REPORTS OF PRACTICAL ONCOLOGY AND RADIOTHERAPY 20 (2015) 204–209

Available online at www.sciencedirect.com

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journal homepage: http://www.elsevier.com/locate/rpor

Original research article

A Monte Carlo study on dose distribution evaluation of Flexisource ^{192}Ir brachytherapy source

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ARTICLE INFO

Article history:
Received 26 April 2014
Received in revised form
28 November 2014
Accepted 28 January 2015

Keywords:
Monte Carlo
Flexiplan treatment planning system
Flexisource
HDR brachytherapy
^{192}Ir source

ABSTRACT

Aim: The aim of this study is to evaluate the dose distribution of the Flexisource ^{192}Ir source.
Background: Dosimetric evaluation of brachytherapy sources is recommended by task group number 43 (TG. 43) of American Association of Physicists in Medicine (AAPM).
Materials and methods: MCNPX code was used to simulate Flexisource ^{192}Ir source. Dose rate constant and radial dose function were obtained for water and soft tissue phantoms and compared with previous data on this source. Furthermore, dose rate along the transverse axis was obtained by simulation of the Flexisource and a point source and the obtained data were compared with those from Flexiplan treatment planning system (TPS).
Results: The values of dose rate constant obtained for water and soft tissue phantoms were equal to 1.108 and 1.106, respectively. The values of the radial dose function are listed in the form of tabulated data. The values of dose rate (cGy/s) obtained are shown in the form of tabulated data and figures. The maximum difference between TPS and Monte Carlo (MC) dose rate values was 11% in a water phantom at 6.0 cm from the source.
Conclusion: Based on dosimetric parameter comparisons with values previously published, the accuracy of our simulation of Flexisource ^{192}Ir was verified. The results of dose rate constant and radial dose function in water and soft tissue phantoms were the same for Flexisource and point sources. For Flexisource ^{192}Ir source, the results of TPS calculations in a water phantom were in agreement with the simulations within the calculation uncertainties. Furthermore, the results from the TPS calculation for Flexisource and MC calculation for a point source were practically equal within the calculation uncertainties.

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http://dx.doi.org/10.1016/j.rpor.2015.01.006

1. Background

Brachytherapy, treatment at short distance, is a radiotherapy modality in which sealed radioactive sources of radiation are placed at short distances from the tumor. It is performed using intracavitary, interstitial or surface application techniques. With this treatment method, a high radiation dose is delivered to the tumor volume with rapid dose fall-off in the surrounding normal tissues.[1] Brachytherapy is characterized by the time duration of the irradiation and it is divided into two types: permanent implant and temporary implant. In the latter one, ^{137}Cs and ^{192}Ir are two radionuclides which are commonly used as sources. When considering the dose rate, three classifications have been established: low dose rate (0.4–2 Gy/h), medium dose rate (2–12 Gy/h) and high dose rate (>12 Gy/h) treatments.[2]

