to U-235 assay, moderation, geometry, or the contents of a single container.

4. The safety factors inherent in the specification of the basic interaction criteria,[1] as previously developed, are more than adequate to compensate for any non-conservatism introduced by the effects of heterogeneity considered possible in plant operations at the ORGDP.

Methods Used

1. The General Interaction Principle

Although, as noted above, it may frequently be difficult to determine an appropriate spacing between 2 or more units of a system which are dissimilar in geometry, content, or both, it is usually adequate to use a value which is both calculable and can be shown to be conservative.* Since, as shown in the previous reports,[1,4] the spacing between identical units may be comparatively easily calculated, it is perhaps obvious that a safe spacing between each of the dissimilar units and a hypotethical

---

* From the standpoint of nuclear safety, a conservative result is one where the factors concerned are so chosen that criticality is predicted for an experimentally subcritical assembly and, correspondingly, a critical assembly is predicted to be supercritical.

"twin" may be determined. Accordingly, as a basis of a general interaction principle,* the assumption is made that a safe spacing for dissimilar units can be determined from similar spacings which have been determined to be safe for each of the units and its "twin". The principle, which is identified in this report as the general interaction principle, may then be simply stated:

> "Two containers which are dissimilar or which contain dissimilar quantities of fissionable materials will be safe if they are separated by a distance which is not less than the average of the corresponding distances by which each would be safe if separated from a container which is identical to itself."

Several interesting conclusions of practical significance can be drawn from the application of this principle. A simple one is the fact that if the separation between 2 dissimilar containers is the greater of the 2 distances determined to be safe as noted above, an additional safety factor in their spacing will be introduced; this is obviously applicable to storage locations where the floor is marked off, or "spotted", for locating miscellaneous containers of fissionable materials. Similarly, if it is determined that it will be desirable to place a large number of similar containers in individual "birdcages" or on single "dollies" so that they will be safe no matter how they are moved or stacked, the principle also indicates that these will be safe even though intermingled with other and dissimilar containers which are also placed in individual "birdcages" or on single "dollies" similarly designed for nuclear safety.

A very useful extension of this principle is its application to 2 or more systems of several units each, such as actually can occur with shipments of fissionable material involving several containers in each carrier. Since it may be impossible to predict what other shipments of fissionable material will be encountered en route and thus determine adequate spacing between trucks or other carriers on an individual basis for all such meetings, validation of this principle and its use by all shippers would obviously provide adequate nuclear safety for all types of over-the-road shipments.

2. Basic Interaction Theory

The method employed in evaluating systems in accord with the basic theory which relates the multiplication factor, k, to the interaction angle, Ω, has previously been described for homogeneous units,[4] and essentially all determinations of k were made by this method. In practice, except where a test of the effect of interaction of different geometries was desired, attempts were made to use identical geometries in the evaluation of experimental results since the "average" solid

---

* The basic principle, which was first suggested by H. F. Henry in 1953 with respect to a specific shipment of material, was more formally stated as being applicable to truck shipments in general in 1955[6]; a discussion of its validity was made in 1956 by C. E. Newlon.[7]

angle for non-identical systems is, in general, difficult to evaluate without a fairly straightforward but detailed mathematical treatment; in these cases, also, it is not feasible to depend upon approximations of these angles due to the fact that separations between the interacting units are small in comparison to their own dimensions.

3. General Comments

Where applicable, the experimental results and their theoretical interpretation are presented in both tabular and graphical form and, in many cases, the conclusions are drawn directly from these data. Pertinent information concerning the experimental results reported is given in these tables and on the graphs. All experimental work was done by A. D. Callihan and his group at ORNL by appropriate modifications of the methods detailed previously.[8] It may be noted, the data were obtained with systems where the only reflection occurring was that due to incidental reflection from the walls, floors, etc.

Results

1. Differing Geometries

Data obtained with a 10 in. I.D. aluminum cylinder interacting with a slab 47.5 in. wide by 6 in. thick were used to determine if the non-symmetrical interaction was more effective in neutron exchange than the symmetrical; the height of the 2 units was kept the same and was varied to attain criticality as the separation was changed. The data obtained are given in table I and presented graphically in figure 1 along with similar data obtained for interaction of 2 identical cylinders and 2 identical slabs of the dimensions given. The U-235 enrichment was 93.2% and the H/U-235 atomic ratio was approximately 330 in all cases. It will be observed that, for criticality, the spacing of the 2 dissimilar units, as shown in figure 1 and listed in table I, is actually less than half-way between the corresponding spacings for the respective similar units; thus, if spaced in accord with the general interaction principle defined above, the system obviously will be safe. Although the interaction solid angles for the 2-slab and 2-cylinder systems are determined by the accurate analytical method previously developed,[9,10] those for the slab-cylinder system are merely good approximations.

