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Some Effects of Packaging Materials on Critical Arrays of Fissile Materials

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INTRODUCTION

The Computer Science Division of the Oak Ridge National Laboratory has undertaken a program to evaluate the criticality criteria for transport packaging of fissionable materials as expressed in Title 10 of the Code of Federal Regulations Part 71. The study presently is focused on the definition of criticality for water-reflected cubic arrays of loaded containers as a function of container volume, type of insulating material and its thickness, and the number of packages. Some study of the effects of packaging materials on concrete-reflected arrays is also carried out.

CALCULATIONAL METHOD

The calculational method employed in the study utilizes the KENO Monte Carlo Code[1] with the Hansen-Roach neutron cross section sets.[2] The method has been validated against critical experiments performed by D. W. Magnuson[3,4] and was also used to establish the basis for the ANSI Standard Guide for Nuclear Criticality Safety in the Storage of Fissile Materials, N16.5-1975. The data base represents criticality of reflected arrays of air-spaced units, has an analytic representation,[5,6] and provides a suitable vehicle for interpretation of the relative effects on criticality of the packaging materials.

In Magnuson's critical experiments, polyethylene-reflected 2 x 2 x 2 arrays of U(93.2) metal cylinders having different insulating materials were assembled to delayed criticality. Figure 1 shows the different types of insulating materials used in the experiments. The neutron multiplication factor k_{eff} determined by experiments and calculated by KENO is compared in Table I. Five insulating material were examined. The vermiculite insulated array has 15 centimeter polyethylene reflector while the other four arrays have 20 centimeter polyethylene reflector. Except for the last two arrays, KENO calculations agree with the experiments quite well. In general, the agreement between the experiments and the calculations is considered satisfactory.

RESULTS

Initial calculations for the transport packaging study are of U(93.2) metal cylinders having a height to diameter ratio, h/d, of unity. Figure 2 shows the geometric arrangement of the package used in the calculations. The outer container is a cube of carbon steel and the inner container is a 304 SS cylinder with h/d of unity. The insulating material is Celotex and is placed at the cell boundaries immediately inside the outer container. Calculated results of critical water-reflected arrays are represented in terms of the array limiting surface density versus the unit mass in Figure 3. With the air-spaced arrays curve as a reference, the introduction of Celotex as the insulating material results in a reduction of the unit mass needed to maintain criticality. That is, the reactivity of the arrays would have increased if the unit mass were not reduced. The results for three thicknesses of Celotex at a density of 225 Kg/m^3 (15 lb/Ft^3) are presented in the figure. The calculations were of 216 unit arrays having cubic cell volumes of 56.8, 113.6 and 208.2 liters (15, 30, and 55 gal respectively).

The introduction of an inner 304 stainless steel container, 3.18-mm-thick (1/8 inch), to these Celotex-moderated arrays results in a negative reactivity effect which about nullifies the positive reactivity caused by the Celotex.

The addition of the outer steel container causes a further decrease in array reactivity as indicated in the figure by the larger masses necessary to maintain criticality. Allowing the number of units to become indefinitely large, $k_\infty = 1$, establishes the three asymptotes shown for the three volumes and three Celotex thicknesses.

The variation of number of containers for a constant volume of 30 gal is shown in Figure 4. As N increases the mass necessary for criticality decreases and the curves for the three thicknesses of Celotex asymptotically approach the $N = \infty$ values of mass. Also shown in the figure, for comparison, is the line depicting the data from the N 16.5 Standard.

The reactivity response of a given array to perturbations is interpretable as the reactivity response of an individual unit in the array to its mass change. Thus, for the water-reflected arrays, the reactivity associated with the total change in Celotex thickness examined, which may be interpreted as a twenty percent range of density variation, is the order of 3%.

The effects of packaging materials on concrete-reflected arrays are examined for 216-unit arrays at three different outer container volumes. Results of the concrete-reflected arrays are shown in Figure 5 as darkened symbols. The introduction of 8.9 cm (3.5 in.) Celotex at cell boundaries results in positive and negative array reactivity, depending on the size of the outer containers. The addition of both inner and outer containers into the Celotex-moderated arrays causes further decreases in array reactivity as evidenced by larger unit masses necessary for array criticality.

