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Shielding experiments of concrete and iron for the 244 MeV and 387 MeV quasi-mono energetic neutrons using an organic scintillator (at RCNP, Osaka Univ.)

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Abstract. A shielding benchmark experiment has been performed using a quasi-monoenergetic ^{7}Li(p,n) neutron source with the peak energies of 244 and 387 MeV at the Research Center for Nuclear Physics (RCNP) of Osaka University, in order to assess the accuracy of nuclear data and calculation codes used in high-energy accelerator shielging design. Energy spectra behind bulk shields of 10- to 100-cm-thick iron, 25- to 300-cm-thick concrete and their composite are measured using a NE213 organic liquid scintillator with a diameter and thickness of 25.4 cm each with a time-of-flight and an unfolding method. The neutron attenuation lengths are illustared for iron and concrete as a function of the incident energy.

1 Introduction

In recent years, accelerators have been used for various purposes of not only fundamental research fields such as nuclear physics, material and life science but also industrial and medical applications. The developments of recent accelerator technologies are rapidly increasing the maximum energies and intensities that can be handled. In high-energy accelerator facilities, the shielding of high-energy neutrons is of prime importance for keeping the radiation level of the working area and surrounding environment below the dose limits determined by law and the facilities. Adequate shielding designs are necessary for saving of the building costs as well as radiation safety issue.
The shielding benchmark experiment using the p-^{7}Li quasi-monoenergetic neutron sources have been performed for 40 and 65 MeV in Takasaki Ion Accelerators for Advanced Radiation Application (TIARA), Japan Atomic Research Agency [1, 2] and for 137 MeV in the Research Center for Nuclear Physics (RCNP), Osaka University, Japan [3, 4], because the data are very useful to investigate the attenuation length of monoenergetic neutrons and the accuracy of nuclear data libraries and nuclear reaction models implemented in the simulation codes used for accelerator shielding designs.

In order to extend the shielding benchmark experiment using p-^{7}Li quasi-monoenergetic neutron sources to higher energies, we have developed the irradiation field of p-^{7}Li quasi-monoenergetic neutron sources with the peak energies of hundreds of MeV in RCNP. [3, 5] In 2009, we have performed a seris of benchmark experiments using a NE213 scintillator of 25.4-cm in diameter and 25.4-cm in thickness [6] and a Bonner sphere spectrometer [7] for the hundreds of MeV p-^{7}Li quasi-monoenergetic neutron sources, and obtained the pleliminary neuron spectra in time and energy behind iron and concrete shields with several thicknesses from 10- to 300-cm for the p-^{7}Li quasi-monoenergetic neutron sources with the peak energies of 244 and 387 MeV. The attenuation lengths for neutrons with energies of 244 and 387 MeV were estimated by fitting the attenuation profile of peak neutrons as a function of shield depth with single exponential form. Some difference between measured and calculated spectra are observed especially for thick shields and for the 387 MeV neutron source, due primarily to counting of the charged hadrons produced in the shields.
We have reanalized the neutron spectra transmitted through the iron, concrete and their composite shield with thickness from 10- to 300-cm, which were measured with a TOF and an unfolding method by a large NE213

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scintillator of 25.4 cm in diameter and 25.4 cm in thickness. The energy spectra measured by the NE213 scintillator are compared with those measured by a Booner sphere spectrometer. The neutron attenuation length were obtained for iron and concrete as a function of neutron incident energies.