2. Differing Moderation

a. Solutions:

The available data concerning interaction between containers of identical geometry but of different moderations, together with the corresponding information on identical containers, are listed in table II and graphed in figure 2 where the common critical height is plotted as a function of the separation. The reactors were 10 in. I.D. aluminum cylinders which contained UO_2F_2 solutions of 93.2%

TABLE I

SYSTEMS OF INTERACTING SLABS AND CYLINDERS

Aluminum Containers, U-235 Assay 93.2%, H/U-235 Atomic Ratio ~ 330

	HOMOGENEOUS SYSTEMS				HETEROGENEOUS SYSTEM		
	Two 10 in. I.D. Cylinders*		Two 6 in. x 47.5 in. Slabs		10 in. Cyl. and 6 in. x 47.5 in. Slab		
Separation (inches)	Common Critical Ht. (inches)	Fractional Solid Angle Ω	Common Critical Ht. (inches)	Fractional Solid Angle Ω	Common Critical Ht. (inches)	Fractional Solid Angle (Cyl. on Slab)*** Ω	Fractional Solid Angle (Slab on Cyl.)*** Ω
0 to 0.1	16.80	0.173	7.73	~50	12.10	0.184	0.272
2.0	21.1**	0.123	10.01	0.305	14.9**		
3.0	23.00	0.108	11.0**	0.275	16.0**		
6.0	26.60	0.079	12.91	0.205	18.82	0.088	0.201
9.0	29.88	0.061	14.8**	0.160	21.0**		
12.0	33.0**	0.048	16.2**	0.130	22.90	0.051	0.153
15.0	35.1**	0.040	17.67	0.112	24.6**		
16.0	35.80	0.037	18.1**	0.108	25.2**		
18.0			19.0**	0.098	26.18	0.033	0.121
20.0			19.79	0.092	27.0**		
30.0			23.51	0.061	31.18	0.018	0.073
42.0			27.0**	0.041	35.07	0.012	0.051
48.0			28.83	0.036			
66.0			32.33	0.024			

* Data previously reported[8] for 10 in. I.D. cylinders were obtained with the cylinders enclosed in a thin-walled rectangular tank, approximately 4.5 ft. x 2.25 ft. x 3.5 ft. deep.

