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MICROWAVE HEATING SIMULATIONS OF FISSION ENERGY GENERATION IN VOLUME-BOILING POOL SYSTEMS**

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The transition phase of the (hypothetical) loss-of-flow accident in LMFBR's may be characterized by the temporary entrapment of boiling pools of molten fuel and steel within the original core boundaries.[1] Experiments to investigate the multiphase flow and heat transfer characteristics of such systems have been performed[2,3] and are planned[4] in which simulant fluids are volume-heated by microwave electromagnetic radiation. It has been assumed that the microwave radiation provides a spatially uniform energy source per unit volume of liquid in multiphase flow geometries. It is known, however, that energy absorption by dielectrics in a microwave electromagnetic field is a function of geometry, dielectric properties, and wavelength of the radiation.[5] At high power density, volume-heated boiling pools exhibit a complex two-phase, liquid-vapor, geometric structure. Dispersed droplets, with diameters less than 1 mm, in a vapor continuum may coexist with continuous liquid structures of centimeter scale or greater. This study was performed to: (i) investigate the uniformity of microwave heating in boiling pool systems as a function of liquid geometry and (ii) design an experimental system employing microwave heating in which the heat generation rate per unit volume of liquid is independent of geometric structure.

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The initial conceptual approach to the problem was to ask: given a microwave electromagnetic field of a given intensity, what is the rate of energy absorbed per unit volume by spheres of liquid of diameters ranging from 10^{-4} cm to 10 cm. The effects of droplet size, dielectric properties and wavelength on the energy absorption efficiency have been investigated. Materials and wavelength combinations were sought in order to obtain uniform volumetric heating rates.

The physics of the absorption and scattering of microwaves by droplets is part of the general theory of scattering of electromagnetic radiation by spherical particles[5]. The quantities of interest in a quantitative analysis of microwave absorption is the cross section C_{ABS} and the corresponding efficiency factor Q_{ABS}.

The energy absorption rate is

$$P = \phi_{INC} \cdot C_{ABS} = \phi_{INC} \cdot Q_{ABS} \cdot A \tag{1}$$

and the absorption rate of energy per unit volume is

$$Q''' = \frac{P}{V} = \phi_{INC} \cdot Q_{ABS} \cdot \frac{A}{V} \tag{2}$$

To satisfy the objectives of uniform volume heating, independent of liquid geometry, Q''' should be independent of the droplet radius.

The behavior of the quantities Q_{ABS} and Q''' were evaluated as functions of droplet radius for various combination of wavelengths and materials. The computer code DILISCA,[6] representing a solution to Maxwell's equations in spherical geometry, was used in the study.

Water was investigated over a range of microwave wavelengths and temperatures. Figures 1 and 2 present the results for Q_{ABS} and the dimensionless power density

$$\psi \equiv Q'''(a)/Q'''(a = 5\ \text{cm}) \qquad (3)$$

The results indicate that water exhibits a strong dependence of power density on liquid geometry. The power density of water droplets of diameters less than 0.5 cm is two orders-of-magnitude lower than for centimeter-scale droplets exposed to the same incident energy flux. In a water system, therefore, uniform heating independent of liquid geometry cannot be achieved in the range of interest.

A search for an alternate fluid system was performed. It was found that the dielectric properties of mixtures of polar ethanol and non-polar cyclohexane could be tailored to optimize uniform volume-heating conditions. Results for a 25 mol percent ethanol solution are presented in Figs. 1 and 2. The power density of the ethanol/cyclohexane solution varies by only $\pm$ 25 percent over a range of droplet radius 10^{-4} cm to 10 cm.

In summary, volume-boiling of water by microwave radiation does not provide uniform energy generation per unit volume of liquid, when coexisting liquid structures are widely divergent in dimensions. It is possible, however, to create conditions close to uniform volume heating for both the liquid-continuous and dispersed droplet regimes by the appropriate choice of dielectric properties together with the use of microwaves of a matched wavelength as the heating source.

