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Neutron irradiation field produced by 25 MeV deuterons bombarding on thick beryllium target for radiobiological study

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Abstract

A fast neutron irradiation field for biological studies was established at the cyclotron facility in the National Institute of Radiological Sciences. Neutron spatial distributions and absorbed dose distributions were measured to characterize the neutron field. By using a simple technique that an aluminum plate activated by neutrons was exposed to the imaging plates, the width of the neutron-irradiated area was measured to be 23.6 cm with 2.5 mm spatial resolution. The absorbed dose distributions of neutrons and γ rays were obtained separately by using a tissue-equivalent plastic- and a graphite-walled low-pressure proportional counter. The neutron absorbed dose in a tissue-equivalent plastic was measured to be 144.6 (Gy/C). It was confirmed that this neutron field has only 1.8% contamination of γ-ray dose and has good quality for neutron irradiation to biological samples.

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Keywords: Neutron; Gamma ray; Absorbed dose; TEPC; Spatial distribution; Imaging plate; Biological study

1. Introduction

Astronauts and aircrews are exposed to cosmic rays at about 1 mSv d^{-1} and, on average, 2 mSv y^{-1}, respectively. In these radiation exposures, neutrons occupy 50% for aircrews and 10–20% for astronauts of the total dose, which requires neutron protection. The criticality accident occurred in 1999 in Japan where the generation of neutrons caused a serious health damage problem and recognized the necessity of researches on biological effects of neutrons. The radiation weighting factor, w_R, for the protection quantity is based mainly on the RBE data from in

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vivo investigations with animals. It can be argued that RBE of lethal tumors is more important for extrapolation of values in the estimation of risk for humans. ICRP and ICRU give diversely scattered RBE values [1,2]. Two major subjects RBE of neutrons for carcinogenesis (murine myeloid-leukemia, rat mammary tumor) and for effects on developing nervous systems in rodents have been evaluated by the National Institute of Radiological Sciences (NIRS) [3]. Biological sensitivity of neutrons strongly depends on neutron energy and indicates the largest value at 550 keV neutrons [4].

In order to investigate the biological sensitivity of neutrons to mice, the neutron irradiation field was produced by the d(25 MeV)-Be reaction at the NIRS-cyclotron facility [5]. In our previous work [6], the neutron energy spectrum in this field was measured from thermal energy up to 30 MeV. Here in this successive study, the neutron absorbed dose distributions and neutron spatial distributions were measured. Since 10 mice are irradiated in the neutron field at the same time for time saving, this neutron field is required to be uniform in order to irradiate the same neutron absorbed dose onto every mouse. For the spatial distribution measurements, a simple technique combined with imaging plates (IPs) and an activated aluminum plate [7] was employed. Although biological experiments are usually specified by absorbed doses measured by using only an ionization chamber [8], microdosimetric spectra are more useful, since biological effectiveness of a given absorbed dose is dependent on the microscopic distribution of energy deposition. Lineal energy is employed to specify the distribution which is more closely related to the biological effect of radiation. The microscopic distributions of energy depositions were measured based on the microdosimetry by using an A150-walled low-pressure proportional counter. In the neutron fields, the co-existent γ rays must be discriminated. Therefore, both a tissue-equivalent plastic (A150)- and a graphite-walled counter were employed to measure differential neutrons and γ-ray absorbed dose distributions in the neutron field. Neutrons are, however, scattered in the body, then neutron field in the body differs from the primary field, such that secondary photons are produced mainly by the H(n,γ)D reaction and also in the decay of excited nuclei from neutron-induced nuclear reactions. Depth absorbed dose distributions were therefore measured in the acrylic phantom.

2. Neutron irradiated field

At the C-3 course in the NIRS-cyclotron facility, fast neutrons were produced by 25 MeV deuterons bombarding onto the 3 mm thick (stopping length) beryllium target. Beam current was measured as 30 μA on the target. The Be target heated by deuteron beams was cooled by flowing water attached to the target. Samples were irradiated on the movable bed at 2.0 m downstream from the target and 1.1 m away from the floor, as shown in Fig. 1. Neutron irradiation area is changeable up to $240 \times 230\,\mathrm{mm}^2$ by using the Benelux (pressed wood) and the iron collimators. The neutron dose rate was measured as $0.2\,\mathrm{Gy\,min}^{-1}$ at 30 μA beam current by using the ionization chambers [8]. Total irradiated neutron fluences were estimated from incident deuteron beam current measured at the target.

The d-Be reactions are suitable for biological studies because of an intense neutron source with strong forward angle dependence; $\theta < 17^\circ$ was calculated from the internal momentum on the stripping reaction [9]. In our previous study [6], neutron energy spectrum above 5 MeV has been measured using an NE213 organic liquid scintillator and below 5 MeV using multi-sphere moderated ^{3}He proportional counters, as shown in Fig. 2. On the beam line, the neutron energy spectra extend from 0.1 eV to 30 MeV and a neutron peak at 10.5 MeV was observed. A gap around 5 MeV was caused from disagreement on the spectrum measurement by using both counters. Gamma-ray flux accompanying the neutron beam indicated 3.8% of total neutron flux and neutron flux transmitted through the collimators was $\leqslant 1\%$ of total neutron flux in the irradiation area, which clarified that this well-collimated neutron irradiated facility is suitable for radiobiological studies.