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Measurements of Neutron Attenuation through Iron and Concrete at ISIS

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A deep penetration experiment through a thick bulk shield was performed at an intense spallation neutron source facility, ISIS, of the Rutherford Appleton Laboratory. ISIS is an 800MeV-200 μ A proton accelerator facility. Neutrons are produced from a tantalum target, and are shielded with approximately 3m thick iron and 1m thick ordinary concrete. On the top of the shield, we measured the neutron flux attenuation through concrete and iron shields which were additionally placed up to 1.2 m and 0.6m thicknesses, respectively, using activation detectors of carbon, aluminum and bismuth, and also indium-loaded multi-moderator spectrometer. The dose attenuation was simultaneously measured with the neutron and photon survey meters. The attenuation lengths of concrete and iron for high energy neutrons above 20MeV were obtained from the $^{12}\text{C}(n,2n)$ reaction of carbon, and the neutron spectra penetrated through the additional shield and on the target shield top were obtained from the $^{12}\text{C}(n,2n)$, $^{27}\text{Al}(n,\alpha)$ and $^{209}\text{Bi}(n, xn)$ reactions, and multi-moderator spectrometer.

We are now analyzing the measured results to compare with the shielding calculation.

KEYWORDS: 800MeV proton, Spallation neutron source, Attenuation length, Activation detector, Concrete, Iron, Deep penetration

I. Introduction

Shielding design is important for the construction of an intense high energy accelerator facility, since the cost for the radiation shielding contributes a considerable part of the total cost. Most shielding design for high energy accelerators has been generally performed by using a point kernel method, that is the Moyer model, which is based on single exponential attenuation of neutron dose equivalent after penetrated through a thick shield to be in a spectral equilibrium state. In this deep penetration problem, the dose attenuation length which is ruled by high energy neutrons above about 100MeV is essentially important in the Moyer model. Neutron shielding experiments at several accelerator facilities have ever been performed to get the attenuation length, but the reliable experimental data penetrated through a very thick shield are still very scarce and dispersed.^{1),2)}

Since 1992 the shielding experiments of deep penetration have been performed at an intense spallation neutron source

facility, ISIS, of the Rutherford Appleton Laboratory (RAL)³⁾. We measured the neutrons penetrated through an additional shielding of iron and concrete which were put upon the top of neutron source shield consisting of approximately 3m iron and 1m ordinary concrete to obtain the attenuation length of high energy neutrons⁴⁾. But it was found that the additional shields were too small to decrease the background neutrons. In this succeeding study, we used the larger additional shields for better experimental geometry to decrease the background neutrons.

This benchmark shielding experiment at an intense high energy accelerator facility will also give useful informations for estimating the accuracy of the transport calculation for deep penetration.

II. Experiment

1. ISIS Facility

The experiment was performed at the ISIS spallation neutron source facility, RAL. The ISIS facility consists of 70MeV H linear accelerator, 800MeV proton synchrotron and a spallation neutron target station. The beam intensity was about 170 μ A at the target with 50Hz repetition rate.

A cross sectional view around the target station along the 800MeV proton beam axis is shown in Fig. 1. The tantalum target is placed at the center of the helium-filled stainless-steel vessel. The moderators and reflectors to produce thermal and cold neutrons are placed around the target.

The spallation target is shielded with approximately 3m thick iron and 1m thick ordinary concrete. This experiment was per-

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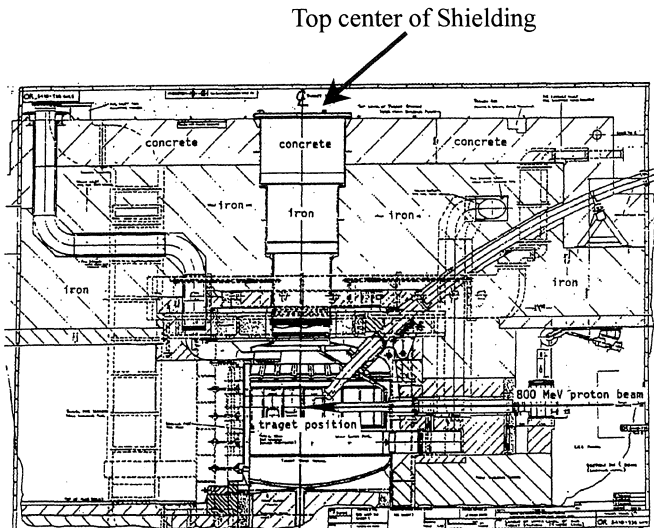


