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Original Article

Monte-Carlo Calculation of Radon Absorbed Dose in Optical Fiber as a Novel Method in Dosimetry and Radon Measurement

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Abstract

Introduction
Radon is a colorless and tasteless gas which exists in most soils. It is a substance that poses a potential risk for lung cancer in case a person is exposed to high levels over long periods of time. The Environmental Protection Agency (EPA) estimates that 90% of lung cancers per year are caused by radon. The aim of this paper is to estimate the absorbed doses of ^{222}Rn by MCNPX simulation in single-mode optical fiber (SMF) as a method proposed for dosimetry test.

Materials and Methods
To calculate the absorbed dose of ^{222}Rn in SMF using MCNPX-2.6 code, the *F6 tally was applied. SMF was simulated by being exposed to radon while being located in the axis of the pipe.

Results
The absorbed doses due to beta, gamma, and alpha radiations emitted from radon in SMF obtained by Monte Carlo simulations were equal to 5.76311E-13, 5.06973E-15, and 4.83457E-14Gy/particle, respectively. Therefore, the total absorbed dose for radon in SMF was in the order of 6.29727E-13 Gy/particle. The MCNPX outputs are always normalized to one source particle. Therefore to calculate the absorbed dose in various radon concentrations, this result must be multiplied to the number of source particles in active volume around the SMF. The daily radon absorbed dose in a one-meter of SMF and 1 kBq/m^3 radon concentration is about 0.017 mGy which is in a dose range of TLD dosimeters.

Conclusion
The results show that the SMF can be regarded as a radon dosimeter and may be used for beta-particles dosimetry.

Keywords: Absorbed Dose, Lung Cancer, MCNPX, Radon, Single–Mode Optical Fiber

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1. Introduction

“The risks to human health exposed to ionizing radiation are well known. Radon gas is by far the most important source of ionizing radiation among those that are of natural origin” [1]. ^{222}Rn is a noble radioactive gas that its concentration in Iran is in the ranged 82-31000 Bq/m^3 [2]. Radon is produced by the decay of ^{238}U, which is found in varying concentrations in most soils, rocks, and ground water. As mentioned above, as ^{238}Udecays, ^{222}Rn is formed and decays itself to a new radionuclide in the environment [3].

Radon is the second cause of lung cancer in general population, right after smoking. According to the Environmental Protection Agency (EPA), radon is estimated to be responsible for 21000 lung cancer deaths every year [4].When radon gas is inhaled, densely-ionizing alpha particles are emitted by deposited short-lived decay products of radon (^{218}Po and ^{214}Po) and can interact with biological tissues in the lungs, consequently leading to DNA damage. Radon-related DNA damage can occur at any level of exposure [1].

Determination and measurements of ^{222}Rn and ^{220}Rn in air are of great significance. Many techniques have been developed over the years to measure radon and its progeny in air [5]. Several effects of radiation on optical fibers have currently been investigated including the increase in attenuation, radiation-induced loss, radiation-induced luminescence light and scintillation, radiation damage, and change of refractive index [6-13] which can be introduced by optical fibers as a dose detector. Therefore, the advantages of using optical fiber dosimeters can be summarized in the three following points:1) modern fibers can be produced with identical composition and quality in great lengths, enabling the radiation control of very lengthy objects or spacious areas, 2) The dosimeter sensitivity can be adjusted to the dose (or dose rate) of interest via selecting the wavelength or the fiber type with very small dimensions for the dosimeter, and 3) The length of each fiber section can exceed several kilometers [6].

The present paper, aims to introduce a method to determine the effects of radon on SMF in air. Our proposed method was based on the variation of optical fiber properties by alpha, beta, and gamma radiations emitted by radon and its progeny. Moreover, the radiation dose of radon and its progeny in optical fibers which is a useful parameter for measuring the amounts of radon is simulated by MCNPX-2.6 code. Besides, the accuracy of this new optical fiber dosimeter was compared with TLD dosimeter.

2. Materials and Methods

The first step in MCNPX-2.6 simulation was to prepare the input file. The MCNPX-2.6 input file describes the geometry problem, specifying the materials and sources that define the desired result from the calculation. Therefore, a single-mode optical fiber with diameters of 9, 125, and 250 μm in core[1], cladding[2], and buffer[3] was positioned in the pipe by 0.1 m radius and 1 m length, containing the source of radon uniformly disturbed as shown in Figure 1. This SMF sample was made of pure silica core fibers of 2.32 g/cm^3 density and Germanium dioxide (GeO_2) doped cladding with 1.43 g/cm^3 density.

