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THERMAL CONDUCTIVITY OF $Na_3(U_{1-y}Pu_y)O_4$, A PRELIMINARY IN-PILE DETERMINATION

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During Run-Beyond-Cladding-Breach (RBCB) operation in an oxide LMR, the performance of a breached fuel element is intimately associated with the formation of fuel-sodium reaction product (FSRP), $Na_3(U_{1-y}Pu_y)O_4$. In-pile experiments coupled with destructive examinations of breached fuel have consistently revealed noticeable changes in fuel structure accompanying FSRP formation at the fuel surface. Previous analyses (Ref. 1) have also indicated a significant impact of FSRP on fuel centerline temperature. Successful modelling of breached fuel thermal behavior therefore requires a reasonably accurate knowledge of the thermal properties of the FSRP, especially its thermal conductivity. But laboratory investigations have been scarce (Refs. 2 and 3) and limited to the Na/UO_2 system because of the toxicity of plutonium and hygroscopicity of the FSRP. Hence, post-irradiation observations of fuel samples remain the most amenable way of deriving the thermal conductivity of the FSRP. Such work is a spin-off of the RBCB program in the Experimental Breeder Reactor-II (EBR-II), a program jointly sponsored by the U.S. Department of Energy and the Power Reactor and Nuclear Fuel Development Corporation of Japan (Ref. 4).

To investigate the thermal conductivity of the FSRP, test fuel elements of different burnups (~3-9 at.%) and linear powers (26-33 kW/m) were selected. They had been irradiated for 110 and 150 full-power (~57.5 MWt) days to ensure a fully reacted and chemically equilibrated FSRP, a condition reflecting a late stage of RBCB operation. Fuel samples were taken from test elements having either a pin-hole breach in the upper plenum (simulating weld failure), or induced breach near the top of the fuel column. For the latter case, samples were chosen away from the breach site to avoid the presence of excessive gas bubbles in the FSRP region, which would complicate matters. The determination of the FSRP thermal conductivity involved measurement of the morphological features of the restructured fuel (especially the thickness and porosity of FSRP layer), and heat-transfer calculations relating fuel surface temperature with temperature at the FSRP interface. The thermal conductivity integral of FSRP was then obtained by the following lump-parameter relationship:

$$\int_{T(r_{Rp})}^{T(r_s)} K(T)dT = \frac{Q'}{2\pi}\left[(1 - \frac{\rho_{RP}}{\rho_A}) * \ln\frac{r_s}{r_{RP}} + \frac{\rho_{RP}}{2\rho_A} * \frac{r_s^2 - r_{RP}^2}{r_s^2}\right]$$

where the subscripts RP represent reaction product, S means fuel surface, and A means fissile isotopes. The remaining parameters have the usual meanings. The effective thermal conductivity was subsequently calculated as follows:

$$K_{eff} = \frac{1}{T(r_S) - T(r_{RP})} \int K(T)dT$$

The upper limit of the FSRP interface temperature, $t(r_{RP})$, was taken as 1100°C, a temperature above which the reaction product decomposes (Ref. 5). For a fully reacted and equilibrated FSRP layer, this chemical instability gives an excellent mark of fuel temperature.

Shown in Figure 1 are the three fuel cross sectons used for this investigation. In the order of (a) - (c), they were irradiated with linear powers of 32, 33 and 35 kW/m to burnups of 2.9, 8.4 and 8.4 at.%. The thermal conductivity integrals were determined to be 320, 345 and 319 W/m respectively for corresponding temperature rises across the FSRP layer of 350, 381 and 336°C. Since the layer contained 5-10% of mostly spherical voids, a Maxwell-Euken relation was employed to account for the effect of porosity on thermal conductivity. An axial scan of fission-product Zr-95 activity was used to better estimate local linear power. The values of the effective thermal conductivity of the FSRP were found to be 0.92 kW/m•°C, 0.91 kW/m•°C, and 0.95 kW/m•C for the three sections.

This determination of the thermal conductivity of the FSRP $Na_3(U_{1-y}Pu_y)O_4$ led us to the following conclusions:

1. The effective thermal conductivity of the FSRP falls between 0.9 to 1 kW/m•°C in the temperature range of 550-1100°C, or less than one third of the thermal conductivity of stoichiometric mixed-oxide fuel over the same temperature range.
2. The thermal conductivity of the mixed-oxide FSRP is about 75% that of the U/Na system. This seems to follow the same trend as the thermal conductivity of the bulk fuels.

