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Dose Measurements through the Concrete and Iron Shields under the 100 to 400 MeV Quasi-Monoenergetic Neutron Field (at RCNP, Osaka Univ.)

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Shielding benchmark experiments are useful to verify the accuracy of calculation methods for the radiation shielding designs of high-energy accelerator facilities. In the present work, the benchmark experiments were carried out for 244- and 387-MeV quasi-monoenergetic neutron field at RCNP of Osaka University. Neutron dose rates through the test shields, 100-300 cm thick concrete and 40-100 cm thick iron, were measured by four kinds of neutron dose equivalent monitors, three kinds of wide-energy range monitors applied to high-energy neutron fields above 20 MeV and a conventional type rem monitor for neutrons up to 20 MeV, placed behind the test shields. Measured dose rates were compared one another. Measured results with the wide-energy range monitors were in agreement one another for both the concrete and the iron shields. For the conventional type rem monitor, measured results are smaller than those with the wide-energy range monitors for the concrete shields, while that are in agreements for the iron shields. The attenuation lengths were obtained from the measurements. The lengths from all the monitors are in agreement on the whole, though some differences are shown. These results are almost same as those from others measured at several hundred MeV neutron fields.

KEYWORDS: 100-400MeV, Shielding Experiments, Concrete, Iron, Neutron Dose

I. Introduction

In the radiation shielding designs and safety analyses, calculation methods were used(1) for high-energy and high-intensity proton accelerator facilities. In order to verify the accuracy of calculation methods for the dose estimations of shielding designs, shielding benchmark experiments for several hundred MeV neutrons are useful, especially for those performed at the fields that the intensity and the energy spectrum of source are well known.

In the present work, neutron dose rates through the concrete and the iron test shields were measured by four kinds of neutron dose equivalent monitors for 244- and 387-MeV quasi-monoenergetic neutrons generated from the ^{7}Li(p,n) reactions at the Research Center of Nuclear Physics (RCNP) ring cyclotron of Osaka University(2). Dose rates measured by the monitors were compared with one another. The attenuation lengths were obtained from the measurements for the concrete and the iron shields, and compared.

II. Experiments

1. Experimental Setup

Experiments were carried out at the neutron time-of-flight (TOF) beam course in the RCNP of Osaka University. Figure 1 shows a schematic view of the experimental arrangement. The experimental room is a tunnel of 100-m in length, 4-m in width and 3.5-m in height. Quasi-monoenergetic source neutrons, the peak energies were 244- and 387-MeV, were produced in a 1.0-cm thick ^{7}Li target(99.9%) bombarded with 246- and 389-MeV protons, respectively. Source neutrons emitted in the forward direction reached an experimental room through a 10.0-cm-wide and 12.0-cm-height aperture, and 150-cm-long iron collimator embedded in a concrete wall. The protons penetrating through the target were bent towards a beam dump by the swinger magnet to measure the proton beam intensity with a Faraday cup inside the dump. The test shields, 100-, 200- and 300-cm thick concrete and 40-, 70- and 100-cm thick iron, were placed on the neutron beam at the position of 17.66 m from the Li target. Atomic densities of the concrete and the iron test shields used in the

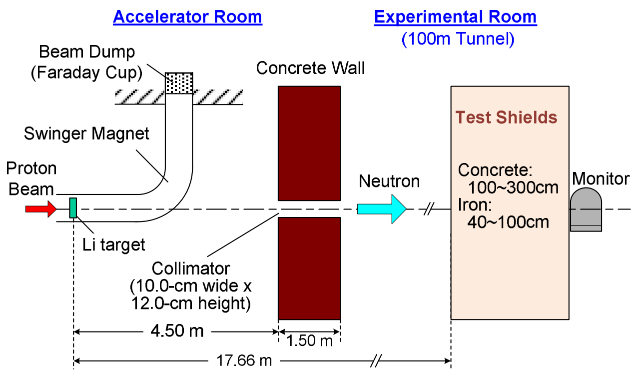

Figure 1: **Schematic View of the Experimental Arrangement at RCNP**

experiments were listed in Table 1. Neutron dose rates were measured with four kinds of neutron monitors placed behind the test shields.

