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by

A.Kocić, V.Marković

1. INTRODUCTION

Zirconium and zircaloy-2 alloy, as constructive materials, have found wide application in reactor technology, especially in heavy water systems for two reasons:

a) low neutron absorption cross section

b) good mechanical properties

The thickness of the zirconium and zircaloy-2 for different applications varies from several tenths of a millimeter to about ten millimeters. Therefore, to calculate reactor systems it is desirable to know the effective neutron absorption cross section for the range of thicknesses mentioned above. The thermal neutron cross sections for these materials are low and no appreciable variation of the effective neutron cross section occurs even for the largest thicknesses. However, this is not true for effective resonance absorption. On the other hand, due to the lack of detailed knowledge of the zirconium resonances, calculations of the effective resonance integrals cannot be performed. Therefore it is necessary to measure the effective total and resonance absorption cross section for zirconium.

2. METHOD OF MEASUREMENT

Of the five zirconium isotopes Zr^{91} has the largest absorption cross section. However, neutron capture in Zr^{91} leads to the stable Zr^{92} isotope, and it is not possible to use an activation technique. The pile oscillator is appropriate for the measurement. The measurements were made in the reactor neutron spectrum of the heavy-water 2% enriched uranium reactor RB (1), with a square form of the sample oscillations in time scale with a 36 s period.

The signal amplitude of the reactor response is connected with the effective absorption cross section of the sample in the following way

$$A = KN\sigma_{eff} \qquad /1/$$

K - proportionality constant

N - total number of the absorbing nucleus in the sample

σ_{eff} - effective absorption cross section for sample material

With regard to Westcott's convention Eq./1/ may be written as

$$A = KN(f_1 g \sigma_o + f_2 \cdot x \cdot \sigma_o \cdot RI) \qquad /2/$$

f_1 - self-shielding factor for thermal neutrons

f_2 - " " epithermal "

g - Westcott's g factor

σ_o - absorption cross section for 2200 m/A neutrons

RI - resonance integral (1/v part excluded)

x - measure of the ratio of the epithermal to total neutron densities

β - relative importance of the epithermal neutrons.

The evaluation of σ_{eff} requires a knowledge of the proportionality factor k, and for effective resonance integral evaluation it is necessary to measure the product $\alpha(\gamma)$. K was determined with a boron standard, and $\alpha(\beta)$ with a gold standard.

In the case $\alpha(\beta) \to 0$, and by extrapolation to zero thickness, i.e., $d \to 0$, $f_1 \to 1$, one may obtain from Eqs./1/ and /2/

$$\sigma_M = \lim_{d \to o} \tilde{\sigma}_{eff}(d) \qquad /3/$$

where $\sigma_{M1} = g\,\sigma_o$

For the case $\alpha(\beta) \neq 0$ from Eqs./1/ and /2/ the following form is

$$RI = \frac{1}{\alpha(\beta)} \lim_{d \to o} \left[\tilde{\sigma}_{eff}^{epi}(d) - \tilde{\sigma}_{eff}^{th}(d) \right] \qquad /4/$$

$\tilde{\sigma}_{eff}^{epi}(d)$ - effective total absorption cross-section as a function of the sample thicknesses

$\tilde{\sigma}_{eff}^{th}(d)$ - effective absorption cross-section for thermal neutrons as a function of the sample thicknesses

3. EXPERIMENTAL ARRANGEMENT

The samples were zircaloy-2 in the form of plates, 200 mm long and 36 mm wide, whose thicknesses were varied in seven steps from 0.30 mm to 3.80 mm. Table I shows the chemical composition of zircaloy-2. The sample oscillations were made in the vertical experimental channel of the

reactor RB. The diameter of the channel is 41 mm and the constant reactor power 5 W. The time function for the oscillations was an approximate square wave with a 36 s period, and the transit time for the samples to more from the "in" position to the "out" position or vice versa was about 1 s. The samples oscillated between the center of the reactor and out of the reactor.

TABLE I (2)

a) Composition alloy (%)		b) Impurity (ppm)	
Sn	1.41	Al	22
Fe	0.155	B	0.25
Cr	0.098	Ca	20
Ni	0.056	Cd	0.25
		Co	10
		Cu	20
		Hf	88
		Mg	10
		Mn	20
		Mo	20
		Na	10
		Pb	20
		Si	33
		Ti	20
		V	20
		W	20
		U	0.2

To minimize the signal from the sample holder a mechanical oscillator PP-2 (3) with "continual funicular" was constructed. The fundamental mode coefficient in a

Fourier expansion was obtained by integration over a whole number of periods in the way described earlier (4). A block diagram of the apparatus is shown in Fig.1. As the detector the ionisation chamber was placed on the surface of the reactor tank. From the D.C. amplifier the signal posses through a comparator and is fed to a correlator. An integration is made by two analog-digital converters and four scalers.

An 80 cm diameter thermal pit and a 9.9 cm lattice pitch was used for the measurement of the thermal neutron absorbtion cross section. A reactor system with a 7 cm lattice pitch and without four central elements was used for resonance integral measurements.