2 EXPERIMENT AND ANALYSIS

2.1 Experimental facility and setup

The experiment was performed at the neutron time-of-flight beam course in RCNP. Figure 1 illustrates the experimental setup used in this study. Proton beams of 246 and 389 MeV extracted from the ring cyclotron were transported to the experimental room and hit a 1.0-cm-thick ^{nat}Li target installed in a vacuum chamber. Protons passing through the target were bended towards the beam dump by the swinger magnet to measure the proton beam intensity with a Faraday cup. Neutrons produced at 0-degree from the target were extracted into the TOF tunnel through a 150-cm-thick iron collimator with 10 × 12 cm aperture embedded in a 150-cm-thick concrete wall located 4.5 m away from the target, while charged particles were rejected by a vertical bending magnet located in the collimator. The neutron beam size was 30 × 36 cm at 18 m from the target, which was determined by the 10 × 12 cm aperture. The details of the p-^{7}Li quasi-monoenergetic source neutrons were described in Ref. 5.
We used 118 × 118 × 10 cm-thick iron blocks and 120 × 120 × 25 cm-thick concrete blocks as shielding materials. In the shielding experiments, these blocks were assembled with thickness from 10 to 100 cm for the iron shield, from 25 to 300 cm for the concrete shield and for the composite shield, 70 cm-thick iron before 200 cm-thick concrete were used. The shielding assemblies were placed ~18 m away from the target. The density of the iron and concrete used in this experiment was 7.87 and 2.33 g·cm^{-3}, respectively, and the atomic compositions of the concrete are listed in Ref. 4.

2.2. Measurement of neutron spectra behind Shields

We used a large NE213 scintillator of 25.4 cm in diameter and 25.4 cm in thickness for the neutron detector [8], because the NE213 can stop recoil proton up to 180 MeV and therefore has good energy resolution for high energy neutrons. The NE213 was placed on the neutron beam axis in contact with the back surface of the shields. The distance between the target and the NE213 were changed from 18 m to 21 m with increasing the thickness of the shields. The proton beam was used of intensity between 1 nA to 1 μA. The data taking system was the same as that used in the previous measurements. [3, 5]

In order to deduce the energy spectra of neutrons transmitted through the shields, we applied a time-of-flight (TOF) method and an unfolding method based on the FORIST code [3] for the peak energy region and the continuous energy region, respectively, because it was difficult to obtain the energy spectra by the unfolding method alone due to oscillation caused by the sharp monoenergetic peak of the p-^{7}Li neutron source and the poor accuracy of responses for high-energy neutrons above 180 MeV which is the upper energy that recoil protons can be stopped in the detector and deposit their full energy. Thus, we separately analyzed the energy spectra for the peak energy region and the continuous energy region using the TOF and unfolding method, respectively. The TOF method was applied above the boundary of the times corresponding to 231 and 361 MeV in the TOF spectra for the incident proton energies of 246 MeV and 389 MeV, respectively. In order to deduce the energy spectra including the scattered neutrons for the TOF peak region, we used the relation between the TOF and the energy spectra calculated by the PHITS code. [9] The energy spectra for the TOF peak region were normalized with the measured fluence of the TOF peak region considering the detector efficiency on the calculated energy spectra. The energy spectra for the continuous energy region were deduced by the FORIST unfolding code coupled with the response matrix which was prepared by the calculation with the SCINFUL-QMD code [10] based on the measured response data [8]. The energy spectra separately analyzed for the two TOF regions (peak and continuous region) were combined by summing them in each energy bin. The details of this technique are described in the Ref. 3. The energy calibration of the light output was performed using the Compton edge of 4.43 MeV γ rays from ^{241}Am-Be source and the recoiled proton edges. The proton energy was converted to electron energy of the equivalent light output (MeVee) by using the calibration value from Ref. 10.

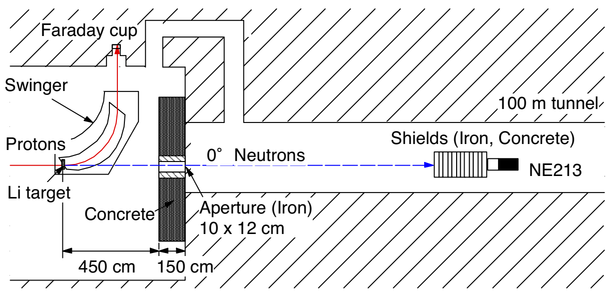

Figure 1. Illustration of the experimental setup used in this study

3 Results and discussion

3.1. Energy spectra

Figure 3 shows the typical resluts of energy spectra of neutrons transmitted through the iron measured by an NE213 with energies above 30 MeV, in comparison with tthose measured by a Bonner sphere spectrometr [7]. The both measured spectra are generally in good agreement in the overlap energy region, although the NE213 data are generally several tens % higher than the Bonner data. This difference might come from counting protons produced in the shields. This effect will be corrected in the final papaer.