Figure 5 also presents a comparison of the effects of packing materials on the criticality of the 216-unit arrays under concrete and water reflection conditions. Results of the water-reflected arrays are represented in the figure by open symbols. It is evident that arrays with packaging materials exhibit a less dependence on the reflector condition as indicated by the smaller change in mass of units as the reflector is changed from water to concrete. The decrease of influence of the reflector condition on packaged arrays may be due to Celotex and container materials which reduce the neutron leakage fraction from the fuel region and thus reduce the neutrons reflected back by the reflector.

CONCLUSIONS

The surface density representation of array criticality provides a comprehensive display of criticality parameters of arrays of packaged fissile materials. The present study leads to the following conclusions which are also reported in Reference 6.

- The mass limits established by the N 16.5 standard for air-spaced spherical units in water-reflected arrays may be adequate for transportation packages.
- Criticality assessments made for one fissile material can be extended to other materials which have defined equivalent masses for array criticality of air-spaced units.
- A uniform minimum margin of subcriticality can be established for transportation of packaged fissile materials.

TABLE I.

CRITICAL EXPERIMENTS OF 2 x 2 x 2 POLYETHYLENE-REFLECTED ARRAYS OF U(93.2) METAL CYLINDERS WITH DIFFERENT SPACING MATERIALS AND KENO CALCULATED K_{eff}

	References [3,4]		Present KENO
	EXP	KENO[a]	Calculations[b]
VERMICULITE SPACING[c]	1.0005	1.0082 ± .0036	1.0064 ± .0051
PLYWOOD SPACING	1.0005	1.002 ± .005 0.989 ± .004	0.9908 ± .0065
CELOTEX SPACING	0.9979	0.999 ± .004	0.9970 ± .0050
FOAMGLASS SPACING	1.0004	1.017 ± .004	0.9848 ± .0046
BORATED PLASTIC FOAM SPACING	0.9997	0.987 ± .004	0.9808 ± .0046

[a] 50,000 histories

[b] 30,000 histories

[c] This array is reflected by 15 centimeters polyethylene, but the other four arrays are reflected by 20 centimeters polyethylene.

