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TO R. Kropp AT DATE May 27, 1971

FROM E. Fass AT COPY TO

SUBJECT Criticality Safety Analysis of Shipping Container Model UNC-2800 with One Yankee Rowe (PWR) Fuel Assembly per Container

1.0 Summary and Conclusions

An analysis has been performed to determine the criticality safety of individual shipping containers Model UNC-2800 and arrays of these containers.

Individual packages are safe under normal transport conditions (dry) and have a maximum diffusion theory calculated k_{eff}=0.881 under accident conditions.

Arrays of packages also are safe under normal transport conditions (dry). Under accident conditions (optimum water inside and between individual containers) a water reflected array of 512 containers had a Monte Carlo calculated k_{eff}=0.817 $\pm$ 0.004.

2.0 Description of Containers

The Model UNC-2800 Shipping Container consists of a fuel assembly support nine inches high by 10 inches wide by 192 inches long; seven-gage steel "U" shaped strong-back with adjustable end clamps and cross support brackets. The fuel element support is shock mounted to an outer container by shear mounts. The outer container is a 12-gage steel cylinder 36 inches I.D. by 207 inches long with flange closure, skids, stacking brackets and roll rings. The container is described in Applied Design Company's Drawings, numbers 874A1-874A7, 874A99-874A114, and 874A116-874A136.

3.0 Method of Analysis

3.1 Description of Transport - Diffusion Theory Methods

The diffusion coefficient and macroscopic cross sections for the fuel assembly were calculated using the LOCALUX-2[1] one dimensional (cylindrical) multi-energy unit cell reactivity and depletion code. The LOCALUX code is an improved version of the LASER[2] code. Fast and thermal energy spectra effective cross sections are obtained from an included MUFT - THERMOS[3,4] calculation.

Diffusion coefficients and macroscopic cross sections for the water regions between the strong-back and outer container and outside the outer container were calculated using the FORM[5] and TEMPEST[6] codes. Conservative values of the diffusion coefficient were assumed for conditions of low water content by clipping the rising values at 10 cm.

Array infinite multiplication calculations were performed using AIM-6, a multigroup, one dimensional diffusion theory code. AIM-6 is based primarily upon the AIM-5[7] code and differs from it in that provision is made for the use of a macroscopic cross section library. Array calculations were performed assuming four regions: (1) the fuel assembly, (2) the space between the fuel assembly and the outer container, (3) the outer container, and (4) a water region around the outer container. Two energy groups were used and zero boundary current was assumed.

Infinite cylinder representations of individual shipping containers are made in AIM-6 by applying zero flux boundary conditions outside the outer container.

3.2 Description of Monte Carlo Methods

Reactivity levels for one infinite and seven finite reflected arrays were calculated using the KENO[8] multigroup Monte Carlo criticality code. The 16 group Hansen-Roach cross sections[9] were used with P_1 linear anisotropic hydrogen scattering, other nuclei were assumed to scatter isotropically in the laboratory system at all energies. The calculational model for KENO assumed homogenous regions of materials as in the AIM-6 model but the three dimensional geometry more faithfully describes the shipping container (see Figure 1).

The reactivity of the containers is dependent on the moderating ratio and fuel pellet dimensions because of the U^{238} resonance captures. The homogenization proceedure for the fuel assembly must take account of this effect by an appropriate choice of the U^{238} cross section set. The nominal pellet O.D. for the Yankee Rowe fuel is 0.3105"; the nominal enrichment 4.0 w/o U^{235} but, in the interest of conservatism, an upper limit of 4.1 w/o U^{235} was used in this analysis. The LOCALUX-2 calculation of cross sections for the AIM-6 analysis also gives the effective resonance integral and resonance escape propability for the assembly. The U^{238} cross section set for KENO is determined by the effective potential scattering cross sections per resonance absorber atom, i.e., $\sigma p = \Sigma p/N_A$. It is determined from the resonance data by:

$$p = e^{-N_A I / \xi \Sigma p}$$

$$\sigma p = \Sigma p / N_A = - \frac{I}{\xi \ln p}$$

The value of ξ is not appreciably affected by the presence of heavy nuclei and it was assumed that ξ could be adequately represented by $\xi_{H2O} = 0.95$, a conservative assumption when the U^{238} cross section set is chosen.

4.0 Nuclear Safety Evaluation - Normal Transport Condition

Under normal transport conditions, both the individual packages and arrays of packages are dry. There is no water or other moderating material within the fuel assembly, within the container voids, or outside the container. It has been shown that "... exponential experiments indicate that unmoderated uranium cannot become critical if the U^{235} content is below 5 or 6 wt. % .."[10] Therefore, both individual packages and arrays of packages are subcritical under normal conditions.

