Topic: **Thermal Neutron Cross-Section Measurements by Transmission Testing**

Date: April 14, 2007

Purpose: To determine the total thermal neutron cross sections of various materials through thermal neutron transmission experiments

Location: UCD/ MNRC's Bay 4

Description of Neutron Beam:

Thermal neutron beam at UCD/ MNRC's Bay 4 is filtered by 11"-thick of sapphire crystal (Al_2O_3) with relatively low contamination of fast neutrons and gamma rays. This neutron beam is used for high quality neutron radiography of inspected parts and materials. The beam aperture is 1.25" x 1.25" and built with a 1"-thick B_4C piece. The exit beam size is 6" x 6" and it becomes about 9" x 9" at the fast shutter location. L/D ratio is 168 at the fast shutter and 270 at the NR inspection stand where the thermal neutron flux (< 0.1 eV) is $\approx 3.8 * 10^5$ n/cm^2.sec at 1.5 MW operating power.

L/D ratio is commonly used to describe the beam quality for a neutron radiographic beam. L is the length from the beam aperture to the imaging plane and D is the diameter of the beam aperture that is placed inside the graphite insert. A higher L/D ratio means the beam is more parallel and forward-directed but at a loss of flux intensity.

Neutron spectrum of the beam source end (bismuth crystal) is a typical Maxwellian distribution of neutrons at 40 ^oC.

Materials List:

¼"-thick Al-2024	x 1 piece (up to 5 wt% of Cu)
¼"-thick steel 1020	x 1 piece
40-mil-thick Boral	x 1 piece
1"-thick B_4C-poly	x 1 piece

(Additional testing materials available)

Theory:

Total "neutron" cross section (= scattering + absorption)

σ_t

$= \sigma_s + \sigma_a$

$= (\sigma_e + \sigma_i) + (\sigma_\gamma + \sigma_f + \sigma_p + \sigma_\alpha + \ldots)$

σ_t (Microscopic cross section)

of a material means its unique capability of removing neutrons, especially thermal ones, from their tracks.

Thermal neutron transmission

I_t

$= I_o * \exp(-\sigma_t * n * x)$

$= I_o * \exp(-\Sigma_t * x)$

Σ_t (Macroscopic cross section)

= Probability per unit path length that a neutron will interact as it moves about in a medium.

Experiments:

1. **Reactor steady at 1.5 MW operating power (>2 hrs).** [An alternative method requires a separate beam detector].
2. Record the transmission count rates for **5 minutes** (I_o and I_t, cpm) on the BF_3 detector.
3. Continue and complete the following table.

Sample Description	Sample Thickness	I_o	I_t
None	-----	$I_{o,1}$ =	-----
Al 2024	0.64 cm / 0.25"	-----	
Steel 1020 (Fe)	0.64 cm / 0.25"	-----	
Boral (B_4C+Al)	0.1 cm / 40 mil	-----	
B_4C-poly	2.54 cm / 1.0"	-----	
None	-----	$I_{o,2}$ =	-----

$I_o = (I_{o,1} + I_{o,2}) / 2$… background count rate is negligent.
$I_t = I_o * \exp(-\Sigma_t * x)$

Discussions:

1. Compare measured σ_t to corrected σ_t for thermal neutrons, what cause the discrepancy? (good counting geometry? scattered neutrons reaching BF_3 detector? impurities in sample materials?)

	N (10^{24} /cm^3)	σ_s (b)	σ_a (b)	σ_t (published)	σ_t (corrected)	σ_t (measured)
Al	0.06024	1.49	0.23	1.720	1.687	---
Al (Cu)	**0.06024**	**---**	**---**	**---**	**1.895**	
Cu	0.08493	7.90	3.79	11.69	11.15	---
Fe	**0.08487**	**10.9**	**2.55**	**13.45**	**13.09**	

Data from "Introduction of Nuclear Engineering", J.R. Lamarsh, 3rd edition.

Effective σ_a at 40 °C $= \sigma_{0.0253\text{ eV, a}} * \pi^{0.5}/ 2 * (293/ T{=}313)^{0.5} = \sigma_{0.0253\text{ eV, a}} * 0.857$

σ_t (corrected) = σ_s (approximately constant at lower energies) + σ_a * 0.857

Al 2024 has up to 5 wt% of Cu.

Atom percent ratio of Al vs. Cu… 95%/ 27.0 : 5%/ 63.5 = 0.978 : 0.022
Therefore, 1.687 * 0.978 + 11.15 * 0.022 = 1.895

2. Calculate the HVL (half value layer) of shielding materials, such as **Boral** and **B_4C-poly**, for thermal neutrons. **($I_t = 0.5\ I_o$)**