** Interpolated value.

*** Estimated.

FIGURE 1

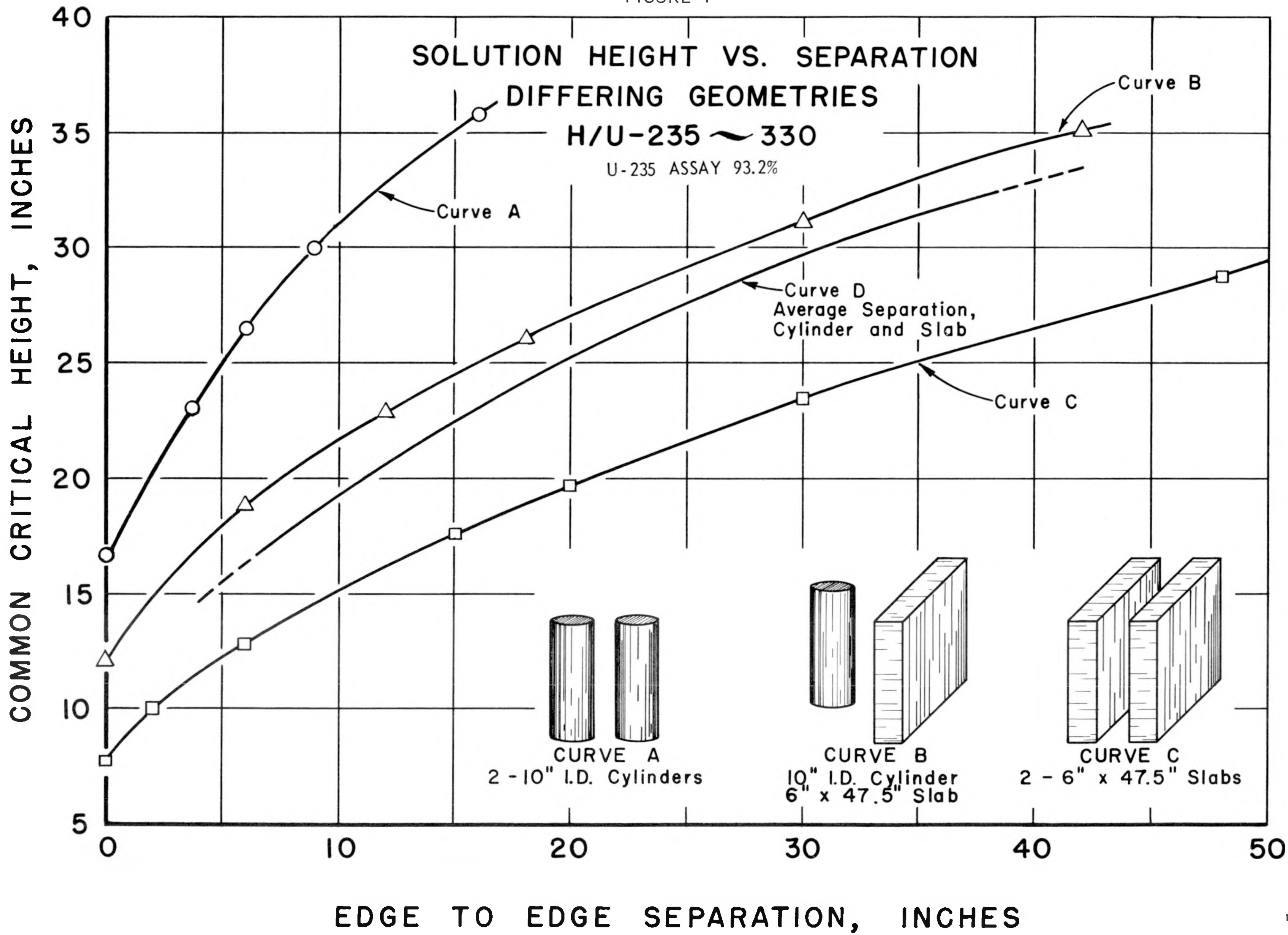

SOLUTION HEIGHT VS. SEPARATION
DIFFERING GEOMETRIES
H/U-235 ~ 330
U-235 ASSAY 93.2%
Curve A
Curve B
Curve D
Average Separation,
Cylinder and Slab
Curve C
CURVE A
2 - 10" I.D. Cylinders
CURVE B
10" I.D. Cylinder
6" x 47.5" Slab
CURVE C
2 - 6" x 47.5" Slabs
COMMON CRITICAL HEIGHT, INCHES
EDGE TO EDGE SEPARATION, INCHES
5
10
15
20
25
30
35
40
0
10
20
30
40
50

TABLE II

INTERACTING PAIRS OF 10 IN. I.D. CYLINDERS

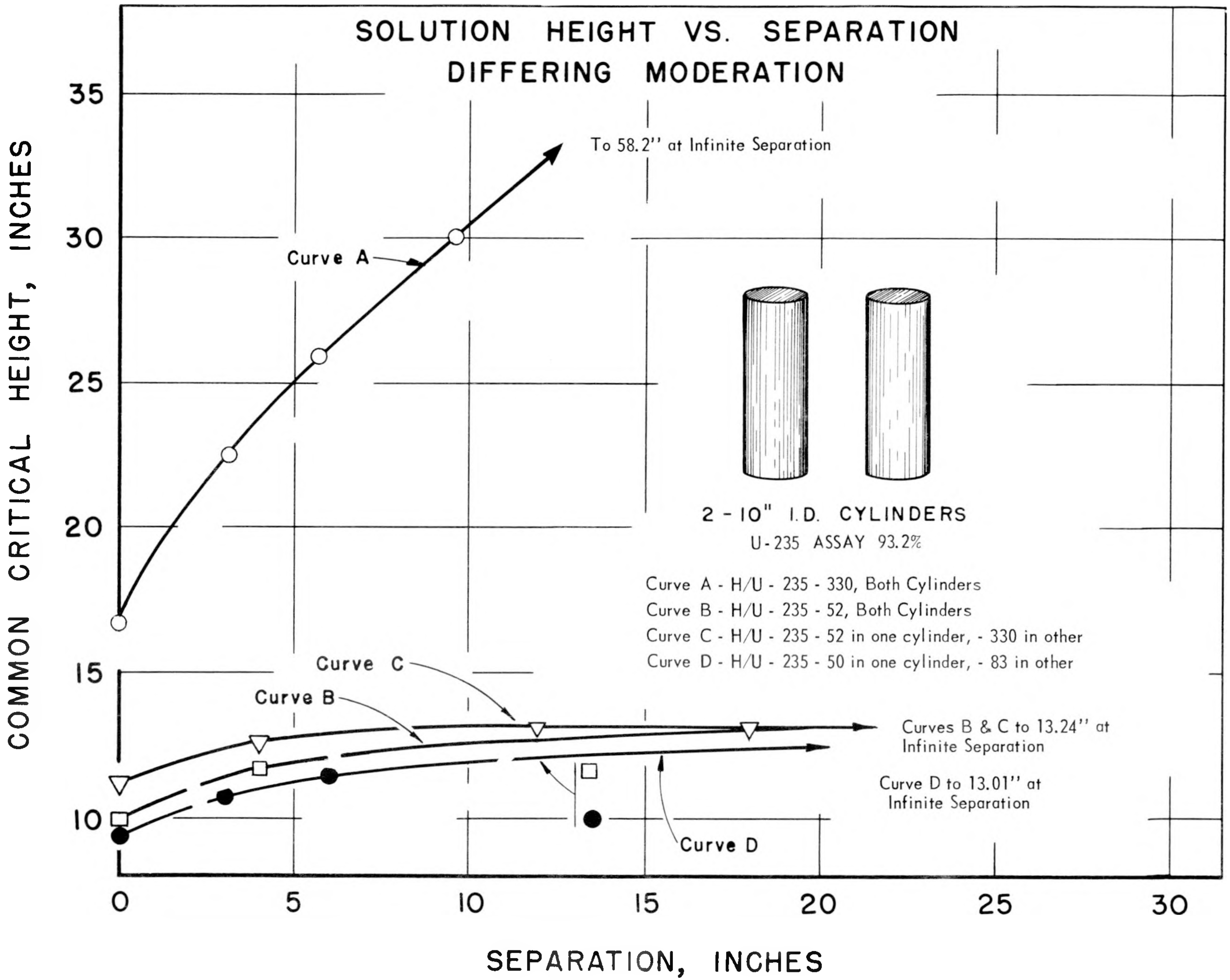
Aluminum Containers, U-235 Assay 93.2%, Differing Moderation