5.0 Nuclear Safety Evaluation - Accident Transport Conditions

Under accident conditions, for finite array calculations it is assumed that the containers are damaged such that the outer mean diameter is reduced from 36 inches to 34 inches.[11] For infinite arrays, the k_∞ is not affected by the unit spacing so the I.D. of the shipping containers was kept at 36 inches. The results of the structural tests indicate that the integrity of the strong-back and the fuel assembly were resistant to the tests performed. Sufficient damage to the outer container seal was noted so that water inleakage is possible.

The basis of the accident evaluation is:

1. Individual Containers
   a. Full moderation of the fuel assembly
   b. Full density water between fuel assembly and outer container.
   c. Container reflected by water

2. Array
   a. Damaged containers (I.D=34") for finite arrays
   b. Full moderation of the fuel assemblies
   c. Variable water density between the fuel assembly and outer container
   d. Variable thicknesses of water outside outer container.

5.1 Individual Container

The AIM-6 infinite cylinder representation of the individual container has a k=0.887, when an axial buckling correction is made to account for the finite height k_{eff}=0.881 Decreases in internal moderation and/or reduced reflection would result in decreased unit k_{eff} values. Therefore, individual containers are subcritical.

5.2 Arrays of Containers

The AIM-6 infinite multiplication factors for arrays were calculated varying the density of water between the fuel assembly and outer container and varying the thickness of the water region outside the outer container. The maximum k_∞ = 1.082 occurs with full moderation of the fuel assembly and no water between the fuel assembly and outer container or between individual containers. Increasing water density inside the shipping container and increasing water thicknesses between individual containers resulted in decreased k_∞ values. These results are shown in Table 1. To check this most reactive infinite array, a KENO problem was run for 18,000 neutron histories and calculated a k_∞ = 1.077 $\pm$ 0.004.

Since the most reactive infinite array will be critical, it is now necessary to establish the number of shipping containers which can be safely transported. For this phase of investigation, levels of reactivity were calculated soley by the KENO Monte Carlo code. The array considered was one of 512 units in a 16 x 16 x 2 configuration and had an array shape factor (i.e. array height/$\sqrt{\text{base area}}$) of 0.75; the I.D. of the containers was reduced to 34". The array was surrounded by a 15 cm thick water reflector. The first type of unit considered in the finite array was the one which gave the highest k_∞, that is, a fully moderated fuel assembly but no water elsewhere. KENO calculated a k_{eff}=0.817 $\pm$ 0.004 for this array. Since this is less than the maximum single unit k_{eff} predicted by AIM-6, a series of KENO problems were run to determine if a more reactive finite array could be made. The unit and array dimensions were maintained the same, the fuel assembly was fully moderated but now water was added to the region between the fuel assembly and outer container wall. The results of these calculations are shown in Figure 2. The curve in Figure 2 has a minimum at about 15% water content between the fuel assembly and outer container wall. The reason for this seemingly unorthodox behavior of the k_{eff} curve is due to the absorptions in the steel walls of the outer container. The k_∞ of the fuel alone is 1.3979 (LOCALUX) while the k_∞ of the fuel in the shipping containers is about

1.08 which shows the importance of the absorptions in the steel. As small amounts of water are added to the system the k decreases because of the additional moderation and absorptions in the added water. However, as the amount of added water becomes significant, it begins to act as a uniformally distributed reflector around the fuel elements. The units in the array are neutronically decoupled and relatively few neutrons are absorbed in the steel.

This result is also predicted by AIM-6, which gave a single unit $k_{eff} = 0.881$ a value higher than some k_∞ values for small amounts of water inside the shipping container. Note should be made that KENO predicts a single unit $k_{eff} = 0.796 \pm .015$, this is derived from the assumption that fully flooded shipping containers will be neutronically decoupled.

Analysis of critical arrays at UNC with KENO has shown that it tends to underpredict k by a couple of percent. AIM-6, on the other hand, will overpredict k for small diameter cores. These two effects help to explain the 10% difference in k_{eff} calculated for the fully flooded container by the two codes.

