Neutron penetration experiment using several-hundred-MeV mono-energetic neutrons

The neutron is one of the most important particles in radiation protection. This uncharged particle can travel a long distance through a material without losing kinetic energy until it collides with a nucleus. They have small cross sections with materials to pass though, but the cross sections are still sufficiently high and hazardous to human body or electronic devises. Monte Carlo codes have recently become well developed, and many physical quantities may be calculated by a computer without experiments. Most of the cross sections in these codes, however, have been estimated theoretically and have not been confirmed by experiments, especially for neutrons above a few hundred MeV. Even a small discrepancy on a microscopic scale may be substantially magnified on a macroscopic scale. Both microscopic and macroscopic experimental data are therefore useful for improving neutron transport calculations.

A neutron penetration experiment on a macroscopic scale, the so-called shielding experiment, has been performed at the Research Center for Nuclear Physics (RCNP), Osaka University. It was the first shielding experiment to use several-hundred-MeV mono-energetic neutrons. A new neutron energy determination analysis, which was developed in a previous experiment, was used in this experiment. The neutron energy spectra behind shielding materials of different thicknesses were measured and the attenuation length λ was estimated. This was a collaboration involving KEK, JAEA, Tohoku Univ., Kyoto Univ., and RIKEN, together with CERN and Helmholtz München as new members.

Mono-energetic neutrons of two different energies, 246 and 389 MeV, were produced using a $^{7}Li(p,n)$ reaction with incident proton energies of 250 MeV and 400 MeV (nominal), respectively. The neutrons produced were collimated using a 10 × 12 × 350 cm^3 collimator and transported to the next hall, where the experiment was located. The neutron energy spectra (Fig. 1) were measured using an NE213 liquid scintillator located 18 m downstream from the target in the hall [1]. The setup for the shielding experiment is shown in Fig. 2.

The NE213 neutron detectors, two sets of Bonner spheres, and several neutron dosimeters were used in the experiment. The NE213 is commonly used for neutron detection above several MeV. The Bonner spheres were composed of a ^{3}He neutron counter and multi-moderators, for the entire kinetic energy range of neutrons. Different moderator sets are used in AIST and Helm. München. The NE213 and Bonner spheres had different neutron detection efficiencies (only some of the neutrons were counted in the detectors) for different neutron energies and their efficiency curves were estimated in previous studies. The neutron energy spectra behind the shielding blocks were measured using the NE213 and Bonner spheres. There were also several neutron dosimeters. Although neutron dosimeters

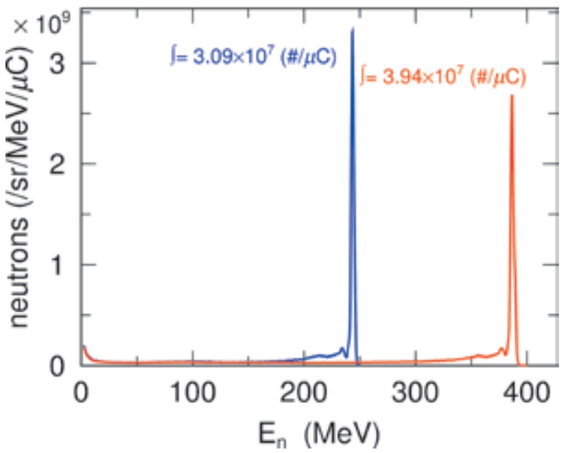

Fig. 1. Initial neutron energy spectra measured in the experiment [1].

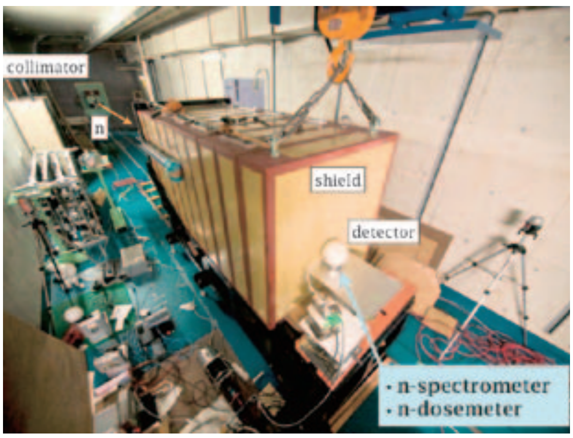

Fig. 2. Experimental setup for 250 cm thick concrete.

were traditionally used for a maximum neutron energy of 20 MeV, the recently introduced wide-range dosimeters, employed in high-energy accelerator facilities, can be used for neutron with energies above 1 GeV. This is the first test in which dosimeters have been used for the mono-energetic several-hundred MeV neutron beams.

