DOCKET NO. 70-133

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A CRITICALITY STUDY OF WTR FUEL ASSEMBLIES

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May 26, 1958

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I. Introduction

A number of problems have warranted a study into the criticalities associated with the grouping of WTR fuel assemblies. Besides the normal grouping of fuel assemblies in the WTR core in the approach to critical, fuel elements will be placed in shipping containers as well as storage containers in the WTR canal. In each of these cases the spacing and number of fuel elements is important in maintaining safe groupings.

On the basis of the calculations performed any number of fuel elements may be stored in the canal where the center to center distance between elements is greater than five inches. It has also been determined that the minimum number of elements needed for criticality using the WTR lattice arrangement will be between 19 and 25 depending on whether the radial reflector savings is closer to 10 cm or 7.5 cm. Using an optimum configuration 17 to 22 fuel elements represent the minimum number of fuel elements which could be critical depending again whether the reflector savings lies near 10 cm or 7.5 cm. These calculations have a direct bearing on the loading scheme to be decided upon in the WTR approach to critical.

II. Method and Assumptions

For a given number of fuel elements, the maximum reactivity will be present when the elements are cold and, for fully enriched uranium, when the elements have not been irradiated, hence this study was done for cold (68°F), clean assemblies. The WTR lattice consists of a triangular lattice of fuel elements whose center to center spacing is 3.125 in. The fuel assemblies consist of concentric cylinders; an aluminium center mandrel capable of containing samples, three aluminium clad-90% enriched uranium-aluminium alloy fuel tubes and an aluminium shroud which directs the coolant flow. For these calculations the assemblies are assumed to be placed side by side in an optimum array for criticality with a constant water spacing between assemblies. The criticality of this system has been determined as a function of the triangular lattice pitch. Increasing the pitch has the effect of increasing the extent of the water region surrounding the fuel assembly shroud tubes and consequently decreasing the metal to water volume ratio.

The WANDA Code, which computes the multiplication and flux distributions of a multiple region core having one dimensional flux variations, facilitated the computations necessary for this study. By specifying an effective outer radius for the outside water region surrounding the fuel assemblies and by setting the slope of the fluxes at the outer radius to zero, the nuclear characteristics of an infinite array of fuel assemblies can be obtained by studying a single assembly. The WANDA Code was used in obtaining the characterisitcs of an infinite array of these assemblies, the assemblies themselves being taken as 11 separate regions. The minimum number of fuel assemblies which will result inan effective multiplication of 1.00, 0.95 and 0.90 was computed from the neutron leakage from a cylindrical core. This is a conservative assumption as the leakage from a cylinder will be normally less than that from the actual lattice array of cylindrical elements. An infinite water reflector was also assumed outside the cylinder in the determination of the leakage.

The axial reflector savings was taken as 7.5 cm, and the radial reflector savings was varied. In determining the leakage the τ and L^2 characteristic of each case were computed by suitable flux weighting using flux values obtained from the WANDA Code. Five cases were studied, the results of which are presented in the attached curves.

III. Results

Figure 1 is a curve relating k_∞ to the metal to water volume ratio. This ratio has a value of 1.0 for the WTR lattice. Lower metal to water ratios correspond to an increased lattice pitch. The relationship between these quantities for the WTR fuel assemblies can be expresses as

$$p = \left[4.9498 \frac{(C+1)}{C} \right]^{1/2}$$

where p = triangular lattice pitch (in.)

and C = metal to water volume ratio.

As is seen from these curves the maximum k_∞ possible for a metal to water volume ratio of 0.25 is 0.90 which is considered quite conservative. This metal to water volume corresponds to a triangular lattice spacing of 5 in. A further increase in pitch is seen to result is correspondingly lower infinite multiplication factors.

Figure 2 shows the minimum number of assemblies which will result in k_{eff} equal to 1.0, 0.95 and 0.90 as a function of triangular lattice pitch. The minimum exhibited in this curve on going to a pitch greater than that of WTR is due to the fact that the decreased neutron leakage more than compensates for the increased neutron absorption in the water. The radial reflector savings is assumed to be 10 cm. It is seen that 10 fuel assemblies can be considered an always safe loading as an initial fuel loading in the approach to critical. This also indicates the number of elements which can be shipped in a single container.