	HOMOGENEOUS SYSTEMS H/U-235 Atomic Ratio:			HETEROGENEOUS SYSTEMS H/U-235 Atomic Ratio:	
Separation (inches)	~ 52 Common Critical Ht. (inches)	~ 83 Common Critical Ht. (inches)	~ 330 Common Critical Ht. (inches)	No. 1 Cyl. ~ 52 No. 2 Cyl. ~ 330 Common Critical Ht. (inches)	No. 1 Cyl. ~ 50 No. 2 Cyl. ~ 83 Common Critical Ht. (inches)
0 to 0.1	10.02	10.03	16.80	11.20	10.0*
3.0	11.5*	11.44	23.00	12.4*	11.4*
4.0	11.78	11.7*	24.0*	12.72	11.6*
6.0	12.3*	12.18	26.60	13.0*	12.05
9.0	12.6*	12.5*	29.88	13.1*	12.4*
12.0	12.83	12.72	33.0*	13.17	12.60
16.0	-	-	35.80	-	-
18.0	-	-	-	13.20	-

* Interpolated values.

Note: Due to dimensional variances, the critical heights of the individual reactors differed by 0.2 in. at near optimum moderation for minimum geometry.

FIGURE 2


SOLUTION HEIGHT VS. SEPARATION
DIFFERING MODERATION
COMMON CRITICAL HEIGHT, INCHES
SEPARATION, INCHES
35
30
25
20
15
10
0
5
10
15
20
25
30
To 58.2" at Infinite Separation
Curve A
2 - 10" I.D. CYLINDERS
U-235 ASSAY 93.2%
Curve A - H/U - 235 - 330, Both Cylinders
Curve B - H/U - 235 - 52, Both Cylinders
Curve C - H/U - 235 - 52 in one cylinder, - 330 in other
Curve D - H/U - 235 - 50 in one cylinder, - 83 in other
Curve C
Curve B
Curves B & C to 13.24" at Infinite Separation
Curve D to 13.01" at Infinite Separation
Curve D

U-235 enrichment and whose H/U-235 atomic ratios varied between 50 and 330. It will be noted that, as the separation was increased, the solution height of the system approached that value for the individual cylinder with the lowest critical height, particularly where the H/U-235 atomic ratios were significantly different. Although the critical heights of the heterogeneous system with H/U-235 of 50 in one container and H/U-235 of 83 in the other appear to be slightly lower than those of the homogeneous systems with identical fuel in both containers, this height difference may be only apparent rather than real since the critical heights of the 2 isolated 10 in. I.D. cylinders with a fuel moderation of H/U-235 of 52 varied by 0.2 in. which is approximately twice the maximum difference noted for the heterogeneous system and either of its homogeneous counterparts; in addition, it is obvious that the difference involved, if real, is small. From these data, it may thus be inferred that, in general, the homogeneous system where the units are those with the greater reactivity is more reactive than its heterogeneous counterpart and that any spacing based upon consideration of these most reactive units will be safe for one of these units and a less reactive one.

On the basis of these particular experiments, however, it becomes difficult to verify the general interaction principle, as was the case for differing geometries, particularly where the moderation changes are slight. However, it is apparent from the data with the cylinders at H/U-235 atomic ratios of 52 and 83 that the effect of interaction is essentially independent of moderation, both as it applies to interaction between 2 identical cylinders or to 2 with differing moderations. Thus, in addition to the above experiments, the general interaction principle was tested directly for differing moderations by obtaining the heights at which 2 sets of 2 interacting cylinders, the units of each set having identical moderation, would be critical for a given range of separations. One unit of each of these sets was then permitted to interact with a unit of the other, each being filled to its respective height for criticality with its "twin" at a given separation; experimentally, the geometric centers of both units were at the same level. The results are given in table III and figure 3 where it will be noted that the system of dissimilar units was not critical at separations for which both systems of similar units were critical. The solution height in the more reactive container was then increased until criticality was attained; this height difference may thus be interpreted as an indication of the reactivity difference of the systems. Thus, the results of these experiments also indicate the general interaction principle to hold for solutions of different moderations.

b. Solution-Unmoderated Systems:

In order to determine the effect of interaction between 2 systems, one of which is essentially an unmoderated system from which the leakage is predominantly of fast neutrons and the other of which is a well-moderated one from which the leakage is that of both fast and thermal neutrons, 2 sets of experiments similar to the second of the types evaluated for solutions were set up; it was considered particularly important to determine if interaction between units of these types were more effective than had been indicated by the other experiments which involved well-moderated systems only.

