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ATOMICS INTERNATIONAL <small>A Division of North American Aviation, Inc.</small>		NAA-SR- TDR NO. 11604		APPROVALS R.L.Brehm <i>R.L.B.</i>	
TECHNICAL DATA RECORD		PAGE 1 OF 6		W.J.Roberts <i>WJR</i>	
AUTHOR E. H. Ottewitte		DEPT. & GROUP NO. 727-711, Canoga 5		DATE 8/25/65	
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TITLE The Effect of Temperature and Micro-structure of Sintered Beryllium Oxide on the Scattering Cross Section for a SNAP Reactor		S/A NO. 2212		TWR	
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PROGRAM Supporting Technology		SUBACCOUNT TITLE Core Analysis		AUTHORIZED CLASSIFIER SIGNATURE <i>R.L.Brehm</i> DATE 8/25/65	
DISTRIBUTION 720-10, Cano 5 Cockeram, D.		STATEMENT OF PROBLEM: Significant changes to scattering cross sections of sintered BeO by temperature and microstructure variations have been observed. Estimate the maximum worth of these effects to the reactivity of a BeO-reflected SNAP reactor.			
727-70, Cano 5 R. Brehm B. Colston R. Gimera C. Goetz W. J. Roberts					
727-76, Cano 5 L. S. Mims					
727-711, Cano 5 Core Analysis Unit (12)					
727-713, Cano 5 Kinetics & Safety Unit (12)					
		ABSTRACT: The maximum possible effects of the temperature and microstructure dependence of the BeO scattering cross sections are estimated. The estimates are conservative because the effects would be less for the neutron energy spectrum of SNAP 8 which is harder than the Maxwellian-spectrum used here. The maximum possible temperature contribution during a BeO-reflected SNAP 8 rise to power would be a gain of 24¢. As this contribution is both small and positive, it need not be considered in the reflector design. The maximum contribution to the temperature coefficient is estimated as +2.4¢ per 100°F, constant over the range 68F to 981F. The maximum possible effects caused by method of fabrication and grain size should be 3.5¢ and 17¢, respectively.			

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INTRODUCTION

The referenced article* reports an experimental study on the effects of temperature and microstructure on the thermal scattering cross section of beryllium oxide. Essentially, four effects are examined:

- (1) temperature
- (2) method of fabrication, extrusion vs. cold-pressing
- (3) grain size
- (4) anisotropy due to alignment with the direction of extrusion or cold pressing

Temperature Effects

Figure 1 gives the total cross section (essentially equal to the scattering cross section) for some temperatures of interest. The estimated temperature range in the S8DS reflectors should be about 68F (298K) to 1350F (1005K). Zhezherun et al* have averaged σ_t and σ_t^{-1} over a Maxwellian spectrum. Two neutron temperatures (T_n) were considered: T_n = target temperature and T_n = target temperature plus one hundred degrees Kelvin. The cross sections were also averaged over an HZr spectrum to obtain an estimate of the degree of conservatism; the true spectrum lies between the two spectra. Table 1 presents the averaged values.

Table 1. Variation of σ_t and $(\sigma_t^{-1})^{-1}$ with an Increase in Temperature

Cross Sections, barn	Temperature, °K				Spectrum
	290	800	1300	1500	
σ_t	9.56	10.09	10.42	10.32	Maxwellian $T_n = T + 100^\circ K$
σ_t	9.726	10.044	-	-	HZr
σ_t^{-1}	8.56	10.26	10.68	10.5	Maxwellian $T_n = T + 100^\circ K$
σ_t^{-1}	8.53	10.12	10.62	10.4	Maxwellian $T_n = T$

*I. F. Zhezherun, I. P. Sadikov, A. A. Chernyshov, "The Effect of Temperature and Microstructure of Sintered Beryllium Oxide on the Scattering Cross Section of Thermal Neutrons," Soviet Atomic Energy, Vol.13, No.9, pp.250-257, September, 1962.

Figure 1. The Effect of Temperature and Microstructure of Sintered Beryllium Oxide on the Scattering Cross Section.

I.F. Zhezherun et al. Soviet At. Ener. 13, No.9, 250 (1962)

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In going from room temperature to 981F (800 K), the Maxwellian-averaged scattering cross section, σ_t , increases by 5.5%; the diffusion coefficient, D (proportional to σ_t^{-1}) decreases by 17%. The diffusion coefficient is estimated (by interpolation) to decrease 18% in going from room temperature to 1005°K.

