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AEC RESEARCH AND DEVELOPMENT REPORT

EXTENSION OF THE SAFE GEOMETRIC PARAMETERS TO SLIGHTLY ENRICHED URANIUM

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OAK RIDGE GASEOUS DIFFUSION PLANT

Operated by

UNION CARBIDE NUCLEAR COMPANY
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EXTENSION OF THE SAFE GEOMETRIC PARAMETERS TO SLIGHTLY ENRICHED URANIUM

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OAK RIDGE GASEOUS DIFFUSION PLANT
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Oak Ridge Gaseous Diffusion Plant
Oak Ridge, Tennessee

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ABSTRACT

Use is made of a method of buckling comparisons to extend the safe geometric criticality parameters of the infinite cylinder, infinite slab, and the sphere, to uranium of enrichments between 0.72% and 5% U-235 assays. The new criteria complete the determination of the assay variation of these safe parameters and permit their tabulation for uranium of all enrichments. Comparison with the available experimental data which include results of the Hanford Physical Constants Testing Reactor, together with previous ORGDP studies based on the Water Boiler Theory, indicates that the new criteria may be safely applied to the uranium systems normally encountered in gaseous diffusion plant operations.

EXTENSION OF THE SAFE GEOMETRIC PARAMETERS TO SLIGHTLY ENRICHED URANIUM

INTRODUCTION

In view of the considerable interest in the determination of safe criticality parameters for use in the handling and processing of slightly enriched uranium, a method involving buckling comparisons has been developed whereby the relatively more plentiful data for higher assay uranium may be usably extended by a short extrapolation to apply to uranium of less than 5% U-235 assay. From the results obtained, and those based on a new experimental technique for determining the infinite multiplication factor, k_∞, of slightly enriched uranium,[1] it appears possible to establish values of the low assay geometric criticality parameters which will be safe for use under the conditions specified in the current ORGDP nuclear safety guide.[2] It may be noted that the results obtained by buckling comparisons agree closely with those results obtained previously by a somewhat different method of analysis.[3]

METHOD AND EXPERIMENTAL DATA

It is well-known that direct experimental measurements of the criticality parameters for slightly enriched uranium require almost prohibitively large amounts of fissionable materials, especially at low moderations. One figure of considerable interest at the ORGDP would be the minimum U-235 assay for which criticality is possible, this corresponding to an infinite multiplication factor, k_∞, of unity. Obviously, a critical experiment for the determination of this minimum assay would be impossible since it would require an infinite amount of material, and it is also readily apparent that the attainment of criticality at slightly higher assays than the minimum would necessitate a tremendous uranium inventory. However, for the low density homogeneous systems normally encountered in ORGDP operations, this minimum critical enrichment is considered to be equal to or greater than a U-235 assay of 0.72%, the assay of natural uranium, since all data, including theoretical and experimental studies of metal uranium-water lattices,* point to this value as a conservative minimum. Thus, although this may not be the precise value, it does serve to fix a lower limit to the actual value so that an appropriate extrapolation below the assays of the available critical experiments may in reality be considered as a conservative interpolation.

Although the spatial distribution of neutrons will vary in a critical reactor of finite dimensions because of neutron leakage from the reactor, it is postulated that the neutron density in an infinite critical reactor will be constant. Thus, the geometric buckling was the eigenfunction chosen for interpolation of the experimental criticality data. This buckling, which by definition is a measure of the neutron flux curvature, will be zero for

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* A k_∞ of 0.989 has been mentioned as an upper limit for a lattice of natural uranium rods and light water.[4] This is higher than any value obtained for homogeneous systems of natural uranium. See also the Geneva papers for an excellent summary of the work done in this particular field of neutron reactor physics.[5]

an infinite system, will have higher positive values for finite systems, and will assume its maximum value for the geometric minimum critical, or most compact, system. Further, once this maximum geometric buckling value is determined for criticality with the material and assay of interest, the dimensions of various geometrical shapes, such as the sphere, cylinder, and the slab, are then readily obtainable by standard reactor theory transformations.