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Attachments

References

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TABLE 1

Reactivity Levels of Arrays of UNC Type 2800 Shipping Containers with Fully Moderated 4.1 w/o U^{235} Yankee Rowe (PWR) Fuel

AIM-6 RESULTS

Amount of Water Between Inner and Outer Container (%)	Amount of Water Outside The Outer Container (cm)	k_∞
0.0	0.0	1.082
	1.0	0.832
	2.0	0.754
	3.0	0.711
	4.0	0.685
1.6	0.0	1.056
	1.0	0.823
	2.0	0.748
	3.0	0.707
3.22	0.0	0.945
	1.0	0.795
	2.0	0.735
	3.0	0.701
5.0	0.0	0.879
	1.0	0.773
	2.0	0.724
	3.0	0.696
10.0	0.0	0.789
	1.0	0.733
	2.0	0.703
	3.0	0.685
100.0	4.0	0.887
		k_{eff}*
100.0	4.0	0.887

* For infinite cylinder representation for a single shipping container, i.e. zero flux boundary conditions

KENO RESULTS

		k_∞
0.0	0.0	1.077 ± .004
		k_{eff}+
0.0	0.0	0.817 ± .004
2.5	0.0	0.766 ± .005
5.0	0.0	0.737 ± .005
10.0	0.0	0.712 ± .007
25.0	0.0	0.713 ± .007
50.0	0.0	0.759 ± .006
100.0	0.0	0.796 ± .015

\+ For a water reflected array of 512 units (16 x 16 x 2)

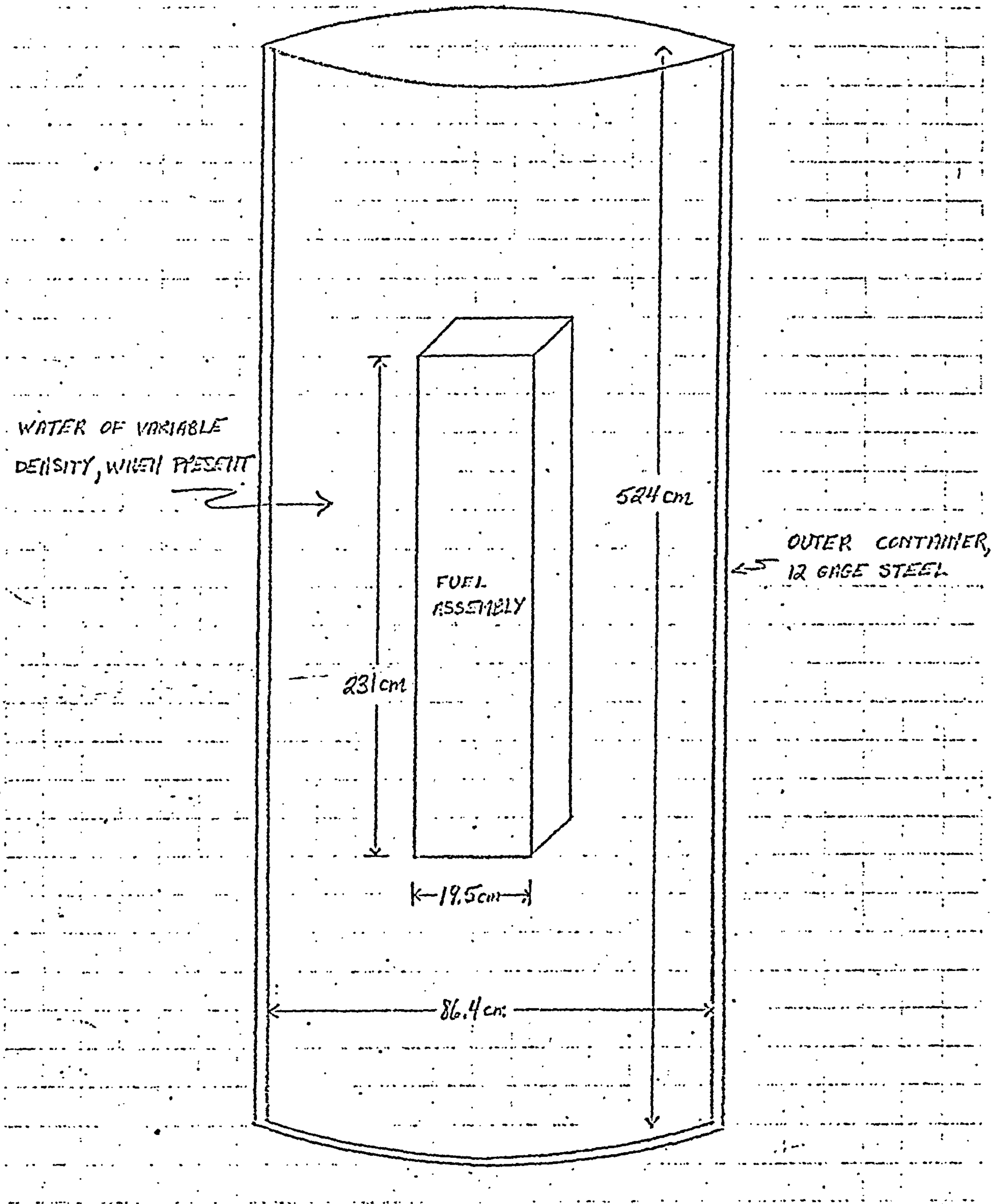

Figure 1
Representation of Model UNC-2800 Shipping Container Used in the KENO Monte Carlo Analysis (not drawn to scale).

