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ABSOLUTE MEASUREMENT OF THE CHROMIUM NEUTRON CAPTURE CROSS-SECTION IN THE 1 keV TO 20 keV ENERGY RANGE

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ABSTRACT

Preliminary measurements were carried out for cross-sections of neutron capture by natural chromium nuclei in the energy range from 1 keV to 20 keV. The measurements were conducted on a electron LINAC using a time-of-flight technique and a coincidence spectrometry method. Capture gamma-rays were detected by a two-layer Na(Ti) crystal 4π detector. The measurements were carried out at a 25m flight path with a resolution of 2.5 ns/m. The cross-section was normalized by the saturated resonance technique. The systematic errors did not exceed 15%. The data are compared with results of other measurements.

Chromium is associated with a number of reactor structural materials, and precise knowledge of its capture cross-section is indispensable for calculating basic reactor specifications and effects such as thermal and radiation damage. The required measurement accuracy of σ_γ is 10% in the neutron energy range from 0.1 to 500 keV [1]. At the same time, the accuracy of the data reported in [2-12] is far from that required, and the results of separate measurements vary from one another by factors of $\approx$ 2-10, which leads to significant uncertainties in the evaluated values.

There are a number of reasons for this, principal among them being that the chromium capture cross-section is on the order of 2-3 times smaller than its scattering cross-section. Accordingly, particular attention has been given in this study to the scattering background while retaining high efficiency in the counting of capture events, and to calculating the residual background correctly.

The measurements were conducted by the coincidence spectrometry method [13] using a two layer 48 section NaI(Tl) 4π crystal detector. The inner layer of the detector comprises 16 sections, each crystal having a dimension of 122 x 122 x 130 mm. The outer layer comprises 32 sections, the dimensions of the crystal in each of those sections being 122 x 122 x 450 mm. The geometric efficiency of the detector is 90%. A 55 mm thick layer composed of a mixture of ^{6}LiH and paraffin, protecting the crystals from neutrons scattered within the sample, and a layer of ^{10}B 10 mm thick were positioned in series between the sample to be analyzed and the scintillators. The ^{10}B sample is intended to partially absorb and to count the scattered neutrons which have passed through the protective layer. These neutrons were detected by counting the gamma rays with an energy of 480 keV which are formed when the neutrons are captured in the ^{10}B. The considerable thickness of the scintillator ($\approx$ 25 cm) and the high geometric efficiency of the detector ensured a near 100% efficiency in the counting of neutron captures made by the chromium nuclei of the chromium, which is notable for its high binding energy ($\approx$ 8 MeV) and intense direct gamma transitions to the ground state. It is thus possible to reduce to a minimum any systematic error caused by a deviation in counting efficiency owing to changes in the gamma ray capture spectrum together with a change in the energy of incoming neutrons. Such changes take place during the transition from a neutron s-wave to a p-wave resulting in fluctuations during the transitions from resonance to resonance. Due to the considerable contribution of the p-wave to the cross-section and the great contribution of gamma transitions to the ground state through the emission of one or two gamma rays, these play an significant role in chromium measurements. The practical insensitivity of the counting efficiency to gamma ray spectrum changes presents the additional possibility of using the saturation resonance method to normalize the relative movement of the cross-section being measured, using the resonances of other nuclei in which the capture gamma ray spectrum can differ considerably from the gamma ray spectrum for chromium resonances. The measured data are consequently absolute.

The measurements were carried out over a flight path of 25 m on the "Torch" linear electron accelerator with a resolution of 2.5 ns/m at the I.V. Kurchatov Institute of Atomic Energy . They involved the use of a sample of natural chromium with a diameter of 57 mm and thickness of $8.17 \cdot 10^{-3}$ at/barn. The dependence of the variable background on the time-of-flight channel number *i* was determined directly in the chromium measurements by separating out the event spectrum B(i,K=1) corresponding to the counting of neutrons captured in ^{10}B layer, i.e. the time-of-flight event spectrum counted by the internal layer of the detector with a coincidence factor K=1 in gamma-ray energy intervals for gamma rays of 0.35 MeV to.60 MeV. The ratio of the number of scattered neutrons counted on capture in the ^{10}B to the number of scattered neutrons counted on capture in the structural materials of the detector (mainly in the NaI(Tl) crystals), was determined by using measurement results carried out with a sample of carbon. A value for the neutron background was obtained by taking the product of that ratio and the spectrum B(i,K=1) in each time-of-flight channel. The background counts not caused by neutron and gamma ray scattering on the sample being analyzed were determined on the basis of "no sample" measurements. The constant background level was determined by means of the resonance dip of gold at E_n = 4.9 eV. The neutron flux measurements were carried out on a sample of ^{10}B with a thickness of $6 \cdot 1.0^{-4}$ at/barn, during which the layer of ^{10}B was removed from the detector. In order to obtain an absolute capture cross-section separate measurements were carried out in which the chromium sample was placed in the neutron beam together with a sample of silver having a thickness of $2.31 \cdot 10^{-4}$ ^{109}Ag at/barn, and the saturation resonance of that isotope at E_n= 5.19 eV used for normalization.

