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Shielding experiments of concrete and iron for the 244 MeV and 387 MeV quasi-mono energetic neutrons using a Bonner sphere spectrometer (at RCNP, Osaka Univ.)

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Abstract. Neutron energy spectra behind concrete and iron shields were measured for quasi-monoenergetic neutrons above 200 MeV using a Bonner sphere spectrometer (BSS). Quasi-monoenergetic neutrons were produced by the ^{7}Li(p,xn) reaction with 246-MeV and 389-MeV protons. Shielding materials are concrete blocks with thicknesses from 25 cm to 300 cm and iron blocks with thicknesses from 10 cm to 100 cm. The response function of BSS was also measured at neutron energies from 100 MeV to 387 MeV. In data analysis, the measured response function was used and the pingpong scattering effect between the BSS and the shielding material was considered. The neutron energy spectra behind the concrete and iron shields were obtained by the unfolding method using the MAXED code. Ambient dose equivalents were obtained as a function of a shield thickness successfully.

1 Introduction

Recently, high-energy and intense beam accelerators, such as the Japan Proton Accelerator Research Complex (J-PARC) are used for various studies and industries. In these facilities, secondary neutrons with energies above 100 MeV are produced around accelerators and beam lines by nucleon-nucleus and nucleus-nucleus reactions. For accurate shielding design of high energy accelerators, experiment data are indispensable to construction of these facilities from the point of view of radiation protection. High-energy neutron penetration data for main shielding materials (concrete and iron) are very important. However, the shielding experimental data for high energy neutrons above 100 MeV are still insufficient both in quality and in quantity as compared with those below 100 MeV [1-3].

In this study, we measured the neutron energy spectra behind concrete and iron shields using a Bonner sphere spectrometer (BSS) for quasi-monoenergetic neutrons produced by the ^{7}Li(p,xn) reaction with 246-MeV and 389-MeV protons at the Research Center for Nuclear Physics (RCNP) of the Osaka University. Moreover, the response function of the BSS was also measured for energy range from 100 MeV to 400 MeV at RCNP. The measured response function of BSS was used in data analysis of the shielding experiments.

2 Experiments

2.1 Shielding experiments

Figure 1 shows a schematic view of a typical experimental arrangement. Shielding experiments were performed at the time-of-flight (TOF) beam course of RCNP. Quasi-monoenergetic neutrons with peak energies of 243.5 MeV and 386.6 MeV were produced by the ^{7}Li(p,xn) reaction by bombarding a 1-cm thick Li

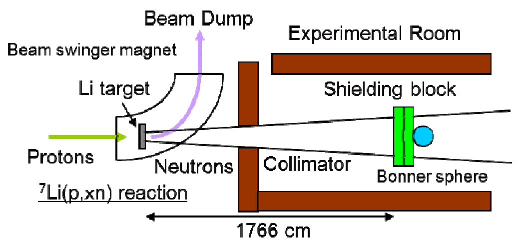

Figure 1. Schematic view of typical experimental arrangement at RCNP.

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target with 246-MeV and 389-MeV protons from the AVF cyclotron and the ring cyclotron of RCNP. A the neutron beam emitted in the forward direction was extracted into the TOF room through an iron collimator of 12-cm wide and 10-cm high aperture embedded inside a concrete wall with a thickness of 15 cm. The proton beam penetrated through the target was guided to a beam dump using a beam swinger magnet. Neutron source spectra in the TOF room were measured with liquid scintillators by means of the TOF method [4, 5].

Shielding materials are concrete blocks (2.33 g/cm^3) with thicknesses from 25 cm to 300 cm and iron blocks (7.87 g/cm^3) with thicknesses from 10 cm to 100 cm. The components of concrete are given in **Table 1**. The distance between the Li target and upstream surface of the shielding materials was 17.7 m. The BSS was contact with the backward surface of shielding material.

Neutron energy spectra behind the shields were measured with the BSS [6]. The BSS consists of a ^{3}He spherical proportional counter (CENTRONIC LTD, SP9, gas pressure: 21.3 kPa) and polyethylene (PE, 0.95 g/cm^3) moderators with diameters from 7.62 cm to 24.1 cm. In addition, measurements were performed using inserting metal shells made of lead (457p: 10.2-cm-diameter PE sphere + 1.27-cm thick Pb shell + 2.54-cm thick PE shell) and copper (457c: 10.2-cm-diameter PE sphere + 1.27-cm-thick Cu shell + 2.54-cm thick PE shell) [7].

2.2 Response measurements of BSS

The responses of BSS were measured at neutron energies from 100 MeV to 387 MeV in neutron feilds of RCNP. The responses for mono-energetic neutrons were evaluated by the two-angle differential measurement method, which was described in detail elsewhere [6]. The responses at neutron energies of 144 keV, 565 keV, 5.0 MeV and 14.8 MeV were also calibrated in the mono-energetic neutron standard fields [10] of the National Institute of Advanced Industrial Science and Technology.

The response function of BSS was also simulated with the MCNPX code [8]. The JENDL-HE[9] file was used in the simulation.

3 Data Analysis and Results

The measured and the calculated response results of BSS are in good agreement within measurement uncertainties above 100 MeV for the BSS with the polyethylene moderator. However, there is the difference between the measured and calculated results for the BSS with the Pb or Cu shell. The measured responses were reflected in data analysis of shielding experiments.

The BSS was contacted with the surface of shielding block, actual response functions were affected by the neutron multi-scattering effect between the moderator of BSS and the shielding block, called ping-pong effect. The response function with the ping pong effect was also evaluated with the MCNPX code. The response function including the ping-pong effect was used in the data analysis to obtain more precise results.

Neutron energy spectra behind the shields were obtained by unfolding method using the MAXED code [11]. From the neutron energy spectra with the BSS, the ambient dose equivalent was obtained using conversion coefficients based on the International Commission on Radiological Protection recommendations in 1990 [12, 13]. **Figure 2** shows results of neutron ambient dose equivalent per proton beam charge for the 244 MeV experiment of the concrete shielding. Figure 2 shows the results obtained using the response function of BSS with and without the ping pong effect.

In the shielding experiments, other measurements with a 25.4-cm-diameter and 25.4-cm-thick NE213 scintillator were also performed. The final results of neutron ambient dose equivalents and the attenuation length will be obtained after comparing with the experimental data obtained by the NE213 scintillator in fast energy region and calculated results in all energy region.

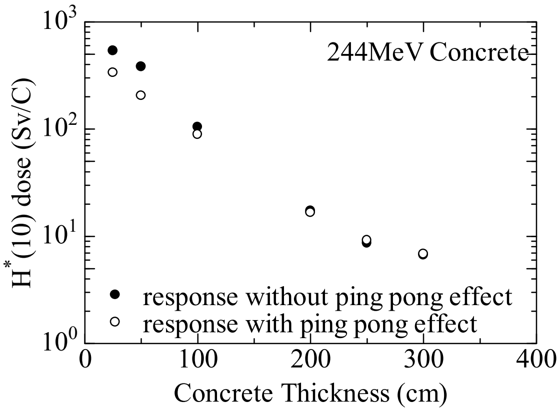

Figure 2. Ambient dose equivalents as a function of the concrete shield. The results were obtained using the response function with and without the ping pong effect.

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