WCAP9224 "PROPERTIES OF FUEL AND CORE COMPONENT MATERIALS"

APPENDIX A

9.0 HAFNIUM

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9.1 THERMAL/PHYSICAL PROPERTIES

9.1.1 DENSITY

A theoretical density of 13.36 g/cc, or 0.4827 lbs/in^3 is calculated for pure hafnium based on reported cell size[1]. However, nearly all hafnium contains significant amounts of zirconium in solution. The zirconium reduces the density significantly. Figure 9.1-1 shows the variation of density with zirconium content.

For Westinghouse hafnium design applications a conservative value of 13.12 g/cc was chosen for mechanical design purposes.

9.1.2 MELTING POINT

The recommended value[1] for the melting point for pure hafnium is 4032$\pm$ 54°F. The melting point decreases as zirconium content increases at a rate of 14.4°F (8°C) per weight percent up to a total of 10 weight percent[1]. Allowing for the reduction in the melting point due to the maximum permissible 4.5 weight percent of zirconium and the uncertainty in measured value, a minimum melting point of 3913°F is used as a design value.

9.1.3 THERMAL EXPANSION

The thermal expansion coefficient of hafnium is reported to be 3.3 x 10^{-6} in/in/°F (5.9 x 10^{-6} in/in/°C),[2] and this value is used in design.

9.1.4 THERMAL CONDUCTIVITY

Values for the thermal conductivity of hafnium have been reported by Goldsmith, et al[3], and a fit of the experimental data is given in Figure 9.1-2. This curve is used for design purposes at the temperature of interest.

9.2 CHEMICAL PROPERTIES

9.2.1 CHEMICAL COMPOSITION

Westinghouse material specifications require the chemical composition of hafnium bar to be as specified below:

CHEMICAL COMPOSITION OF HAFNIUM
(IN MAXIMUM PPM, EXCEPT WHERE NOTED)

[ ] +(a,c)

9.2.2 CHEMICAL COMPATIBILITY

HAFNIUM: H_2O

The compatibility of hafnium with H_2O only becomes a potential concern in the case of a rupture in the cladding. Hafnium has excellent resistance to corrosion in hot water, and has been used in naval and commercial power reactors in the unclad state for many years. The resistance to corrosion is reported to be far superior to Zircaloy-2[1]. The net corrosion rate reported in Reference 1 would be < 0.1 mils per year and would have negligible impact event if the clad failed.

HAFNIUM: STAINLESS STEEL

The chemical interaction between hafnium and the 304 stainless steel clad is predicted to be negligible for the design life of the control rods. The prediction is based on the observation from the binary Hf-Fe[4] phase diagram that an intermetallic compound ($Hf\ Fe_2$) is formed. The rate of layer formation between the two metals will be controlled by diffusion of iron and hafnium through the compound, which will be less rapid than hafnium diffusion in the 304 stainless steel clad[5]. At the contact temperatures the control rods will experience during operation, the rate of layer formation and total reaction layer formed during design life will be negligible.

HAFNIUM: B_4C (Applicable to B_4C Hybrid Design Only)

Chemical interaction between hafnium and B_4C will be very limited and will not adversely affect the control rod performance. The extent of the interaction can be judged from the formation rate of HfC[6]. Based on HfC formation rates, the total amount of HfC formed during design life will be negligible because of the relatively low temperatures experienced.

9.3 MECHANICAL PROPERTIES

9.3.1 IRRADIATION GROWTH

Available data on irradiation growth of hafnium has been compiled and reviewed[7-11]. This data consists of three sets of density measurements, one set of length measurements, one lattice parameter measurement and one set of isotope measurements. These measurements consistently indicate that the hafnium has slightly increased in density or decreased in volume although the scatter is large. The density increases are greater than can be accounted for by neutron capture and/or transmutation.

In view of the data available and the inexplicable trend indicated, a conservative position is adopted for design purposes. That is, it is assumed that dimensional changes due to irradiation are of negligible magnitude throughout the materials in-pile design life, and no credit is taken for the potential decrease in volume in design.

