

CONF-871101--76

DE88 003034

THERMAL CONDUCTIVITY OF $\text{Na}_3(\text{U}_{1-y}\text{Pu}_y)\text{O}_4$,
A PRELIMINARY IN-PILE DETERMINATION

by

M. J. Lee, and
J. D. B. Lambert
9700 South Cass Avenue
Argonne, Illinois 69439
U.S.A. (312-972-8224)

S. Ukai, and T. Odo
Power Reactor and Nuclear
Fuel Development Corporation
4002 Narita-cho, Oarai-machi
Higashi-Ibaraki-gun, Ibaraki
Japan (0292-67-4141)

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

American Nuclear Society
(Winter Meeting)
Los Angeles, California
November 15-19, 1987

*Work supported by the U.S. Department of Energy, Reactor System, Development, and Technology, under Contract W-31-109-Eng-38.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Thermal Conductivity of $\text{Na}_3(\text{U}_{1-y}\text{Pu}_y)\text{O}_4$,
A Preliminary In-Pile Determination

by

M. J. Lee, J. D. B. Lambert, S. Ukai, and T. Odo

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), $\text{Na}_3(\text{U}_{1-y}\text{Pu}_y)\text{O}_4$. 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 modeling 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:

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

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 sections 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-Eucken 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 $\text{Na}_3(\text{U}_{1-y}\text{Pu}_y)\text{O}_4$ 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.

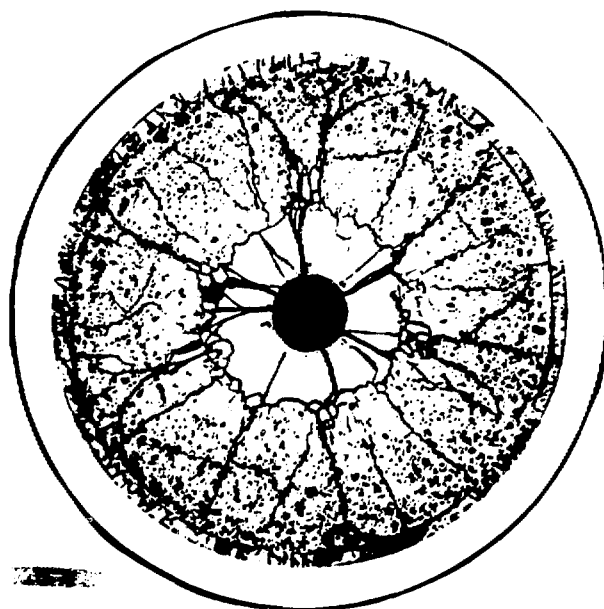
REFERENCES

1. Ming J. Lee, et al., "Thermal Impact of $\text{Na}_3(\text{U}_{1-y}\text{Pu}_y)\text{O}_4$ 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, "Temperatureleitfähigkeit 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).

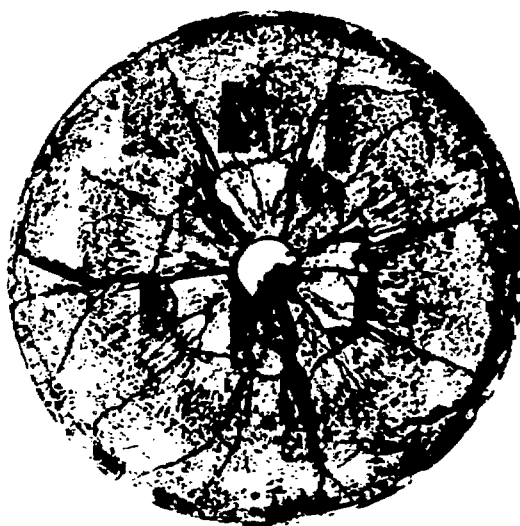
Fig. 1. Transverse mosaic of test elements irradiated at

- (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)

