THE MEASUREMENTS OF THE DIFFERENTIAL ELASTIC NEUTRON CROSS-SECTIONS OF CARBON FOR ENERGIES FROM 2 TO 133 keV

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The measurements of the differential elastic neutron cross-sections of carbon have been carried out at the Kyiv Research Reactor (KRR) using the neutron filter beam technique. Experimental set-up for detection of scattered neutrons has been installed at the eighth horizontal channel of the KRR. The quasi-mono-energetic neutron lines with mean energies 2, 59 and 133 keV were formed by composite filters. The measurements of the angle distribution of scattering neutrons on carbon samples were executed at angles 30^0, 55^0, 90^0, 125^0 and 150^0 for three neutron energies. To determine the differential elastic neutron cross-section on carbon $d\sigma/d\Omega$, the relative method of measurement was used. The isotope ^{208}Pb was used as a standard. The normalization factor, which is a function of detector efficiency, thickness of the carbon samples, thickness of the Pb-208 sample, geometry, etc., for each sample and for each filter energy has been obtained through Monte Carlo calculations by means of own codes. The results of measurements of the differential elastic neutron cross sections on carbon samples at reactor neutron filtered beams with energies 2, 59, and 133 keV have been compared with the known experimental data from database EXFOR/CSISRS.

1 Introduction

Natural carbon is well known as reactor structure material and at the same time as one of the most important neutron scattering standards, especially at energies less than 2 MeV, where the neutron total and neutron scattering cross sections are essentially identical. Though natural carbon was considered for many years as a scattering standard, the elastic scattering cross section is determined ambiguously. The experimental data for the differential elastic scattering cross section of natural carbon in the neutron energy range 1-500 keV are scanty; only two papers [1, 2] have these values.

The set of filter components (including separated isotope materials) that is presented in the Institute for Nuclear Research (INR) of National Academy of Science of Ukraine, makes possible the quasi-monochromatic neutron beams in the range of energies from thermal to several hundred keV. These filtered beams provide sufficient neutron flux to measure differential neutron scattering cross sections with high accuracy.

2 Experimental details

Installations for measurements of differential cross sections were set on the horizontal channel GEK-8 of WWR-M reactor. The forming of quasi-monochromatic beams of neutrons takes place in three disks of shutter and in outside collimator (Figure 1).

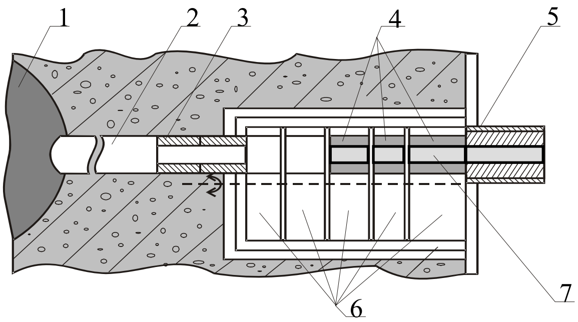

Figure 1. Construction of neutron filtered beam to receive quasi-mono-chromatic neutron flux. 1 – Beryllium reflector; 2 – horizontal channel tube; 3 – preliminary collimator; 4 – filter-collimator assembles; 5 – outside collimator; 6 – shutter disks; 7 – filter assembles.

To receive the quasi-monoenergy beams with the average energies 2, 59 and 133 keV the three composite neutron filters were used. The first of them (2 keV) consisted of ^{10}B, Sc, ^{60}Ni, ^{54}Fe, S, Co and Al, the second one (59 keV) consisted of ^{10}B, S, ^{58}Ni, V and Al, the 133 keV filter consisted of ^{10}B, ^{58}Ni, ^{52}Cr, Si, ^{60}Ni and Al.

GEK-8 provides two compartments shielded from radiation. The first one provides a shielded area for the transposition of standards during the measurements of total neutron cross sections. The second compartment provides a shielded area for neutron detectors. Figure 2 shows the experimental configuration. For total cross section measurements, the sample is located in region 4 and the detector is in region 5. For angular measurements, the sample and detectors are located in region 5.

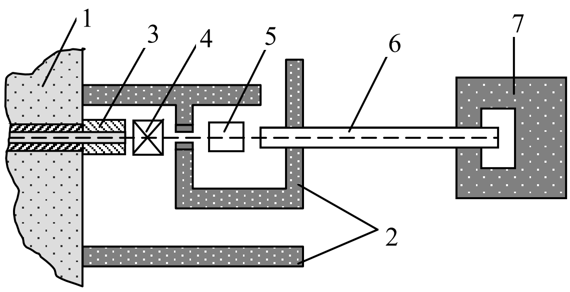

Figure 2. Scheme of scattering measurements. 1 – reactor biological shielding; 2 – radiation shielding of installation ; 3 – outside collimator; 4 – device for sample moving; 5 – installation for angular measurements; 6 – tube for beam conducting to catcher; 7 – beam catcher.