4. A PROPORTIONALITY CONSTANT AND A SPECTRAL INDEX EVALUATION

Boron samples in the B_2O_3 form were used as a standard for proportionality constant evaluation. A B_2O_3 water solution was pipetted on to a filter paper and wrapped in a 50 μ thin aluminium foil. From Eq./1/ one obtains

$$\frac{1}{K} = \frac{\sigma_o^B}{\lim_{N \to 0} \frac{dA}{dN}} \qquad /5/$$

Since the B_2O_3 concentration in the water solution is small calibration curve is a straight line, and for 1/K one obtains:

$$\frac{1}{K} = (0.2017 \pm 0.0010)10^{+19}(b/A)$$

for a 7 cm lattice pitch, and

$$\frac{1}{K} = (0.4450 \pm 0.0015)10^{19}(b/A)$$

for a 9.9 cm lattice pitch.

For σ_o^B we adopted

$$\sigma_o^B = (759 \pm 2)\ (b) \qquad \text{(BNL-325, sup.2, 1964)}$$

The product $\alpha\beta$ was evaluated by measurement of the effective absorption cross section of gold as a foil thickness function and by extrapolation to zero thickness, using the formula

$$\alpha\beta = \frac{1}{RI} \lim_{d \to 0} \left[\sigma_{eff}^{epi}(d) - \sigma_{eff}^{th}(d) \right] \qquad /6/$$

The dimensions at gold foils was 25x100 mm, with thicknesses from 2.65 μ to 17 μ. We adopted the following values of gold parameters

$$\sigma_o = (98.9 \pm 0.2)\ (b) \qquad \text{(BNL-325, 1958)}$$

$$g = 1.0053$$

$$RI = (1540 \pm 30)\ (b) \qquad \text{(Phys.Rev.120, 1960)}$$

and we obtained

$$\sigma_{eff\infty} = \lim_{d \to o} \sigma_{eff}(d) = (196.7 \pm 1.5)\ (b)$$

$$\alpha\beta = 0.0637 \pm 0.0012$$

5. EXPERIMENTAL RESULTS

A thermal pit 80 cm in diameter and a 9.9 cm lattice pitch were used for the thermal neutron absorption cross section measurement. The calibration straight line and the reactor response expressed in arbitrary units are shown in Figs.2 and 3. The absorption cross section for the zero plate thickness is

$$\sigma'_M = 220 \pm 8 \text{ (mb)}$$

In the case of zirconium it is

$$\sigma'_M = 188 \pm 8 \text{ (mb)}$$

The effective resonance absorption cross section for zircaloy-2 was measured in the reactor system of a 7 cm lattice pitch without four central elements. The effective cross sections as a function of the plate thicknesses are plotted in Fig.4.

The resonance integral of zircaloy-2 was

$$RI = (1.01 \pm 0.10) \text{ (b)}$$

and of zirconium

$$RI = (0.91 \pm 0.10) \text{ (b)}$$

Figure 5 gives the effective zirconium resonance integral as a function of effective plate thickness, d_{eff}. d_{eff} is the thickness of an infinite plate giving the same surface to mass value, S/M, as the finite plates. The thermal self-shielding factor is approximately equal to unity by Case's theory (5).

6. DISCUSSION

Zirconium has a low absorption cross section and a heigh s/a ratio. The consequence is a small fundamental mode, and on the other hand the effects due to the neutron streaming and neutron scattering in the transit time between positions "in" and "out" are not neglectable.

The transit time is small in comparison with the oscillating period. Moreover, this signal has a frequency twice that of the oscillator signal. Under ideal conditions it should therefore not contribute to the output signal from the pile oscillator.

Measurement of the effect due to neutron streaming is very difficult. For this reason it is better to have such an arrangement which will give a small possible effect, i.e. a smaller experimental channel diameter, a high critical level in comparison with the diameter, and, if possible to fill the experimental channel with the same material as that of the moderator. In our case the diameter is 41 mm. With our experimental arrangement this effect is about 1 mb per absorber atom taking into consideration Hellstrand's experimental data (6).

The slowing down effect in the sample on the reactor response signal is negligible.

Table II summarizes the results of the earlier authors and our value for infinitely dilute resonance absorption integral.

TABLE II

Reference	RI(b)
1. Macklin and Pomerance	3
2. Klimentov et al	3.6 ± 0.5
3. Dobrynin et al	2.3 ± 0.5
4. Tattersall et al	0.6 ± 0.09
5. Feiner	0.5
6. Hellstrand et al	0.85 ± 0.15
7. Far	1.06
8. Our value	0.91 ± 0.10

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1. S.Jovanović et al., Zero Energy Reactor "RB", NPY-Y-2 Report, 1963.

