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Manchester system brachytherapy simulation using EGSnrc Monte Carlo simulation

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ABSTRACT

One type of cervical cancer treatment is brachytherapy using the Manchester system. In this study, isodose curves were analyzed on tissue phantoms irradiated using several types of radioactive sources with the Manchester system using Monte Carlo simulation, EGSnrc. This study used a homogeneous tissue phantom with dimension $10 \times 10 \times 10$ m^3. The Manchester system uses 2 ovoid and 3 tandem containing radioactive sources placed inside the phantom. The resulting isodose curves were combined and analyzed using MATLAB-based VDOSE GUI. The results showed that the dose distribution for each type of radioactive source at the reference point had different values, namely Cobalt-60 had a dose distribution at reference point A of 15.08% with a dose distribution at reference point B of 0%, Cesium-137 was 13.37% and 0%, Iridium-192 was 13.27% and 0%. The use of radioactive source types can be adjusted to the actual location of cervical cancer.

Keywords: Brachytherapy; EGSnrc; isodose curve; Monte Carlo; Manchester system

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INTRODUCTION

Based on the mode of radiation delivery, radiotherapy is divided into two, namely teletherapy (the source is outside the body) and brachytherapy (the source is inside the body). Brachytherapy refers to a therapeutic technique with the placement of a radioactive source into or very close to the target tissue [1]. The most commonly used radioactive sources for brachytherapy treatment are Iridium-192 [2], Cobalt-60 [3], Cesium-137, and Radium [4]. Each radioactive source has different characteristics [3].

Brachytherapy is commonly used as a therapy for breast, prostate, cervical, and several other types of cancer [5]. Brachytherapy method by inserting a closed radioactive source in the cavity of the cancer cell site or intracavitary brachytherapy is often used in the treatment of cervical cancer [6]. Cervical cancer is an abnormal growth of cervical epithelial tissue in the neck of the uterus [7]. The Manchester system is one of the systems used in the treatment of cervical cancer through the brachytherapy method. The Manchester system is a type of brachytherapy system by implanting radioactive substances into the body through uniform dose distribution. It uses two intravaginal applicators and a rubber tandem tube. This system distributes the dose to several points [8-10]. Dose calculation in the Manchester system can be done through the Monte Carlo (MC) method [11].

Several Monte Carlo codes have been used to calculate dose distributions in several cancers with brachytherapy techniques such as MCNP [12], Geant4 [13], and EGSnrc [11]. EGSnrc is a program to simulate the transport of photon and electron particles using the MC algorithm. In this study, modelling and analysis of the effect of the type of radioactive source on the distribution of radiation dose received by the target and its surroundings through the isodose curve are carried out. This research will use the Manchester system as a method of placing radioactive sources using three radioactive sources, namely Ir-192, Cs-137, and Co-60. The results of the isodose curves of the two types of radioactivity will be compared and analyzed to determine the dose distribution. Therefore, the purpose of this study is to compare and analyze isodose curves on tissue phantoms irradiated using several different types of radioactive sources with the Manchester system through Monte Carlo simulation.

RESEARCH METHODS

Simulation Design

This study uses EGSnrc with the user code DOSXYZnrc as a simulation program. DOSXYZnrc is used to design and simulate absorbed dose with various mediums and phantom sizes [14]. A phantom is a modeling of a human object used in the field of radiology for radiodiagnostics and radiotherapy. DOSXYZnrc has several types of sources as sources used in simulations. The type of DOSXYZnrc source in this study is isource= 6: Uniform isotropically radiating parallelepiped within DOSXYZnrc. The use of this source allows the simulation of a radioactive source placed in a phantom that emits uniform radiation. The volume of the field size can be adjusted as long as it is within the DOSXYZnrc phantom (active volume is limited). The active volume of the radioactive source is bounded in the x direction by xinl, xinu (cm), bounded in the y direction by yinl, yinu (cm), and zinl, zinu, which is the z boundary of the active volume (cm).