Details of the dependence between the capture cross-section values obtained for neutron on energy in the range of 1 to 20 keV are given in Fig. 1. The spread of the data points is caused by the small number of experimental data. The average values of σ_γ for standard energy intervals are presented in Table 1. The systematic error of the data from these measurements does not exceed 15%. A comparison between the results obtained and the available data (Fig. 2) shows that for a neutron energy level from 1 to 5 keV the data from these measurements are significantly higher than those given in Refs [6, 10]. But in the range E_n=5-15 keV they agree well with the results reported in [9] which were measured in the range above 5 keV, and are also consistently higher than the results given in [6, 10] for that range.

A reduction of the statistical error would allow the σ value to be determined far more accurately.

Table 1

Neutron capture cross-section for natural chromium

E1 to E2, keV	$\sigma(n,\gamma)$, barn
1-2	0.118
2-3	0.072
3-4	0.121
4-5	0.141
5-6	0.155
6-7	0.139
7-8	0.118
8-9	0.091
9-10	0.061
10-20	0.031

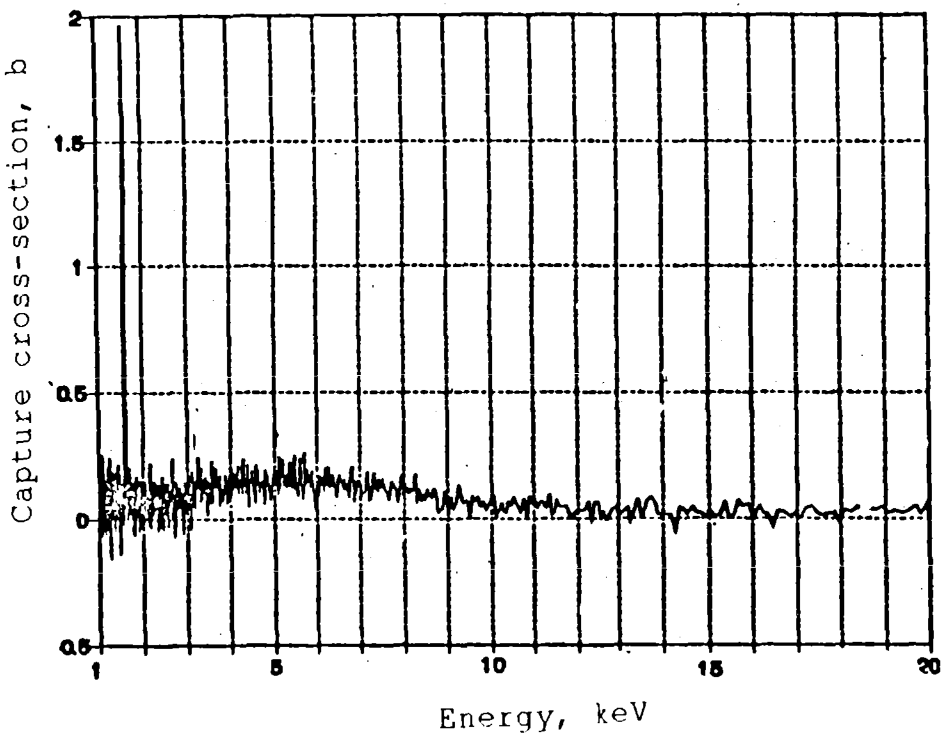

Fig. 1. Capture cross-section of chromium

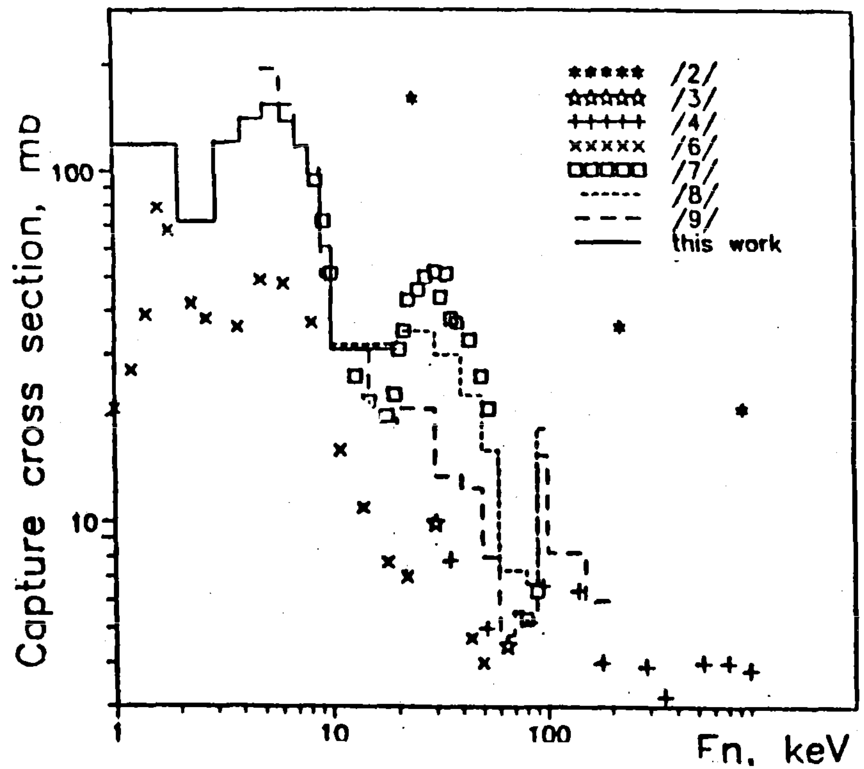

Fig. 2. Neutron radiative capture cross-section for natural chromium

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