

A

Critical Reactor Laboratory
Measurement of Absorption Cross Sections
William M. Conlon

ABSTRACT

The flux averaged microscopic cross sections in element 44 were measured as follows:

<u>Element</u>	<u>Experimental</u>	<u>Literature</u>
lead	.486 b	.17 b
iron	17.2 b	2.62 b
tantalum	55 b	21 b
cadmium	439 b	2450 b
tin	4.96 b	1.25 b



PURPOSE:

The objective of this experiment is the measurement of thermal absorption cross sections of several elements, namely lead, iron, tantalum, cadmium, and tin by relating reactivity changes to that caused by the introduction of an absorber with a known cross section.

THEORY:

As mentioned previously, one purpose of measuring the boron coefficient of reactivity is that unknown cross sections can be related to it. Since we know the cross section of Boron, if the reactivity change is produced only through absorption, the reactivity change introduced by any other element gives its absorption cross section, other things being equal. Of course, all things are not equal and must be accounted for. Remembering the large void coefficient of reactivity in the center element, this must be compensated:

$$\rho_{net} = \rho_{measured} - (\text{void coefficient}) \times (\text{absorber volume}).$$

(The void introduced in measuring the boron coefficient was negligible)

$$\text{Now } \frac{\rho_{net}}{\rho_B} = \frac{N_S \sigma_{as}}{N_B \sigma_{aB}}$$

where σ_{aB} , σ_{as} are the absorption cross sections of Boron and the sample, respectively. Or

$$\sigma_{as} = \frac{\rho_{net} A_s M_B \sigma_{aB}}{\rho_B A_B M_s}$$

where A_B , A_s are the atomic weights of the Boron and the sample and M_B , M_s are the absolute masses of Boron and the sample, respectively.

For this method to be useful, the samples should be 1/v absorbers free from resonances. Samples are placed in element 44, the thermal column, where essentially all neutrons have slowed down below the resonance region. Thus thermal absorption cross sections can be measured provided there are no thermal resonances.

In this experiment the cross section measured is actually the flux averaged cross section

$$\bar{\sigma}_a = \frac{\int \int \sigma_a(E) \phi(r, E) dr dE}{\int \int \phi(r, E) dr dE}$$

Assuming that the flux is monoenergetic in the thermal column, $\bar{\sigma}_a = \sigma_a(0.025\text{ev}) =$ the thermal absorption X-section. In other lattice positions the measured cross section is not the thermal cross section, but is weighted by the flux at that position.

PROCEDURE:

The reactor was brought critical on one calibrated control rod with the three rod bank raised to 22 inches. After a reference critical position was established, samples were placed at the 10" mark in the center of element 44, and the reactivity changes noted. After the last run the reference was checked.

CALCULATIONS:

Absorption cross section of lead

$$\text{Reference Crit} = 16.801''$$

$$\text{Pb Crit} = 16.791''$$

$$\sigma_p = \frac{16.65 \text{ } \mu\text{/in} + 16.55 \text{ } \mu\text{/in}}{2} \times 0.038'' = .63 \text{ } \mu$$

$$\text{Volume} = 0.0512'' \times 1.484'' \times 2.782'' = 3.46 \text{ cm}^3$$

$$\text{@ } 1.5'' \text{ width void coefficient} = .226 \text{ } \mu\text{/cc}$$

$$\text{Boron coefficient} = -.668 \text{ } \mu\text{/mg}$$

$$P_{\text{net}} = .63 \text{ } \mu - (.226 \text{ } \mu\text{/cc})(3.46 \text{ cc}) = -.15 \text{ } \mu$$

$$\sigma_{\text{apb}} = \frac{-.15 \text{ } \mu / 37.109 \times 10^3 \text{ mg}}{-.668 \text{ } \mu\text{/mg}} \times \frac{207.21}{10.02} \times 38136$$

