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Summary

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# THERMAL-HYDRAULIC/THERMO-MECHANICAL TESTING OF SOLID BREEDER BLANKET MODULES USING MICROWAVE ENERGY*

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# THERMAL-HYDRAULIC/THERMO-MECHANICAL TESTING OF SOLID BREEDER BLANKET MODULES USING MICROWAVE ENERGY*

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An examination of the expected thermo-mechanical environment for fusion reactor components such as the first wall, the limiter/divertor, and the breeding blanket indicates that the fusion reactor environment to be more severe than any that exists today. The design studies such as STARFIRE, DEMO, and Blanket Comparison and Selection Study [1-3], of necessity, rely on either the sparse experimental data or extrapolation of the existing data and empirical correlations. It is unlikely that construction of a fusion power plant, as currently envisioned, can be carried out without adequate supporting data. Hence, establishment of a technology base derived from component and realistic model testing is essential to proper design and construction of a fusion power plant.

Both surface heat flux and volumetric heat flux are necessary to provide the prototypic environment for thermo-mechanical testing of fusion reactor components. A recent study [4] examined testing of solid breeder blanket modules using energy sources such as discrete source heating, direct resistance heating, microwave heating, induction heating, and nuclear heating. The nature of the lithium ceramic breeders (e.g. $Li_2O$ and $\gamma$-$LiAlO_2$) and the desire to provide a realistic power profile preclude many of the above energy sources. Since no fusion reactor test facilty currently exists, and testing in a fission reactor is very complex, it would be desirable to carry out the simulation studies in a non-nuclear environment. This paper provides the design and analyses leading to experimentation with a solid-breeder blanket module utilizing microwave energy as the volumetric heat source. A companion paper [5] discusses the design calculations and configuration details of the waveguide.

Analysis based on attenuation of microwaves in lithium ceramics shows that an exponentially decaying power profile simulating nuclear heating in a solid breeder blanket can be generated. Specifically, for $\gamma$-$LiAlO_2$ at 200-MHz microwave energy, the following power profiles corresponding to ~2 $MW/m^2$ of fusion power can be obtained:

$$q_v \begin{cases} = A\, e^{-\alpha(Z-d)}, & -0.173 \le Z \le -0.113 \quad (1) \\ = B \sin^2 K_z Z, & -0.113 \le Z \le 0 \quad (2) \end{cases}$$

where A = 24 W/cc, B = 25.5 W/cc, d = -0.173 m, $K_z$ = 7.1 $m^{-1}$, $\alpha$ = 8.8 $m^{-1}$, and Z = distance in the depthwise direction of the blanket, m.

Since no electric property of lithium ceramics (such as the electrical conductivity and dielectric constant) exist, especially at the desired frequencies, these properties were measured to determine the empirical constants in the above equations.

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The breeder material used for this study was commercial grade $\gamma$-$LiAlO_2$, which was cast into a large cylindrical block and was sintered at 1000°C for 36 h. The blanket module (~10 cm × 10 cm × 20 cm) was machined from this block. The volumetric heating was provided by a 10-kw klystron operating at 200 MHz. An array of nine coolant tubes (9.5 mm o.d.) using ~40°C water was found to provide necessary cooling. The interchannel distances between the coolant tubes were calculated based on the above power profile leading to a maximum temperature of ~1000°C at the adiabatic boundary between the adjacent coolant tubes. The instrumentation system consists of flowmeters, pressure transducers, thermocouples, power supplies, and the associated recorders and controllers. The major emphasis on the instrumentation system is to measure the total amount of microwave energy deposited in the blanket module and the steady-state temperature distribution.

It is expected that the spatial distribution of temperature at a series of power levels up to 10 kW will show whether microwave energy can serve as a potential energy source for non-nuclear testing of solid-breeder blanket modules.

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