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[1] Core: Thin glass center of the fiber where the light travels.

[2] Cladding: Outer optical material surrounding the core that reflects the light back into the core.

[3] Buffer: Plastic coating that protects the fiber from damage and moisture.

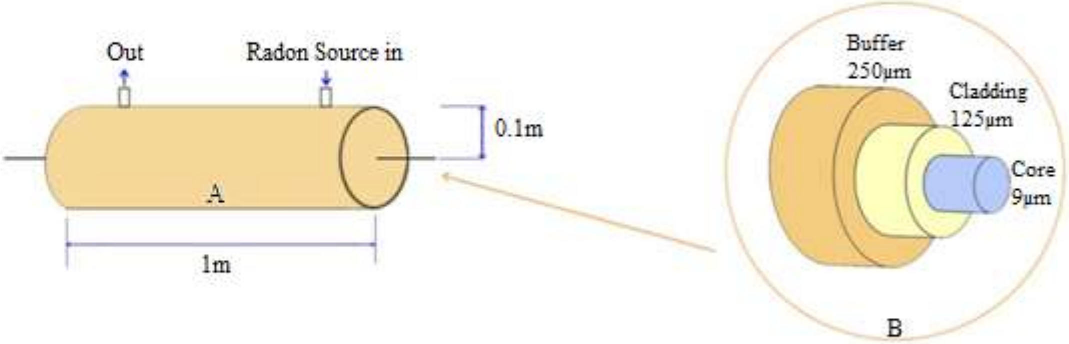

Figure1. A single-mode optical fiber with diameters of 9,125, and 250 µm in core, cladding, and buffer, positioned in the pipe by r=0.1m in radius and L=1 m in length, containing radon and its progeny.

The next step was to describe a source card which defines the basic parameters of a basic source; the card for source-information and the source-probabilities for radon and progeny were extracted from decay series of ^{238}U and ^{232}Th [14]. Depending on the type of decay products, the absorbed doses for alpha, beta, and gamma radiation were calculated on the SMF.

To increase the accuracy and reduce the errors to a level below 1%, the program was run for different numbers of particles associated with 10^8 times performances. Both the F6 and *F8 tallies of MCNPX code can be used for determination of absorbed dose by MCNPX method, but F6 tally of MCNPX-2.6 code can be used for better determination of the absorbed dose of alpha, beta, and gamma radiations of radon and its progeny by MCNPX method. The F6 tally gives results in MeV/g but *F6 converted it to jerks/g (1 jerks/g=10^{12} Gy).

Since the output in all cases of MCNPX-2.6 was normalized in terms of one particle, the outputs for N particles were multiplied by the time, the volume of the cell, and the concentration of radon, being equal to C×V×t, where C is the concentration of radon, N is number of particles in the cell, V is the volume of the cell, and t is the time of measurement.

At this step, it was possible to design a sampling system that could measure the airborne radioactivity, consisting of two sampling parts: A and B (as shown in Figure 1); *sample part A houses* contained a filter for collecting all radon progeny passing through it and *sample part B houses* contained a series of fiber optics. The alpha and beta activities of radon progeny passing through this filter were measured in part B using the fiber optics technique.

4. Results

Table 1 presents the absorbed doses of alpha, beta, and gamma radiation on the SMF for ^{238}U and ^{232}Th decay series for radon and its progeny in air per one particle (D_1). Figure 2 shows the total dose calculations per one particle versus the number of performances.

Table 1. Absorbed doses of alpha, beta, and gamma radiation on the SMF for radon and its progeny in ^{238}U and ^{232}Th decay series

Number of Performance	Total Dose of Alpha Radiation (jerks/g)	Total Dose of Beta Radiation (jerks/g)	Total Dose of Gamma Radiation (jerks/g)	Total Dose (jerks/g)	Total Dose (Gy/particle)
8192000	5.87024E-25	5.74189E-25	4.73849E-27	1.16595E-24	1.16595E-12
16384000	2.95080E-25	5.71781E-25	4.94304E-27	8.71804E-25	8.71804E-13
24576000	1.96719E-25	5.82995E-25	4.89257E-27	7.84606E-25	7.84606E-13
32768000	1.47539E-25	5.87419E-25	4.85483E-27	7.39812E-25	7.39812E-13
40960000	1.18032E-25	5.83893E-25	4.87011E-27	7.06795E-25	7.06795E-13
49152000	9.83599E-26	5.82359E-25	4.91040E-27	6.85629E-25	6.85629E-13
57344000	8.43091E-26	5.81909E-25	4.99052E-27	6.71208E-25	6.71208E-13
65536000	7.37700E-26	5.82707E-25	4.92382E-27	6.61401E-25	6.61401E-13
73728000	6.55733E-26	5.83533E-25	5.07928E-27	6.54186E-25	6.54186E-13
81920000	5.90154E-26	5.76486E-25	5.09041E-27	6.40592E-25	6.40592E-13
90112000	5.36510E-26	5.73781E-25	5.06303E-27	6.32495E-25	6.32495E-13
98304000	4.91798E-26	5.75982E-25	5.07191E-27	6.30234E-25	6.30234E-13
100000000	4.83457E-26	5.76311E-25	5.06973E-27	6.29727E-25	6.29727E-13