$$= .486 \text{ barns}$$

$$\text{literature} = .17 \text{ barns}$$

<u>Material</u>	<u>Volume</u>	<u>Mass</u>	<u>Crit. Pos.</u>	<u>Ref Crit</u>	<u>top</u>	<u>Pnet</u>	<u>σ_a</u>
lead	3.46 cm ³	37.1089g	16.791	16.827	.634	-.154	4866
iron	6.76 x 10 ⁻² cm ³	.5745g	16.817	16.801	-.2634	-.2784	17.26
tantalum	.96 cm ³	15.6349g	17.321	16.801	-8.3594	-8.5754	556
Cadmium	.379 cm ³	3.1701g	18.540	16.818	-24.74	-24.24	4396
Tin	.913 cm ³	5.3940g	16.799	16.804	8.35 x 10 ⁻²	-.5054	4.966

DISCUSSION:

When an absorber is placed in the core, the thermal utilization decreases. The non-leakage probabilities change if the scattering properties of the absorber are different from the moderator which was displaced. If the material is a resonance absorber, the resonance escape probability decreases. If it is fissionable, the fast fission factor increases and if it is also fissile, η increases. These effects are minimized by placing the absorber in an area of low neutron importance.

In this experiment any material with a known $1/v$ cross-section free from low energy resonances could have served as a standard. Cross sections could have also been measured directly by constructing a beam port into the thermal column and measuring the flux with and without a thin sample present. If the detector areas are much larger than the sample area, scattering can be accounted for and the absorption cross section extracted.

There was disagreement between the experimental results and the published 2200 m/sec absorption cross sections. In comparing these results, consideration of the experimental method is important. The microscopic cross section is defined on the basis of the interaction rate of a collimated beam of neutrons with a thin sample. The cross sections were measured differently in this experiment and some of these differences affect the results. First, not all samples were thin and the possibility of self shielding occurs. In self shielding, the outer layers of a sample rapidly deplete the flux, so there is a flux depression in the center of the sample. Since the flux is not uniform across the sample, the interaction rate is not uniform. In a direct measurement the cross section would have to be calculated on the basis of the 'average' flux in the sample. In our indirect method the atoms within the foil do not contribute to the damping of the chain reaction, but we calculated the cross section as if they did. (That is, we based the reactivity change on the mass of the entire sample, not just the mass which absorbed most of the neutrons.)

Secondly we based the calculation on reactivity measurement. To do this we assumed that every neutron absorbed was of equal importance. That is, we assumed that the adjoint flux was flat in the thermal column. This is a good assumption in the axial direction, but it fails in the radial direction since neutrons closer to the fuel are more important than neutrons farther away. Thus we can expect to see a dip in the thermal adjoint flux in the thermal column. This has the effect of making the energy averaged cross section a function of position. To compensate for this, we based boron reactivity coefficients and void coefficients on width (corresponding to the width of the samples) and presumably averaged out the flux variations.

The cadmium cross section was measured to be 439 b as opposed to a literature value of 2450 b. This difference is due to self shielding since the cadmium was relatively thick (212 mg/cm² as opposed to 1 mg/cm² for Boron). The thermal absorption cross section for tin was measured to be 4.96 b as opposed to 1.25 b in the literature. Similar trends were observed in lead, with

a measured cross section of .48 b versus .17 in the literature; iron 17.2 versus 2.62; and tantalum 55 b versus 21 in the literature. Each of these experimental cross sections was about three times larger than the literature value. In each case the elements have cross sections that are very much smaller than that of cadmium.

The question is, why is the reactivity change larger than would be expected? We assumed that these materials were $1/v$ and free from low energy resonances in order to justify this method. If however there was higher energy absorption in these materials the reactivity change would be weighted by this and larger than if it were $1/v$. Of course the fast flux is relatively small in the thermal column, but since the fast neutrons have a higher probability of escaping from the thermal column into the fuel, the fast adjoint flux becomes more important. The Boron cross section decreases by about three orders of magnitude from thermal to epithermal energies, so that the effect of fast neutron absorption in Boron on reactivity is small. The cross sections of the other elements do not decrease anywhere near this much, which explains the extra reactivity change with respect of Boron.