TABLE III

INTERACTING PAIRS OF 10 IN. I.D. CYLINDERS

Aluminum Containers, U-235 Assay 93.2%, Differing Moderation and Geometry

Separation (inches)	HOMOGENEOUS SYSTEMS, H/U-235 Atomic Ratio: ~ 52, Common Critical Ht. (inches)	HOMOGENEOUS SYSTEMS, H/U-235 Atomic Ratio: ~ 330, Common Critical Ht. (inches)	HETEROGENEOUS SYSTEM, H/U-235 Atomic Ratio: ~ 52, Critical Ht. (inches)	HETEROGENEOUS SYSTEM, H/U-235 Atomic Ratio: ~ 330, Critical Ht. (inches)
0 to 0.1	10.02	16.80	-	-
2.0	11.1*	21.0*	11.86	21.50
3.0	11.5*	23.00	12.3*	23.0*
4.0	11.78	24.0*	12.5*	24.0*
6.0	12.3*	26.60	12.89	26.53
9.0	12.7*	29.98	13.2*	30.0*
12.0	12.83	33.0*	13.29	33.00
16.0	-	35.80	-	-

* Interpolated value.

Note: Due to dimensional variances, the critical heights of the individual reactors differed by 0.2 in. at near optimum moderation for minimum geometry.

TABLE IV

INTERACTING PAIRS OF 48 IN. SLABS

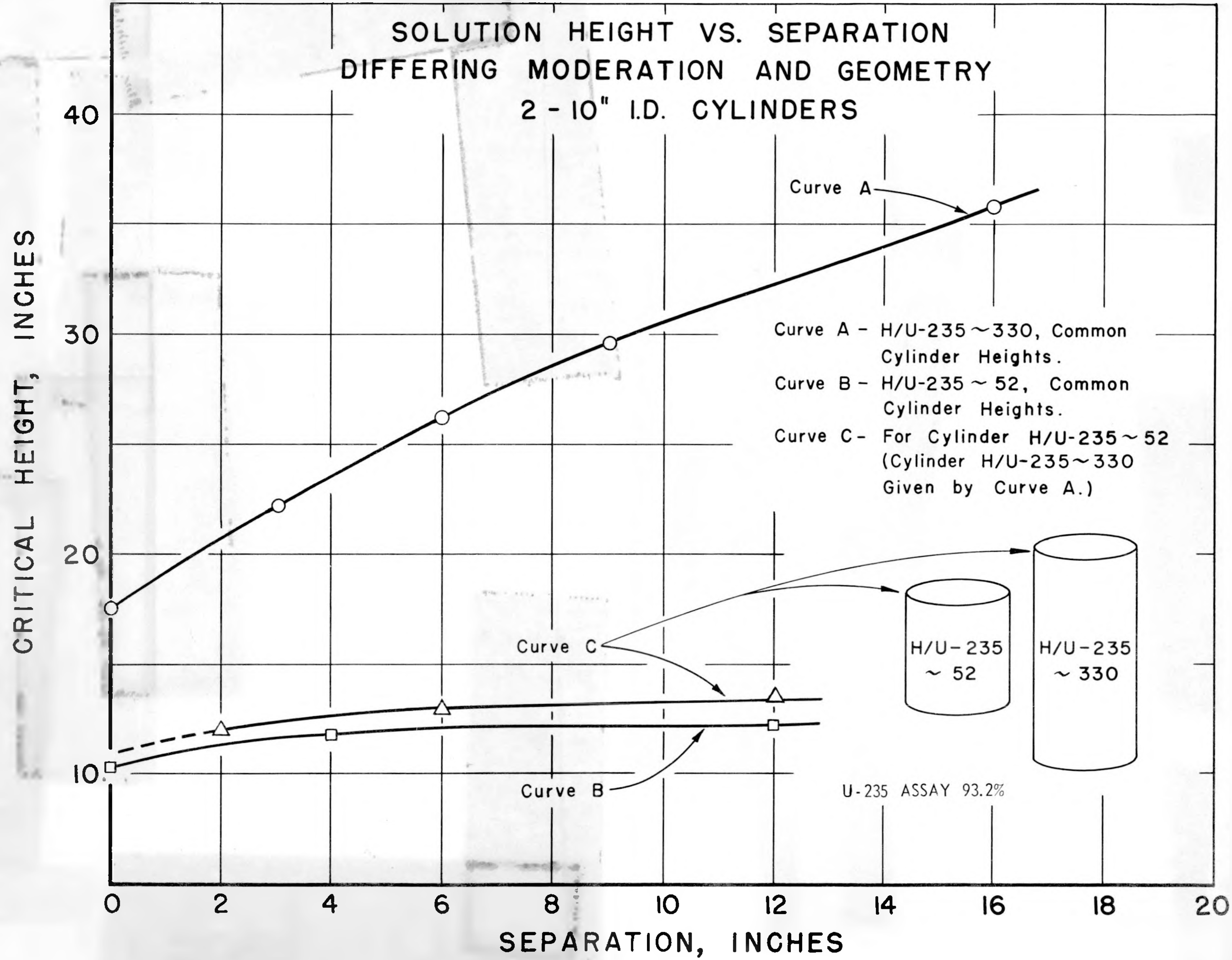
93.2% Assay UO_2F_2 Solution

Separation (inches)	HOMOGENEOUS SYSTEM, Two Solution Slabs*, Critical Ht. (inches)
0	12.54
1.0	16.85**
2.0	
3.0	
4.0	

* All solution slabs, 3 in. x 47.5 in., H/U-235 ~ 52.