Material	Density ($g\ cm^{-3}$)	Element	Atomic density ($10^{22}\ cm^{-3}$)
Concrete	2.31	Hydrogen	1.498
		Oxygen	4.188
		Sodium	0.123
		Magnesium	0.062
		Aluminum	0.312
		Silicon	1.110
		Potassium	0.038
		Calcium	0.430
		Iron	0.141
Iron	7.87	Iron	8.487

Table 1: **Atomic Densities of the Test Shields**

The energy spectra of source neutrons were shown in Figure 2. The spectra have been measured[(3)] by the TOF methods with three sizes of NE213 liquid organic scintillation detectors (25.4 x 25.4 cm2 for neutrons above 100 MeV, 12.7 x 12.7 cm2 for neutrons from 10 to 100 MeV, and 5.08 x 5.08 cm2 for neutrons below 10 MeV in diameter and length).

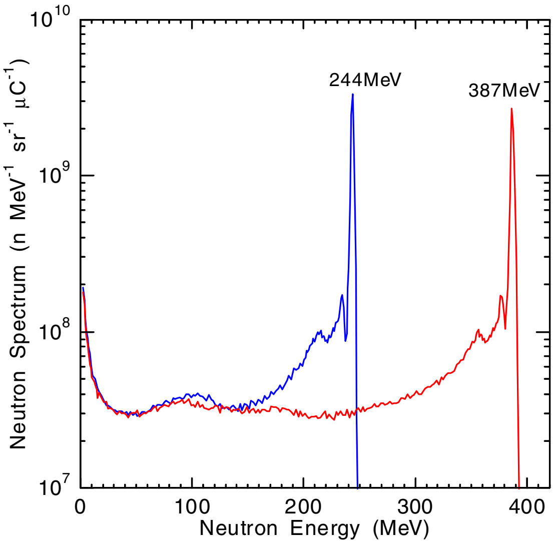

Figure 2: **Energy Spectra of Source Neutrons**[(3)]

2. Neutron Dose Equivalent Monitors

Table 2 shows the neutron dose equivalent monitors used in the present work. Four monitors, two kinds of modified Andersson-Braun type[(4)] monitors with lead or tungsten breeder(JAEA wide range[(5)] and WENDI[(6)]), a liquid organic scintillator type monitor with the response functions applied for high-energy neutron dose(DARWIN[(7)]), and a conventional Andersson-Braun type rem monitor(ALNOR), were used for the measurements. In our previous work, energy responses of these monitors have been measured[(8)] for 134-, 197-, 244- and 387-MeV quasi-monoenergetic neutron fields at the RCNP. Three monitors except the conventional rem monitor were wide-energy range type, and designed for applying to measure dose rate for high-energy neutrons above 20MeV. The JAEA wide range monitor was developed for applying to neutron monitoring for high-energy proton accelerator facility, J-PARC[(9)], and products of the monitor have been stationed in the facility for monitoring neutron dose rates. Because the monitor responses do not underestimate dose rates at high-energy neutron fields, the monitor was designed that the energy responses reproduced the neutron flux-to-dose conversion coefficients for ambient dose equivalent, H*(10)/φ, for the energy below 20 MeV, and effective dose[(10)], E/φ, for the energy above 20 MeV.

III. Results and discussions

1. Comparisons of measured results

Figure 3 shows the measured results of dose rates through the concrete shields for the 244- and the 387-MeV sources. Measured results of neutron dose were normalized to proton beam charge (Coulomb) of beam dump shown in Figure 1. In the figure 3, lines show the interpolation of measured results. It was found from the figure that the measured results of the conventional type rem monitor (ALNOR) are smaller than those of all the wide-energy range monitors, about an order smaller at the 100-cm-thck concrete shields for both the 244- and the 387-MeV sources. For the comparison with the wide-energy range monitors, the results are in agreements one another in less than two. The tendency of attenuations for the measurements of the JAEA wide range monitor was quite larger than those of other wide-energy range monitors (DARWIN and WENDI). This is ascribed to the differences of reproducing the flux-to-dose conversion coefficients on the design for neutrons above 20