Nomenclature

A	frontal area of droplets
C_{ABS}	absorption cross-section
P	energy absorption rate
Q_{ABS}	absorption efficiency
Q'''	heat generation rate per unit volume liquid
V	droplet volume
ϕ_{INC}	incident electromagnetic energy flux

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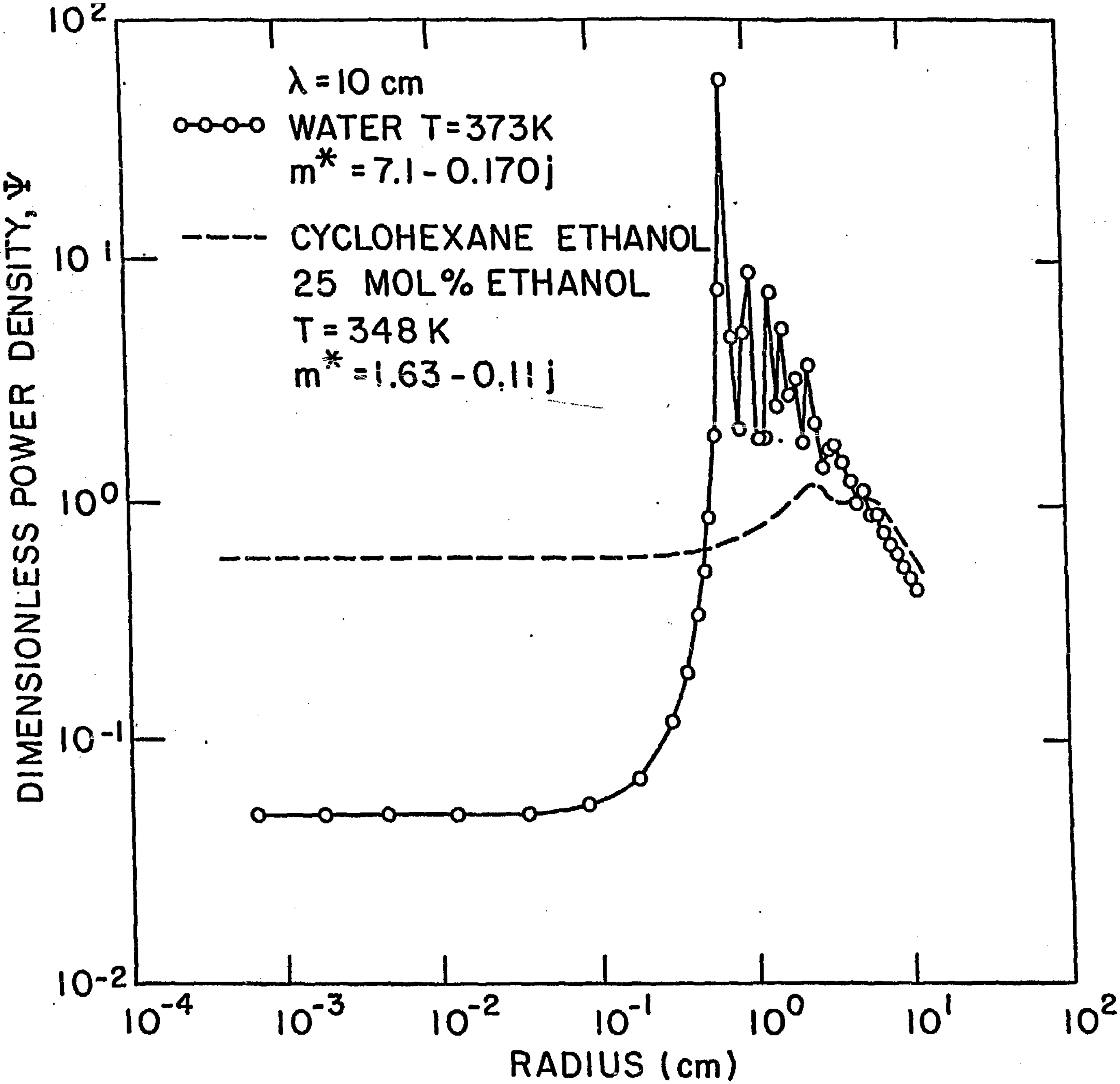

