WCAP 9179, "PROPERTIES OF FUEL AND CORE COMPONENT MATERIALS"

APPENDIX B

10.0 ALUMINUM OXIDE/BORON CARBIDE PELLETS

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10.1 THERMAL/PHYSICAL PROPERTIES

10.1.1 DENSITY

The theoretical density of boron carbide is given in Section 8.1.1.

The room temperature, theoretical density of the burnable poison aluminum oxide/boron carbide (Al_2O_3-B_4C) is given by:

$$\rho_{TD} = 3.95\ V_{f_{(Al_2O_3)}} + 2.52\ V_{f_{(B_4C)}} \qquad \text{(equation 1)}$$

where

Vf = volume fraction of Al_2O_3 or B_4C

ρ_{TD} = theoretical density in g/cm^3

The 3.95 g/cm^3 density value for Al_2O_3 in equation (1) was obtained by using the densities in Reference 1 for α- and γ-Al_2O_3 and by assuming that the Al_2O_3 would be 90 percent α-Al_2O_3. Commercial α-Al_2O_3 generally contains a small fraction of γ-Al_2O_3.

10.1.2 MELTING POINT

Reference 1 gives an average value for the melting point of α-Al_2O_3 as reported by 14 investigators. The value is 3720°F ± 40°F. The variation is the range of values reported by the investigators. As stated in Section 8.1.2, 4400°F is taken to be the melting point of B_4C.

Although the melting point of each constituent is higher, for design purposes the melting point of Al_2O_3-B_4C is conservatively taken as 3500°F; i.e., the maximum reported(2) sintering temperature at which alumina and B_4C are compatible.

10.1.3 THERMAL EXPANSION

The equation for the thermal expansion of B_4C is given in Section 8.1.3.

A compilation of data(1) on high-density polycrystalline Al_2O_3 gives a thermal expansion coefficient of 4.4×10^{-6} in./in./°F over the temperature range of RT to 1000°F. [

]+

(a,c)

Since the bulk moduli are similar for the two compounds, a volume average of the thermal expansion coefficient as given below, is a best estimate approximation for thermal expansion. This assumes the B_4C particles do not crack free from the Al_2O_3 matrix.

Best Estimate Thermal Expansion Coefficient (room temperature to 1000°F):

$$\alpha(\text{in./in./°F} \times 10^{-6}) = F_{B_4C}\ (2.5) + F_{Al_2O_3}\ (4.4) \qquad \text{(equation 2)}$$

where

α = thermal expansion coefficient

F = volume fraction of B_4C or Al_2O_3

The upper-bound thermal expansion of Al_2O_3-B_4C is conservatively established as that of Al_2O_3:

[ ]+ (a,c)

10.1.4 THERMAL CONDUCTIVITY

Out-Of-Pile Thermal Conductivity

The out-of-pile thermal conductivities of $Al_2O_3^{(1)}$ and B_4C (Section 8.1.4) are shown in Figure 10.1-1. A first order approximation to the thermal conductivity of an Al_2O_3-B_4C annular pellet can be obtained by a volumetric averaging of the thermal conductivities of the two components. The equation asumes no significant changes in pore shape for the two constituents.

$$k_p = V_{Al_2O_3} k_{Al_2O_3} + V_{B_4C} k_{B_4C} \qquad \text{(equation 3)}$$

where

k_p = thermal conductivity of pellet

V = volume fraction with respect to the matrix

The values for $k_{Al_2O_3}$ and k_{B_4C} can be obtained from 10.1-1. The volumetric averaging approach is valid for volume fractions of the discontinuous phase (B_4C) of less than 10 percent. For higher volume fractions, a more accurate (lower) thermal conductivity$^{(3)}$ is given by:

$$k_p = k_{Al_2O_3} \frac{1 + 2V_{B_4C} \dfrac{1 - k_{Al_2O_3}/k_{B_4C}}{2k_{Al_2O_3}/k_{B_4C} + 1}}{1 - V_{B_4C} \dfrac{1 - k_{Al_2O_3}/k_{B_4C}}{2k_{Al_2O_3}/k_{B_4C} + 1}} \qquad \text{(equation 4)}$$

In-Pile Thermal Conductivity

In-pile, the thermal conductivies of both Al_2O_3 and B_4C decrease rapidly. Section 8.1.4 discusses the thermal conductivity of B_4C as a function of temperature and fluence. Figure 10.1-2 gives the thermal conductivity of $Al_2O_3^{(4)}$ as a function of temperature and fluence. An estimate of irradiated thermal conductivity is given by applying a correction factor (ranging from 0.1 to 1 in value) to the out-of-pile values. The correction factor varies as a function of fluence until saturation at ~1 x 10^{21} nvt (E > Mev).