Monitor	Detector type	Data of Andersson-Braun type: Counter	Data of Andersson-Braun type: Breeder for high-energy neutron	Data of Andersson-Braun type: Shape	Wide-energy range	Reproduced dose conversion coefficients: ≤ 20MeV	Reproduced dose conversion coefficients: > 20MeV
JAEA wide range	Modified Andersson-Braun	^3He	Lead	Spherical	yes	H*(10)	*E*
WENDI	Modified Andersson-Braun	^3He	Tungsten	Cylindrical	yes	H*(10)	H*(10)
DARWIN	Liquid organic scintillator	---	---	---	yes	H*(10)	H*(10)
Alnor(Studsvik) 2202D	Andersson-Braun	BF_3	none	Cylindrical	no	H*(10)	---

Table 2: **Neutron Dose Equivalent Monitors Used in the Present Work**

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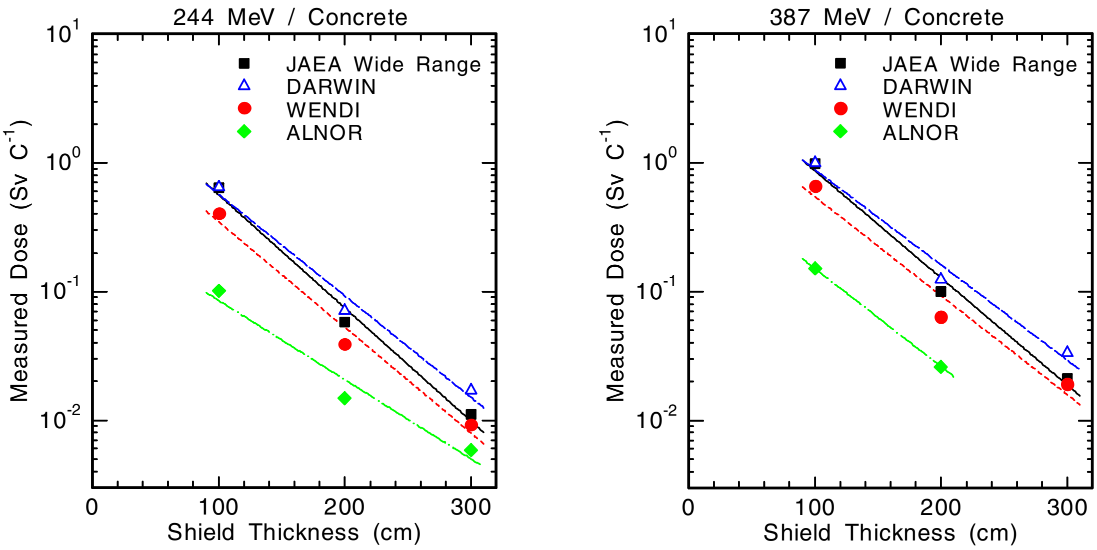

