Available online at www.sciencedirect.com
ScienceDirect
Applied Radiation and Isotopes 65 (2007) 1037–1040
Applied Radiation and Isotopes
www.elsevier.com/locate/apradiso

Distortion of neutron field during mice irradiation at Kinki University Reactor UTR-KINKI

Satoru Endo[a,*], Kenichi Tanaka[a], Kazuo Fujikawa[b], Tetsuo Horiguchi[b], Tetsuo Itoh[b], Gerard Bengua[c], Taisei Nomura[d], Masaharu Hoshi[a]

[a]*Research Institute for Radiation Biology and Medicine, Hiroshima University, 1-2-3 Kasumi, Minami-ku, Hiroshima 734-8553, Japan*
[b]*Atomic Energy Research Institute, Kinki University, 3-4-1 Kowakae, Higashi-Osaka 577-8502, Japan*
[c]*Research Reactor Institute, Kyoto University, Kumatori-cho, Sennan-gun, Osaka 590-0494, Japan*
[d]*Graduate Schools of Medicine and Engineering, Osaka University, B4 2-2 Yamadaoka, Suita, Osaka 565-0871, Japan*

Received 10 August 2006; received in revised form 5 April 2007; accepted 25 April 2007

Abstract

A dosimetry study of mice irradiation at the Kinki University nuclear reactor (UTR-KINKI) has been carried out. Neutron and gamma-ray doses at the irradiation port in the presence of 0, 1, 2, 4 and 6 mice were measured using the paired chamber method. The results show that neutron dose is reduced with increasing numbers of mice. In the six-mice irradiation condition, neutron dose is about 15% smaller compared to a case where no mice were placed in the irradiation port.

To investigate the distortion of the neutron spectrum during mice irradiation at UTR-KINKI, a Monte Carlo calculation using the MCNP4C code has been carried out. The measured variation in dose with respect to the total mouse mass was closely reproduced by the calculation results for neutron and gamma-ray dose. Distortion of the neutron spectrum was observed to occur between 1 keV and 1 MeV.

Keywords: Neutron spectrum; Mice irradiation; Dosimetry; Reactor radiation; UTR-KINKI

1. Introduction

The Kinki University nuclear reactor, UTR-KINKI, has ample space for the irradiation of biological materials in the central portion of its core, where a neutron and gamma dose rate of about 20 cGy/h is available during operation at a nominal output of 1 W. The neutron and gamma-ray mixed field at UTR-KINKI has been evaluated for biological studies. The neutron energy spectra in the irradiation port was evaluated using a multi-foil activation technique with the results analyzed by an artificial neural network (Endo et al., 2002a). The neutron mean energy which is needed in radiation-related biological studies, is estimated and the separate dosimetry of neutrons and gamma rays was carried out using a pair of tissue equivalent ionization chambers (Endo et al., 2002a, b). The UTR-KINKI is useful for radiobiological studies because of the stable output and the neutron spectrum that is similar to that of a nuclear disaster such as an atomic bomb detonation or a criticality accident. Various radiobiological experiments on cultured cells, plant seeds, mice and other samples have been carried out using this facility (Kagawa et al., 2004; Hanmoto et al., 2003; Fujikawa et al., 2000a, b). In experiments on mice, however, the number of organisms that can be irradiated simultaneously in the irradiation field have been limited to two or three, because of its small dimensions.

Recently, we designed a series of experiments in which mice irradiated with neutrons, as fetuses or embryos were to be assayed for multiple end points involving genetic effects, malformations and tumor formation so as to obtain the necessary information in considering the late effects of applied fission neutrons on human developmental stages.

*Corresponding author. Tel.: +81 82 257 5874; fax: +81 82 257 5873.
E-mail address: endos@hiroshima-u.ac.jp (S. Endo).

0969-8043/$ - see front matter
doi:10.1016/j.apradiso.2007.04.018

The dose range of these studies was up to 1 Gy, irradiations taking up to 5 h. For this program, the irradiation system configuration was improved in order to accommodate more samples during irradiation. This led to the central irradiation portion being fully occupied by the mice. Under such condition, the mice would act as a significant neutron absorber, and this could result in a distorted neutron field. To have an accurate dose estimation for the mice irradiation in the improved field at UTR-KINKI, a dosimetry study was carried out using the paired chamber method and simulation by the general Monte Carlo N-Particle Transport Code Version 4c (MCNP4C) (Briesmeister, 2000). Results of this investigation are presented and discussed in this report.