Thus, figure 1 shows the results obtained by plotting the maximum critical buckling as a function of the U-235 assay. The curve identified as curve I represents the estimated maximum critical bucklings as derived from the experimental buckling values. The actual experimental figures are designated by points, all of which, with the exception of the one at zero buckling representing the minimum critical enrichment, were obtained by direct critical experiments with UO_2F_2 solutions.[6,7,8,9] In this latter case, relatively small quantities of fissionable materials in the form of a UO_3-H_2O mixture were used in indirect criticality measurements recently performed in the Physical Constants Testing Reactor at Hanford.* The results of these experiments indicate that the minimum critical enrichment lies between U-235 assays of 1.00% and 1.15%, and may be about 1.03%.[1]

Curve II represents the maximum critical bucklings estimated by a previous ORGDP study[3] using the Water Boiler Theory.[10] It may be noted that, where results of actual critical experiments are available for direct comparison, this being at U-235 assays of 5% and greater, the theory gives generally conservative results. At the point of zero buckling, the theory predicts the minimum critical enrichment to be at a U-235 assay of 0.95%, which not only agrees with other predictions of 0.9% and 1.07%, which were obtained using simple calculation methods,[11,12] but also is well below an estimate of 1.7% obtained with a multi-group technique,[13] and is slightly conservative with respect to the prediction of 1.03% obtained with the Physical Constants Testing Reactor.

Curve III represents the bucklings of containers considered geometrically safe at the ORGDP for assays above 5%,** and also includes the extension of these safe buckling values to a point of zero buckling at 0.72% U-235 assay. It may be noted that these safe buckling values of the intermediate enrichments between 0.72% and 5% assays are considered to be adequately conservative, since, as indicated by the experimental and theoretical curves, there is no reason to anticipate any condition which would cause a significant perturbation of the buckling curve in the low assay regions. Thus, curve III appears to be sufficiently conservative to compensate for any random inhomogeneities in actual plant materials since a high density metal uranium-water lattice would be required to even approach the safe buckling value given at 0.72%.

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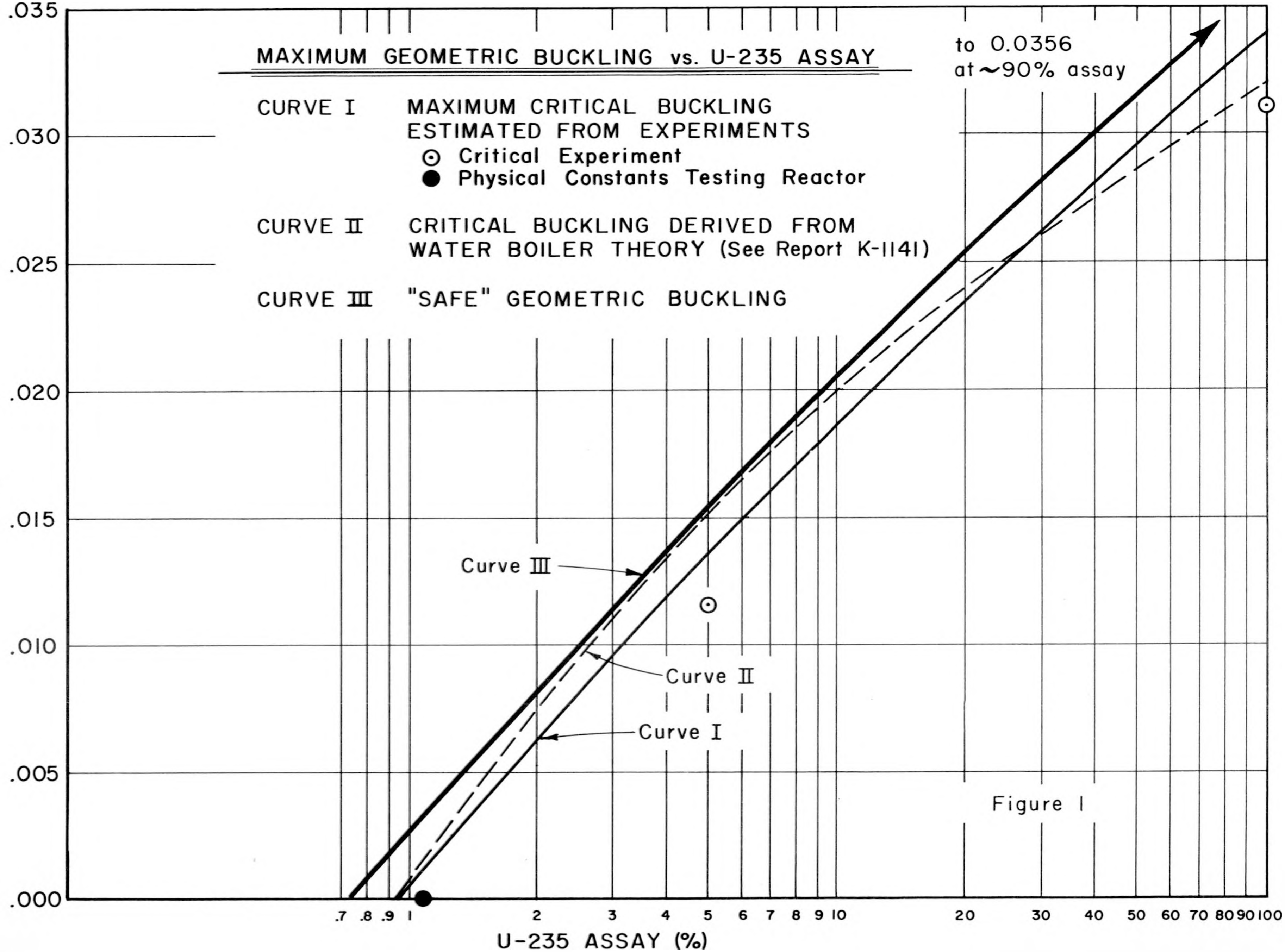
* The nuclear properties of the UO_2F_2-H_2O system and the UO_3-H_2O system under consideration are very similar.