Fig. 1 Cross sectional view along the beam axis of the ISIS target station

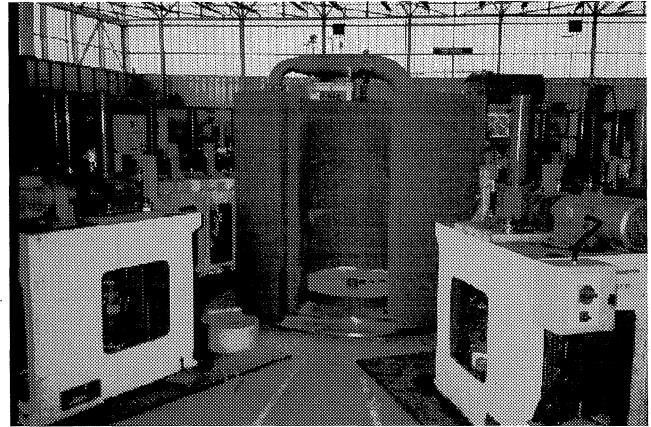


Fig. 2 A graphical view of the shielding experiment on the shield top of the ISIS target station. The igloo and the additional shield can be seen.

Table 1 Physical properties of activation detectors

Reaction	Detector Type	Detector Size Diam—Thick [mm]	Average Mass [g]	Half life	Threshold energy [MeV]
$^{12}\text{C}(n,2n)^{11}\text{C}$	Disk	80—30	265.6	20.4 min	20.40
$^{27}\text{Al}(n,\alpha)^{24}\text{Na}$	Marinelli	See Fig.4	901.7	"	"
$^{209}\text{Bi}(n,10n)^{200}\text{Bi}$	Marinelli	See Fig.4	1425	11.8 min	3.247
$^{209}\text{Bi}(n,9n)^{201}\text{Bi}$	Disk	80—11	529.6	36.4 min	70.89
$^{209}\text{Bi}(n,8n)^{202}\text{Bi}$	"	"	"	1.77 hr	61.69
$^{209}\text{Bi}(n,7n)^{203}\text{Bi}$	"	"	"	1.67 hr	54.24
$^{209}\text{Bi}(n,6n)^{204}\text{Bi}$	"	"	"	11.76 hr	45.37
$^{155}\text{In}(n,\gamma)^{156\text{m}}\text{In}$	"	"	"	11.22 hr	38.13
	Sphere	14.7	2.875	54.1 min	thermal

formed at the top of the shield just above the target station. As seen in Fig.1, a big bent duct in which the helium gas flows for target cooling reaches the shield top through the bulk shield downstream from the target.

2. Shielding Materials

In this shielding experiment, the additional shielding blocks of ordinary concrete and iron were placed upon the top center of the bulk shield just above the target as shown in Fig. 2. Concrete shields of 20-,40-,60-,80-,100-, and 120-cm thicknesses were assembled by using the 119-cm diam by 20-cm thick blocks of 2.33g/cm³, and iron shields of 10-,20-,30-,40-,50- and 60-cm thicknesses were assembled by using the 119-cm diam by 10-cm thick blocks of 7.8 g/cm³.

3. Detectors

The neutrons were produced from the target as the burst pulses corresponding to the 50Hz synchrotron operation, and the pulse counters could not be used here because of the pulse pile-up problem.

We therefore used the activation detectors listed in Table1. The γ rays from the activation detectors after irradiation in this experiment were measured with two HP Ge detectors (GC-1818

and GC-2020, Canberra Industries, Inc.).

We also used the ionization-type neutron (Rem Ion Monitor by Harwell Co. Ltd.) and γ ray (R02 by Eberline Co. Ltd.) survey meters to measure the dose equivalent data behind the shield.

(1) $^{12}\text{C}(n,2n)^{11}\text{C}$ activation detector

The $^{12}\text{C}(n,2n)^{11}\text{C}$ reaction has the half life of about 20 min and the threshold energy of about 20MeV, which is a shortly-activated good neutron flux monitor of energy above 20MeV. The reaction cross section has recently been measured by our group.⁵⁾ as shown in Fig. 3 and has almost constant value of about 20mb above 20MeV. The disk type, 8cm diam by 3cm thick, and the Marinelli type shown in Fig. 4, detectors were used in this experiment mainly for measuring the spatial neutron flux distribution on the shield top and in the additional concrete and iron shields.

(2) $^{27}\text{Al}(n,\alpha)^{24}\text{Na}$ activation detector

The $^{27}\text{Al}(n,\alpha)^{24}\text{Na}$ reaction has the half life of about 15 hours and the threshold energy of about 5MeV. We used the same size detector as the carbon Marinelli detector (Fig.4).