2. Materials and methods

2.1. Dosimetry of neutrons using a pair of ionization chambers

The ionization chambers used in this study were the A150-walled, tissue-equivalent gas flow chamber (TE-TE) and graphite-walled, carbon dioxide gas flow chamber ($C\text{-}CO_2$), with model numbers IC-17 and IC-17G (Far West Tech. Inc., California), respectively. Correction factors for the general recombination, the initial recombination and the atmospheric conditions were made to the chamber readings; the detailed procedure for this is described in previous publications (ICRU, 1978; Endo et al., 1996). The sensitivities of the TE-TE and the $C\text{-}CO_2$ chambers to the UT-KINKI neutrons were assumed to be the same as those for ^{252}Cf-fission neutrons ($k_T = 0.98$ and $k_U = 0.08$, respectively) (Kawashima et al., 1977). The mean neutron energies of UTR-KINKI and ^{252}Cf were estimated to be 1.3–1.6 and 2.1 MeV, respectively (Endo et al., 2002b). The sensitivities do not change significantly in this energy range (Endo et al., 1996, 2000; Waterman et al., 1979). The neutron and gamma-ray doses are given by

$$D_n = \frac{R_T - R_U}{k_T - k_U}, \tag{2}$$

$$D_\gamma = \frac{k_T R_U - k_U R_T}{k_T - k_U}, \tag{3}$$

where R_T and R_U are responses of the TE-TE and the $C\text{-}CO_2$ chambers, respectively. From these equations, neutron and gamma-ray doses were obtained, separately.

The measurements were performed with no mouse at the central irradiation portion and for irradiation conditions with 1, 2, 4 and 6 C57BL/6J mice in it. The ionization chamber was positioned at the center of the irradiation portion with the mice positioned around the chamber.

2.2. Monte Carlo calculation

A Monte Carlo calculation was carried out to evaluate the distortion of the dose and neutron energy spectrum in the mouse bodies. For this purpose, the measured neutron doses as a function of the number of mice were firstly compared with the results obtained for fission neutrons in the irradiation field of UTR-KINKI calculated using MCNP4C. The simplified geometry of UTR-KINKI used for the MCNP calculation was the same as that in our earlier work (Endo et al., 2002a, b). The ionization chamber was positioned at the center of the irradiation region and A150 plastic phantoms (1.8 cm in diameter × 10 cm long, mass 25.4 g), representing individual mice being irradiated, were positioned around the chamber. The calculations for the dose readings in the ionization chamber and the dose delivered to the mouse body were carried out for conditions with 0, 1, 2, 4 and 6 mice in the central irradiation region. The average dose in the ionization chamber was compared with those obtained for the mouse phantoms. Additionally, the neutron spectrum for each irradiation setup was also calculated and compared with the others. For the transport calculation, the input data were taken from the cross section library of the ENDF B/VI, and the neutron reproduction factor (k_{eff}) used in this calculation was 1.01.

2.3. Fraction of neutron-induced kerma

Neutrons transfer their energy through various reactions. The main component of this energy transfer occurs in the ^{1}H(n, n) elastic scattering reaction. However, in the case of a thermal neutron-rich field like the one produced at UTR-KINKI, the ^{14}N(n, p) reaction contributes very significantly to the neutron dose. The kerma from the ^{1}H(n, n), ^{14}N(n, p), ^{1}H(n, γ) and the other reactions can be separately estimated from the calculated neutron spectrum for each irradiation condition. The kerma factor k_F^i, where i indicates the type of reaction, for each reaction are taken from Ref. Caswell and Coyne (1980). The neutron kerma (K_i) for each process and fraction (F_i) were obtained as follows;

$$K_i = k_F^i \Phi$$

$$F_i = \frac{K_i}{\sum_i K_i}.$$

3. Results and discussions

3.1. Dose dependency on number of the irradiated mice

Compared to the neutron dose when no mice are irradiated, the neutron dose drops by about 22% when six mice are placed in the irradiation location. This shows that the fast neutrons are absorbed by mouse bodies. In contrast, the gamma-ray dose did not change at all for the irradiation conditions considered in this study. Fig. 1 shows the dose in an irradiated mouse as a function of weight. It is also shown in this figure, that the calculated doses were normalized using a scaling parameter