** A geometrically safe container is defined as one which may be filled with uranium materials of unlimited hydrogen moderation, may be completely reflected with water, and whose volume and mass limitations are imposed by the physical dimensions of the vessel itself. The uranium density, for ORGDP considerations, is assumed to be no greater than 3.2 grams per milliliter.



MAXIMUM GEOMETRIC BUCKLING vs. U-235 ASSAY
CURVE I MAXIMUM CRITICAL BUCKLING ESTIMATED FROM EXPERIMENTS
Critical Experiment
Physical Constants Testing Reactor
CURVE II CRITICAL BUCKLING DERIVED FROM WATER BOILER THEORY (See Report K-1141)
CURVE III "SAFE" GEOMETRIC BUCKLING
to 0.0356 at ~90% assay
Curve III
Curve II
Curve I
Figure 1
.035
.030
.025
.020
.015
.010
.005
.000
Bg2 (cm.-2)
.7 .8 .9 1 2 3 4 5 6 7 8 9 10 20 30 40 50 60 70 80 90 100
U-235 ASSAY (%)

SAFE CRITICALITY PARAMETERS OF SLIGHTLY ENRICHED URANIUM

Since the portion of the safe buckling curve for the intermediate assays between 0.72% and 5% appears to be appropriately conservative for general plant use, these bucklings were therefore used in preparing safe curves of the criticality parameters according to standard reactor theory transformations[14]; an extrapolation distance of 6.4 cm. was used in all calculations. The results are given in figure 2 for the geometries of the infinite cylinder, infinite slab, and the sphere. Those portions of the safe curves in figure 2 involving U-235 assays of 5% and greater correspond to the safe criticality parameters which may be found in the current ORGDP nuclear safety guide.[3] The data plotted in figure 2 are also given in table I.