Figure 3 is a graph relating to the effect of the assumed radial reflector savings on the computed minimum number of fuel assemblies necessary for criticality as a function of triangular lattice pitch. It is seen from this curve that criticality should be obtained in the WTR with a minimum of between 19 and 25 fuel elements depending on whether the radial reflector savings is closer to 10 or 7.5 cm. The exact value of the reflector savings is known to depend on the critical radius but its value is difficult to calculate precisely. A radial reflector savings of 12.5 cm is not considered probable and is included only as an extreme case.

Figure 4 represents the relative thermal flux variation through the fuel assembly, shroud, and surrounding water region for the two extreme cases. Case 1 corresponds to the actual WTR lattice and Case 5 to a triangular lattice pitch of 4.2 in. The corresponding fast fluxes show little variation through the cell. For Case 1 the maximum to average volume integrated fast flux is 1.008. For Case 5 this value is 1.076.

Figure 5 shows the reciprocal subcritical multiplication as a function of the number of fuel elements present in the WTR lattice. This curve is idealized in so far as a constant radial reflector savings is assumed and that fuel is effectively added uniformaly along the circumference of a cylinder.

Figure 1
Criticality vs Metal to Water Volume Ratio

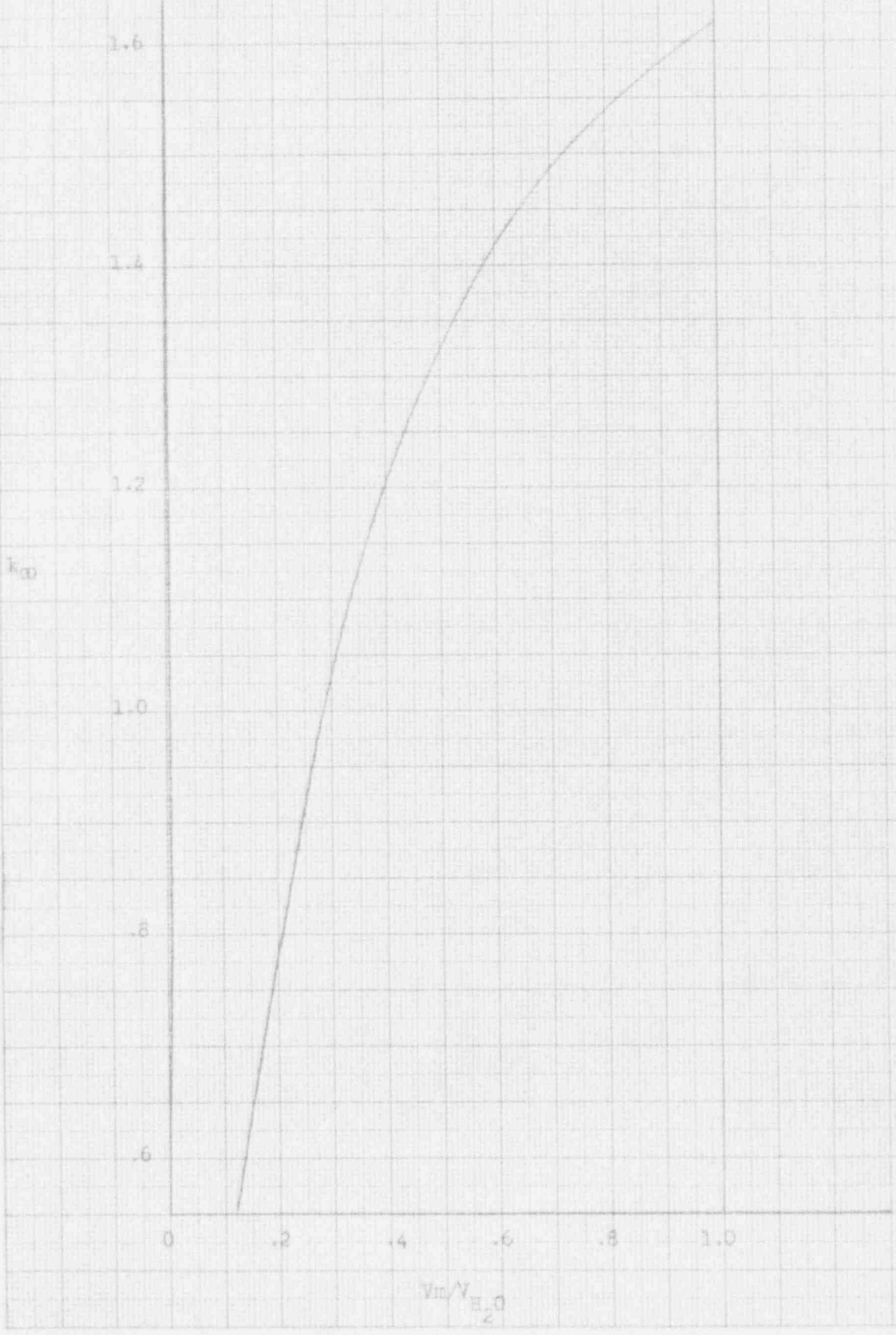
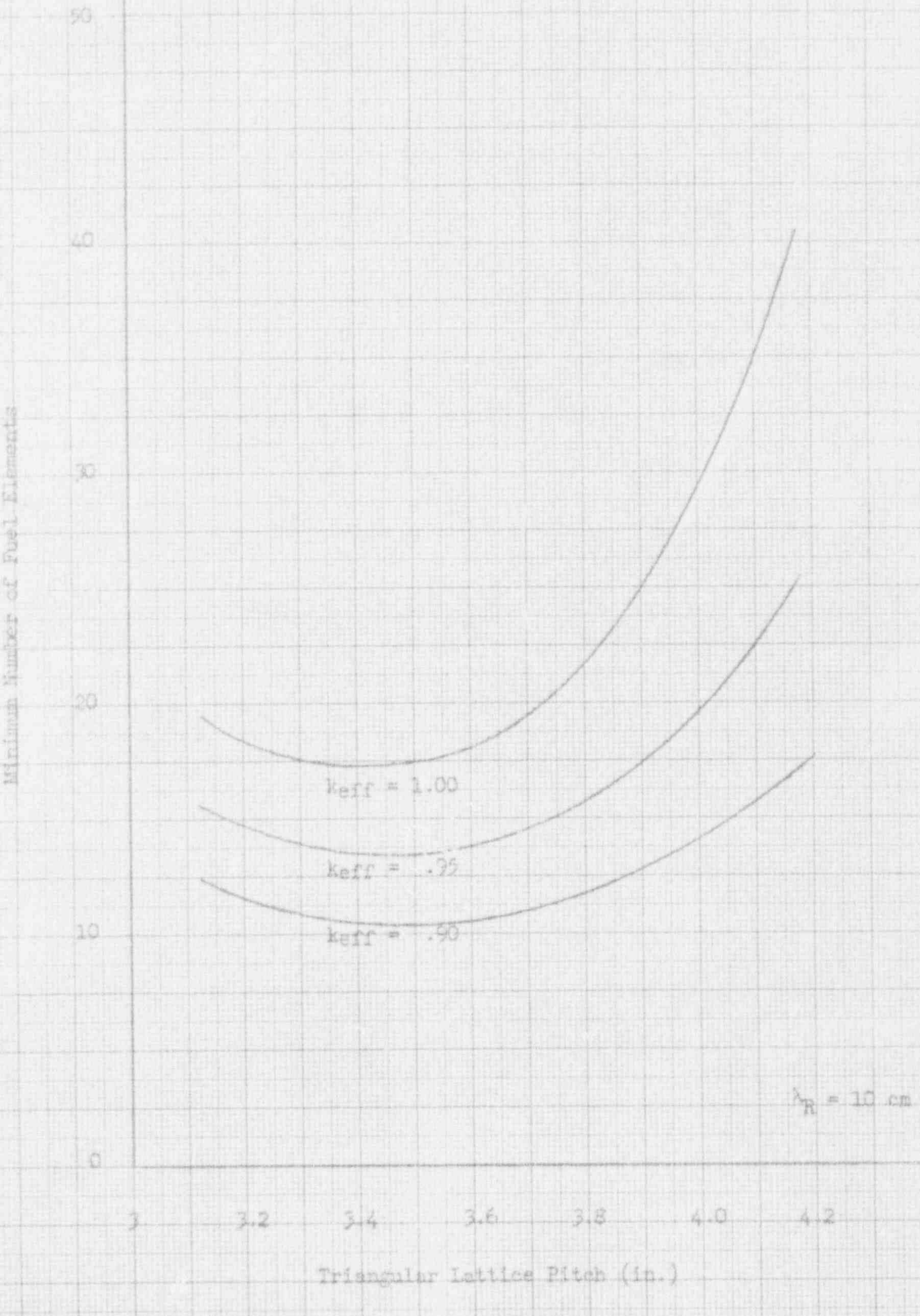