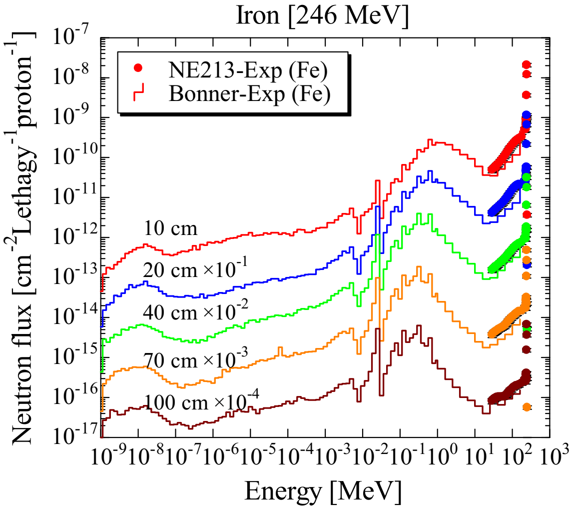

Figure 2. Comparison of the neutron energy spectra transmitted through the iron with various thicknesses for the 246 MeV p-^{nat}Li quasi-monoenergetic neutrons between experimental data measured by a NE213 scintillator (indicated by symbols) and a Bonner sphere spectrometer (indicated by lines).

3.2. Attenuation length

The attenuation profile of the peak neutron flux for iron and concrete shields are fitted by a single exponential curve as a function of depth of the shields. The measured attenuation lengths give good agreement with the calculation results by PHITS within 6 %.[6] Figure 3 shows attenuation length of neutrons transmitted through iron and concrete shields as a function of incident neutron energies. The plotted data for neutrons energies less than 140 MeV were obtained from the Refs. 1-3. The attenuation lengths show signs of the plateau above 250 MeV.

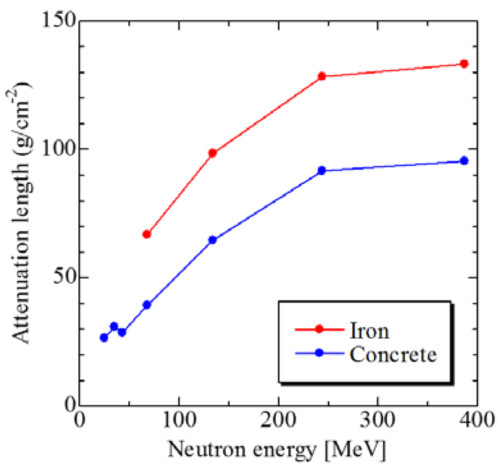

Figure 3. Attenuation length of neutrons transmitted through the iron and concrete shields as a function of incident neutron energies. The plotted data for neutrons energies less than 100 MeV were obtained from the Refs 1-3..

4 CONCLUSION

Neutrons transmitted through 10- to 100-cm-thick iron, 25- to 300-cm-thick concrete and their composite shield (70-cm-iron before 200-cm-concrete) were measured in the energy spectra with a 25.4 diameter × 25.4 thick NE213 scintillator using the 244 and 387 MeV p-^{7}Li quasi-mono-energetic neutron sources at RCNP. The comparison between the experimental data measured by a NE213 scintillator and a Bonner sphere spectrometer shows generally good agreement in the overlap energy region. The neutron attenuation length were obtained for iron and concrete as a function of neutron incident energies.The both attenuation lengths show signs of the plateau above 250 MeV.

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