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A practical alpha particle irradiator for studying internal alpha particle exposure

Ki-Man Lee, Ui-Seob Lee, Eun-Hee Kim*

Department of Nuclear Engineering, Seoul National University, 1 Gwanak-ro, Gwanak-gu, Seoul, Korea

HIGHLIGHTS

- An alpha particle irradiator has been installed for exposure of cells *in vitro.*
- A setup of cells on a slide was made specially for the gamma-H2AX assay.
- The operational condition for dose uniformity among the exposed cells was suggested.

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ABSTRACT

An alpha particle irradiator has been built in the Radiation Bioengineering Laboratory at Seoul National University (SNU) to investigate the cellular responses to alpha emissions from radon and the progeny. This irradiator is designed to have the energy of alpha particles entering target cells similar to that of alpha emissions from the radon progeny Po-218 and Po-214 residing in the human respiratory tract. For the SNU alpha particle irradiator, an irradiation system is equipped with cell dishes of 4 μm thick Mylar bottom and a special setup of cells on slide for gamma-H2AX assay. Dose calibration for the alpha particle irradiator was performed by dual approaches, detection and computer simulation, in consideration of the source-to-target distance (STD) and the size of a cell dish. The uniformity of dose among cells in a dish is achieved by keeping the STD and the size of cell dish in certain ranges. The performance of the SNU alpha particle irradiator has been proven to be reliable through the gamma-H2AX assay with the human lung epithelial cells irradiated.

1. Introduction

Humans are exposed to some mSv/yr of natural radiation, which includes cosmic radiation, terrestrial radiation, and the radiations from airborne and waterborne radioactive materials and from food. Radon mainly contributes to the annual dose of natural radiation sources (UNSCEAR, 2000). Inhalation of radon gas leads to substantial radiation doses to the respiratory system (Altshuler et al., 1964; Haque and Collinson, 1967; Puskin and James, 2006). The inhaled radon gas is exhaled or transformed to daughter radionuclides to stay inside the respiratory tract. The radon progeny Po-218 and Po-214, the alpha emitters, are the main contributor to the internal exposure of the lung (ICRP, 2010). The increasing demand for the governmental control of the risk from radon has provided extensive studies on the biological effects of alpha particles on the human respiratory tract (Bouffler et al., 2001; Chauhan et al., 2011; Hofmann et al., 2002; Liu et al., 2014; Soyland and Hassfjell, 2000).

Several experimental setups for cells to be exposed to alpha particles have been reported in earlier studies (Babu et al., 2013; Dahle et al., 2011; Esposito et al., 2006; Esposito et al., 2009; Goodhead et al., 1991; Hakanen et al., 2006; Metting et al., 1995; Neti et al., 2004; Soyland et al., 2000; Tisnek et al., 2009; Wang and Coderre, 2005). The alpha sources of choice in such studies are Pu-238, Am-241, Cm-244, and Pb-212/Bi-212. In the Radiation Bioengineering Laboratory at the Seoul National University (SNU), we have built an alpha particle irradiator to investigate the cellular responses to alpha emissions from the radon progeny. The system is designed to have the energy of alpha particles entering target cells similar to that of alpha emissions from Po-218 and Po-214 residing in the human respiratory tract.

2. Materials and methods

2.1. System requirements

2.1.1. Alpha source

Commercial alpha sources are available mainly in disk type. The energy of alpha particles at approximately 5 MeV complies with

* Corresponding author.
E-mail address: eunhee@snu.ac.kr (E.-H. Kim).

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the ultimate use of the SNU system. The source activity would determine the range of the cellular dose rate delivered.

2.1.2. Cell dish

A dish with Mylar film bottom has been the most common choice in earlier studies (Babu et al., 2013; Dahle et al., 2011; Esposito et al., 2006, 2009; Goodhead et al., 1991; Hakanen et al., 2006; Metting et al., 1995; Neti et al., 2004; Soyland et al., 2000; Tisnek et al., 2009; Wang and Coderre, 2005) for the alpha particle exposure to cells *in vitro*. For the SNU alpha particle irradiator, we have equipped an irradiation system with cell dishes of 4 μm thick Mylar bottom to enable alpha particles to reach the cells through the dish bottom.

2.1.3. Source chamber

Alpha particles attenuate in energy while transporting through air from the source to the target cells. A vacuum chamber would enable the alpha particles to reach the target cells without loss in energy. Given that the cells under atmospheric pressure face the alpha particles through the Mylar bottom, the inner pressure of the source chamber should keep balanced with the outer atmospheric pressure to avoid deformation of the Mylar bottom of cell dish. A source chamber filled with a light inert gas can be a solution.