The simulation was carried out by placing the radioactive source on a 10×10×10 m^3 homogeneous phantom which all voxel parts contained tissue material with the information of each voxel shown in Table 1. The radioactive sources used were Iridium-192, Cesium-137, and Cobalt-60. The Manchester system applicator was inserted into the phantom with one intrauterine rubber tandem tube containing 3 radioactive seeds inside and two ovoids (intravaginal applicators) each containing a radioactive seed. In direct clinical use, points A and B are located on the right and left sides. Point A is located 2 cm to the right, left of the tandem and 2 cm above the ovoids. Point B is located 5 cm and 2 cm to the right, left of the tandem and above the ovoids. This point is 3 cm lateral to point A. Point B is used to deliver the dose to the distal parametrium [3].

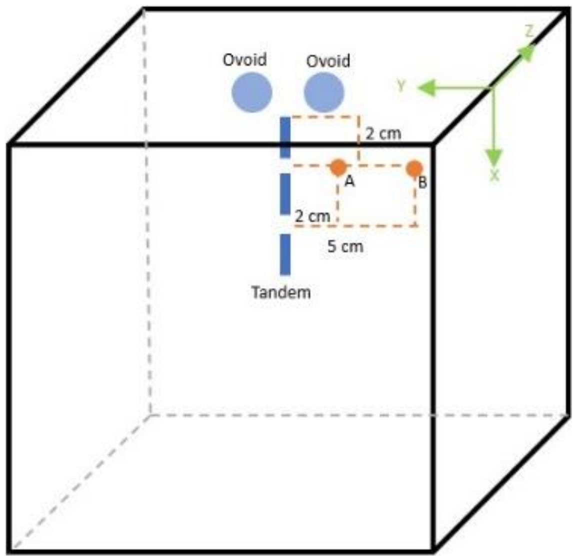


Figure 1. Set-up of the phantom simulation.

Table 1. Virtual phantom information.

Axis	Voxel number	Voxel size (cm)	Voxel Boundaries (cm)
x	100	0.1	-5 to + 5
y	100	0.1	-5 to +5
z	100	0.1	0 to 10

Dose Distribution Analysis

Each simulation produces output files that are used in the data analysis process, namely .3ddose files and .egsphant files. The dose profile is a dose distribution curve in a certain direction in one dimension obtained by analyzing the .3ddose file through the STATDOSE program. Isodose curves can be obtained using dosxyz_show or VDOSE. The .3ddose and .egsphant files of each radioactive source applicator location (2 on ovoid and 3 on tandem) will be merged using the MATLAB-based VDOSE GUI. The merged results will produce isodose curves. The isodose curve will be analyzed at point A and point B of the Manchester system. The results of the dose distribution analysis are compared between the three types of radioactive sources used in this study.

RESULTS AND DISCUSSION

Dose Profile

The three-dimensional dose distribution data generated by the simulation process by DOSXYZnrc is stored in a .3ddose file. The data file can be analyzed using STATDOSE to produce dose profiles for each radioactive type. The dose profile is a picture of the dose distribution curve in two dimensions. Figure 2 below displays a graph of the dose profile received along the phantom Y-axis versus depth using Cobalt-60 radioactivity (Figure 2). The relative dose was obtained from normalizing the .3ddose data to the maximum dose after analysis by the STATDOSE program. The radioactive isodose profile curve images between Cobalt-60, Cesium-137 and Iridium-192 are similar.

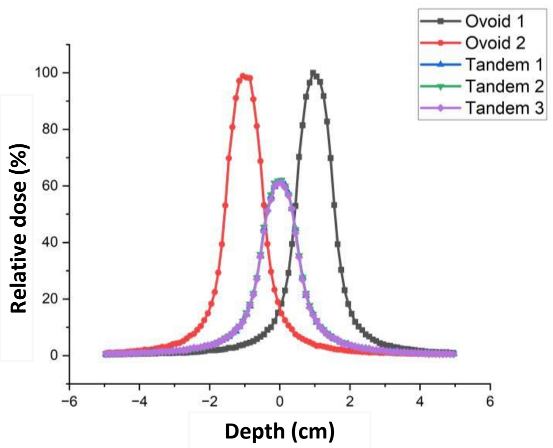


Figure 2. Dose profile using Cobalt-60 radioactive in 2 cm depth.