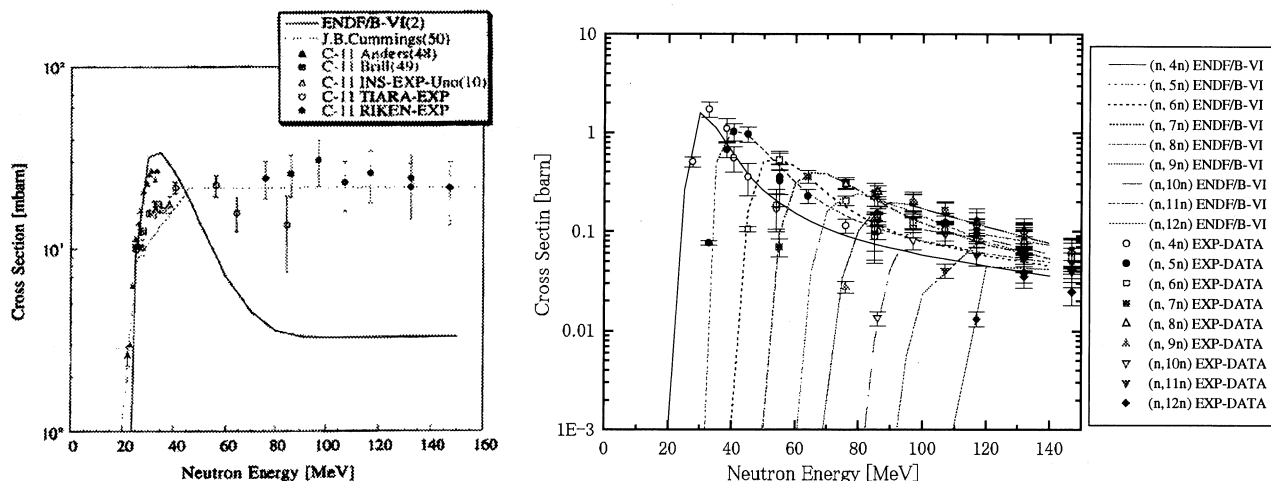


Fig.3 Cross section of $^{12}\text{C}(n,2n)^{11}\text{C}$ reaction and $^{209}\text{Bi}(n,xn)$ reaction

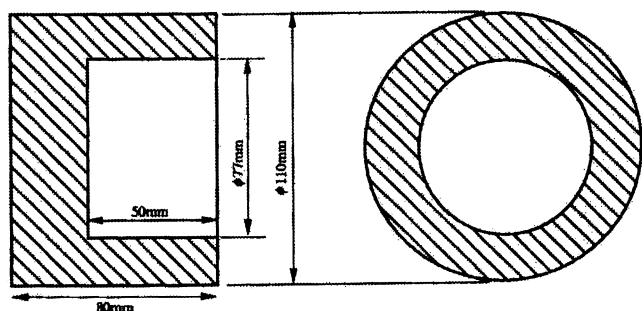


Fig.4 Cross sectional view of the Marinelli detector

(3) $^{209}\text{Bi}(n,xn)$ activation detector

The bismuth detector was used to get the high energy neutron spectrum by using the $^{209}\text{Bi}(n,6n)^{204}\text{Bi}$ to $^{209}\text{Bi}(n,10n)^{200}\text{Bi}$ read. Their threshold energies are from 38MeV to 70MeV as seen in Table 1.

(4) Indium-loaded multi-moderator spectrometer

The In_2O_3 powder of 2.875g is sealed in a spherical cavity of a small Lucite cylinder which is placed in the center of a spherical polyethylene moderator.⁴⁾ Five different moderators of 9.8-, 5.5-, 3.2-, 2.0- and 0-cm radius were used. This spectrometer was mainly used to measure the neutron energy spectrum in the energy region below 10MeV.

4. Experimental Procedure

This experiment was performed during the beam time of about six weeks from 29th of September to 7th of November by changing the thickness of iron and concrete shields. The activation detectors were set upon the shield for irradiation, and then γ rays from them were measured with two HP Ge detectors. In order to get good statistics of photo-peak counts, repeated irradiations and activity measurements were performed for each shielding material and thickness several times a day, and the photo-peak counts in the same condition were summed up to get the reaction rates.