The main components of the installation for angular measurements are the following: 1) vacuum cell for neutron beam conducting and location of investigated samples; 2) neutron detector and registration system; 3) system of radiation shielding.

For angular measurements, the vacuum chamber is placed on special supports which allign the chamber to the beam. The neutron beam passes through thin aluminum diaphragms on entry and exit of the vacuum segments of neutron tube. Inside the chamber the electromechanical device is located for placing of experimental samples and their automatic transposition. The system of neutron detectors consists of 4 detectors. Measurements can be conducted on 4 samples in series: two experimental samples, standard (^{208}Pb) and holder of standard.

It is worth to notice that during conducting of measurements on powder-like samples in one of holders it is necessary to put the equivalent of container for powder. In this case a standard is also placed in a similar container, to take into account the part of neutrons scattered in container. All containers preliminary have to be adjusted on the neutron beam for an account at treatment of experimental spectrums for possible non-identity of containers.

At measurements, the detectors are placed in horizontal half-plane round a chamber. Signals from every detector on-line are passed to the measuring and storage center, where the necessary electronic equipment is concentrated for registration and accumulation of experimental spectrums.

In the electronic measuring section the special block of detector numbering (DN) enters except for traditional electronic blocks (preamplifier, main amplifier and digital converter). Signals from every detector at first enter this block, where the number of detector is appropriated to them, and already then it goes to digital converter. The special program ZERKIN-3 controls the data acquisition electronics. It records all data, sorted by detector.

In addition to overall shielding, each detector is shielded separately. The detectors are individually shielded with boron carbide to reduce sensitivity to scattered neutrons.

Each set of measurements includes a background measurement with polyethylene sample (PE) intercepting the beam. The PE is located in region 4 in Figure 2 and is moved by the sample positioning device used for total cross section measurements.

The typical sequence of measurements in one cycle is the following: sample №1, sample №1+PE, ^{208}Pb, ^{208}Pb+PE, sample №2, sample №2+PE, sample holder alone and sample holder +PE. Time of irradiation of every sample on the beam is 60 sec, the time of samples transposition is 5-7 sec; the amount of cycles in one display is 25-30. Thus, when the measurements are conducting for 4 angles, we receive 32 spectrums.

The vacuum chamber of the installation for angular measurements is an aluminum cylinder with 130 mm height and 214 mm diameter; its butt-ends are closed by flanges. One of them is the foundation for an electromechanical device for investigated samples; the second has the special configuration that provides the identical thickness of aluminum on the way of scattered neutrons from the sample to detector; it is due to the thin-walled semi-cylinder lug on the flange, the center of which coincides with the center of sample-scatterer, that is on the beam. Neutron guides have 74 mm internal diameter and 850 mm length. The butt-ends of these guides are closed by aluminum diaphragms with 1mm thickness. The axis of chamber occupies the horizontal position relative to the beam. The scheme of chamber with the electromechanical device and the position of neutron detectors are presented in Figure 3.

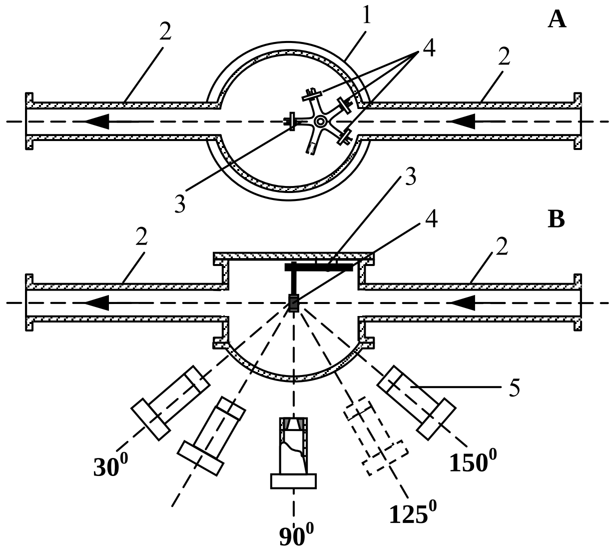

Figure 3. Installation for angular measurements: vacuum chamber scheme. A – side view, B – top view. 1 – chamber; 2 – neutron guide; 3 – sample changing gear ; 4 – samples; 5 – neutron detector with preamplifier.