Cobalt-60 has the highest relative dose where ovoid 1 is 100% at a depth of 0.95 cm, ovoid 2 is 98.30% at a depth of -0.95 cm, tandem 1 is 61.56% at a depth of 0.04 cm, tandem 2 is 61.06% at a depth of 0.04 cm, and tandem 3 has a relative dose of 61.08% at a depth of 0.04 cm. Radioactive Cesium-137 and Iridium-192 had the same relative dose in each applicator. The relative dose in ovoid 1 for both radioactive is 100% at a depth of 1.05 cm, ovoid 2 is 98.97% at a depth of -0.95 cm, tandem 1 is 61.44% at a depth of -0.05, tandem 2 is 60.24% at a depth of 0.04 cm, and tandem 3 is 59.18% at a depth of -0.05. The similarity between iridium-192 and Cesium-137 and the difference between the two against Cobalt-60 may occur due to differences in average energy. Iridium-192 and Cesium-137 have an average energy of 0.4 MeV and 0.66 MeV, respectively, so they have an energy difference of 0.26 MeV. However, Cobalt-60 has an average energy of 1.17 MeV so it has a larger difference of about 0.51 – 0.77 MeV which affects the dose difference.

Isodose Curve

The isodose curve shows the dose distribution over a given area at a given depth. This study uses a radioactive source applicator that will be separated into 5 sections. The sections are ovoid 1 which is the section located at the bottom left position (Figure 3a), ovoid 2 which is the section located at the bottom left position (Figure 3b), tandem 1 which is the source located at the center of the Y voxel direction and the left in the X voxel direction, tandem 2 which is the source located after tandem 1, and tandem 3 which is located after tandem 1 and 2. The colors on the curve represent the amount of dose distribution received. The red color represents the location with the highest level of dose distribution and the blue color represents the location with the lowest dose distribution. The location of the source placement is the same for each radioactive type. All three types have similar isodose curves. Figure 3 below illustrates the radioactive isodose curve for each section of the applicator.