10.1.5 SWELLING

The following relationship was developed by Westinghouse and represents the expected swelling behavior of the Al_2O_3-B_4C pellets and is supported by data given in Reference 5.

$$\frac{\Delta V}{V} = [\qquad\qquad]^{+} \qquad (a,c)$$

where

$$N = [\qquad\qquad]^{+} \qquad (a,c)$$

%ΔV/V = volume fraction increase (%)

10.2 CHEMICAL PROPERTIES

10.2.1 CHEMICAL COMPOSITION

The chemical requirements for the individual B_4C and Al_2O_3 powders are those given in Section 8.2.1 and ASTM F7 respectively. The nominal chemical requirements on the pellets are limited to restricting impurities as follows:

Element	Maximum Weight Percent
[	]+ (a,c)

10.2.2 CHEMICAL COMPATIBILITY

Al_2O_3-B_4C: H_2O

Section 8.2.2 established that irradiated B_4C readily corrodes in coolant water. Since the Al_2O_3-B_4C pellet [ ],+ the B_4C particles in the Al_2O_3 matrix would have intimate contact with coolant water should it enter the rodlet, and the boron would likely be readily leached from the pellets. (a,c)

Al_2O_3-B_4C: Zircaloy-4

The reaction rate of Al_2O_3-B_4C with Zircaloy-4 is considered to be negligible.

The potential for internal hydriding of the Zircaloy cladding is minimized via stringent manufacturing controls on pellet and internal cladding moisture.

10.3 REFERENCES

1. Lynch, J. F., Ruderer, C. G. and Duckworth, W. H., editors, Engineering Properties of Selected Ceramic Material, American Ceramic Society, Columbus, Ohio, 1966.

2. Anderson, W. K. and Theilacker, J. S., editors, Neutron Absorber Materials for Reactor Control, USAEC, Washington D.C., 1962.

3. Kingery, W. D. Introduction to Ceramics, Wiley New York, 1960, p. 501.

4. Thorne, R. P., and Howard, V. C., "Changes Induced in Polycrystalline Alumina by Fast Neutron Irradiation," Proc. Brit. Ceram. Soc. 7, 439-447 (1967).

5. Krastins, G., "Preliminary Results of Irradiation Tests of B_4C, B_4C-Al_2O_3, and B_4C-Zircaloy-2," KAPL-2000-5, Reactor Technology Report No. 8-Metallurgy, March, 1959.

