DOI: 10.15669/pnst.4.197

Progress in Nuclear Science and Technology
Volume 4 (2014) pp. 197-200

ARTICLE

Measurement and analysis of neutron and photon dose rate in concrete shield of 120-GeV proton accelerator facility

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The dose rate measurements of neutrons and photons by using dosimeter (Quixel badge) have been performed in the concrete shield at the 120 GeV anti-proton production facility (AP0) in Fermi National Accelerator Laboratory. The concrete shield was established backward of 183 cm thick iron shield. The thickness of the concrete shield was 122 cm. The dosimeters were set in the concrete shield at 0, 15, 30, 45, 60, 90 and 120 cm from the front surface. The proton beam intensities varied from 2.40x10^{12} to 5.18x10^{17} (protons/sec) according to the sensitiveness of the dosimeters. The calculations of dose rate in the concrete shield have also been performed by using PHITS-2.24 calculation code with its related cross section library JENDL3.3. From the comparisons between measured and calculated results, good agreements within factor 2 were obtained in the case of photons. However, some disagreements were observed in the case of neutrons, especially near the front surface up to 15 cm. These discrepancies might be caused by the estimation of neutron dose rate and/or detector resolution around 100 keV.

Keywords: high-energy accelerator; 120 GeV proton; dose rate; concrete shield; PHITS code

1. Introduction

The simple calculation methods were applied for the shielding design of high energy accelerator facilities. One the other hand Monte Carlo calculation code system, such as MCNP and PHITS, are widely used for the shielding calculation of complex geometry. In the case of clean geometry, relatively complete data are now available, but there is only a few benchmark data in the complex geometry [1-4].

Benchmark experiment for PHITS calculation code has been performed under the Japanese and American Study of Muon Interaction and Neutron detection (JASMIN) collaboration with the high energy particle beams at the Fermi National Accelerator Laboratory (FNAL) [5].

In this study, the spatial distributions of dose rate in concrete shield placed in the complex geometry were measured to obtain the experimental data for high energy secondary particle transport from Pbar target at FNAL bombarded by high energy protons. The measured results were compared with the calculated ones to verify the calculation code system PHITS [6] for the practical accelerator facility.

2. Experiment

2.1. Assembly

The cross sectional view of the Pbar target station is shown in **Figure 1**. The target made of inconel and copper disks covered with beryllium case were bombarded by 120 GeV protons. The proton beam intensities varied from 2.40x10^{12} to 5.18x10^{17} (protons/sec) according to the sensitiveness of the dosimeters. There existed a correction lens, collimator and a pulsed magnet in the downstream of the target. They are placed to focus, collimate, and extract the produced antiprotons. The remaining protons and secondary particles are absorbed by the dump placed in downstream of the pulsed magnet.

Iron and concrete shields are placed upper side of the target station. The thickness of iron and concrete above the target are 188 cm and 122 cm, respectively. There also existed air gap of 179 cm height between the iron and concrete shields. The distance between target and iron shields is 46 cm.

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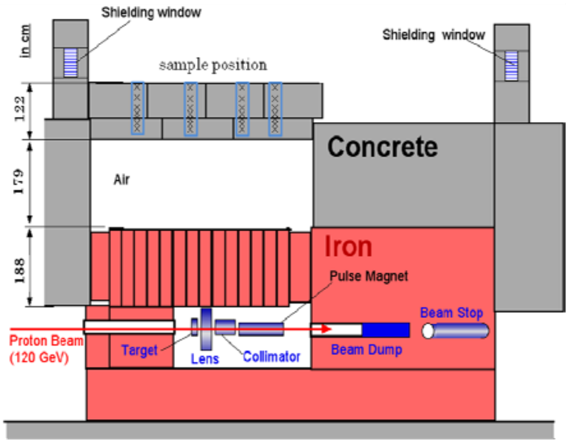

Figure 1. Cross sectional view of the Pbar target station.

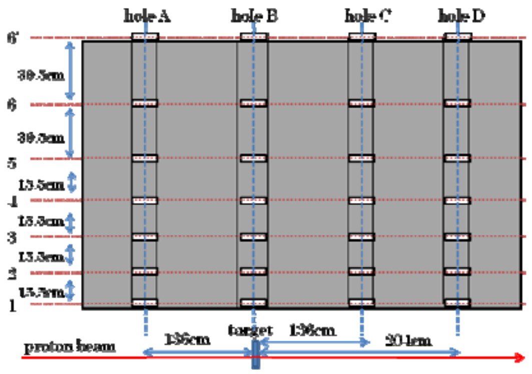

Figure 2. Positions of installed detectors in concrete shields.

