

Total Cross Section and Self-Shielding Effects of the Cr-52 Isotope Measured at Kyiv Research Reactor Neutron-Filtered Beams

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Abstract. Self-shielded values of a total neutron cross section of a set of Cr-52 samples were measured with 24- and 58-keV neutron filtered beams at the Kyiv Research Reactor. These investigations were done to obtain the real unshielded values of the Cr-52 cross section for neutron energies 24 and 58 keV, as the Evaluated Nuclear Data Libraries give the dispersion of the total neutron cross section for these energies at about 60% and 40%, correspondingly.

INTRODUCTION

The development of the filtered neutron beam technique at the Kyiv Research Reactor (KRR) and the existing experimental base allow performance of the precise measurements of the total neutron cross section with an accuracy of better than 1%. Experimental investigations of total neutron cross sections and self-shielding effects for ^{52}Cr were fulfilled at the 24- and 58-keV neutron filtered beams using a transmission method. The need for such measurements is formulated in the document *The NEA High Priority Nuclear Data Request List, May 1998*, where the necessary accuracy of the Cr-52 total neutron cross section in the energy range 10 eV – 20 MeV is shown at about 3%. To receive the quasi-mono-energy beams with average energies 24.34 and 58.8 keV we used the composite neutron filters consisted of Fe, Al, S, and B-10 for the first and of ^{58}Ni , S, V, ^{10}B , Al, and Pb for the second one. To define the dependence of self-shielding factors from a thickness, sixteen ^{52}Cr samples of different thickness, made of a metal powder and loaded into aluminum containers, were measured. The proportional hydrogen recoil counter CHM-38 was used as a neutron detector. The results of measurements are presented together with the analysis of the known previous experimental data and the evaluated nuclear data from ENDF/B-VI, JEFF-3, JENDL-3.3, BROND-2, and CENDL-2 libraries.

EXPERIMENTAL SET-UP AND MEASUREMENTS

Filter 24 keV. We used here the composite neutron filter consisting of Fe, Al, S, and B-10 to obtain the quasi-mono-energy beam with the average energy 24.34 ± 1.80 keV and neutron flux of about $4.4 \cdot 10^5$ n/cm²s. The beam purity was about 99% - only 1% of neutrons had the energies 70, 120, and 250 keV.

The filter components (g/cm²) used in these experiments for filtered neutron beam forming at the energy 24 keV, are presented in Table 1.

TABLE 1. 24-keV filter components.

B-10	Al	S	Fe
1.0	115.02	19.0	236.1

The filter component optimization, to receive the highest intensity of the main energy line in the neutron spectrum, was carried out by means of calculation using our code FILTER_L.

The observed total neutron cross sections of the chromium-52 isotope at the 24-keV neutron filtered beam were measured on the 9th horizontal reactor channel at KRR using a transmission method.

The experimental set-up for this investigation included:

- the system of filtered neutron beam forming,
- neutron detector and registration system,
- sample management system, and
- system of radiation shielding.

The forming system consisted of the elements of beam collimation and neutron filtration on the way from reactor core to detector. The collimation system provided beam narrowing to 12 mm/m, which corresponded to a beam diameter at the sample of 10 mm. The elements of the neutron filtration system take place in the first three disks of the shutter and in the outer collimator.

The detection and neutron registration systems included: the proportional hydrogen recoil counter CHM-38 (the counter is filled: 90% H₂ + 9.56% CH₄ + 0.44% ³He₂, pressure 3 at, voltage 2500 V), electronic blocks, personal computer IBM 286/287, and communication lines.

The management system for experimental samples provides the establishment of the samples on neutron beam with definite alternation, which is programmed in ZV1M_6 code. Simultaneously three samples can be loaded into the system and placed in the beam at any sequence and combination. This experimental set-up was presented in detail in our previous report [1].

⁵²Cr samples were made of a metal powder, loaded into aluminum containers. Characteristics (Lx) of the chromium powder, used for making the ⁵²Cr samples, are given in Table 2.

TABLE 2. Chromium powder content.

Cr-52	Cr-50	Cr-53	Cr-54
0.9930 ± 0.0005	0.0010 ± 0.0001	0.0050 ± 0.0004	0.0010 ± 0.0001

For determination of the background counting rate the polyethylene samples with thickness 0,731-0,550 g/cm² were used. For high statistics accuracy, the measurements were carried out during 30-40 hours for each sample. To remove the influence of instability factors, the samples at the neutron beam were replaced every minute.