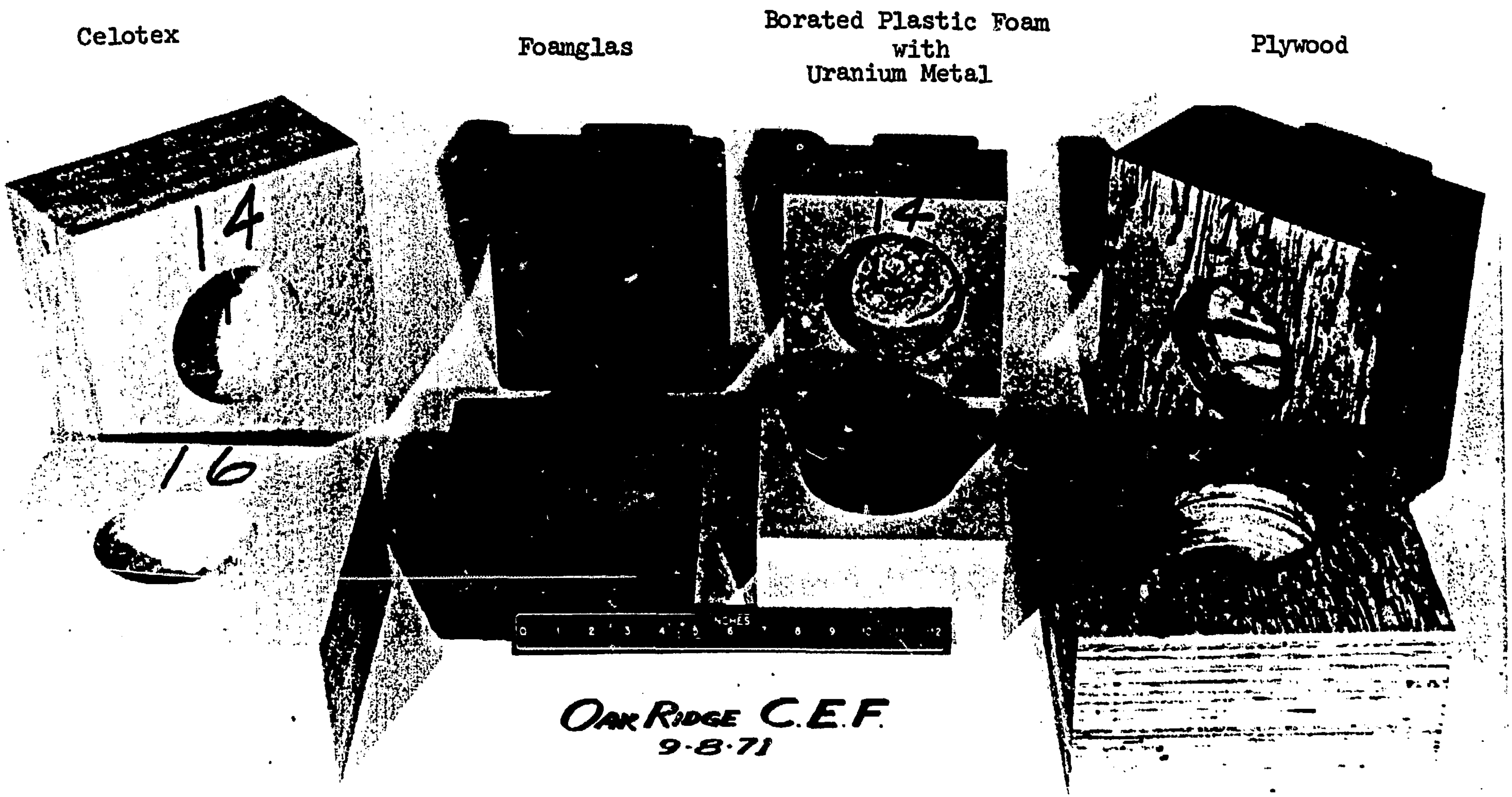

Fig. 1. Celotex, Foamglas, Borated Plastic Foam, and Plywood Units for Separating U(93.2) Metal Arrays.