9.4 REFERENCES

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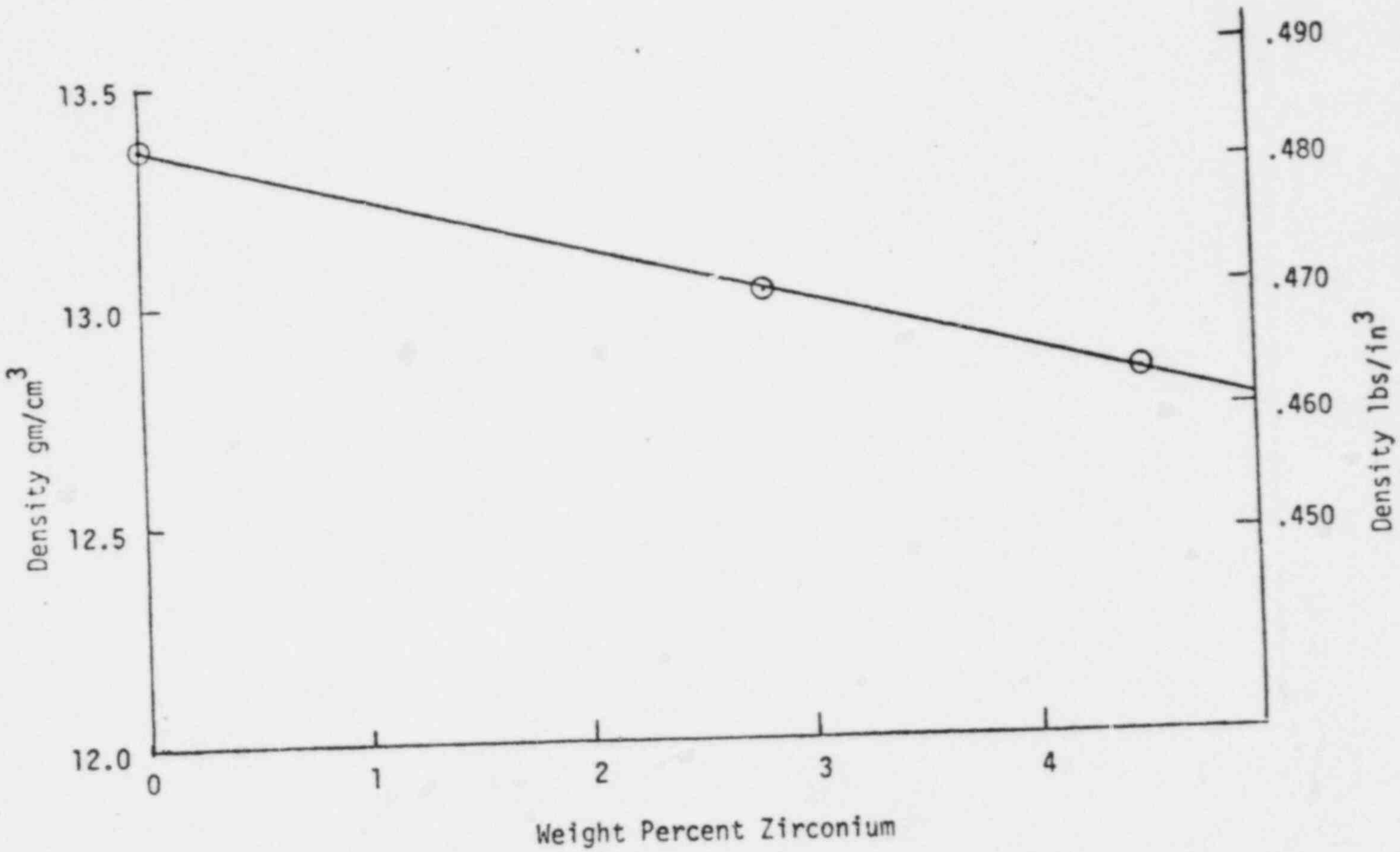

Figure 9.1-1 Hafnium Density Change with Zirconium Content

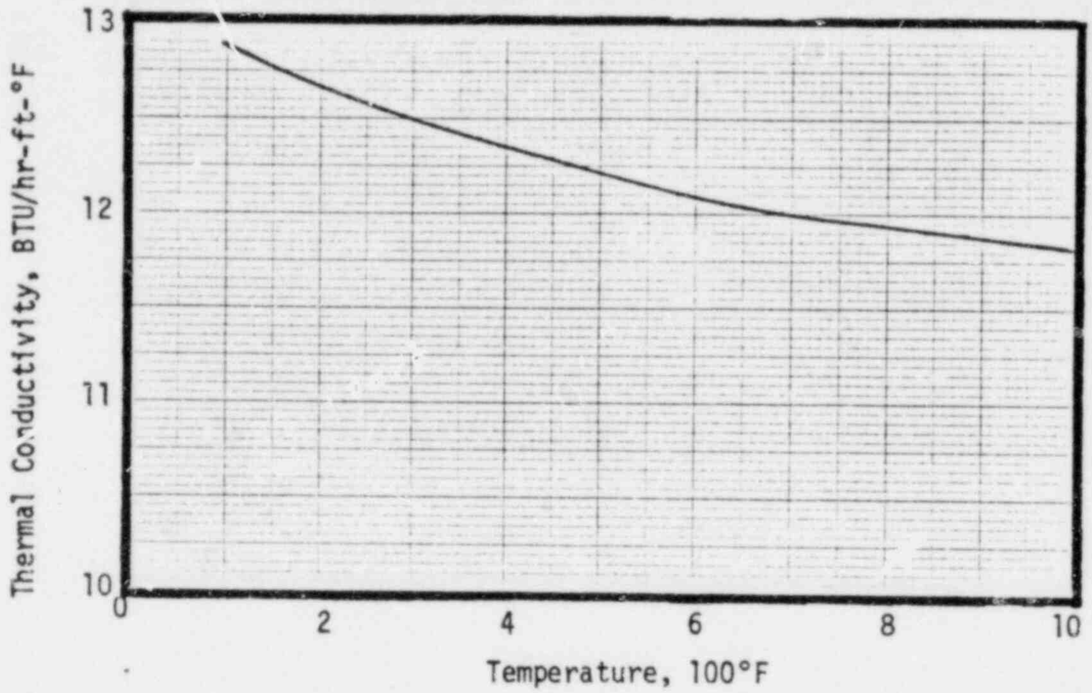

Figure 9.1.2 Thermal Conductivity of Hafnium