DOCKET NO. 70-139

EXHIBIT 8 TO APPLICATION FOR SPECIAL NUCLEAR MATERIALS AND SOURCE MATERIALS LICENSE SUBMITTED BY POWER REACTOR DEVELOPMENT COMPANY

Criticality Considerations

A. Summary

The design of the fuel storage area is such as to assure a substantially subcritical configuration either when the area is dry or in the event of partial or complete flooding. The flooded condition dictates the spacing requirement since, at any given spacing, a flooded array of highly enriched metallic uranium is more reactive than a dry array. A 14-inch center-to-center square pitch was selected because this spacing in water effectively isolates each subassembly; i.e., the multiplication factor for an infinite array is essentially the same as that for a single subassembly and equal in this case to approximately 0.6. Under dry conditions the multiplication factor for an infinite array with 14-inch spacing is approximately 0.2. At intermediate levels of flooding the array is also substantially subcritical, with the multiplication factor varying from 0.2 to 0.6 as the level is raised.

B. Dry Storage

Each core subassembly for the Enrico Fermi reactor has a central 144-pin section containing 19.16 kg of uranium - 10 w/o molybdenum alloy. The uranium component of this alloy is enriched to 25.6 percent and each subassembly therefore contains 4.90 kg of U-235. In the reactor, these subassemblies will be placed immediately adjacent to each other in approximately cylindrical geometry.

The enriched uranium core will be surrounded by depleted uranium axial and radial blankets and the void regions will be filled with sodium coolant. Multigroup diffusion theory calculations of this configuration predict that approximately 91 of the enriched uranium containing subassemblies will have to be loaded in the central region in order to achieve criticality. If the sodium coolant is removed, approximately 15 additional core subassemblies are needed to achieve criticality since sodium increases reactivity in the neutron spectrum of the reactor.

The calculations referred to above have been verified by a critical experiment carried out in the ZPR-III facility of Argonne National Laboratory at Arco, Idaho. Calculated and experimental values for critical mass agreed within three percent.

As a check on dry storage criticality, two calculations have been made. The first of these calculations was done to obtain the multiplication of a single subassembly in air, assuming however that the subassembly was infinitely long. This calculation was done by Los Alamos for PRDC as a part of a series of special criticality calculations. Using the S_n method, k was found to be about 0.2. The second calculation was done by APDA to obtain the multiplication of an infinite array of subassemblies stored on 14-inch centers. This was a multigroup, diffusion theory, homogenous calculation, which gave a k equal to 0.1. This result is less than the correct value because homogenizing such a widely spaced array does not account for self-multiplication of individual subassemblies. The result, however, does show that leakage from the array is very high so that individual units are effectively isolated from each other. The multiplication factor for the array is then [illegible] tely the same as that of a single subassembly which, because of the assumed infinite length, is conservatively estimated by the Los Alamos calculation to be 0.2.

These calculations together with the results of the critical experiment show, if dry storage only was considered, that a separation of only a few inches would be sufficient to assure subcriticality of 200 subassemblies.

C. Flooded Storage

Fuel subassemblies for the Enrico Fermi reactor are highly enriched since a fast reactor is unmoderated. At optimum spacing in water, far less than a normal core loading of subassemblies would be needed to form a critical array. As a first precaution, all storage and handling of fresh fuel will be done dry with every effort made to prevent fuel from becoming immersed in water. All handling of fresh fuel to be stored will be done singly, all shipment or storage will be with a minimum of 14-inch center-to-center spacing.

The storage area using 14-inch center-to-center tubes to hold subassemblies is substantially subcritical when flooded with water. On Figure 1 attached is a summary of calculated data obtained for Enrico Fermi core subassemblies spaced in water in square lattices of different pitch. The points shown were obtained by the use of 2-dimensional, 3-group, diffusion theory calculations using the PDQ code on an IBM-704 computer. Constants needed for the calculation were obtained by a method outlined by R. W. Deutsch.* The

*R. W. Deutsch, "Computing Three-Group Constants for Neutron Diffusion," Nucleonics 15:1, 47-51, January, 1957.

results of these calculations agree with information given in various AEC documents,**in that units separated from each other by one foot of water are shown to be effectively isolated from each other; i.e., the multiplication for an infinite array with center-to-center spacing equal or greater than 12 inches is essentially the same as that of a single subassembly.