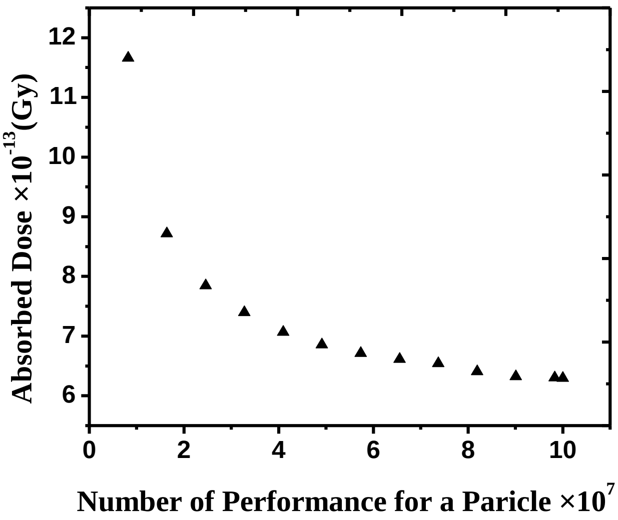

Figure 2. Total dose calculated based on the number of performances per one particle.

As it is shown in Figure 2, the best performance was achieved for more than 10^7 particles so that the best results would be the last row of data in Table 3. The results of conducting a comparison on the absorbed doses of alpha, beta, and gamma radiations on SMF are represented in Figure 3, showing that 91% of the absorbed dose was from beta radiation of ^{238}U and ^{232}Th decay series.

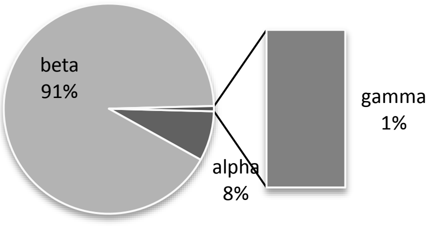

Figure 3. Comparison of the absorbed doses from alpha, beta, and gamma radiations on SMF for radon in ^{238}U and ^{232}Th decay series.

Radon-absorbed doses D_n (Gy) in an optical fiber which located in cylinder with radius r(m) and length L(m), for radon concentration C (kBq/m^3) in air at any time t(s) was calculated through Equation 1:

$D_n = D_1 \times N$ (1)

Where N is number of radon particle and D_1 is absorbed doses of the SMF (Gy/particle). According to Equation 1, for example, the daily (t=86400s) radon-absorbed dose in one meter (L=1 m) optical fiber and radon concentration (C=1kBq/m^3) equals to 0.017 mGy, which is about the accuracy of TLD dosimeters [15-17].

4. Discussion

Monte Carlo techniques have been extensively used in medical physics applications, providing the most powerful tool for modeling the radiation transport in different media. The availability of general purpose MCNPX codes combined with the ever-increasing computer speed and decreasing costs have all led to a boom in MCNPX studies in recent years. MCNPX techniques are going to dominate the field of radiation dosimetry and bench mark dose-calculations in radiotherapy for many years to come. In this study, the absorbed doses of radon and its progeny in optical fiber were calculated by MCNPX-2.6 code. The results of MCNPX-2.6 code showed that the optical fiber can be regarded as a useful measuring device for radon-radiation dosimeter in comparison with other common dosimeters as TLDs.

5. Conclusion

According to absorbed doses due to beta, gamma, and alpha for radon and its progeny in single-mode optical fiber which were equal to 5.76311E-13, 5.06973E-15, and 4.83457E-14 Gy/particle, respectively, and the total absorbed dose in the air which was in the order of 6.29727E-13 Gy/particle, it is apparent that MCNPX calculations of radon dose in optical fiber can be introduce as a method of dosimetry in radiotherapy. Therefore, according to MCNPX results, the optical fiber can be applied as a radon detector and the beta dosimeter can be proposed as a method for diagnosis of lung cancer.

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