^{192}Ir radionuclide has been used since 1958 as a brachytherapy source. At that time ^{192}Ir wires were used with the Paris dose calculation system, which was established by Pierquin et al.[3] ^{192}Ir has become a popular radionuclide and it is used as a substitute for ^{226}Ra.[4] At present, ^{192}Ir is commonly used in most radiotherapy centers as a source in clinical brachytherapy.[5] There are several studies on dose distribution evaluation for ^{192}Ir Flexisource source model, determined by MC simulations. Granero et al.[6] obtained the dose distribution for a ^{192}Ir Flexisource source by the MC method using GEANT4 code. They calculated dose rate per air kerma strength, anisotropy function and radial dose function at various points. In their study, it was recommended to use the obtained data for this source to verify the TPS calculations. Ballester et al.[7] calculated dosimetric parameters of ^{192}Ir wires with the use of Sievert integral, Task Group No. 43 (TG-43) formalism and Monte Carlo (MC) techniques. They then obtained the absorbed dose values of the ^{192}Ir wires with 1.0–5.0 cm sizes by utilizing GEANT4 Monte Carlo code. In another study, Bozkurt et al.[8] compared the values of dose rate per air kerma strength at distances of 0.1–10.0 cm for the ^{192}Ir wires with sizes of 1.0–5.0 cm. The study was performed using the MCNP Monte Carlo code and the obtained results were shown to be in agreement with the data from the XiO CMS commercial treatment planning system (TPS). In a comparative study between MC and TPS calculations, Zhang et al.[9] characterized dosimetric parameters for ^{125}I and ^{137}Cs sources in a collaborative ocular melanoma study (COMS) in eye plaque brachytherapy and their results showed that there was a complete adaptation between the MC and TPS data. Granero et al.[10] compared dosimetric parameters of a BEBIG ^{192}Ir source through calculation by utilizing the GEANT4 Monte Carlo (MC) code with the literature for other high dose rate (HDR) sources. They showed that the use of the obtained datasets for this source is justified. ^{192}Ir is the most frequently used source in HDR brachytherapy, especially in the treatment of prostate cancer. While there are various studies on dosimetric evaluation of ^{192}Ir sources, to the best of our knowledge, there is no study on dosimetric evaluation of the calculations of the Flexitron brachytherapy unit which contains Flexisource ^{192}Ir sources.

2. Aim

The aim of this study is to evaluate in-phantom dose rate distribution from various aspects for a Flexisource HDR ^{192}Ir source using MC simulation of the source.

3. Materials and methods

3.1. *Geometry of Flexisource ^{192}Ir source*

The geometry of Flexisource HDR ^{192}Ir source is illustrated in Fig. 1. This source is composed of an active iridium cylinder (density: 22.42 g/cm^3) with active length of 3.5 mm and diameter of 0.6 mm. The active part is covered by a stainless-steel capsule (composition by weight: Fe: 67.92%, Cr: 19.00%, Ni: 10.00%, Mn: 2.00%, Si: 1.00% and C: 0.08%, density: 8.00 g/cm^3). The outer diameter of the source is 0.85 mm and the total length of the source is 4.6 mm. The cable of the source is made of 304 stainless-steel in the form of a cylinder with 5 mm length and 0.5 mm diameter.[6] The radiation characteristics of the Flexisource ^{192}Ir source used in this study are listed in Table 1.[6]

3.2. *Calculation of TG-43 dosimetric parameters by MC simulations*

Report of Task Group No. 43 was published in 1995 by the American Association of Physicists in Medicine (AAPM) and was updated later in 2004.[11] Based on the updated version of this formalism (TG-43U1), dose rate is obtained from the below formula:

$$\dot{D}(r,\theta) = S_K \Lambda \frac{G(r,\theta)}{G(r_0,\theta_0)} g(r) F(r,\theta) \tag{1}$$

$$\Lambda = \frac{\dot{D}(r_0,\theta_0)}{S_K} \tag{2}$$

$$G(r,\theta) = \begin{cases} \dfrac{\beta}{Lr\sin\theta} & \text{if } \theta \neq 0 \\ \left(r^2 - \dfrac{L^2}{4}\right)^{-1} & \text{if } \theta = 0 \end{cases} \tag{3}$$

where r is the distance from source's center; r_0 is the reference distance which is 1.0 cm usually; θ is the polar angle between the longitudinal axis and the line connecting the calculation point and the source's center; θ_0 is the reference angle which is usually 90°; S_K is the air kerma strength; Λ is dose rate constant; $G_L(r,\theta)$ is geometry function; $g(r)$ is radial dose function; $F(r,\theta)$ is anisotropy function; β is the angle subtended by two hypothetical lines at the calculation point connected to the two ends of the active length; and L is the effective length.[11] The geometry and characteristics of the Flexisource ^{192}Ir source were simulated in a water phantom and a soft tissue phantom, separately. The chemical composition of the soft tissue phantom had nine components which were adopted from the report No. 44 of the International Commission on Radiation Units and Measurements (ICRU). Based on this report, the soft tissue has the following elements and