Figure 2 - Power Densities for Dielectric Liquids in Microwave Field. (No BNL Neg. No)

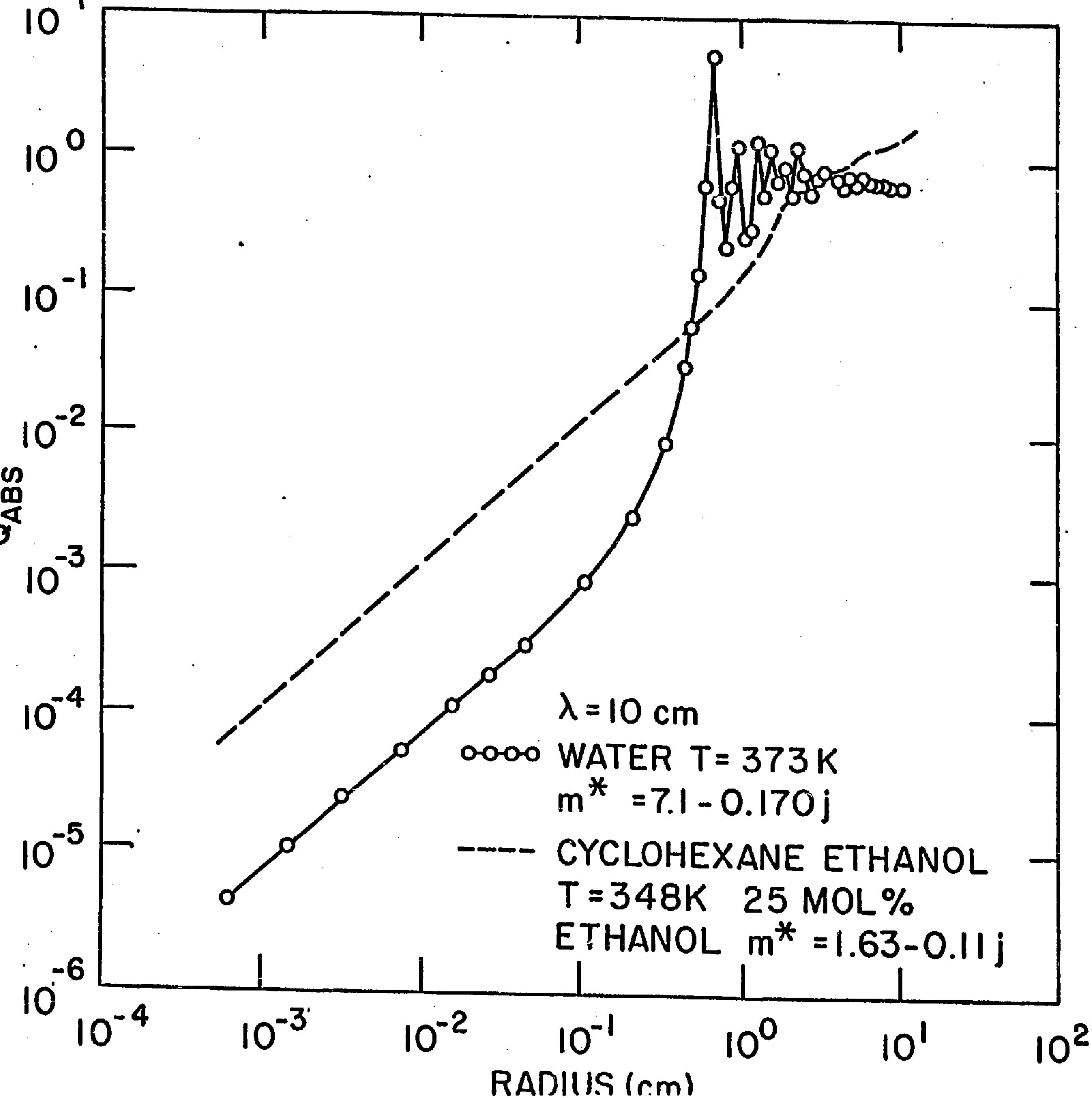

Figure 1 - Absorption Cross Sections for Dielectric Liquids in Microwave Field. (No BNL Neg. No)