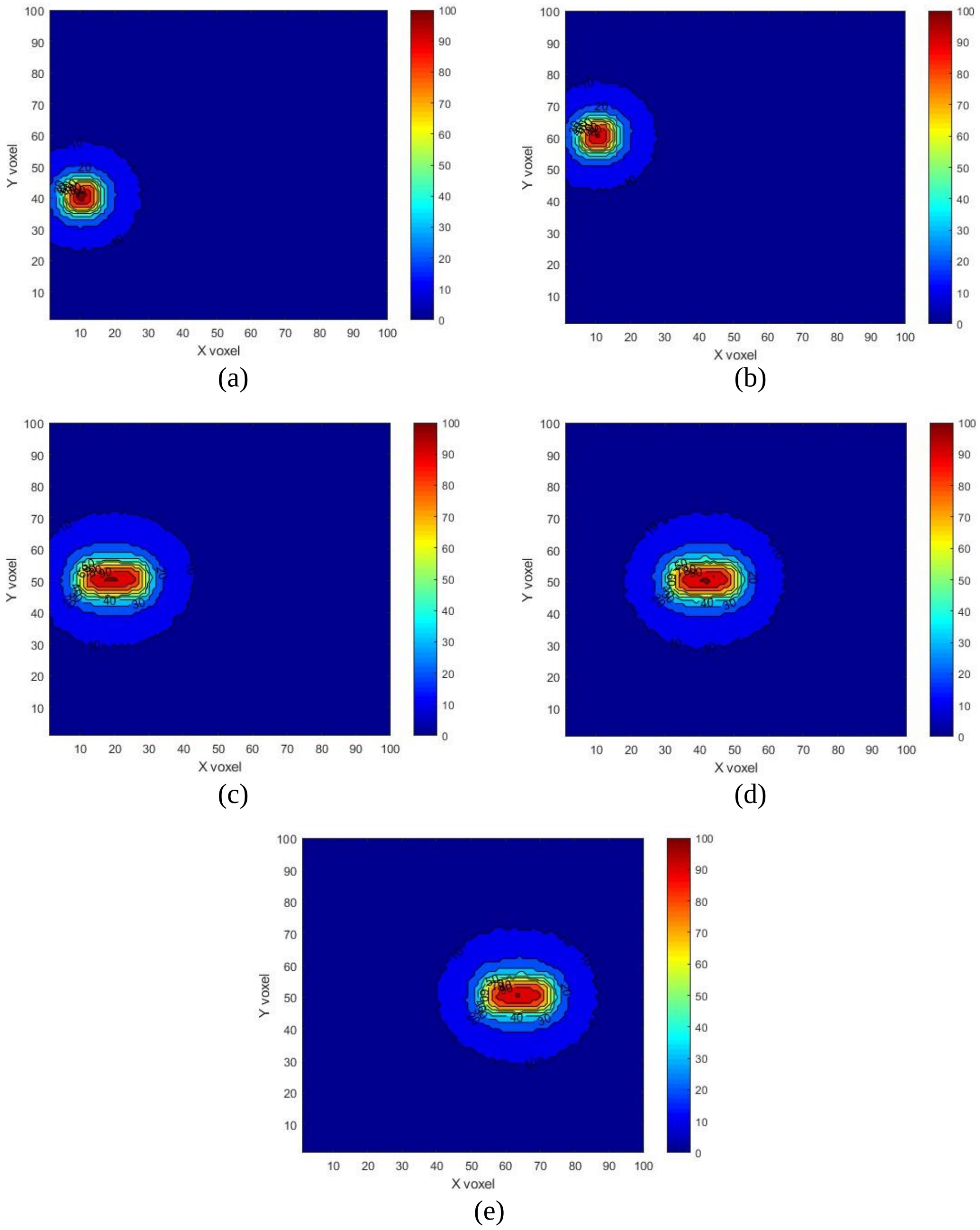
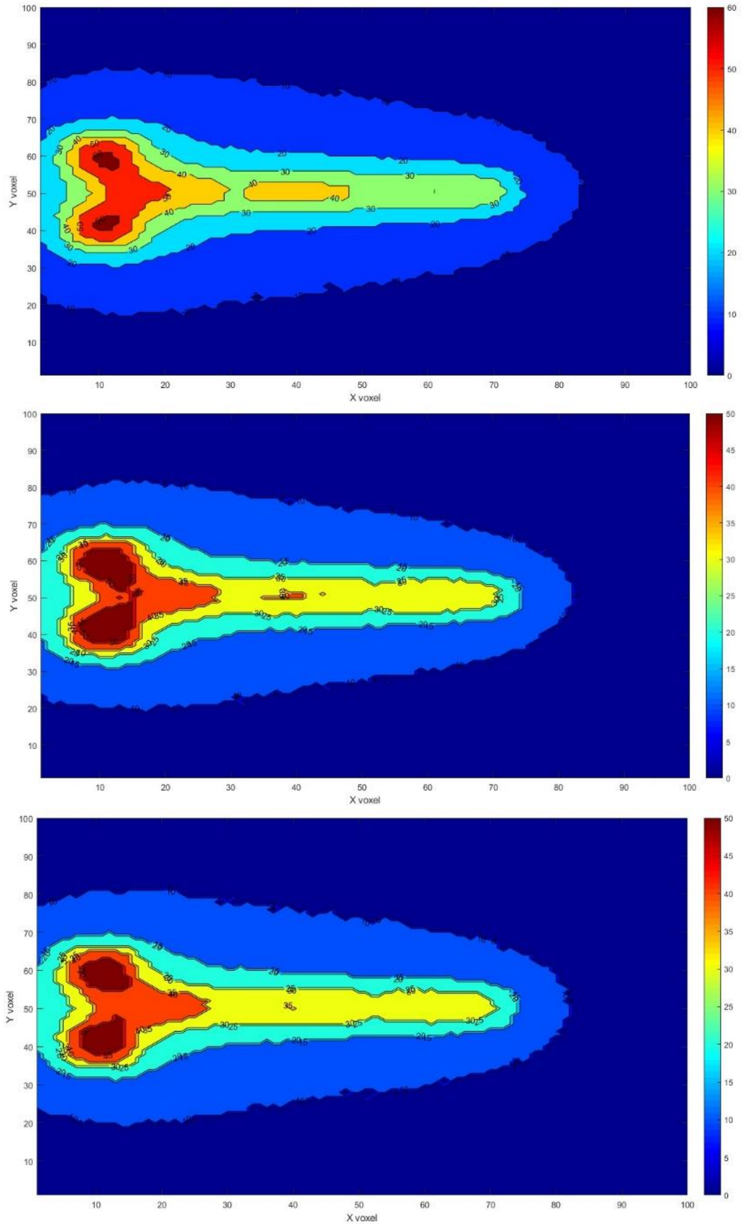