Figure 2
Criticality vs Number of Fuel Elements



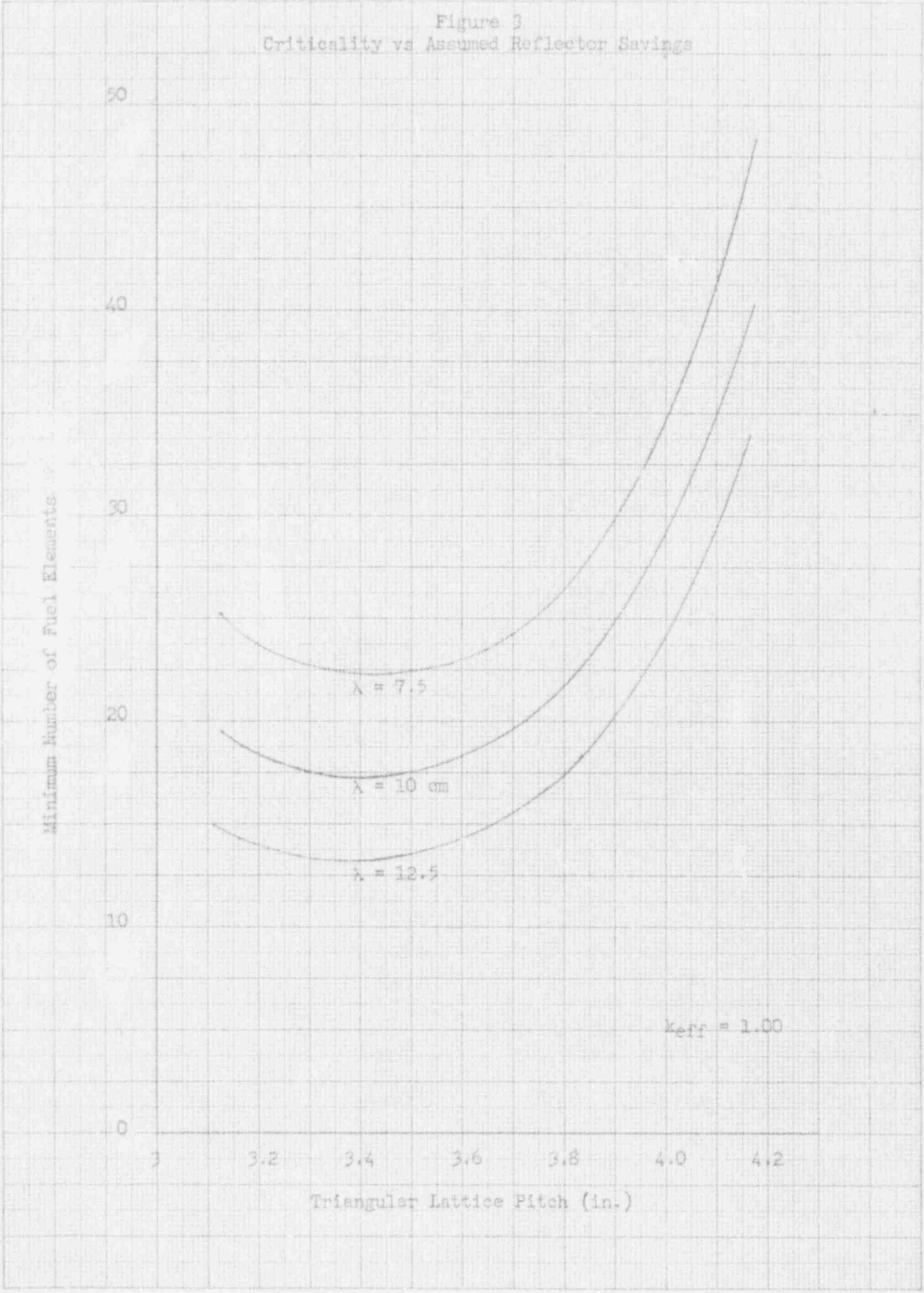


Figure 3
Criticality vs Assumed