Nuclear Inst. and Methods in Physics Research B 429 (2018) 27–33

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research B

journal homepage: www.elsevier.com/locate/nimb

Neutron energy spectrum measurement using an NE213 scintillator at CHARM

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ARTICLE INFO

Keywords:
CHARM
Neutron energy spectrum
Fluence
NE213 scintillator
Unfolding

ABSTRACT

To establish a methodology for neutron spectrum measurement at the CERN High energy AcceleRator Mixed field facility (CHARM), neutron spectra were measured using an NE213 scintillator on top of the CHARM roof shielding where is the CERN Shielding Benchmark Facility (CSBF). The spectra were derived as fluences into the scintillator by the unfolding method using an iterative Bayesian algorithm. The methodology was verified based on the agreement of two spectra measured for different positions and directions of incident neutrons by changing the detector orientation. Since the spectra on the roof-top were obtained within a reasonable beam-time, this methodology is suitable for measuring the spectrum when there is less shielding material. Thus, experimental data for neutron transition can be obtained as a function of shielding thickness using this facility.

1. Introduction

The energy spectra and attenuation lengths of secondary neutrons, which are generated through hadronic cascade reactions in a target, in a beam line tunnel, and shielding structure are of primary importance for the shielding design of high-energy and high-power hadron accelerators. These quantities have recently been estimated using Monte Carlo codes such as FLUKA [1,2], GEANT4 [3], MARS [4], and PHITS [5], which are based on theoretical models and parameters for not only a simple bulk geometry but also complex maze structures. For verification and validation of these codes, results of the codes should be examined through the comparison with experimental data obtained for an actual, well-defined geometry as well as models and parameters.

To date, several experiments have been performed to obtain the energy spectra and attenuation of secondary neutrons at high-energy accelerator facilities. Neutron energy spectra from several target materials have been measured for a 40 GeV/c mixed beams of protons and pions at the CERN-European Union High-Energy Reference Field (CERF) using Bonner spheres [6] and for 120 GeV protons at the MTest of the Fermi National Accelerator Laboratory (FNAL) using time-of-flight method with an NE213 scintillator [7–9]. Neutron energy spectra behind shielding have been measured at the CERF using Bonner spheres [10,11] and an NE213 scintillator [12] with the unfolding technique, and at the FNAL pbar using 120 GeV protons with Bonner spheres [13]. According to these experiments, there are notable differences between calculation and experimental results. To explore the reasons for these differences experimentally, a facility is needed to measure neutron energy spectra and attenuation under various-conditions, such as different target and shielding materials, and its thicknesses, with various types of neutron detectors.

The CERN High energy AcceleRator Mixed field facility (CHARM) has been constructed to evaluate the radiation hardness of devices and equipment subjected to secondary-particle fields from high-energy hadron cascade reactions [14,15]. It receives a proton beam with momentum of 24 GeV/c and adjustable intensity. The facility, consists of a large irradiation space inside its shielding enclosure, a remote-controlled target holder, four movable shielding walls, a maze structure for access to the irradiation space, and replaceable roof shielding blocks

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https://doi.org/10.1016/j.nimb.2018.05.024
Received 24 August 2017; Received in revised form 27 March 2018; Accepted 14 May 2018
Available online 22 May 2018

that are more than 3 m thick. Thus, this facility is suitable to obtain systematic data for neutron energy spectra and attenuation under various conditions.

In this study, we measured neutron spectra using an NE213 scintillator on top of the CHARM roof shielding where was the CERN Shielding Benchmark Facility (CSBF), to establish a methodology for neutron energy spectrum measurement at this facility. The top of the roof is located 6.75 m laterally above the target with a shielding structure. This corresponds to the maximum shielding condition for 90 degrees vertically to the beam axis. If neutron spectrum can be obtained under this condition within a reasonable beam-time, then the spectrum can be obtained when there is less shielding material, owing to sufficient beam intensity. The thickness of removable shield was estimated to be 170 cm for concrete under the same detector position and beam intensity of this measurement. This would mean that experimental data for neutron transition could be obtained as a function of the shielding thickness using this facility.

We chose an NE213 scintillator as the neutron detector since it provides a neutron spectrum in the energy range from several to a few hundred MeV. The unfolding technique was applied to deduce the neutron energy spectrum behind a shielding wall, where the time-of-flight technique was not applicable. Bonner spheres are another type of detector that could be used, as it covers the energy range from eV to MeV. There are overlaps in the energy range of both spectra. However, the spectrum obtained with an NE213 scintillator provides a more detailed shape in the energy range in which the physical models treat nuclear reactions in the calculation codes. Furthermore, higher energy neutrons are sources of lower energy neutrons, so the detailed spectrum in the higher energy range is important for validating the calculation results given by the codes.