D. <u>Partially Flooded Condition</u>

In the case of partial flooding, direct calculational evidence that the multiplication will not increase above 0.6 is very difficult to obtain. A direct calculation would require the use of 3-dimensional geometry to adequately describe the flux shape and multigroup methods to describe the spectral variation from one region to the other. In situations such as this where k need not be known accurately, the usual practice in reactor theory is to compute a simple problem which is known to be more reactive than the complex one, and/or to resort to experimental measurements.

For the particular geometry involved here, it is very difficult to define a simple problem which is known to be a little more reactive than the actual problem to be solved. Our most reliable information thus must be obtained from experiments and from the interpretation of these experiments by people closely associated with this type of work.

Babcock & Wilcox Company has performed many critical experiments in their facilities at Lynchburg, Virginia, and they have given PRDC the results

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**See, for example, TID-7019, <u>Guide to Shipment of U-235 Enriched Uranium Material</u>, p. 18

of two water height experiments which were performed in connection with their thermal reactor design work. Data from these experiments are plotted in Figures 2 and 3 for Cores I and II as described in Table I.

Core I had a metal to water ratio of 1.19 and was undermoderated. Core II had a metal to water ratio of 0.48 and was somewhat overmoderated. The PRDC storage facility, when flooded, is more overmoderated than Core II. Note that, with 80 cm of fuel above the water level, the reflector savings due to dry fuel is 9.5 cm in the case of the undermoderated core, and 6.2 cm in the case of the overmoderated core. Eighty cm of fuel is more than the full length of Enrico Fermi Reactor fuel pins and in both experiments there was more U-235 per linear inch of height than will be the case with Enrico Fermi Reactor fuel stored on 14-inch centers. Based on these experiments it is seen for Fermi subassemblies that with any available dry fuel above a flooded level the reflector savings would be significantly less than 6.2 cm. Therefore, the facility is most critical, having an effective multiplication of 0.6, when completely flooded.

In Figure I, k is equal to 0.62 for a spacing of 10.65 inches. The k of 0.62 was obtained assuming an axial buckling of 0.00164 cm^{-2} corresponding to the Fermi fuel length of 77.5 cm. When B^2 was reduced to zero, thus assuming no end leakage, k increased only a very small amount, to 0.64. Very large reflector savings thus have little influence on the multiplication of well-spaced arrays.

Referring again to Figures 2 and 3 note that the absolute value of the slope of the curves is very much less than 1 and is smaller in Figure 3 (the overmoderated case) than in Figure 2. Thus, at all water levels, bare fuel above the core is worth less in reactivity than is the same height of fuel plus water, so that k continually decreases as the water level is lowered. Since the PRDC storage spacing has even less U-235 per linear inch of height than was present in either of these experiments, k will similarly reduce in value as the water level is lowered.

In the absence of water flooding, there is no moderator present in the fuel region of the PRDC storage facility. PRDC is not aware of any reactor or criticality experiment in which reactivity has increased as a result of lowering the moderator level about solid fuel which is otherwise unmoderated.

E. Blanket Subassemblies

Blanket subassemblies are made of uranium depleted to 0.36 percent U-235. Criticality is not possible either dry or in water, regardless of how many or in what geometry they are stored.

TABLE I

PHYSICAL DATA

Pin Lattice	Core 1	Core 2
Pin pitch (square), in.	.3805	.4810
Pin O.D., in.	.3120	.3090
Clad thickness, in.	.0190	.0340
Pellet diameter, in.	.2740	.2340 (1)
Pellet density, gm/cm^3	8.20	8.45
Metal-to-water	1.119	.480
N_{02}/N_{25}	25.8	25.34
Fuel length, in.	48	60
K infinite	1.15(effective)	1.287
Clad Material	SS-304	Al-2S
Pellet Composition	(ThO_2, UO_2 - U_3O_8)	

Core		
Radius, in.	38.8	24.27 (2)
Control rods	21	None
Can (Al) thickness, in.	.1875	None

(1) Nominal 3.5 mill air gap

(2) In Core 2 experiments the core radius was varied for criticality