The peak efficiencies of the Ge detectors including the self-

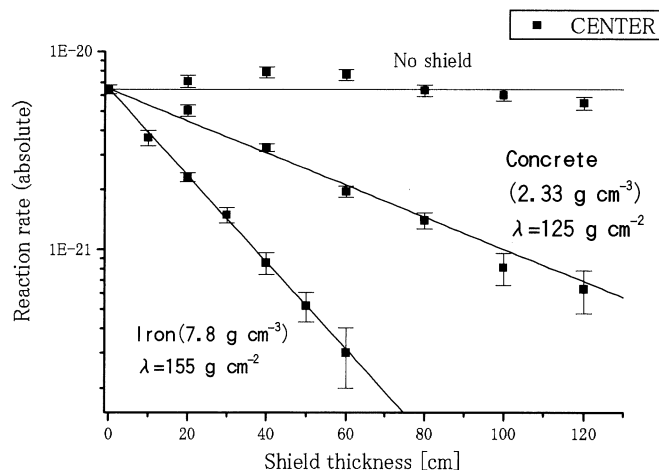


Fig. 5 Reaction rate of $^{12}\text{C}(n,2n)^{11}\text{C}$ reaction on the additional iron or concrete shield on the shield top

absorption effect were estimated by using the EGS4 Monte Carlo code⁶⁾.

The relative proton beam current was monitored by the electromagnetic coil voltage at the muon target during the experiment. These data were converted to the beam current (Coulomb) and used in the analysis of the activation detectors.

III. Results and Discussions

Figure 5 shows the attenuation profiles of the ^{11}C production rates by the $^{12}\text{C}(n,2n)^{11}\text{C}$ reaction with the iron and concrete thicknesses. The errors of the results are the statistical errors of the photo-peak counts of the 511keV γ rays. This figure also gives the spatial distribution along the vertical axis of the bulk shield upward from the tantalum target without any additional shield on the shield top. These three curves are the results on the center of this vertical axis. The data without additional shield (No shield) keep almost constant with the shield thickness, which means that the neutrons penetrated through the bulk shield are approximate to form a uniformly spread parallel beam around the center axis. The attenuation lengths of this reaction rates correspond to those for neutron flux above

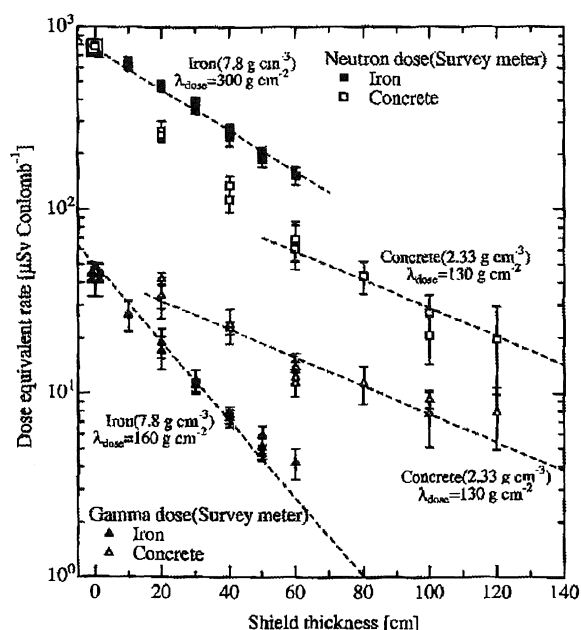


Fig. 6 Attenuation profiles of the neutron and γ ray dose equivalents measured with the survey meters with the additional shield thickness

20 MeV, and are 155 g/cm² for iron (7.8 g/cm³) and 125 g/cm² for concrete (2.33 g/cm³). These values are just between the results given by Stevenson et al.¹⁾ and Ban et al.²⁾ as seen in Table 2.

Figure 6 gives the attenuation profiles of the neutron and γ ray dose equivalents measured with the survey meters with the additional shield thickness. This attenuation profiles correspond to those for lower energy neutrons. The attenuation lengths of concrete for $^{12}\text{C}(n,2n)^{11}\text{C}$ reaction rate, neutron and γ ray dose equivalents are quite close altogether to 1/E slowing-down spectrum in an equilibrium state, and the γ rays which are dominantly produced by high energy neutrons also approach to the neutron attenuation profile. On the contrary, the attenuation length of iron for neutron dose equivalent is much larger than

those for $^{12}\text{C}(n,2n)$ reaction rate and γ ray dose equivalent. This indicates that the neutron dose equivalent includes a large fraction of low energy neutrons in keV region which appear through the transmission of iron shield.

IV. Conclusion

The deep penetration experiment was performed at the ISIS neutron source using the 800 MeV proton synchrotron. The shielding configuration is rather simple and the measured attenuation lengths of iron and concrete are the good benchmark data for investigating the accuracy of deep penetration calculation.

We are now performing to analyze the measured data to get the neutron spectrum through the shield and to compare with the shielding calculation.

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