Sample transmission was calculated for each Cr sample measurement series (from 6 to 26) with formulae:

$$T = \{N_{SMP} - N_{SMP+PE}\} / \{N_{DB} - N_{DB+PE}\}, \text{ where}$$

- N_{SMP} – beam after sample,
- N_{SMP+PE} – beam after sample + polyethylene,
- N_{DB} – direct beam, and
- N_{DB+PE} – direct beam + polyethylene.

Then the transmission was averaged over 200-500 channels of 1024 channels of a proton recoil counter. These averaged values then were averaged over all series of measurements. The total cross section for the sample was determined as

$$\sigma_x = -\frac{1}{n_x} \left(\ln \langle T \rangle + \frac{4PA_{AW}}{\pi D^2} \sum_i^{n_{adm}} \sigma_i \frac{I_i}{A_i} \right) \quad (1)$$

The total uncertainty included the statistical inaccuracy of measurements, sample weight and dimensions inaccuracies, the inaccuracy of isotopes, and admixtures content (2):

$$\Delta\sigma_x = -\frac{1}{n_x} \sqrt{\left(\frac{d \langle T \rangle}{\langle T \rangle}\right)^2 + (\sigma_x dn_x)^2 + \left(\sum_i^{n_{adm}} \sigma_i dn_i\right)^2 + \left(\sum_i^{n_{adm}} n_i d\sigma_i\right)^2} \quad (2)$$

Cross sections for these admixture isotopes were defined as an average for five libraries of evaluated nuclear data ENDF/B-VI, JENDL-3.3, JEFF-3.0, BROND-2, and CENDL-2 (see Table 3):

TABLE 3. Calculated cross sections of admixture isotopes (barn).

Admixture	Cr-50	Cr-53	Cr-54
σ ± Δσ	1.2206 ± 0.2845	2.6278 ± 0.5995	28.4391 ± 1.4986

Table 4 and Fig. 1 represent our experimental results in comparison with the calculated cross sections averaged over our filter spectra (19.3-25.8 keV), which correspond to a 95% response function. For calculations the data from ENDF libraries were used.

The recommended unshielded value of the ⁵²Cr total cross section for the 24-keV energy region we received by linear extrapolation to zero thickness in our experimental results. As a final value we recommend the total cross section to be 2.478 ± 0.053 barn.

TABLE 4. ⁵²Cr total neutron cross sections averaged over the filter spectrum at 24 keV (barn).

ENDF/B-6	JENDL-3.3	JEFF-3.0	BROND-2	CENDL-2	Our experiment.
2.826	1.560	1.331	1.195	1.560	2,4785 ± 0,0535

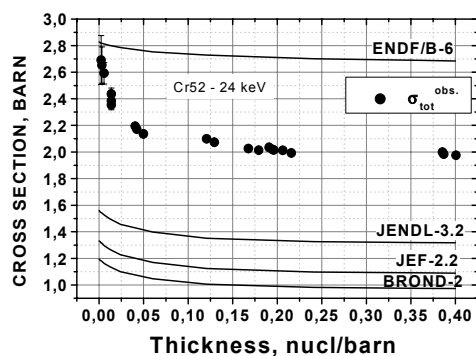


FIGURE 1. ⁵²Cr calculated and observed experimental total neutron cross sections, averaged over the 24-keV filtered beam spectrum.

Filter 58 keV. This investigation was made to obtain the real unshielded value of the Cr-52 cross section for neutron energy 58 keV, as the ENDF libraries give the dispersion of the cross section for energy 58 keV at more than 40%. We used here the composite neutron filter consisting of ⁵⁸Ni, S, V, ¹⁰B, with the average energy 58.8 keV and neutron flux about 10⁵ n/cm²s. The purity of beam was about 94%. Filter components (g/cm²) used in this experiment are presented in Table 5.

TABLE 5. 58-keV filter components.

⁵⁸ Ni	S	V	Al	¹⁰ B	Pb
84.55	157.7	17.4	5.4	0.2	2.5

The energy region 50.7-60.4 keV included a 95% response function of the filter spectrum.

All other experimental details and computational procedures are the same, as in the case of the 24-keV filter. The only distinction is that we used here the set of very thin Cr-52 samples (0.002-0.02 at/barn).