3. The effect of porosity on the thermal conductivity of FSRP is not negligible. For porosity less than 10%, the effect may be very similar to that for fuel; for a more porous FSRP, however, one may have to account for sodium in the pores.
4. The temperature dependence of the thermal conductivity cannot be inferred from the limited range in linear power of the present test elements; the thermal performance of breached oxide elements should be investigated in a broader range of irradiation variables.

REFERENCES

1. Ming J. Lee, et al., "Thermal Impact of $Na_3(U_{1-y}Pu_y)O_4$ Formation on a Breached LMr Fuel Element," Trans. Am. Nucl. Soc. 53, pg. 215 (1986).
2. G. L. Hofman, et al., "Thermal Conductivity and Thermal Expansion of Hot-Pressed Trisodium Uranate (Na_3UO_4)," J. Nucl. Mater., 139, pg. 139 (1986).
3. B. Schultz, "Temperatureleitfahigkeit von Na_3UO_4 bis 600°C," J. Nucl. Mater. 114 (1985), pg. 208-212.
4. J. D. B. Lambert, et al., "Performance of Breached LMFBR Fuel Pins During Continued Operation," Proc. SNES Mtg. Nuclear Fuel Performance, British Nuclear Energy Society, (March 1985).
5. M. G. Adamson, E. A. Aitken, S. K. Evans, "Thermodynamics Studies of the Sodium Fuel Reaction at General Electric," IAEA-PL-463/23 International Atomic Energy Agency, Vienna (1974).

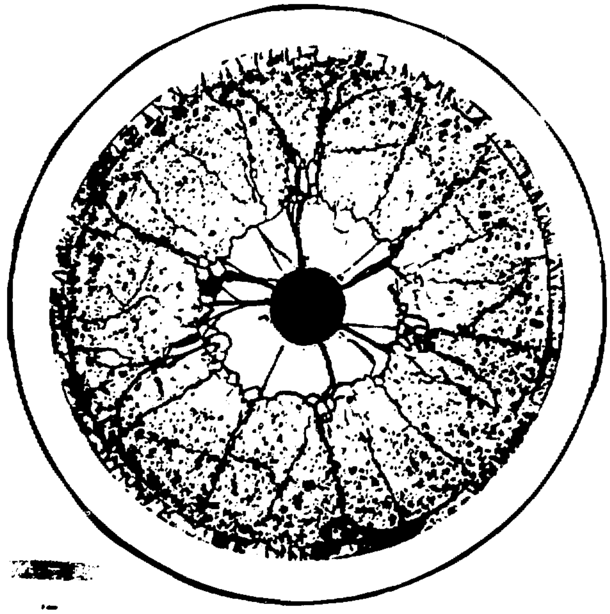
Fig. 1. Transverse mosaic of test elements irradiated at

(a) linear power 32 kW/m, Burnup 3 at.%

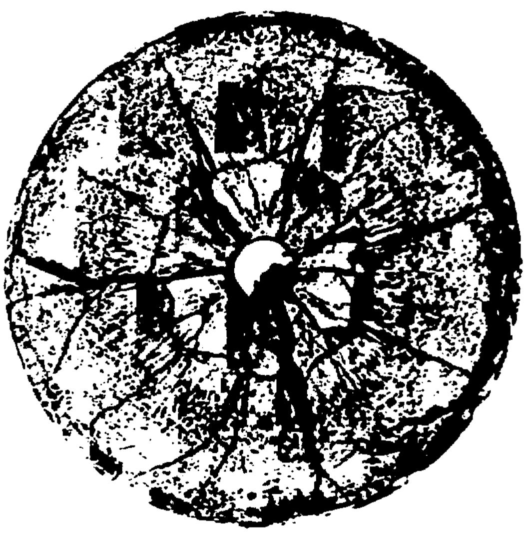
(b) linear power 33 kW/m, Burnup 8.4 at.%

(c) linear power 35 kW/m, Burnup 8.4 at.%

(a)



(b)



(c)