2.2. Design specifications

A schematic of the SNU alpha particle irradiator is shown in Fig. 1. The source chamber has an opening on the top, right up from the source mount. A cell culture dish is fixed in the opening for cell exposure to alpha particles. For the energy spectrometry of alpha particles at the cell position, a detector instead of a cell dish is fixed in the same opening. The duration of alpha particle exposure is controlled by using an aluminum shutter. The alpha particle exposure rate is controlled primarily with the source activity at 1, 10, or 100 μCi and secondly by positioning the source on the mount at a varying distance of 5 mm to 70 mm from the cell dish bottom. A spare gate near the opening is prepared for the coincident measurement of alpha particles during the exposure of cells at the opening. Once a dish or a spectrometer is fixed in the opening, the continuous helium gas flow maintains the balance between interior and exterior pressures.

2.3. Measurement of alpha energy spectrum

An **i**on-**i**mplanted **s**ilicon-charged particle **d**etector (IISD) (BU-020–450-AS, ORTEC, USA) was employed to measure the energy spectra of alpha particles. The IISD is specified to have an active area of 450 mm^2 and an active depth of 100 μm. The detector is connected to an electronic chain implemented by nuclear instrumentation method modules, which include a preamplifier with its bias supply, a linear amplifier, a multichannel analyzer (MCA), and data management software (MAESTRO-32, ORTEC, USA). The energy calibration of the MCA was performed with Am-241 and Cm-244 sources in a commercial chamber (807, ORTEC, USA) vacuumed by a portable pump station (ALPHA-PPS-230, ORTEC, USA). The alpha energy spectrum was obtained also by transport simulation of alpha particles using the **a**dvanced **a**lpha spectrometric **si**mulation (AASI) Monte Carlo code (Siiskonen and Pollanen, 2005).

2.4. Dose calibration for alpha emissions

Dose calibration for the alpha particle irradiator was performed by dual approaches. First, the normalized energy distributions of alpha particles, that is, $f_{layer\text{-}in}(E)$ at entering the cell layer and $f_{layer\text{-}out}(E)$ at leaving it, were obtained by employing the AASI code for the transport simulation of alpha emissions from the source. The total energy deposition to the target cell layer E_{layer} and the average dose $\bar{D}_{layer}$ was then calculated by

$$E_{layer} = F_{layer-in} \cdot \sum_E \left(E \cdot f_{layer-in}(E)\right) - F_{layer-out} \cdot \sum_E \left(E \cdot f_{layer-out}(E)\right), \quad (1)$$

and

$$\bar{D}_{layer} = E_{layer}/M_{layer}, \quad (2)$$

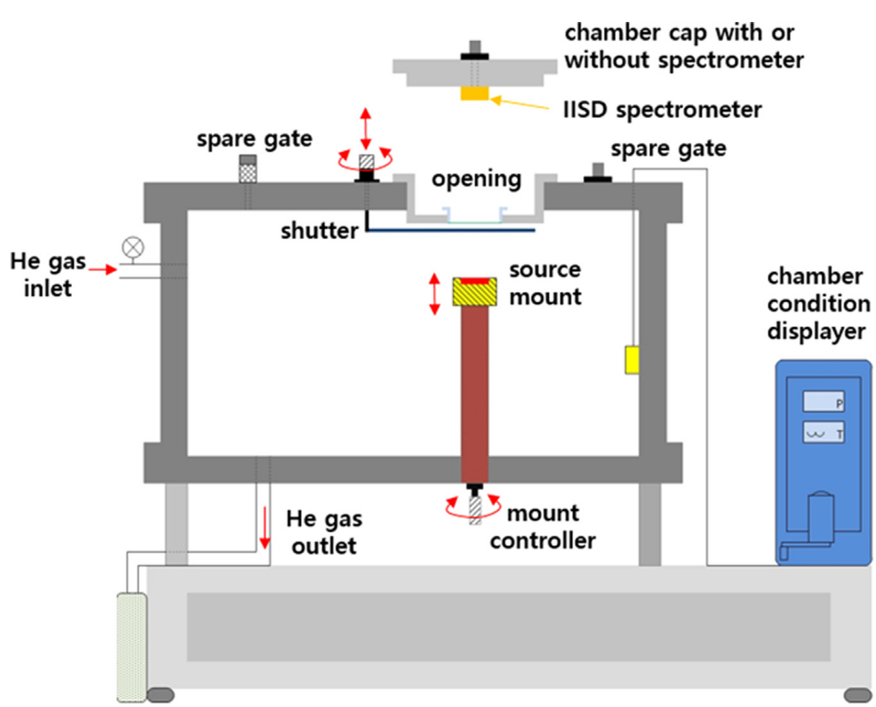

Fig. 1. Schematic of the SNU alpha particle irradiator.