The device for stationing of samples, as it can be seen from Fig. 3, has the shape of five-ray star. At the ends of rays (65 mm distance from the center) on thin spokes the holders for samples are set. The holder is ring-shaped with 30.4 mm diameter, 6 mm width and 0.1 mm thickness. For prevention of sample fall-out the holders have the 0.5mm welt and from other side a sample is fixed in a holder with a spring clamp. The centers of samples inserted at holders are at the75 mm distance from the rays of five-ray star, to prevent the influence of installation structure components on the experimental results.

Every sample at their transposition occupies the fixed position on the axis of chamber. The special reducing gear of "maltese cross" type is used for the transmission of engine axis rotation to the rotation of five-ray star with samples and that provides the fixing of samples position on the neutron beam.

At right angle to the surfaces of flange in a horizontal plane there is set the metallic slab for neutron detectors placing. Detectors can be set under any angle in relation to the axis of neutron beam, as each of them is the separate construction. A mobile platform is also foreseen with set on it of one detector; it is possible to remove this platform on the slab at any angle within the limits of 30^0-150^0. Direction of axis over which a platform is rotated coincides with the center of sample that is at the beam. Due to this, it is possible to conduct the measurements under necessary angles with the same detector. It enables to check up the isotropic dispersion of scattering neutrons on the certain sample.

For registration of the scattered neutrons, five specially designed detectors were used. Every detector is the assembly of seven helium-3 counters CNM-17 (18 mm diameter, 220 mm length, 7 at pressure), which works with one preamplifier. For every assembly of the counters the units were picked up with the identical gas amplification, so that no expansion of helium peak took place in spectrums. These assemblies have the individual radiation shielding as the cylinder thin-walled container (100 mm external diameter, 300 mm length) filled with the boron carbide. Internal diameter in a container for detector assembly was 65mm. Detector assemblies were placed on the slab so that the axis of the assembly was in a horizontal plane on one line with the center of the sample on the neutron beam.

3 Measurements and results

The measurements of the angular distributions were executed under the angles 30^0, 55^0, 90^0, 125^0 and 150^0 at quasi-monochromatic neutron energies 2, 59 and 133 keV. From two to four carbon samples were used for measurements at each energy. The samples are a set of carbon disks (from one to three units), each with a thickness of 1mm and a diameter of 30.4 mm (C 99.997 %). These carbon disks were made by GoodFellow Cambridge Limited Company (England).

To determine the elastic scattering cross section on carbon, the relative method of measurement was used. The isotope ^{208}Pb was used as the standard. The choice of this standard was based on the following: 1) Values of the total neutron cross section and elastic neutron cross section for the ^{208}Pb are well known; 2) Resonances in the ^{208}Pb cross sections are absent in the energy regions that are covered by the neutron filters used in these measurements. The thickness of the ^{208}Pb sample was 0.00616 ±1E-05 nucl/barn (enrichment of ^{208}Pb to 98.3%, chemical purity 99.98%).

The following spectrums of the scattered neutrons were measured in the experiments: on the *i-th* sample - $N_i(n)$, on the sample when the beam was screened by polyethylene - $PE_i(n)$, on a standard - $N_{Pb}(n)$, on a standard at the beam screened by polyethylene - $PE_{Pb}(n)$, on the holder of sample – $N_0(n)$ and on a holder at the beam screened by polyethylene – $PE_0(n)$, n – channel number. In the analysis of the data, the sum of counts in the neutron peaks was calculated for each detector and geometry. These were used as input to the following equations:

- for the *i-th* sample - $N_i = \sum N_i(n) - \sum PE_i(n)$,
- for standard - $N_{Pb} = \sum N_{Pb}(n) - \sum PE_{Pb}(n)$,
- for the holder - $N_0 = \sum N_0(n) - \sum PE_0(n)$.

For each measurement and for each carbon sample the experimental value of the ratio $N_x(\theta) / N_{Pb}(\theta)$ was calculated with formula:

$$\frac{N_x(\theta)}{N_{Pb}(\theta)} = \frac{N_i - N_0}{N_{Pb} - N_0} \tag{1}$$

Then all $N_x(\theta) / N_{Pb}(\theta)$ values, obtained for this investigated carbon sample, were averaged over all its measurements, and this averaged value was used for the determination of the elastic scattering cross section. Analysis of the measured spectra was performed by our C_SG-W7 code.