ORNL-DWG 77-13206

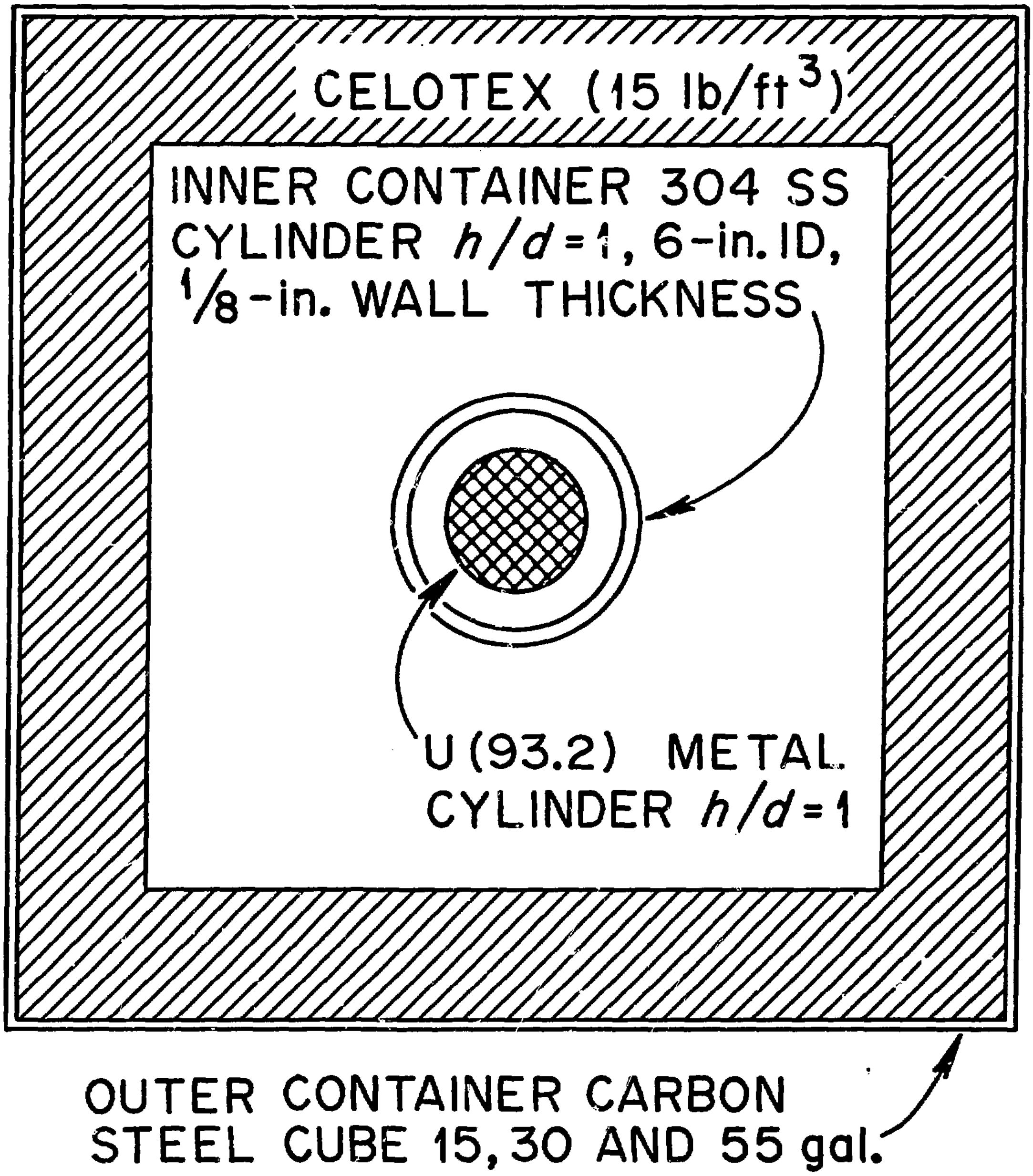

Fig. 2. Top View of a Fissile Material Tranport Package.