Figure 2 shows the position of installed detectors in concrete shields. There were 4 holes which were placed just above the target for the hole B. The other holes were placed 136 cm upstream and 136 cm, 204 cm downstream from the target for holes A, C, D, respectively. The diameter of the hole was 14 cm. The small cylinder cans filled with concrete were prepared. Their heights were 15cm and 30cm. The dosimeters were set between these small cylinder cans. Seven dosimeters were installed to each hole.

2.2. Detectors

The detectors we have applied were OSL (Optical Stimulated Luminescence) and CR-39 Alloy Diglycol Carbonate plastic for photons and neutron, respectively. These detectors were supplied by Nagase-Landauer Co., Ltd. The dynamic ranges of measured dose were 0.1mSv~10Sv and 0.1mSv~50mSv for photons and neutrons, respectively. For neutrons we have examined the results which energy was greater than 100 keV.

3. Calculation

Calculations have been performed by using 3-dimensional Monte Carlo calculation code PHITS [6]. JENDL3.3 nuclear data library was applied for neutron and proton which energy is lower than 20 MeV. Internal cross sections in PHITS code were used for energy greater than 20 MeV. The energy of source proton was 120 GeV. The target assembly, beam dump and so forth were included in the calculation geometry and shown in **Figure 3**. The composition of concrete assembly was analyzed by chemical analysis and listed in **Table 1**. The flux to dose conversion factor was based on ICRP-74.

The FSD of calculated results were less than 5% at all detector positions.

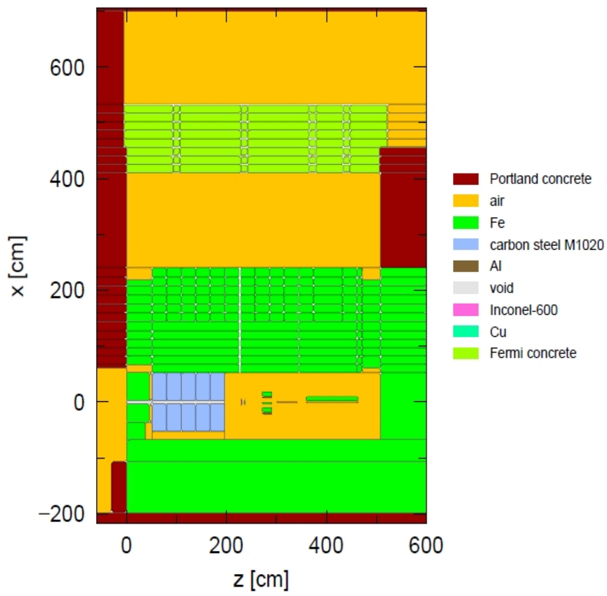

Figure 3. Geometry for calculation.

Table 1. Composition of concrete assembly.

Element	Wt%	Element	Wt%
H	0.93	Si	7.04
C	8.40	Si	0.31
O	49.17	K	0.22
Na	0.08	Ca	24.10
Mg	7.11	Fe	0.73
Al	1.46	total	99.55

4. Experimental results and comparison with calculated ones

Figure 4 shows the experimental and calculated results for each hole. The horizontal axis is the distance from the bottom of the concrete assembly. The vertical axis is dose rate and the unit is Sv/proton.

