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The aim of these integral experiments using spherical assemblies is to obtain experimental data which can be used to test evaluated nuclear data libraries. Continuing work done previously on other elements [1], in this paper we describe an experiment for measuring neutron leakage spectra from an iron sphere - a common construction material. Experiments of this type have so far only been done in one laboratory [2], and using a sphere with a significantly smaller diameter (8.5 cm).

The neutron leakage spectra from the sphere were measured using time-of-flight spectrometry employing the KG-0.3 pulsed neutron generator at the Institute of Physics and Power Engineering (FEI) [3]. The main parameters of the pulsed regime in this experiment were as follows: accelerated deuteron energy - 250 keV, pulse length - 3 ns, pulse frequency - 800 ns, mean current at the target - $\approx$ 1 μA. The main components of the experimental facility are shown in Fig. 1.

The sphere we used was a hollow ball with an external diameter of 24 cm and an internal diameter of 9 cm (wall thickness - 7.5 cm, or 1.7 14-MeV-neutron mean free path lengths). An ion guide was introduced into the sphere through a cylindrical opening 5 cm in diameter so that the centre of the target coincided with that of the sphere.

In experiments of this kind it is important to know the characteristics of the neutron source, and we therefore measured the angular dependence of the neutron yield from the target unit. In the experiment, we used a T_1T target on a copper substrate 2.8 cm in diameter and 0.7 mm thick positioned in the target holder, a diagram of which is included in the insert in Fig. 2.

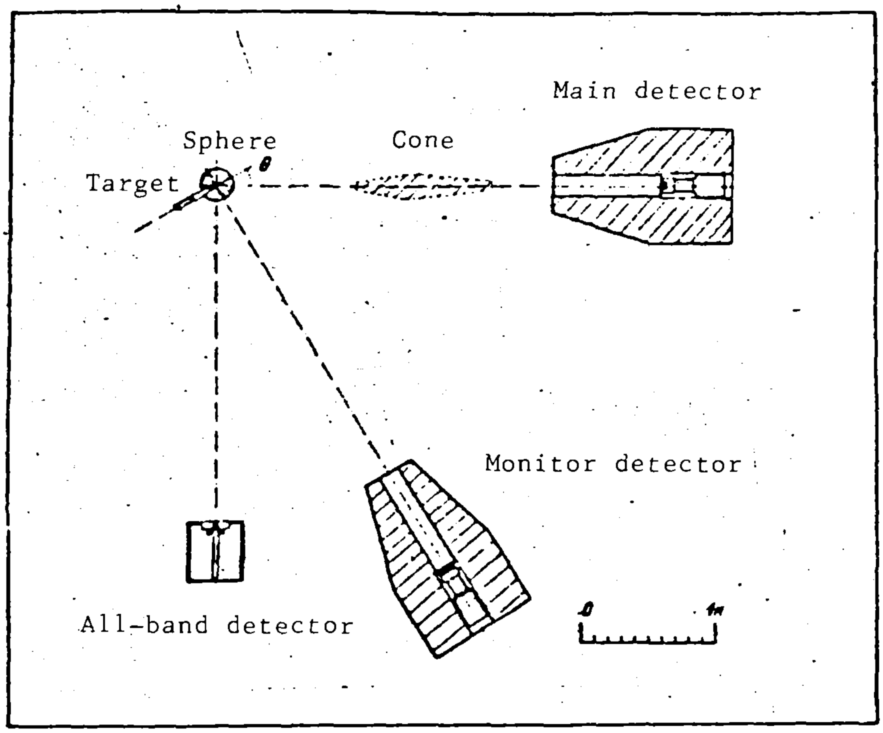

Fig. 1. Experimental set-up

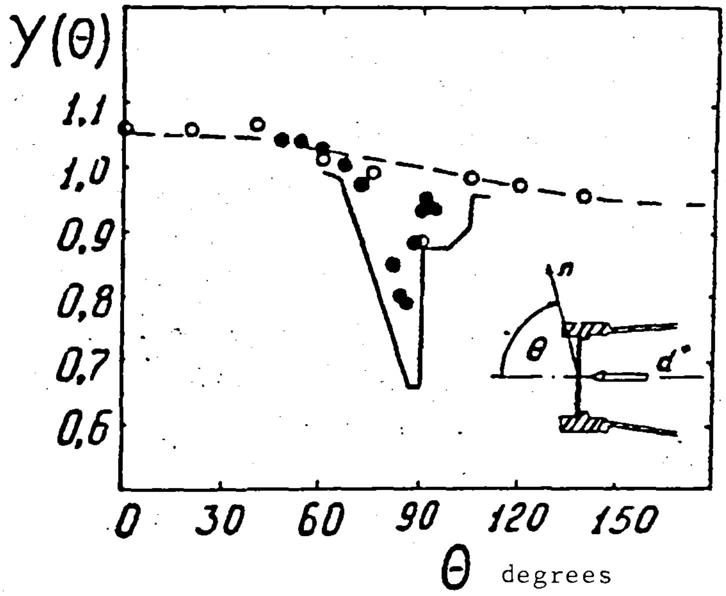

Fig. 2. Dependence of neutron yield on angle for the target unit shown in the insert

Experimental data:

o - Measured using the aluminium foil activation method;

● - Measured using the time-of-flight method.

Calculated data:

--- - Evaluation from Ref. [4];

—— - The same, but with allowance for attenuation in the materials of the target unit.