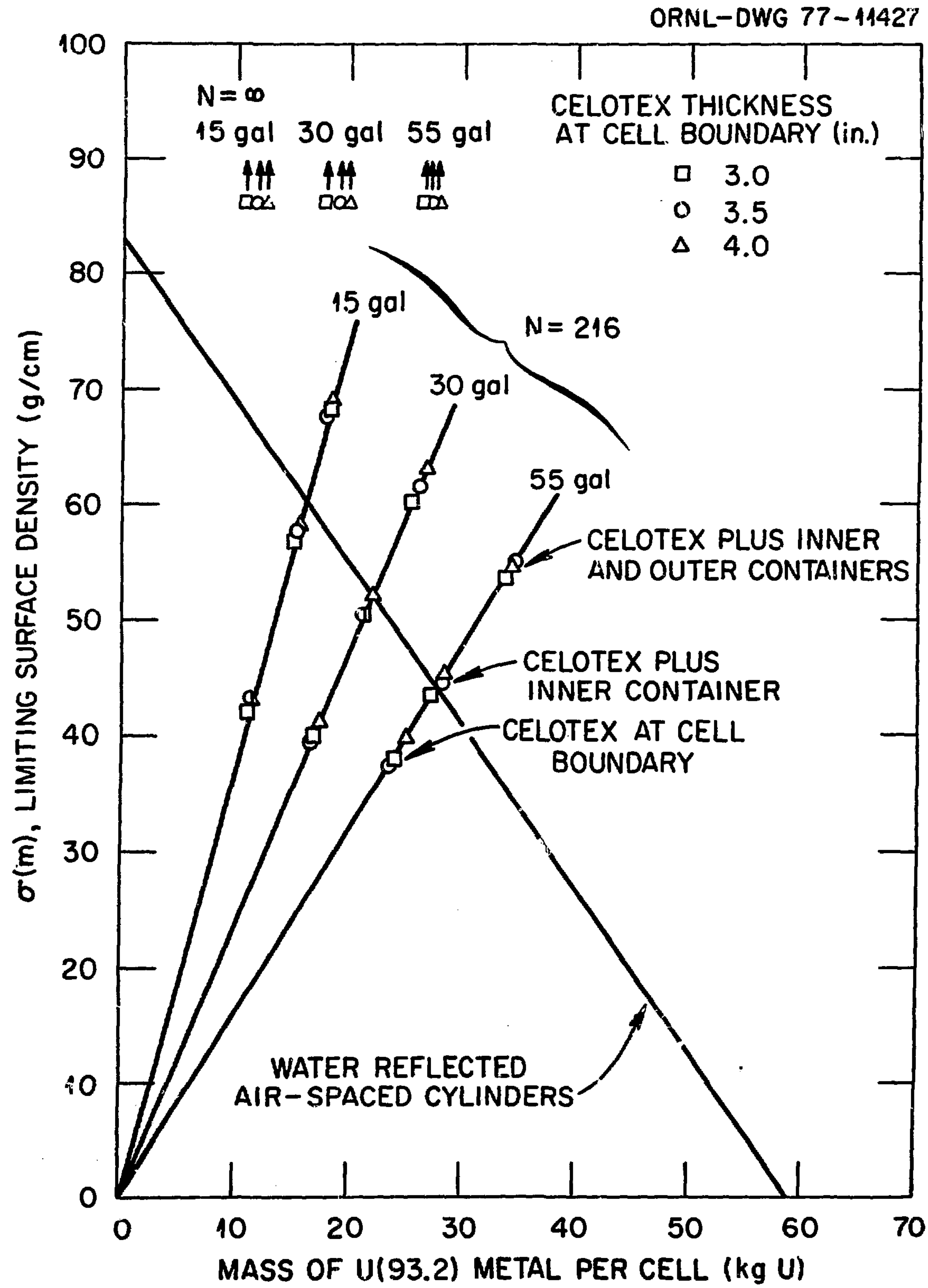

Fig. 3. Effect of Packaging Materials on the Criticality of a 216 Unit Array Reflected by Water. Variation of Cell Volume and Thickness of Celotex Insulation is shown.

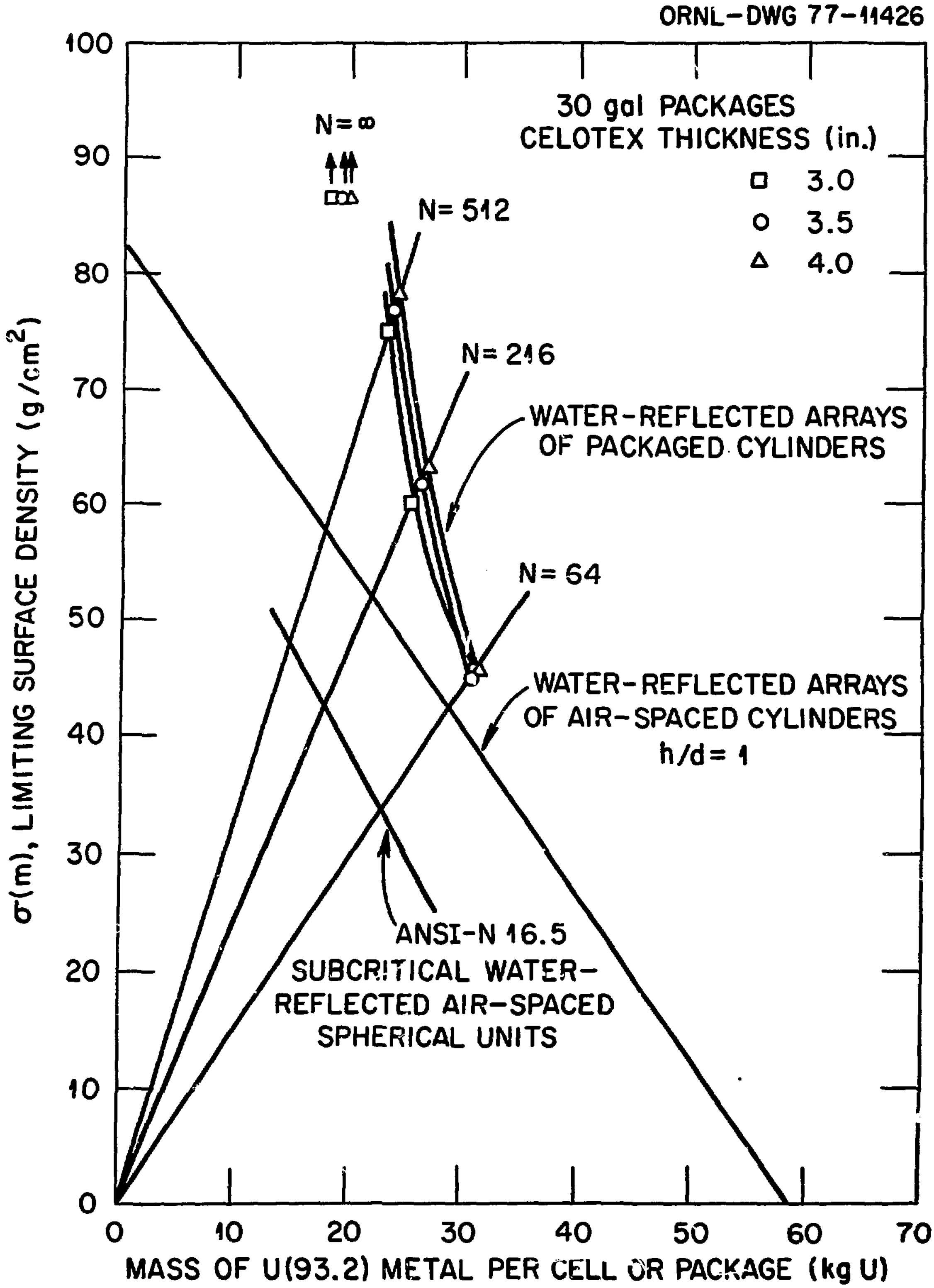

Fig. 4. Criticality of Arrays of 113.6 Liter Containers with Various Celotex Thicknesses.