** Extrapolated or interpolated value.

FIGURE 3


SOLUTION HEIGHT VS. SEPARATION
DIFFERING MODERATION AND GEOMETRY
2 - 10" I.D. CYLINDERS
CRITICAL HEIGHT, INCHES
SEPARATION, INCHES
40
30
20
10
0
2
4
6
8
10
12
14
16
18
20
Curve A
Curve A - H/U-235 ~ 330, Common Cylinder Heights.
Curve B - H/U-235 ~ 52, Common Cylinder Heights.
Curve C - For Cylinder H/U-235 ~ 52 (Cylinder H/U-235 ~ 330 Given by Curve A.)
Curve C
Curve B
H/U-235 ~ 52
H/U-235 ~ 330
U-235 ASSAY 93.2%

The results are given in table IV [illegible]. It will be again observed that the 2 interacting "half-slabs" are subcritical under conditions where each would be critical with a "twin". It will also be noted that for one height of the solution in each case, the dimensions of the interacting surfaces were identical and the angles of interaction thus simply determinable. It is of interest that when the thickness of the unmoderated slab was increased by about 30% [illegible] its reactivity, as far as interaction at close spacing is concerned, is about equal to that of a 3 in. solution slab for the geometries involved.

c. Varying Moderation

A very common type of problem to which considerations of variations in moderation may be cogent is the storage of uranium solutions in geometrically unsafe cylinders on the basis that they contain not more that a safe U-235 mass; obvious considerations in this problem are the possibilities of precipitation from solution and the settling out of slurries or suspensions as well as changes in solution moderation by evaporation. Although the method previously developed can be used to determine a value of the multiplication factor, k, and consequently a safe separation based on an interaction angle, Ω, for the container in which the material is homogeneously distributed, it is desirable to determine if any changes in the uranium concentration, such as those noted above, could so change the reactivity of the various system units that their separation would no longer be sufficient to meet the safe interaction criteria. Conversely, in specifying separation, it is obviously of value to determine the general conditions of geometry and concentration for which a safe separation of containers with a given mass will always be specified; this means, of course, that any change in the geometrical factors

* [illegible]

or concentration for a given mass will permit a smaller separation than the limiting one noted. It is, of course, apparent in this analysis that the basic interaction criteria, including safety factors, are being considered as the limiting safe conditions and that no attempt is made to evaluate the actual critical conditions.

In evaluating this problem, therefore, the values of k for a given cylindrical container having a specified mass of U-235 were determined by the previously described 2-group theory[4] 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. Figure 5 shows the results of these determinations for a variety of cylinders where the masses in the individual containers were so selected that a k-value of 0.90 was obtained for their most reactive configuration. Under these conditions, a separation between the cylinders necessary to give an interaction angle of 8% of 4π and thus meet the basic interaction criterion for unreflected containers was selected. It will be noted that, as a concentration was varied from this most reactive value, the resultant values of k for both the more dilute and more concentrated solutions dropped so rapidly that the actual interaction solid angle was less than the "permissible" one. Thus, for each cylinder, a safe spacing based on its most reactive configuration would be safe for any other configuration. For a k-value of 0.90, the minimum mass found was about 1.05 kg., this being contained in a 12 in. I.D. container at an H/U-235 atomic ratio of about 550.

In general, it is not the practice at the ORGDP to consider geometrical factors of safety for individual containers where nuclear safety is made dependent upon the control of the U-235 mass. Accordingly, a similar analysis with several cylinders of different diameters was made, except that a mass of 1.0 kg. was considered as being in each cylinder, regardless of its diameter, and the separation selected was that meeting the basic interaction criterion for the most reactive concentration and configuration of this mass. The results are shown in figure 6 where the data are presented in the same manner as for figure 5. It will again be noted that, for a given mass, there is an optimum concentration and configuration for which the separation, as determined by the basic interaction criterion, will be a maximum. For cylindrical geometry, it appears that this maximum separation will be specified for conditions where an approximately equilateral cylinder contains material at an H/U-235 ratio of about 600. Accordingly, it may be inferred that where the U-235 mass is the primary control factor, a separation based on the basic interaction criterion for a sphere containing the material at an H/U-235 ratio of 600 will be more than adequate for any other concentration or configuration. Conversely, it should thus be concluded that under conditions where settling or other moderation change is considered possible, the basic interaction criteria should be applied only to the k-value of the most reactive configuration. Determinations of k for masses of 350 and 700 g. of U-235 in spherical geometry have been reviewed in a previous report.[1]