The first irradiation was performed without shielding blocks. After the spectrum measurement, all the dosimeters were irradiated in the neutron fields with the energy distribution shown in Fig. 1 so that the dose response of the detectors could be checked and calibrated. The shielding experiment then began by placing a shielding block on the beam axis. The concrete and Fe blocks were 25 × 100 × 100 and 10 × 80 × 80 cm^3 and had maximum thicknesses of 300 and 100 cm, respectively. The distance from the Li target to the face of the shielding materials was 18 m to reduce the background neutrons produced around the target area.

One of the neutron detectors was placed behind the shielding block on the beam axis, and the front face of the shielding block was irradiated with neutrons. During their passage through the material, the neutrons collided with nuclei, and their numbers and kinetic energies gradually decreased. The attenuated neutrons were counted by the detector. This measurement was repeated for all of the combinations of shielding blocks and neutron detectors. Each measurement took 10 to 45 min, depending on the number of neutrons penetrating the shielding blocks and the detection efficiency of the detector. The measurements were conducted non-stop for 4 days at 250 MeV and for 4 days at 400 MeV.

Figure 3 shows the preliminary results of the neutron energy spectra behind Fe blocks with different thicknesses. The peaks indicate the projectile neutrons that penetrated the shielding without collision or with several elastic collisions (with small scattering angles). Neutrons that experienced an inelastic collision lost a certain amount of energy and can be counted in the flat region of the spectra. The excellent energy resolution of the peaks for the measurement conducted behind the thick materials could only be obtained by the analysis that was developed in the previous study [2] (the time of flight cannot be simply converted into velocity because of multiple scattering). Consequently the neutron attenuation length can be better determined at the peak energy. Because the attenuation length becomes larger with the energy and determines the minimum thickness of the shielding, accurate estimation of the attenuation length becomes more important for high energy neutrons. It is also very important to confirm that the microscopic neutron cross sections used in the codes reproduce the measured macroscopic data. The analysis using the Particle and Heavy Ion Transport code System (PHITS) [3] is underway, as shown in Fig. 3. Neutron transport on a macroscopic scale at several hundred MeV is expected to be well understood based on this study.

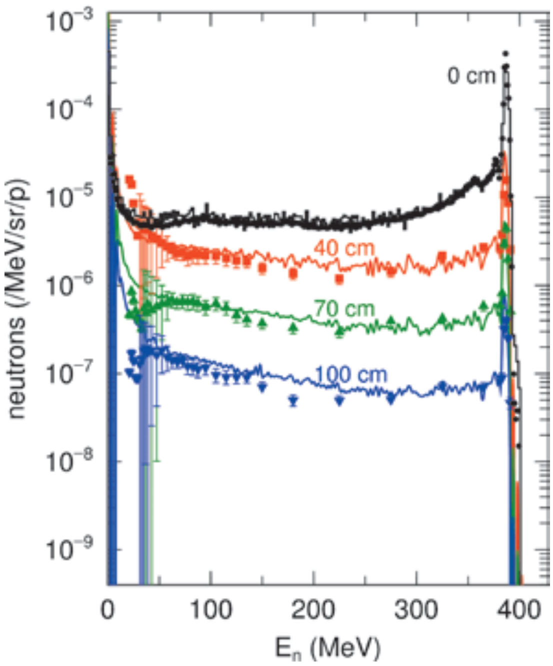

Fig. 3. Neutron energy spectra measured (points) and calculated (lines) behind Fe shielding blocks of different thicknesses.

References

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[2] M. Hagiwara *et al.*, *Nucl.Technol.* **168**, 304 (2009) (awarded by the American Nuclear Society (best of RPSD 2008)).

[3] K. Niita *et al.*, *JAEA-Data/Code*2010-022 (2010).