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IMPLICATION OF TRIO-01 HEAT TRANSFER RESULTS ON SOLID BREEDER BLANKET DESIGNS*

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The greatest uncertainty in recent solid breeder blanket designs[1-3] is associated with the thermophysical properties of lithium ceramics. The thermal conductivity of a solid breeder (κ) and its dependence on nuclear irradiation can be a major design-limiting factor. The TRIO-01 experiment[4] studied in-situ recovery of tritium from a miniature solid breeder blanket (γ-$LiAlO_2$, 65% dense). The data of the TRIO-01 experiment provide an indirect measurement of κ of γ-$LiAlO_2$. This paper briefly discusses calculation of κ from TRIO-01 data and its implications on STARFIRE-type blanket designs.

The boundary conditions for the TRIO-01 experiments were that (1) the nuclear heat generated in the capsule flowed radially into the heat sink (60°C water), and (2) the temperature maintained in the solid breeder (range 450-750°C) was controlled by a gas mixture (He/Ar) in a gap between an outer wall and an inner wall enclosing the γ-$LiAlO_2$. Two sets of thermocouples measured the inner and the outer surface temerature of the breeder at four axial positions. The Mason-Saxena[5] method was used to calculate the κ of the gas mixture from the individual thermal conductivities.[6] These values were then used in a two-dimensional heat transfer model to calculate the κ of γ-$LiAlO_2$.

For the upper range (600-750°C), four data points, representing 0% ^6Li burnup (initial period) to 33% ^6Li burnup (90 days), were the basis of thermal conductivity calculations. The low temperature experiments are currently being analyzed. After analysis of all of the experiments,

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the temperature dependence of thermal conductivity and the effects of irradiation will be evaluated. An estimate of the effect of irradiation[7] for other ceramics was a 40% reduction in thermal conductivity.

Our best estimate of thermal conductivity from the high temperature TRIO data (600-760°C) is $\kappa = 1.4 \pm 0.1$ W/m-K. This is in contrast to the estimated $\kappa = 2.37$ W/m-K used in STARFIRE design calculations. For purposes of comparison, the thermal conductivity of γ-$LiAlO_2$ was calculated by the empirical equations[8] (Gurwell and Hollenberg) (with appropriate correction for porosity). The experimental data agree with Hollenberg's equation within 5%. The empirical equation of Hollenberg appears to agree with the high temperature thermal conductivity. However, the predicted thermal conductivity from Gurwell's equation is ~20% lower. The implication of κ values lower than predicted for solid breeder blanket designs is presented below.

In order to assess how κ influences the blanket design, the breeder-outside-coolant tube design[1,3] was used as the basis. One dimensional calculations for pressurized water-cooled (inlet/outlet = 280/320°C) breeder blanket (temperature window = 850/500°C) were used to size the blanket region for each coolant channel (10 mm I.D. x 0.75 mm wall) in the depthwise direction of the blanket. The blanket region diameter as a function of the blanket thickness is presented in Figure 1. Since the coolant temperature is significantly lower than the lower temperature limit (500°C), a thermal barrier was assumed to be present between the coolant channels and the breeder material. Three thermal barriers (He gas, stainless steel felt and Li_2ZrO_3) were considered. The thickness of the thermal barriers varied from 1-3.1 mm, 1.8-5.3 mm and 0.4-1.3 mm,

respectively for the above three materials. The volume fraction (excluding containment structure, tie rods, and thermal barrier, etc.) of the breeder was calculated for κ = 1.5 W/m-K and κ = 2.73 W/m-K. The results are summarized in Figure 1.