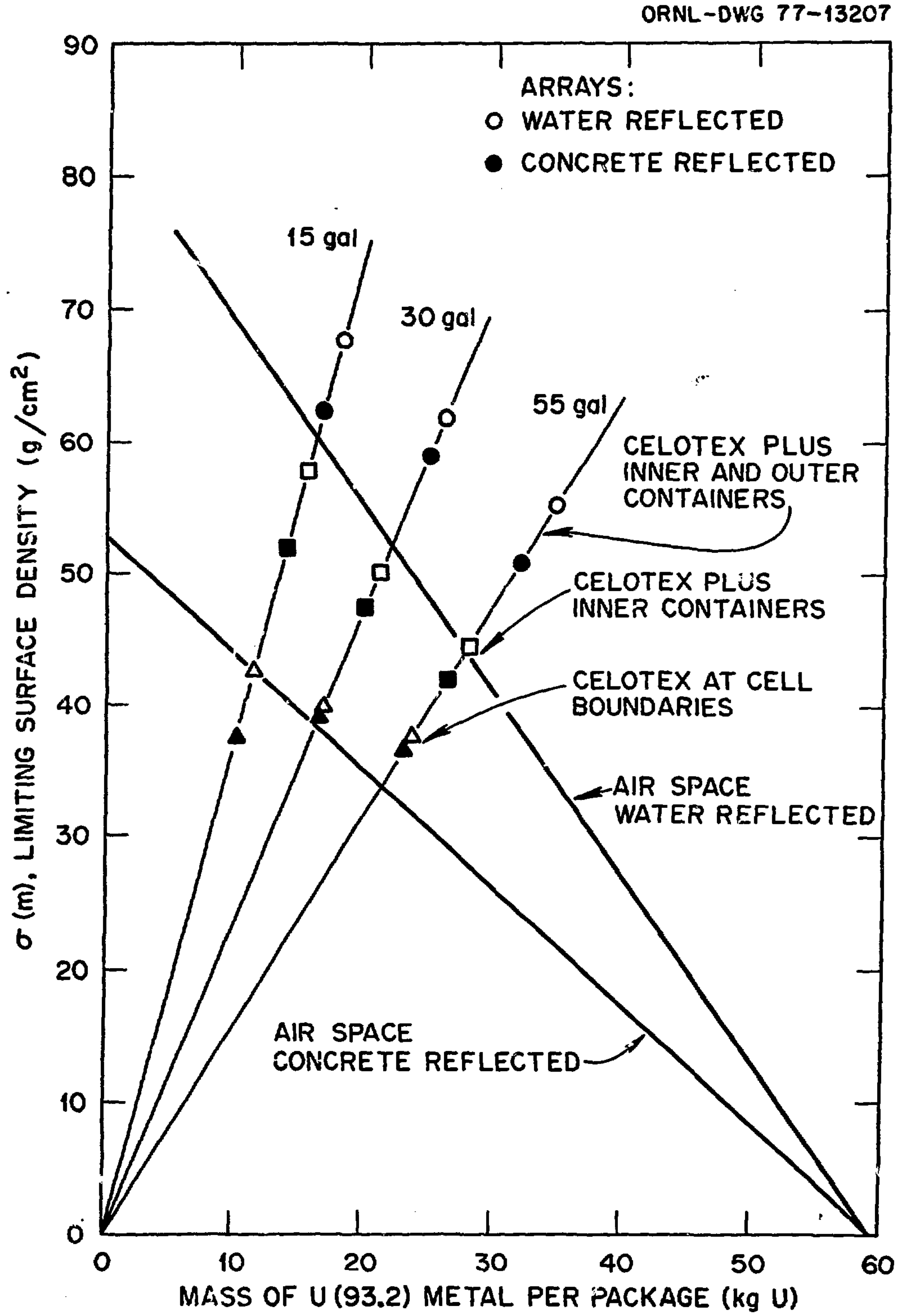

Fig. 5. Effect of Packaging Materials on the Criticality of a 216 Unit Array Reflected by Water and Concrete. Celotex Thickness is 3.5 Inches.

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