The angular dependence of the neutron yield was measured in two ways. The first was the aluminium foil activation method with subsequent measurement of the activity level of the foils using a beta-gamma coincidence spectrometer. During irradiation, 10 aluminium foils 1.9 cm in diameter were placed at the same distance (10 cm) from the centre of the target; this produced an angular resolution of 11°. The second method used was the time-of-flight method employing a scintillation detector with a 370 cm path length. The angular resolution was 0.8°.

The results of the measurements are shown in Fig. 2, and it is clear that they are in agreement. This figure also shows the calculated angular dependence of neutron yield for a solid-state tritium target [4] and the calculated yield attenuation due to scattering in the target substrate and target holder. The divergence between the experimental and the calculated data may be caused by bending of the target in the ion guide, which reduces the effective attenuation length. Integration of the measured angular distribution in the whole solid angle yields a neutron attenuation coefficient of 0.96. However, approximately half the scattered neutrons undergo elastic collisions with no noticeable energy change. Consequently, the 14 MeV neutron ejection coefficient for the whole solid angle is 0.98; this was taken into account when standardizing the measured leakage spectrum.

Neutrons emitted from the sphere were registered using a scintillation detector located in the shielding. The path length was 366 cm and the time resolution of the spectrometer ≈ 3 ns.

Since the majority of leakage neutrons have a low energy, we tried to reduce the threshold of the detector. A detector comprising a paraterphenyl scintillator Ø 5 cm x 5 cm [5] and FEhU-143 photomultiplier was used. As a result of both the high light emission level of the paraterphenyl (approximately 1.7 times greater than stilbene) and the low level of inherent noise in the FEhU-143 photomultiplier, it was possible to obtain an energy threshold of 60 keV for the detector and to begin unfolding the energy spectrum from 200 keV.

The dependence of neutron detector efficiency on energy was measured using three methods. In the 0.2-7 MeV range it was measured relative to the spontaneous fission neutron spectrum for ^{252}Cf [6]. In the 5-12 MeV range it was measured relative to the neutron scattering cross-section [7]. To obtain absolute efficiency values using this method, the neutron beam was determined by the aluminium foil activation method at the point where the hydrogen-containing scatterer was positioned. At 14.9 MeV, detector efficiency was measured relative to neutron yield from the target which, in turn, was determined from the associated α-particle count.

An all-band detector and a time-of-flight monitor were used to monitor neutron yield from the target. The time-of-flight monitor comprised an SPS-15B fast scintillator (Ø 2.5 cm, height 2.5 cm) and an FEhU-87 photomultiplier; it had a high internal time resolution (0.4 ns for $E_n > 2$ MeV). It was therefore also used to monitor the pulsed regime of the accelerator.

The absolute value of the neutron yield from the target was measured using the associated particle method. For this, a semiconducting surface-barrier silicon detector was positioned in the ion guide at an angle of 173°. A standard ^{238}Pu alpha source was used to calibrate this detector.

The error level of the experimental data may be broken down into the following components: accuracy with which efficiency is determined - 3%, absolute normalization of neutron yield from the target - 2%, statistical error in the number of counts in the energy cell - 1-3%. The total error is therefore 4-5%. The error level was determined as the root-mean-square of the mean for a parameter measured several times during the experiment.

The integral neutron leakage spectrum produced by averaging the spectra measured at the three angles 0°, 40° and 75° is shown in Fig. 3. The observed half-width (2 MeV) of the peak at 14 MeV is higher than the energy resolution of the spectrometer (1.4 MeV). This may be due to the significant contri-

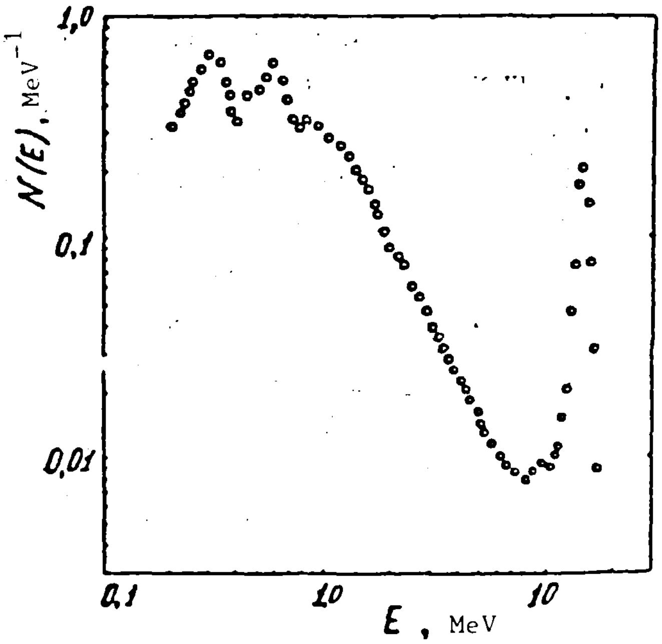

Fig. 3. Integral neutron leakage spectrum from an iron sphere

bution (≃ 75%) of elastically scattered neutrons, and to the variation in the initial neutron energy as a function of the angle of emission from the target.

As can be seen, in the secondary neutron energy region below 1 MeV the spectrum exhibits a resonance structure. A comparison with the total cross-section for interaction of neutrons with the iron, suitably averaged, reveals the following correlation: the peak in the total cross-section corresponds to the well in the neutron leakage spectrum. This dependence is due to the self-shielding effect in the iron sphere.

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