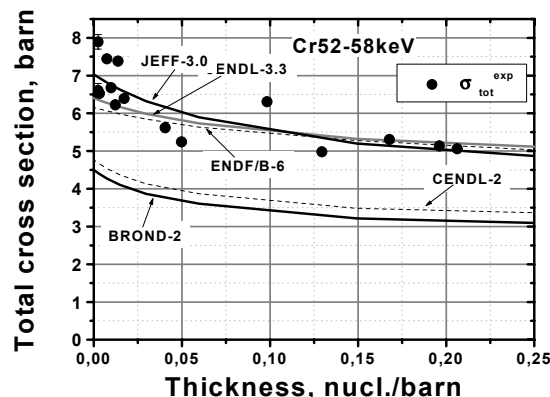


FIGURE 2. ⁵²Cr calculated and observed experimental total neutron cross sections, averaged over the 58-keV filtered beam spectrum.

Just as in the case of the 24-keV filter investigation, we used the linear extrapolation of our experimental results to zero thickness and obtained the recommended value for the total neutron cross section at 58.8 keV:

$$7.220 \pm 0.120 \text{ barn.}$$

TABLE 6. ⁵²Cr total neutron cross sections averaged over filter spectrum at 58 keV (barn).

ENDF/B-6	JENDL-3.3	JEFF-3.0	BROND-2	CENDL-2	Our experiment
6.152	6.404	7.032	4.498	4.7637	7.220±0.120

DISCUSSION OF RESULTS

Figure 3 represents our final results for the ⁵²Cr total neutron cross sections at energies in the intervals 19.3-25.8 keV and 50.7-60.4 keV, together with the known experimental data from database EXFOR/CSISRS [2,3,4] and ENDF libraries. The 24-keV data from the ENDF/B-6 library give the closest result to our value – 2.82 against 2.47 barn in experiment, though the variation of dependence from thickness is rather different. This may show in the inadequate parameters of resonance at 22.98 keV, which play the main role in the self-shielding effect at this energy region.

The result at 58 keV is rather close to the cross section from the JEFF-3 library – 7.02 against

7.22 barn in experiment, though other libraries, except BROND and CENDL, are not too far from the experimental value, and the variation of cross-section dependence from thickness is rather close to experiment.

CONCLUSIONS

1. For the first time the self-shielding effects at ⁵²Cr in the resonance region using neutron-filtered technique were investigated.
2. Results were obtained with accuracy better than 3%, which corresponds to requirements for nuclear reactor technologies.
3. Comparison with evaluated nuclear data from ENDF libraries shows the possibilities for improvement and unification of evaluated nuclear data files.

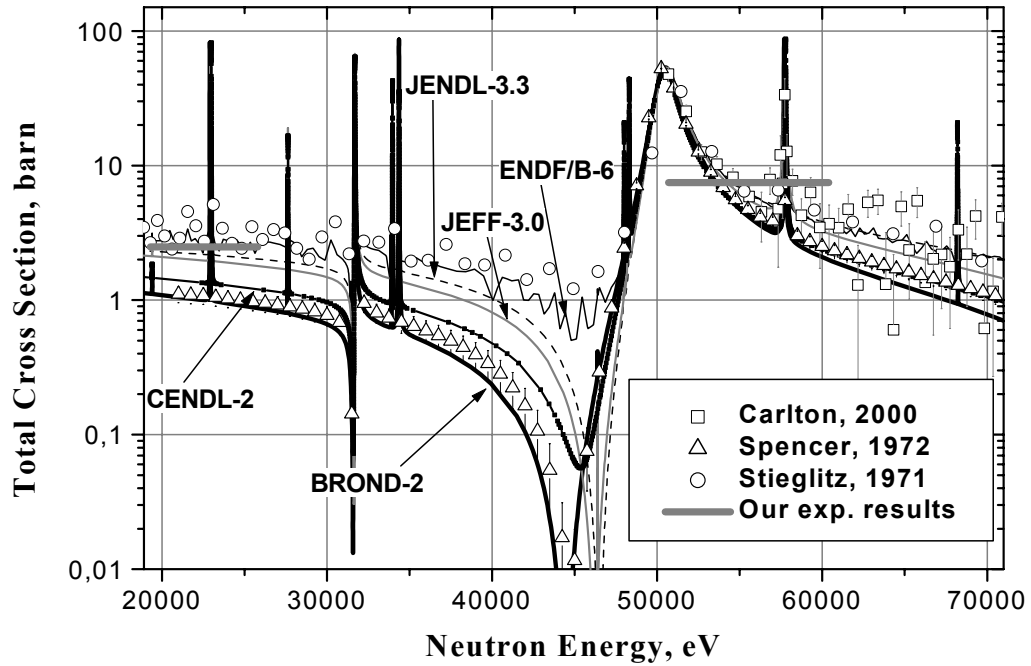


FIGURE 3. Comparison of ^{52}Cr evaluated and experimental total neutron cross sections.

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