FIGURE 5

INTERACTION OF CYLINDERS WITH CONSTANT MASSES

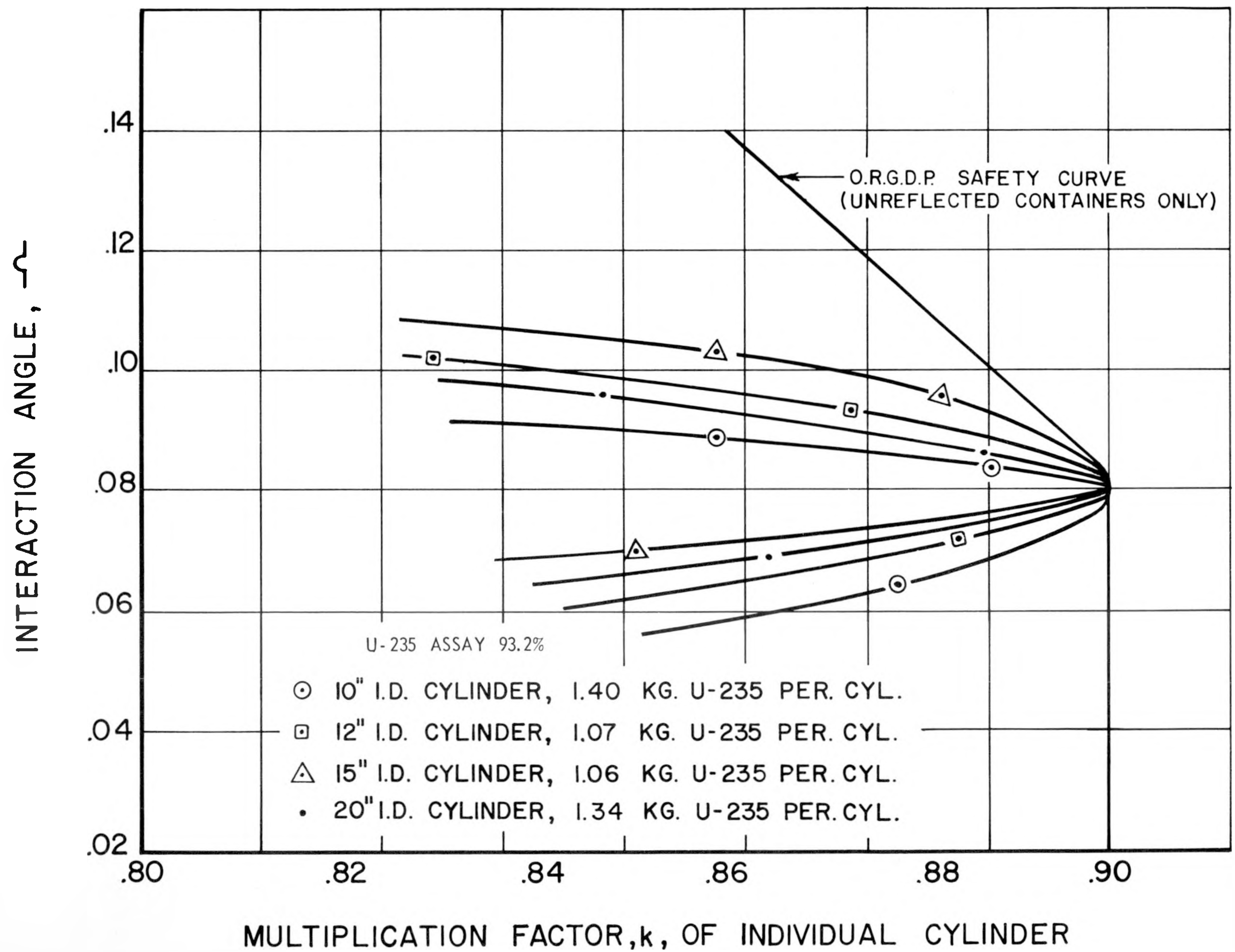
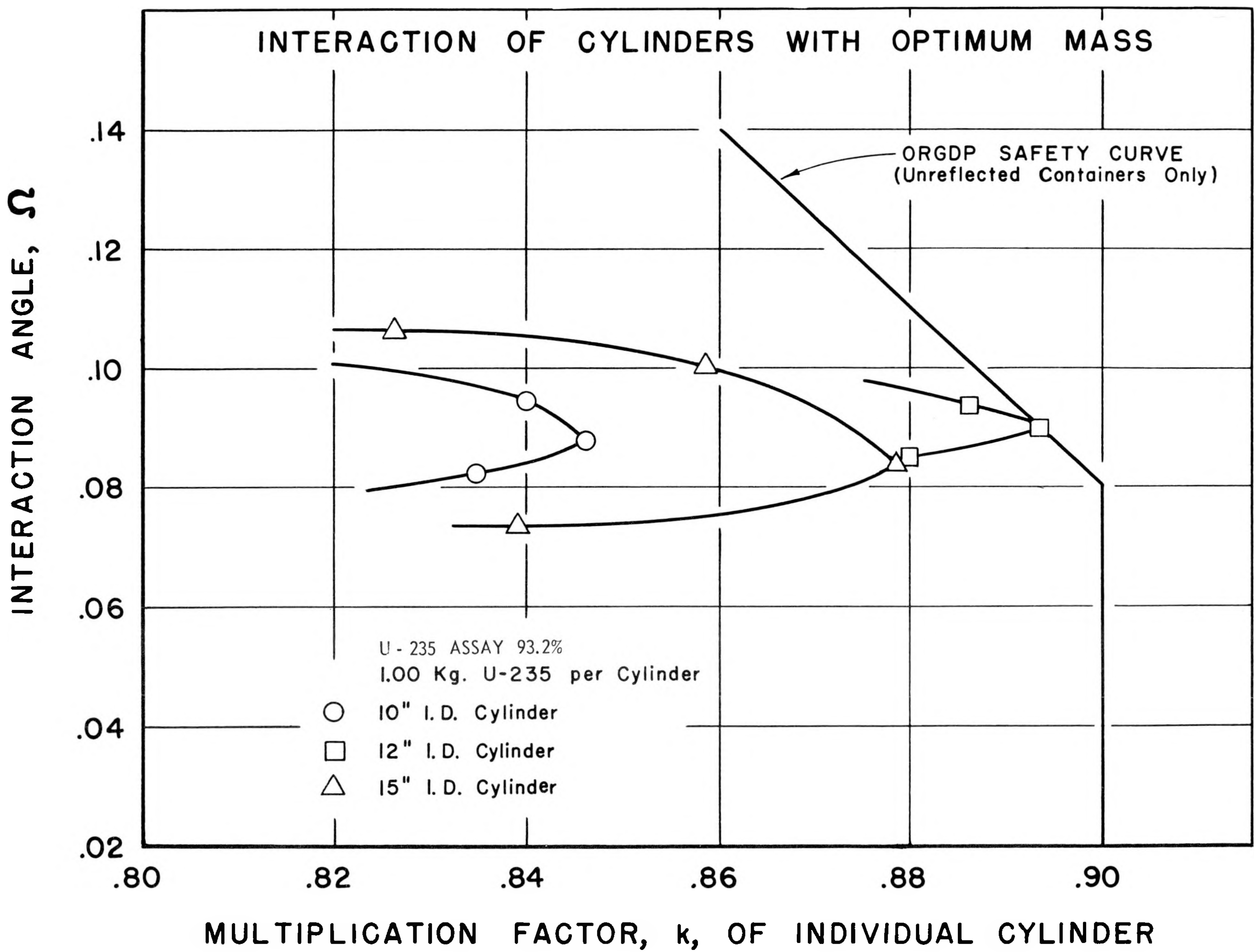