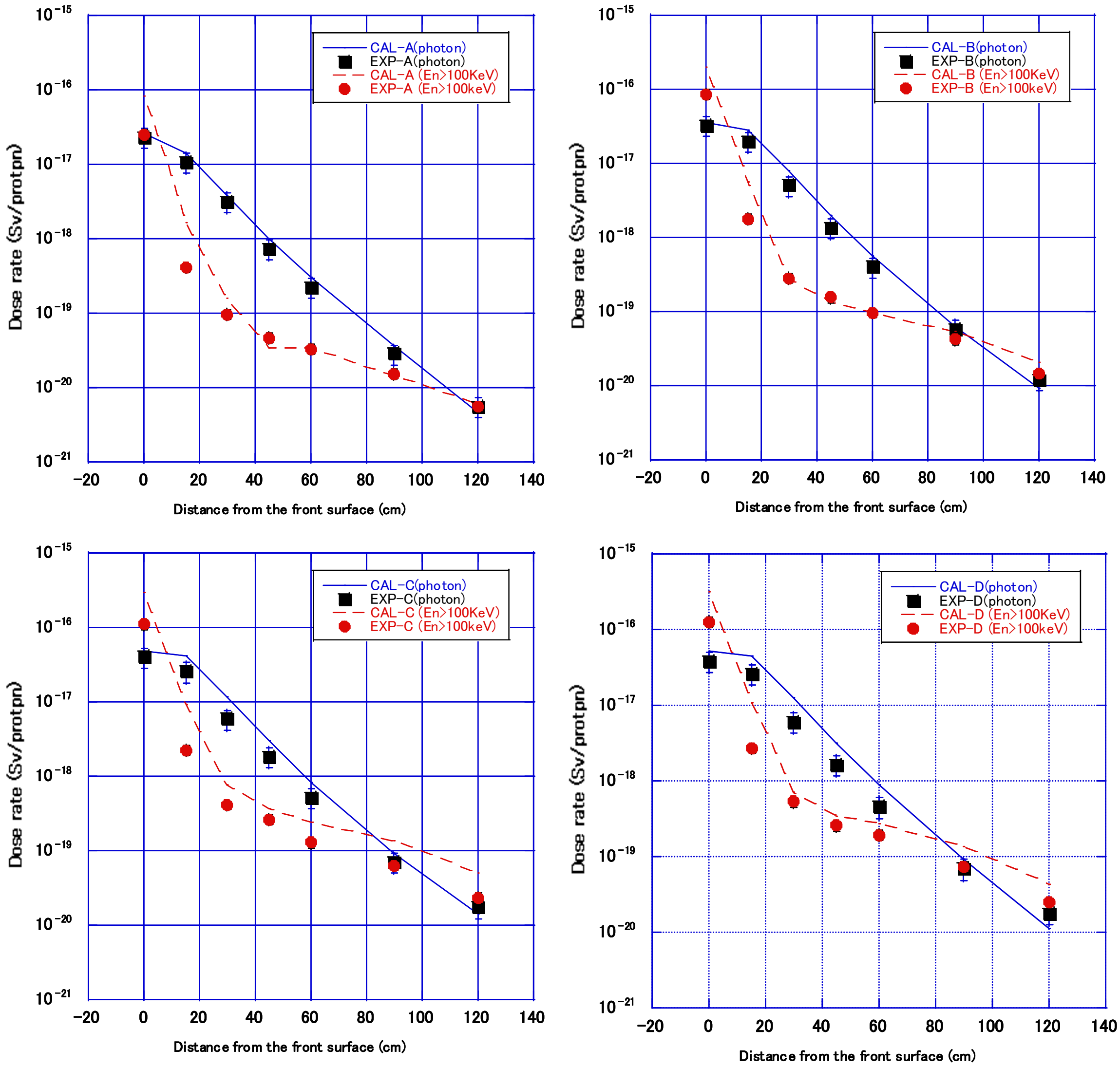

Figure 4. Experimental and calculated results of dose rate for each experimental hole.

4.1. Photons

The attenuation tendencies of all holes were exponential. Calculated results reproduced experimental ones very well, though some overestimation was observed for the forward angle experimental holes and underestimation for 120 cm position.

4.2. Neutrons

The dose rate distribution composed of two constitutions. The inclination became discreasing slope since the high energy components became dominant when the distance of the detector position greater than 30 cm. Discrepancies have been observed near the bottom of the concrete assembly. Some overestimation have been observed for the forward angle of the experimental holes.

4.3. Calculational to experimental ratio

Calculational to experimental ratio (C/E) for photons and neutrons are shown in **Figure 5** and **Figure 6**, respectivey. The horizontal axis is the detector positions and verticle one is C/E.

For photons, good agreements have been obtained from 0.7 to 1.7 within experimental errors.

For neutrons, good agreements have also been obtained between 0.7 to 1.7 within experimental errors, except detector positions at 0 cm and 15 cm. **Figure 7** shows the calculated neutron energy spectra at each detector position for hole B. Since the neutron population around 100 keV at d = 0cm and 15 cm positions is very large in comparison with high energy neutron, the disagreement would be caused by the estimation of neutron dose rate and/or detector resolution around neutron energy 100 keV.

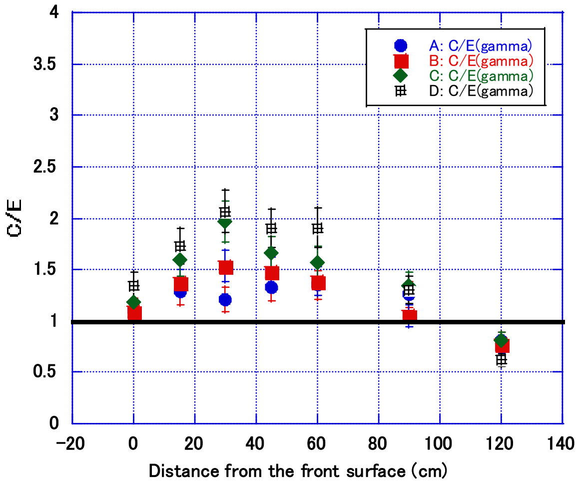

Figure 5. C/E ratios for photons.