Reflector Savings

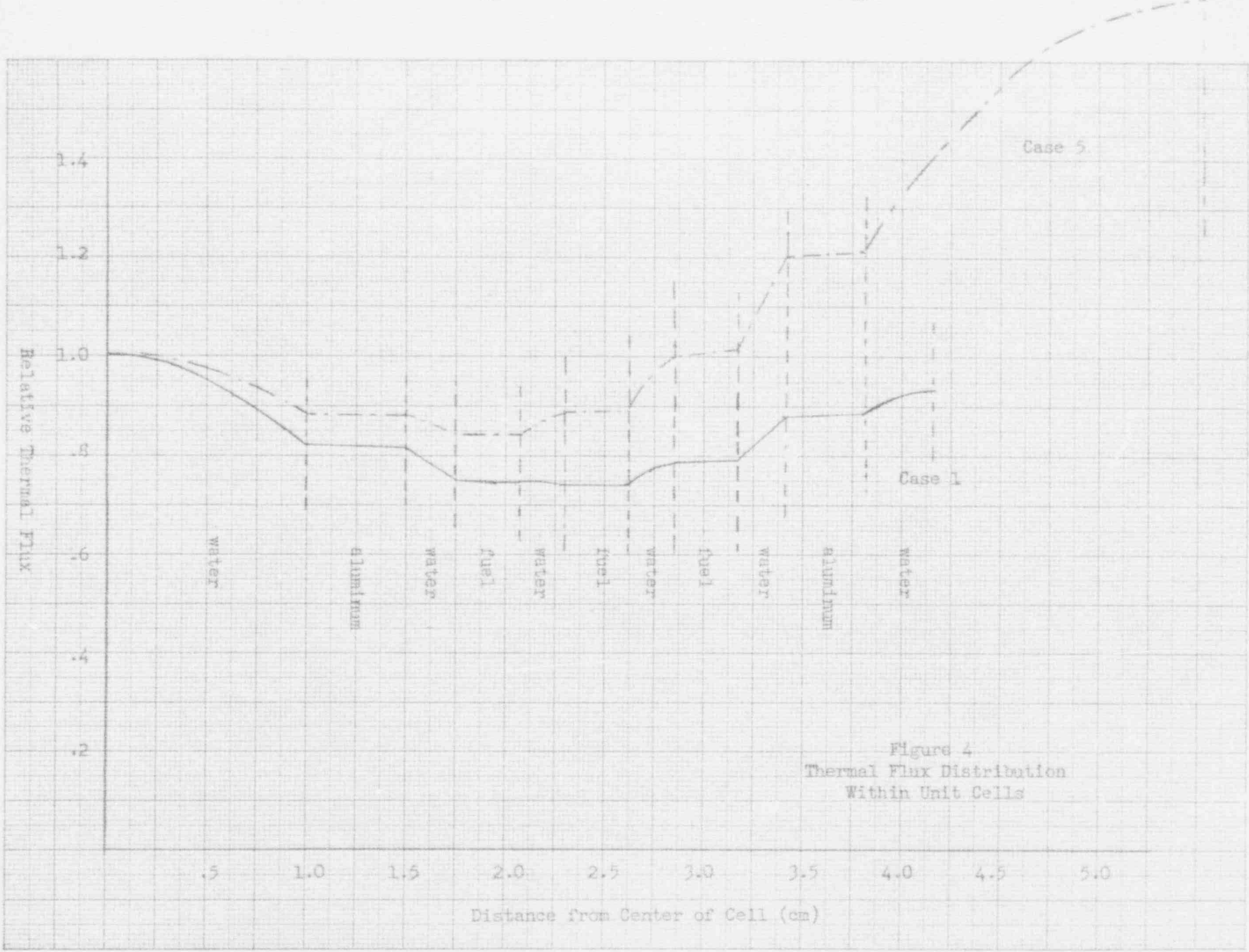


Figure 4
Thermal Flux Distribution
Within Unit Cells