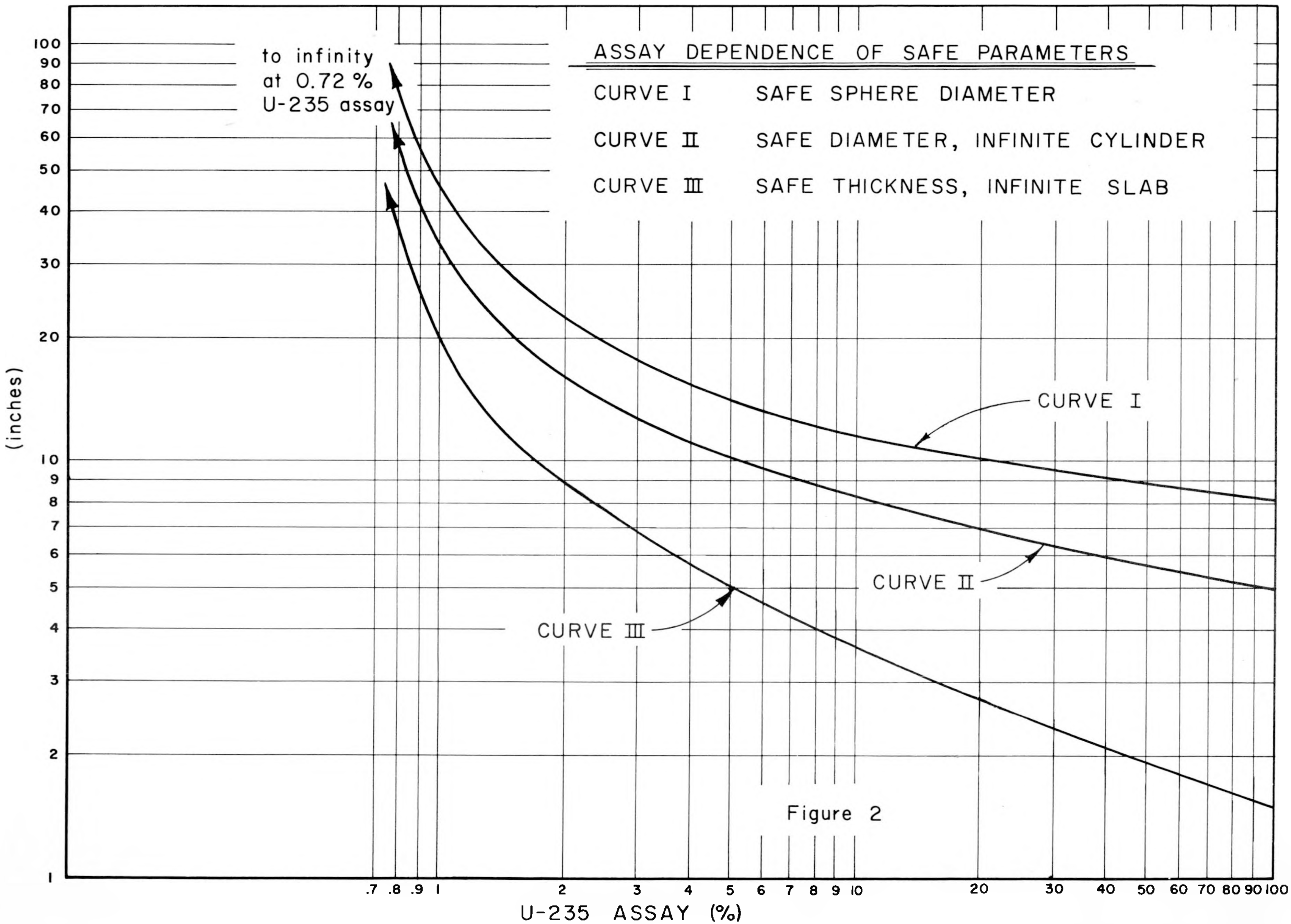

ASSAY DEPENDENCE OF SAFE PARAMETERS
CURVE I SAFE SPHERE DIAMETER
CURVE II SAFE DIAMETER, INFINITE CYLINDER
CURVE III SAFE THICKNESS, INFINITE SLAB
to infinity at 0.72 % U-235 assay
CURVE I
CURVE II
CURVE III
(inches)
100 90 80 70 60 50 40 30 20 10 9 8 7 6 5 4 3 2 1
.7 .8 .9 1 2 3 4 5 6 7 8 9 10 20 30 40 50 60 70 80 90 100
U-235 ASSAY (%)

Figure 2

TABLE I

SAFE GEOMETRIC PARAMETERS

Water Reflected; Maximum Uranium Density - 3.2 g./ml.

U-235 Assay (Wt. % U-235)	Sphere Diameter (Inches)	Sphere Volume (Liters)	Infinite Cylinder Diameter (Inches)	Infinite Slab Thickness (Inches)
100	8.0	4.4	5.0	1.5
75	8.3	5.0	5.2	1.6
50	8.9	6.0	5.7	1.9
40	9.2	6.7	6.0	2.0
30	9.6	7.7	6.3	2.2
20	10.3	9.5	6.9	2.7
15	10.9	11.0	7.4	3.1
12	11.3	12.5	7.8	3.4
10	11.8	14.0	8.2	3.6
8.0	12.3	16.0	8.7	3.9
6.0	13.4	20.5	9.6	4.5
5.0	14.6	27.0	10.25	5.0
4.0	15.8	33.8	11.2	5.5
3.5	16.7	40.0	12.0	6.0
3.0	17.9	49.2	12.8	6.5
2.5	19.6	64.6	14.0	7.1
2.0	22.3	95.1	16.0	8.7
1.75	24.5	126	17.6	9.6
1.5	27.9	186	20.0	11.0
1.25	33.0	308	24.0	13.5
1.0	44.0	731	33.0	19.5
0.8	77.0	3917	58.0	36.0
0.72	Infinite		Infinite	Infinite

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