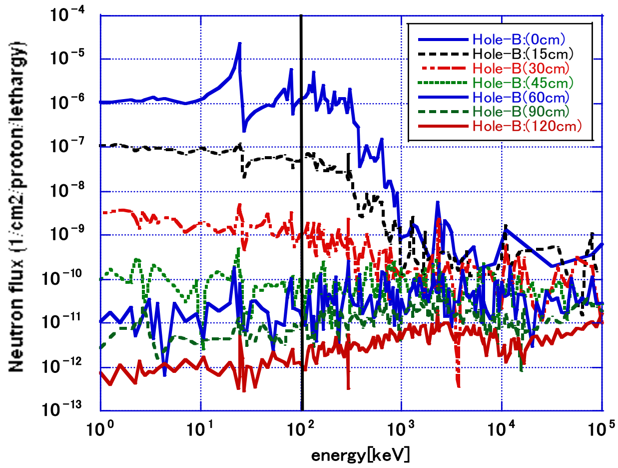

Figure 7. Calculated neutron spectra for each experimental hole.

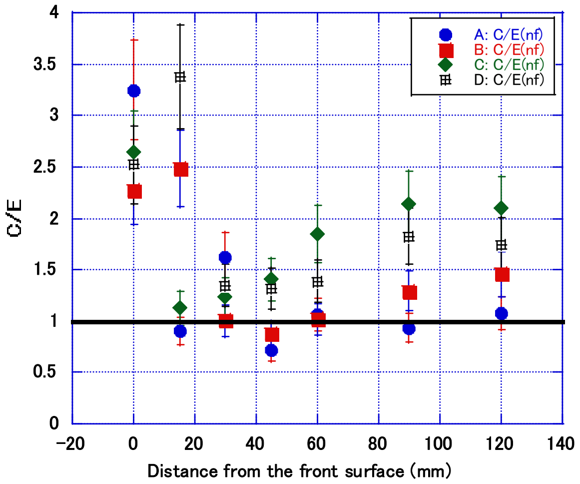

Figure 6. C/E ratios for neutrons.

5. Summary

Measurements of dose rate distributions of induced photons and neutrons (En>100keV) by the 120 GeV protons bombarded inconel target in the complex geometry have been performed and have compared with calculated results by PHITS.

Good agreements have been obtained except near the front surface of the concrete assembly for neutrons. Disagreement would be caused by the estimation of neutron dose rate and/or detector resolution around 100 keV.

It is concluded that PHITS calculation code system is quite available even for the complex geometry in the shielding design calculations, though being a somewhat overestimation.

References

[1] T. Sanami, Y. Iwamoto, N. Shigyo et al., Shielding experiments at high energy accelerators of Fermilab (I) - Dose rate around high intensity muon beam, *Prog. Nucl. Sci. Technol.* 1 (2011) pp.44-47.

[2] H. Yashima, Y. Kasugai, N. Matsuda et al., Shielding experiments at high energy accelerators of Fermilab (II) - Spatial distribution measurement of reaction rate behind the shield and its application for Moyer model, *Prog. Nucl. Sci. Technol.* 1 (2011), pp.48-51.

[3] M. Hagiwara, T. Sanami, Y. Iwamoto et al., Shielding experiments at high energy accelerators of Fermilab (III) - Neutron spectrum measurements in intense pulsed neutron fields of the 120-GeV proton facility using a current Bonner sphere technique, *Prog. Nucl. Sci. Technol.* 1 (2011), pp.52-56.

[4] N. Matsuda, Y. Kasugai, H. Matsumura et al., Shielding experiments at high energy accelerators of Fermilab (IV) - Calculation analysis, *Prog. Nucl. Sci. Technol.* 1 (2011), pp.57-60.

[5] H. Nakashima, Y. Sakamoto, Y. Iwamoto et al., Experimental studies of shielding and irradiation effects at high-energy accelerator facilities, *Nucl. Technol.* 168(2), 482(2009).

[6] K. Niita, N. Matsuda, Y. Iwamoto, H. Iwase, T. Sato, H. Nakashima, Y. Sakamoto and L. Sihver, PHITS: *Particle and Heavy Ion Transport Code System*, Version 2.23, JAEA-Data/Code 2010-022, Japan Atomic Energy Agency (JAEA), (2010).