2. Structure of CHARM from the viewpoint of a shielding experiment

CHARM was constructed in the Proton Synchrotron (PS) East Area hall. Fig. 1 shows a plan view of CHARM at beam line height, 125 cm above the floor. The target is located in the irradiation room, which has an approximately $5 \times 7 \times 3.6\ m^3$ (L × W × H) area enclosed by shielding walls made of marble, concrete, and iron. The 24 GeV/c proton beam bombards the target to produce a radiation field of secondary particles. The space around the target is used for irradiation of devices and equipment that are to be tested for radiation hardness. To control the intensity of the radiation field, the target holder with three targets and four plates of movable shield walls are installed in the irradiation space. A beam dump consisting of 8-m-thick iron is located 7.2 m downstream

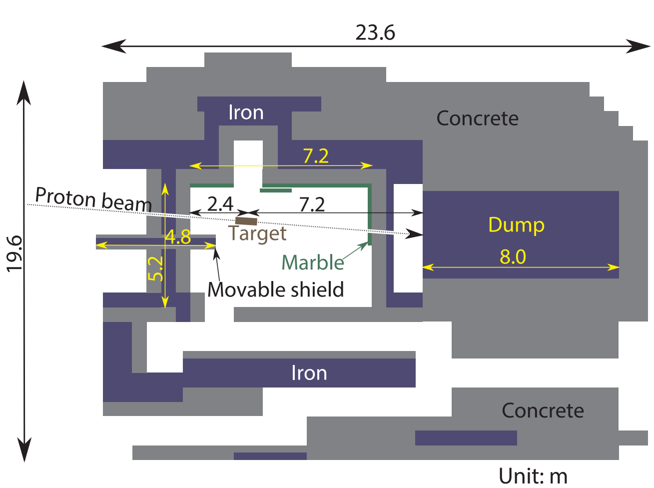

Fig. 1. Plan view of CHARM at beam-line height. The movable shield is set in the off-position in this experiment.

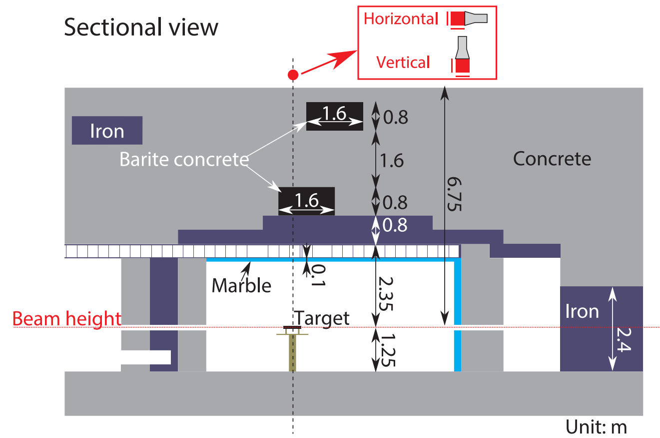

Fig. 2. Sectional view of CHARM on vertical plane of beam line. In this experiment, an NE213 scintillator was set on top of the CSBF that is integrated into the concrete shielding structure of CHARM.

from the target. A wall of concrete and iron with a beam hole is placed in front of the beam dump to avoid particle reflections. This arrangement enables measurement of the secondary particles directly from the target at an angle perpendicular to the primary beam.

The access corridor to the irradiation space has the maze structure to reduce the radiation leakage dose. The structure is suitable for collecting experimental data on the propagation of low-energy neutrons. These data should be useful as a reference for benchmarking Monte Carlo codes, since the radiation field at the entrance of the maze should be well known because of the simple target, the simple room structure, and less reflection from the beam dump.

Fig. 2 shows a sectional view of CHARM on vertical plane along the beam-line. The CSBF is integrated into the roof shielding of CHARM [15]. The roof shielding above the target consists of a 40-cm-thick iron block, an additional 40-cm-thick iron block, and concrete blocks. By removing or replacing the additional iron and concrete blocks, neutron attenuation data can be obtained for quite simple shielding structures consisting of 40-cm-thick iron and material with a thickness between 0 and 3.6 m.

The 24 GeV/c primary proton beam from the PS is transported through the air to the target. The intensity of the beam is 5×10^{11} protons per spill. Each spill has typically a duration of 350 ms. The spills belong to a super-cycle of the PS, and are supplied to not only CHARM but also other facilities. Protons are injected into CHARM at a rated of up to 6.7×10^{10} protons/s. The number of protons in a spill can be reduced down to 10% or less to mitigate the count rate of a secondary particle detector for an experiment.

The beam parameters are monitored using several devices installed along the beam-line. The beam intensity is recorded spill by spill using a secondary emission chamber (SEC) [16]. The SEC is installed right after the extraction port from the PS. The number of protons incident on the target, can be deduced by multiplying the count of the SEC by a calibration factor of 1.87×10^7 (protons/count) [17]. The beam position and size are monitored in real time by four beam profile monitors (BPMs) consisting of 40-channel metal foil detectors. The BPMs are placed on the beam-line more than 8 m upstream of the target.

In summary, the facility has the potential to allow us to measure the experimental data of secondary particles originating from 24 GeV/c protons for both direct exposure and attenuation by concrete with thickness of up to 3.6 m.

3. Experiment

3.1. Experimental setup

The neutron detector, a $\Phi 12.7 \times 12.7\ cm^3$ NE213 scintillator