FIGURE 6


INTERACTION OF CYLINDERS WITH OPTIMUM MASS
ORGDP SAFETY CURVE
(Unreflected Containers Only)
U - 235 ASSAY 93.2%
1.00 Kg. U-235 per Cylinder
10" I. D. Cylinder
12" I. D. Cylinder
15" I. D. Cylinder
INTERACTION ANGLE, Ω
.14
.12
.10
.08
.06
.04
.02
.80
.82
.84
.86
.88
.90
MULTIPLICATION FACTOR, k, OF INDIVIDUAL CYLINDER

It may be noted that in each case depicted in figure 5, the spacing could have been so chosen that the safety criteria would have been satisfied originally; however, it is then also obvious that, upon settling, the reactivity of the fuel would increase so rapidly that the safety curve is exceeded although the effective interaction angle might actually decrease. It will be observed that, where precipitates occur or slurries settle out of moderator mixtures, the resultant material in the bottom of the container may actually be considered as being at least half-reflected. For this case, it may be noted that the interaction criteria specified for the ORGDP actually have been chosen so as to be safe for half-reflected systems and thus the safety factors inherent in the use of the criteria are adequate for this consideration also. It may also be noted that, as described in a previous section of this report, the change in concentration of one container without a corresponding change in the other would produce a less reactive system than would be the case for the 2 to change simultaneously as is assumed in this presentation.

Heterogeneous Fuels

In addition to the interacting systems described above, it is obviously also possible to have systems in which the fissionable material in the individual units themselves is distributed inhomogeneously with respect to the moderator or geometry; in general, such systems would include randomly-distributed fuels in various mixtures, lattices, "moist" systems where the fuel is partly moderated and partly unmoderated, etc.

Although it is practically impossible to evaluate all types of conditions involving these non-homogeneous units, it is perhaps apparent that such detail is not actually necessary if it is possible to determine a limiting condition which is the most reactive, interaction-wise, of any possible configuration and this can then be shown to be safe; this was the type of consideration given above to the possibility of moderation varying in a container. Similarly, it is probably sufficient to show that the variants considered do not particularly affect interaction effects although the use of the interaction criteria suggested may involve serious problems of determining the multiplication factor, k, of an individual unit; in this case, it may be sufficient to show that the value of k calculated by the method selected will be conservative. As an illustration, a previous report[1] indicates that calculations by the methods used at the ORGDP apparently give conservative k-values for systems at low moderation and low U-235 assay, although it is recognized that these methods are not considered to give particularly accurate results in these regions.

Although the experiments described in this report and their interpretation are not clearly applicable to the general problem of heterogeneous fuels, it may be noted that the results of the work with unmoderated-moderated systems, which are unfortunately complicated by using uranium of differing U-235 assays, indicate that differences in neutron energy in the core material apparently have little effect upon the neutron exchange between systems as compared with that for homogeneous units. It seems highly improbable that separate and significant effects due to assay and moderation differences would be so completely offsetting as to give the observed results if this consideration were not valid. It may be noted that the problem of interaction between latticed and unlatticed masses is not clearly defined although, on intuitive grounds, there seems little reason to suspect markedly different interaction effects than those indicated for the homogeneous units alone. Similarly, it appears improbable that interaction between units of systems of high density, such as metals, or between these high-density units and those of low density, would have significantly different effects from those described above. It should be noted further that differences due to all complicating factors reviewed are, in general, small and readily compensable by the comparatively large safety factors inherent in the statement of the basic interaction criteria..

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