As expected, lower κ values lead to more closely-spaced coolant channels, which result in lower breeder fractions (see Figure 1). An examination of data presented in Figure 1 shows that there is a 7% decrease in breeder volume fraction near the first wall, which is the most fertile region for tritium breeding. Significant reduction in tritium breeding ratio will result for solid breeders that have low thermal conductivities. To overcome the adverse effects of low thermal conductivity, a number of design variables must be considered. These are: (1) more dense materials--up to 85% theoretical density, which increases the thermal conductivity; (2) wider temperature windows to increase the interchannel distances which reduce the number of coolant tubes. This is consistent with the recent trend in solid breeder blanket designs which incorporates 85% theoretical density materials over as wide a temperature window as possible.[3] Also, TRIO-01-type experiments with other candidate solid breeders could be used to establish the viability of solid breeder blankets.

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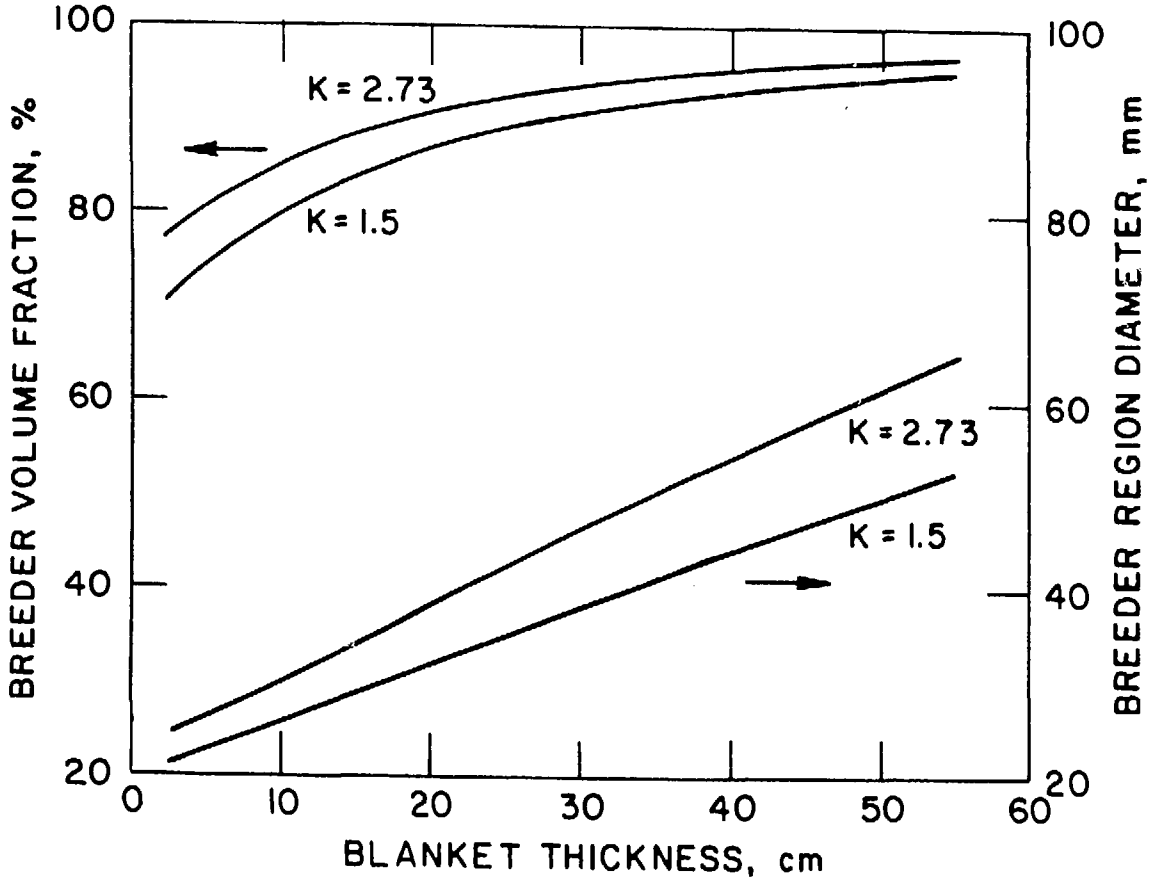

Figure 1. Radial Variation of Breeder Region Diameter and Breeder Volume Fraction.