Figure 3. Cobalt-60 isodose curve of section: (a) Ovoid 1; (b) Ovoid 2; (c) Tandem 1; (d) Tandem 2; and (e) Tandem 3.

Comparison of Isodose Curves at a depth of 4.5 cm

The isodose curve in each voxel layer will be different due to differences in the placement of the radiation source location, density, and energy used. The difference in dose distribution can be seen in the parameter with a color gradation from intense blue to intense red located next to the isodose curve image. In this study, the isodose curve is obtained by cutting the voxel in the Z direction, so the layers to be discussed are layers in the z-axis or depth direction.

Analysis of the isodose curves at a depth of 4.5 cm shows variations in dose distribution for each type of radioactivity used. Cobalt-60 shows the highest dose distribution of 60%, with the dark red area in Figure 4, while Cesium-137 and Iridium-192 have the highest dose distribution of 50%. The colors in the isodose curve indicate the level of dose distribution, with red indicating the highest dose and blue indicating the lowest dose. The dose distribution is also outlined in Y and X voxels for each radioactive type, with the highest dose area located at the ovoid position. Colors such as orange, yellow, green, navy blue, and dark blue indicate decreasing levels of dose distribution, with distribution values ranging from 50% to 0%.



(a)

(b)

(c)

Figure 4. Isodose curves at the 4.5 cm depth for radioactive: (a) Cobalt-60; (b) Cesium-137; and (c) Iridium-192.

Dose Comparison on Manchester System

Cobalt-60 vs Iridium-192

A comparison of the dose distribution (dose difference at the same voxel) between Cobalt-60 and Iridium-192 is shown in Figure 5. The difference is due to the large energy difference between the two radioactive types, which is 0.77 MeV. The difference in dose distribution is seen in the parameter with a color gradation from intense blue to bright yellow. The parameter shows that the level of difference in dose distribution is 0% to 8.5%. The area that has the largest dose distribution difference is in the area around the two ovoids and tandem 1 (Tandem closest to the ovoid), with a yellow color indicating that there is a dose distribution difference of about 8.5% in that area. Each part of the applicator has a dose distribution difference of 0% – 4%. The locations around tandem 2 and tandem 3 have a dose difference between 5% – 6% and around ovoid 1, ovoid 2, and tandem 1 have a dose distribution difference of 6% to 8.5%.

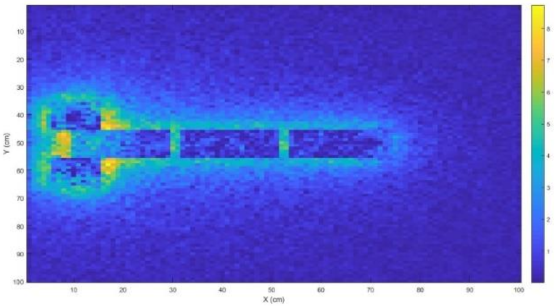


Figure 5. Comparison of Cobalt-60 and Iridium-192 isodose curve.