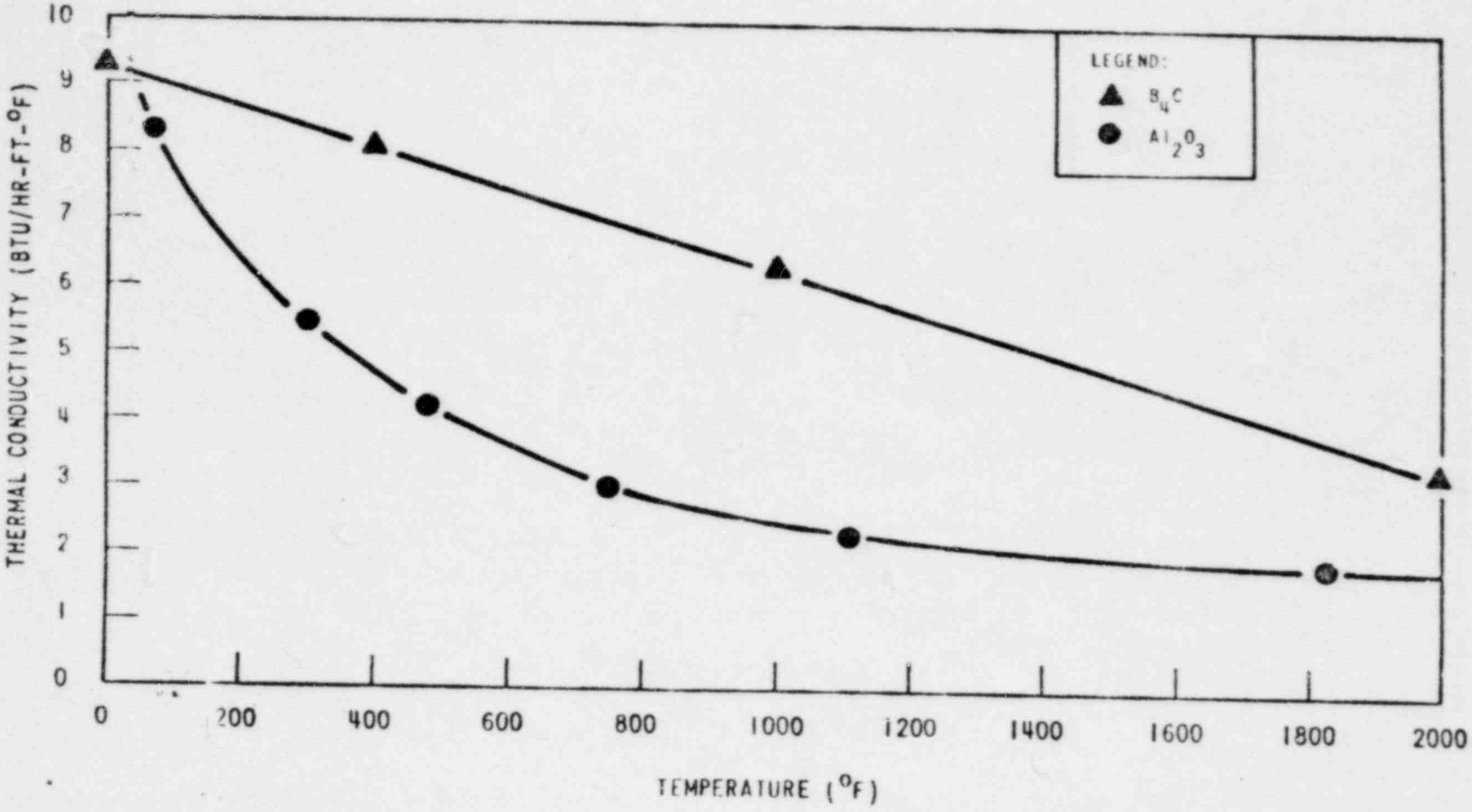

Figure 10.1-1 Thermal Conductivity of Al_2O_3 and B_4C[ ]$^+$ (a,c)

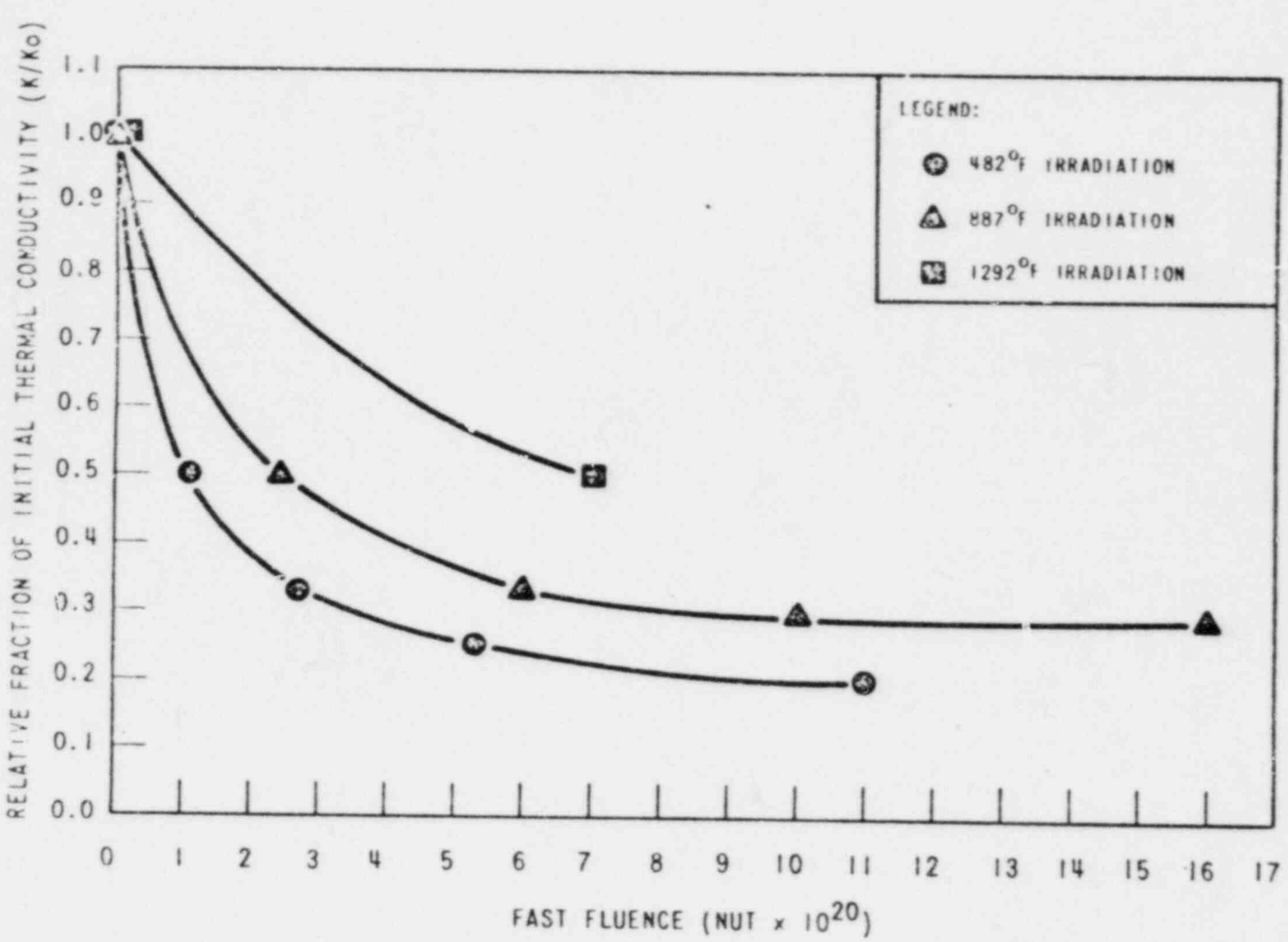

Figure 10.1-2 Irradiation Effects on the Thermal Conductivity of Alumina