To determine the differential elastic neutron cross-section on carbon $d\sigma(\theta)/d\Omega$ the following expression has been used:

$$\frac{d\sigma(\theta)}{d\Omega} = \alpha \frac{N_x(\theta)}{N_{Pb}(\theta)} \cdot \frac{d\sigma_{Pb}(\theta)}{d\Omega} \tag{2}$$

α is a function of detector efficiency, thickness of the carbon samples, thickness of the ^{208}Pb sample, geometry, etc. For each sample and for each filter energy the α value has been obtained through Monte-Carlo calculation with our codes ROZSI and ROZSMK.

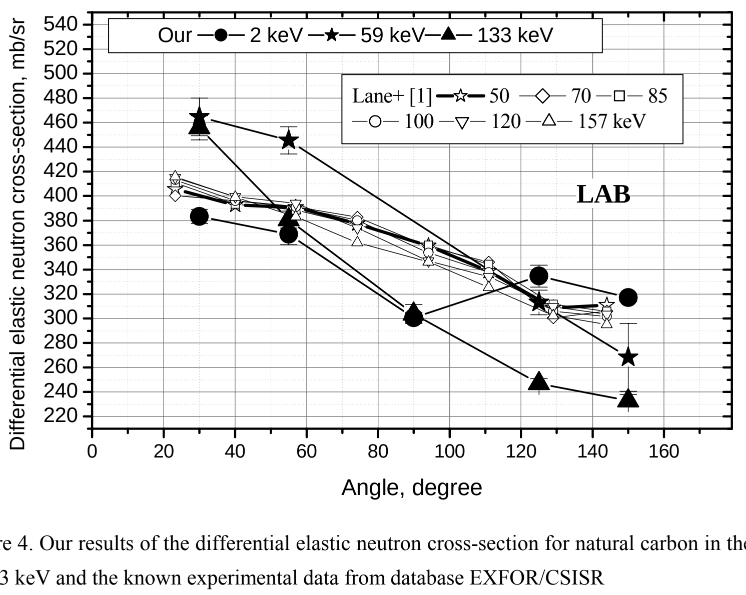

Figure 4. Our results of the differential elastic neutron cross-section for natural carbon in the energy range 2 keV - 133 keV and the known experimental data from database EXFOR/CSISR

The experimental values of the differential elastic neutron cross-section on carbon averaged on all measured samples and obtained at the 2, 59 and 133 keV filters together with the known experimental data from database EXFOR/CSISRS are presented in Figure 4 (LAB system) and Figure 5 (CM system). Uncertainty $\Delta d\sigma(\theta)/d\Omega$, given in these figures includes the statistical inaccuracy of measurements, sample weight, dimension inaccuracies. Amount of uncertainties connected with statistic in Monte-Carlo calculations is small, not more then 0.1 -0.2%, but systematic uncertainties, connected with some simplifications, which were used for this Monte Carlo modeling, may reach 5 – 7%, with the exception of the 90^{o} angle, where they can reach 10-20 %.

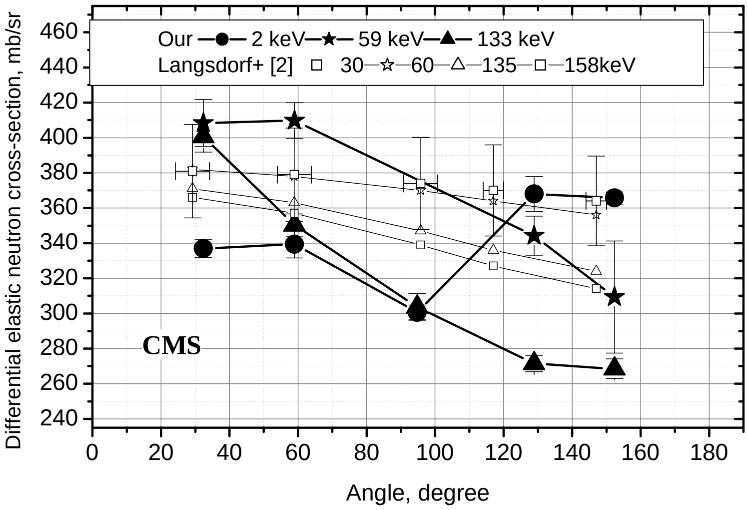

Figure 5. Our results of the differential elastic neutron cross-section for natural carbon in the energy range 2 keV - 133 keV and the known experimental data from database EXFOR/CSISRS.

Unfortunately available data don't permit to draw an unequivocal conclusion about the angle distribution of scattering neutrons on carbon, but hypothetically they indicate that the angle distribution at the 2 keV energy is isotropic in CMS, at the 133 keV energy a forward scattering predominates. These results we consider as preliminary ones and plan to continue this investigation in the future.

Acknowledgments

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