Cobalt-60 vs Cesium-137

Cobalt-60 and Cesium-137 have large difference in dose distribution due to the difference in average energy between the two radioactive types about 0.51 MeV (Figure 6). The difference in dose distribution can be seen in the parameter with a color gradation from intense blue to bright yellow. The parameter shows that the level of difference in dose distribution is 0% to 7.5%. The area that has the largest dose distribution difference is around the two ovoids and tandem 1 with a yellow dose distribution indicating that there is a dose distribution difference of about 7.5%.

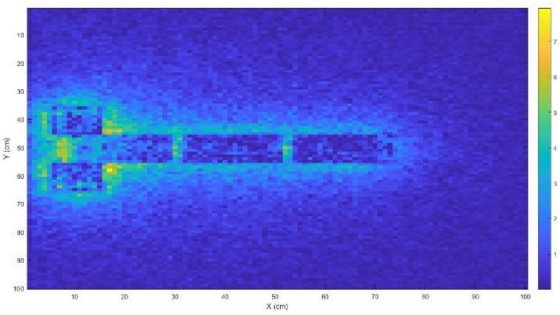


Figure 6. Comparison of Cobalt-60 and Cesium-137 isodose curve.

Iridium-192 vs Cesium-137

The dose distribution comparison between Iridium-192 and Cesium-137 is not as big as the difference with Cobalt-60 (Figure 7). The existence of a comparison that is not too large is caused by the average energy difference between iridium-192 and cesium-137 of only 0.37 MeV. The highest dose difference is 3.5% around both ovoid and tandem 1.

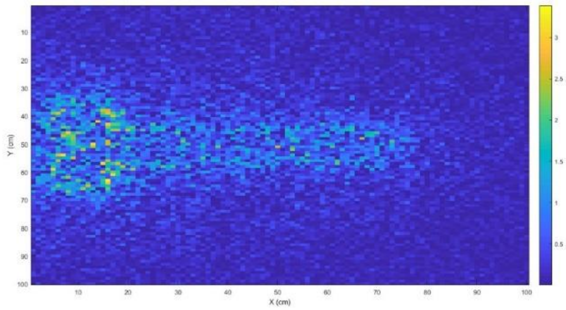


Figure 7. Comparison of Cesium-137 and Iridium-192 isodose curve.

Dose Distribution in Manchester System

Each type of radioactivity using the Manchester system has a different dose distribution which causes the dose at reference points A and B to be different. According to Banahene et al. (2019) point A in the Manchester system is located at 2 cm above the tip of the tandem and also 2 cm lateral from the cervical canal while point B is at a position 3 cm lateral from point A or 5 cm from the centerline of the tandem (Figure 1) [15]. The reference point refers to the rectum and bladder as radiosensitive organs adjacent to the target volume in cervical cancer. In Cobalt-60, the dose distribution exposure received by voxels at reference points A and B was 15.08% and 0%, respectively. Cesium-137 was 13.37% at point A and 0% at point B. Iridium-192 had a dose distribution value at reference point A of 13.27% and reference point B was 0%.

According to Toossi et al. (2012), based on the ICRU (The International Commission of Radiation Units and Measurement) report number 38 recommend the definition of reference points in the implementation procedure. The reference point A dose should be limited to 80% of the defined point A dose [16]. Therefore, the three types of radioactivity used in this study have appropriate reference point values and are not greater than 80%. The use of the type of radioactive source can be adjusted according to the actual location point of cervical cancer.

CONCLUSION

This study used a tissue phantom of 10 × 10 × 10 m^3 with the same radioactive source point location for the three types of radioactivity, Cobalt-60, Cesium-137, and Iridium-192. The isodose curve in brachytherapy using the Manchester system from each radioactive gives different results. The three types of radioactivity have reference point values that are in accordance with the recommendations of the ICRU (The International Commission of Radiation Units and Measurement) report number 38, that the reference point A dose should be limited to 80% of the specified point A dose. Cobalt-60 received a dose distribution exposure at reference point A of 15.08% which is the highest relative dose value compared to the radioactive sources, Cesium-137 and Iridium-192.

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