Figure 3: **Measured Results of Dose Rates through the Concrete Test Shields**

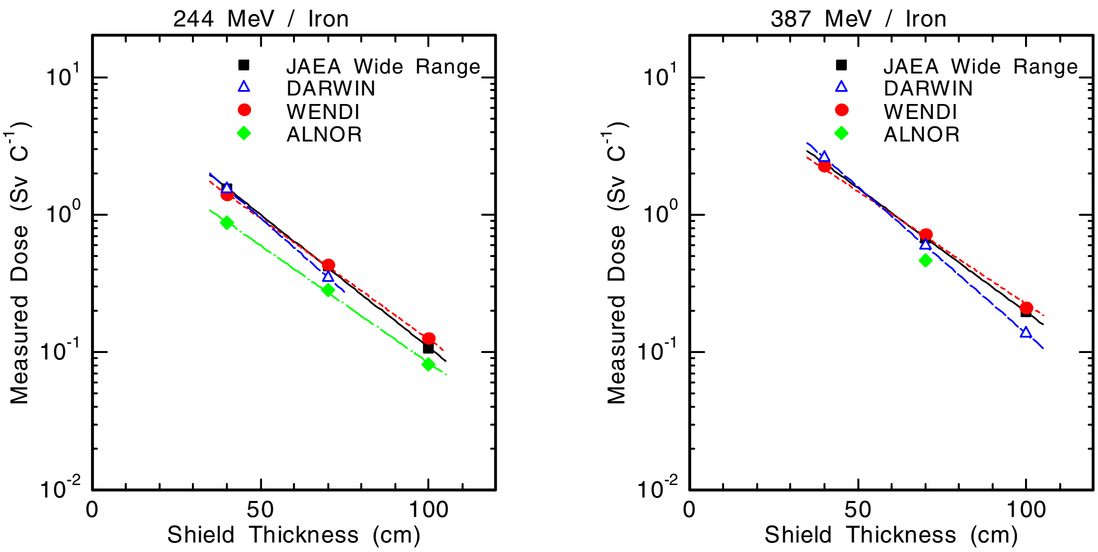

Figure 4: **Measured Results of Dose Rates through the Iron Test Shields**

MeV shown in Table 2.

Figure 4 shows the results of dose rates through the iron test shields for the 244- and the 387-MeV sources. The results of the wide-energy range monitors are in good agreement one another within 30% on the whole. The tendency of attenuations for the measurements of DARWIN was quite larger than those of other wide-energy range monitors (JAEA wide range and WENDI). The results of the conventional type monitor are about half of those of the wide-energy range monitors, not depend on the thickness of the shields and the energy of source neutrons. For the measurements through the iron shields, the differences between the conventional type monitor and the wide-energy range monitors are smaller than those for the concrete shields. It is because that low energy neutrons are dominant for the energy spectra through the iron shields.

2. Attenuation Lengths

The attenuation lengths obtained from the measured results with the four monitors are listed in Table 3. In the table, the attenuation lengths obtained from only two data are shown in italic letter without a standard deviation. For the concrete shields, the attenuation lengths obtained from the measurements of the three wide-energy range monitors are 114~127 and 120~136 (g cm^{-2}) for the 244- and the 387-MeV source, respectively. For the conventional type rem monitor, the length is larger than those of the wide-energy range monitors for the 244-MeV source. On the other hand, that is in agreement for the 387-MeV source. It is guessed that the length is obtained from the measurements only for 100-cm and 200-cm thick shields for the 387-MeV source, of which the tendency of the attenuations of the conventional type monitor is in agreement with that of the wide-energy range monitors. For the iron shields, the attenuation lengths for all the monitors are 159~200 and 160~209 (g cm^{-2}) for the 244- and the 387- MeV source, respectively. The lengths of ALNOR, JAEA wide range and WENDI are in agreement, while that of DARWIN is smaller than those of other monitors. For the comparison with the concrete and the iron shields, the attenuation lengths for the iron shields are larger than those for the concrete shields. These values are almost same as those from others measured(11-13) at CERN, KEK and ISIS for several hundred MeV neutron fields.

Monitors	Attenuation Length (g cm^{-2})			
	Concrete Shield		Iron Shield	
	244 MeV	387 MeV	244 MeV	387 MeV
JAEA Wide Range	114 ± 12	120 ± 13	177 ± 3	190 ± 0
WENDI	122 ± 17	130 ± 24	194 ± 2	209 ± 11
DARWIN	127 ± 16	136 ± 18	*159*	160 ± 0
ALNOR	163 ± 34	*132*	200 ± 5	---

Table 3: **Attenuation Lengths of Doses Measured with the monitors**

V. Conclusion

Shielding benchmark experiments were carried out for the 244- and the 387-MeV quasi-monoenergetic neutron fields at RCNP of Osaka University. Neutron dose rates through the concrete and the iron test shields were measured by four kinds of neutron dose equivalent monitors placed behind the test shields. The results measured with the wide-energy range monitors are in agreements one another both for the concrete and the iron test shields. For the conventional type rem monitor, the results are smaller than those with the wide-energy range monitors for the concrete shields, while those are in agreement for the iron shields. The attenuation lengths were obtained from the measurements for the concrete and the iron shields, and the results are almost same as those from others for several hundred MeV neutron fields.

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