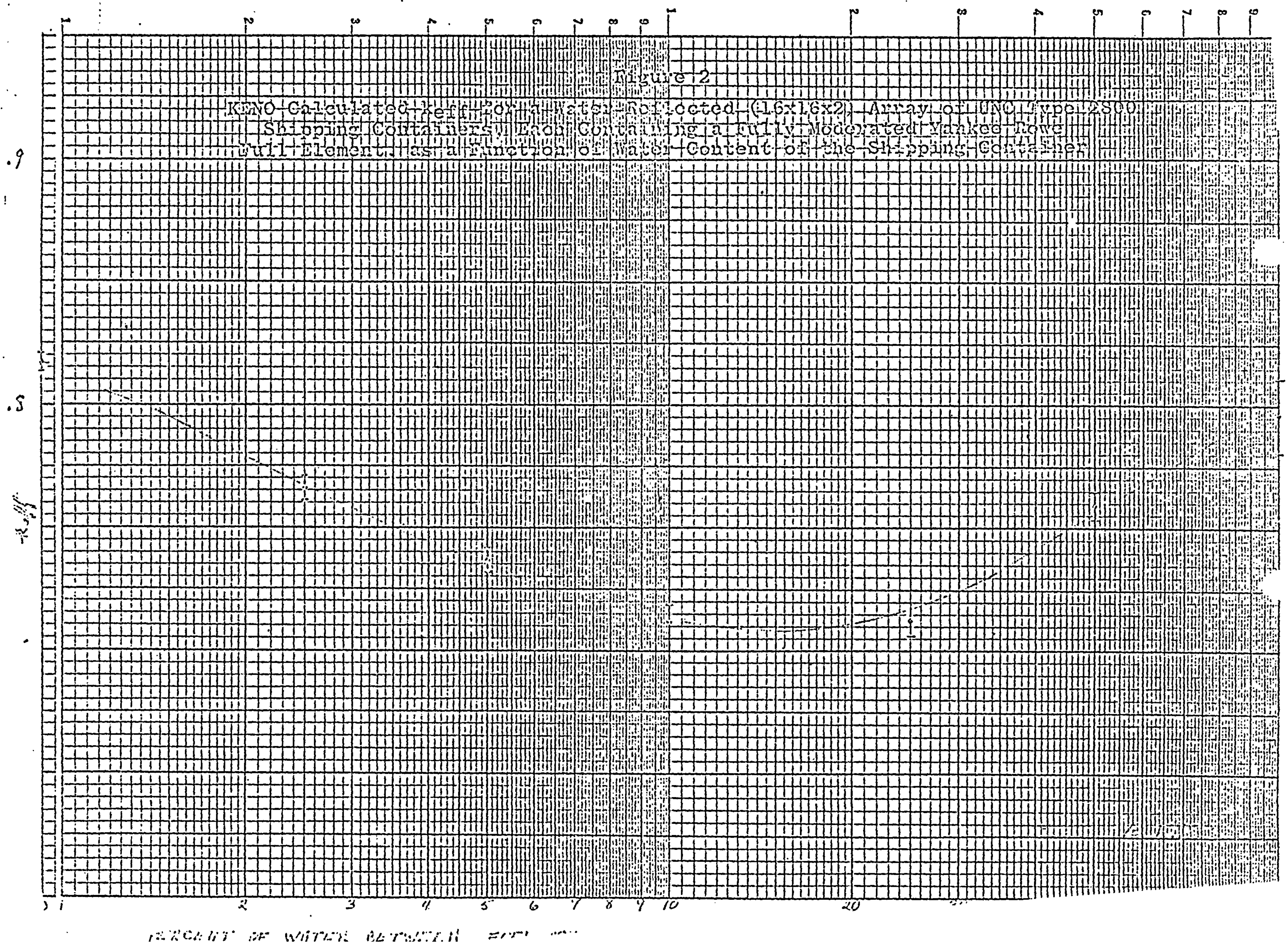

Figure 2
KENO Calculated Keff for a Water-Reflected (16x16x2) Array of UNC Type 2800 Shipping Containers, Each Containing a Fully Moderated Yankee Rowe Fuel Element, as a Function of Water Content of the Shipping Container