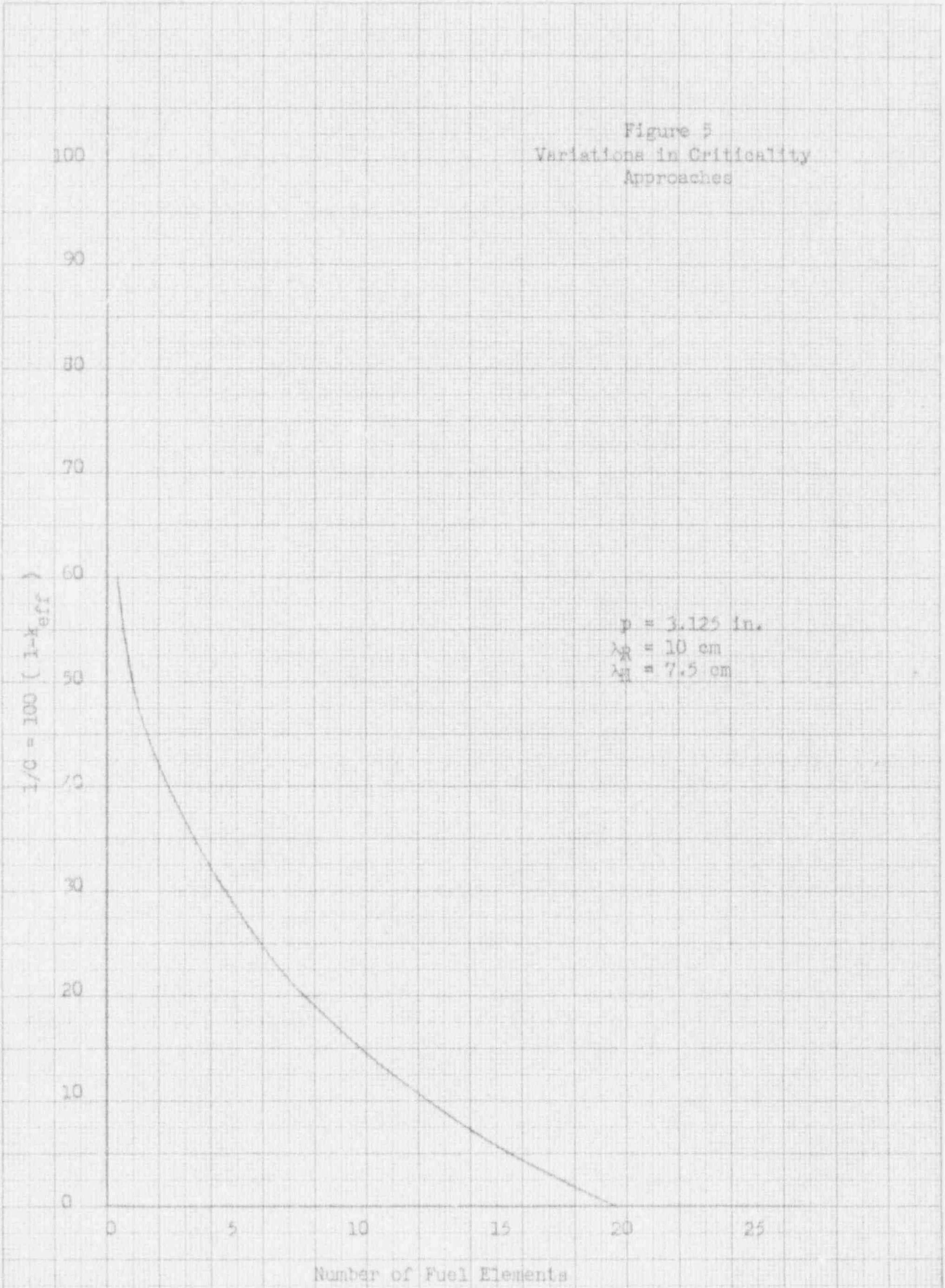


Figure 5
Variations in Criticality Approaches

p = 3.125 in.
λ_R = 10 cm
λ_H = 7.5 cm