2. SANDVIK firm atest

3. Mechanical oscillator PP-2: to be published

4. M.Petrović et al. IBK-359, 1965.

5. K.Case et al: Introduction to the Theory of Neutron Diffusion, Vol.I, 1953.

6. E.Hellstrand et al: Arkiv för fysik, Bd20 ur 41, 1961.

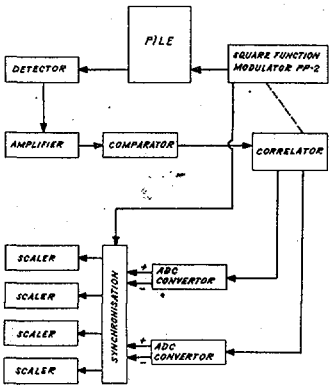

Fig.1 BLOCK DIAGRAM OF THE APPARATUS

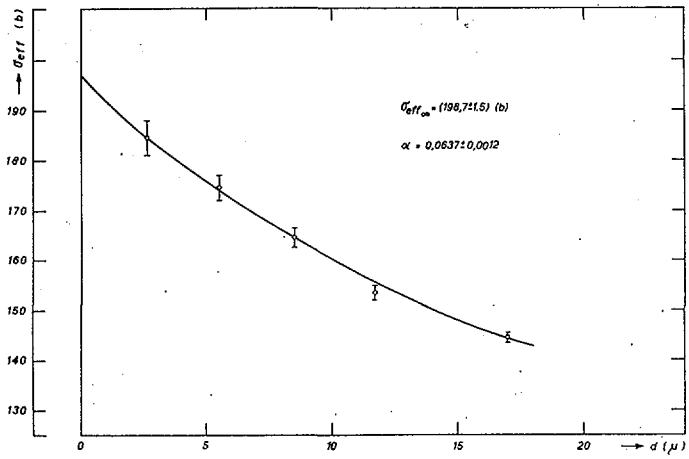

Fig. 3 THE EFFECTIVE ABSORPTION CROSS SECTION OF GOLD VS FOIL THICKNESS

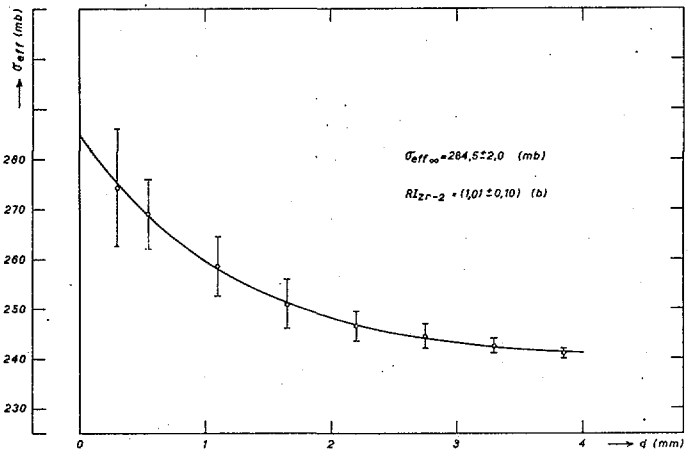

Fig. 4 THE EFFECTIVE ABSORPTION CROSS SECTION OF ZIRCALOY-2 VS PLATE THICKNESS

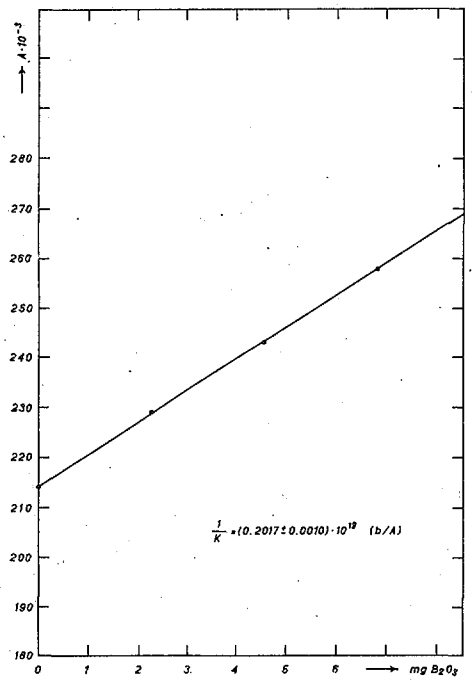

Fig. 2 CALIBRATION STRAIGHT LINE

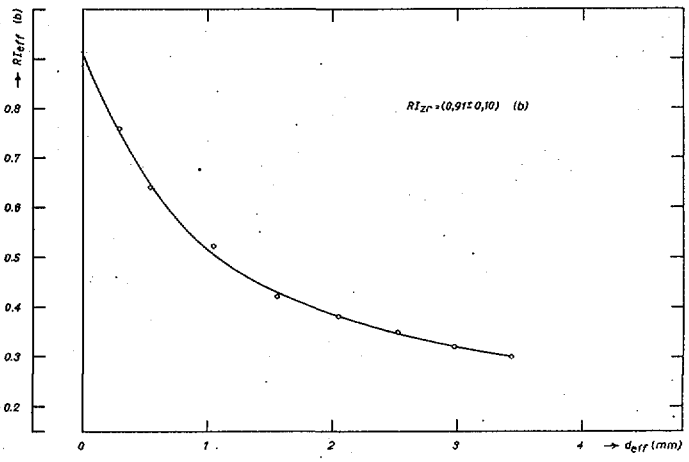

Fig. 5 THE EFFECTIVE RESONANCE INTEGRAL OF ZIRCONIUM VS EFFECTIVE PLATE THICKNESS

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