Now albedo theory gives for slab and spherical geometries:

$$\beta = \frac{1 - 2 \kappa D \coth \kappa a}{1 + 2 \kappa D \coth \kappa a} \quad (\text{slab of thickness } a)$$

$$\beta = \frac{1 - 2 \kappa D \coth \kappa a - \frac{2D}{R}}{1 + 2 \kappa D \coth \kappa a + \frac{2D}{R}} \quad (\text{Spherical shell of thickness } a, \text{ inside radius } R)$$

$$\text{where } \kappa = [\sigma_a / D]^{1/2}$$

σ_a = macroscopic absorption cross section

Taking derivatives with respect to D and introducing constants for a five-in BeO-reflected SNAP 8, one obtains

$$\frac{\Delta \beta}{\beta} = \frac{2 \kappa D \left\{ \kappa a \operatorname{csch}^2 \kappa a + \coth \kappa a + \frac{2}{\kappa R} \right\}}{\left\{ 2 \kappa D \left[\coth \kappa a + \frac{1}{\kappa R} \right] \right\}^2 - 1} \frac{\Delta D}{D} \quad (R = \infty \text{ for slab})$$

$$= -.147 \frac{\Delta D}{D} \text{ for slab}$$

$$= -.322 \frac{\Delta D}{D} \text{ for spherical shell}$$

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The assumption will be made that the result for the complex cylindrical geometry lies between the plane and spherical results. The albedo increase due to decreased axial leakage is assumed to be compensated for by the use of the spherical result. Thus the 18% decrease in diffusion coefficient should produce a maximum increase of 5.9% in the albedo for thermal (< 0.1 ev) neutrons.

Analysis of a SNAP 8 reactor shows that neutrons with energies below 0.1 ev cause 36.2% of the fissions in the core. The fraction of the thermal neutrons which come from the reflector is 9.32%. These returning neutrons include 9.01% which are reflected thermal neutrons and .31% which are BeO-thermalized neutrons. Thus one should expect a maximum reactivity gain of about

$$36.2\% \cdot \frac{\Delta k}{k} \times .0901 \times .059 = .19\% \cdot \frac{\Delta k}{k} \approx \frac{1}{5} 0.24$$

during a BeO-reflected SNAP 8 rise-to-power. Note that this effect is solely due to the change in the microscopic scattering cross section with temperature. Another temperature effect would be a decrease in target density causing a reactivity loss; this effect is not evaluated here.

The worth of the cross section temperature-dependence to the small-volume SNAP Reactor BeO internal reflectors was assumed proportional to that of the external reflectors by the ratio of their areas. The effect is negligible.

The maximum contribution of this effect to temperature coefficient of reactivity may be roughly estimated from the data of Table 1. Assuming a linear slope (inferred by the reference article), the maximum contribution would be

$$36.2\% \cdot \frac{\Delta R}{R} \times .0901 \times \frac{322 \times .17 \left(\frac{\Delta D}{D} \right)}{510^\circ \text{K.}} \times \frac{100^\circ \text{K}}{180^\circ \text{F}} \times \frac{100 \pm}{0.8\% \cdot \frac{\Delta k}{k}} = \frac{2.4 \pm}{100^\circ \text{F.}}$$

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Effects Caused by Method of Fabrication

Samples were prepared for cross section analysis by extrusion and by cold-pressing. For a given grain size the cold-pressed samples exhibited Maxwellian-averaged diffusion coefficients 2.6% higher than the extrusion samples. In a manner similar to that above this difference would be worth a maximum of

$$36.2\% \frac{\Delta k}{k} \times .322 \times .026 \times .0901 = .028\% \frac{\Delta k}{k} \approx 3.5\%$$

Grain Size Effects

For a given method of fabrication the effect of lowering the average grain size from 29 microns to 8 microns is to increase the Maxwellian-averaged diffusion coefficient by 12.7%. In the manner as above this effect should be worth a maximum of

$$36.2\% \frac{\Delta k}{k} \times .322 \times .127 \times .0901 = 1.34\% \frac{\Delta k}{k} \approx 17\%$$

Anisotropy Effects

An anisotropic effect in the scattering cross section was observed in the neutron energy range .011 to .013 ev. The cross sections are 15% higher when the neutrons travel perpendicular to the direction of extrusion or cold pressing than when they travel parallel. The limited portion of the neutron spectrum involved makes this effect negligible.