Application of MCNP for determining the distribution of absorbed dose in lung brachytherapy by using radiation $\gamma^{131}\text{Cs}$

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Abstract. One of the MCNP applications is to determine the radiation dose distribution in the brachytherapy process. In this research performed the calculation of the distribution of radiation doses in the lung organ and some organs at risk, so it can be known whether the doses received by the surrounding organs are still within normal limits or not. The American Association of Physicists in Medicine (AAPM) recommends that the doses administered in patient radiotherapy have inaccuracies that are allowed to be within the range of $\pm 5\%$. This simulation is used to determine the energy of $\gamma$-radiation absorbed per particle transformation in the lung organ and other organs around it. The radioactive source used is $^{131}\text{Cs}$ in the form of points with activity varying from 1.7 mCi to 2.3 mCi, and the number of seeds grown varies from 10 to 60. The simulation of the geometry of the human body is made up of phantom ORNL-MIRD. This research made left lung geometry as target organ with density 0.296 g/cm$^3$ and located at a Cartesian coordinate position that is (8.5; 0; 43.5). From the absorbed dose can be calculated dose distribution on each organ including the target organ and the surrounding organ. If the target organ is considered to receive a dose of 100%, then the surrounding organs are left atrial wall of 59.58%, left atrium content of 14.32%, left ventricular wall of 11.62%, left the ventricular content of 15.5 % and right lung by 0.17%. From the results of the dose distribution can be said that the organs that exist around the target organs are still safe because receiving a radiation dose is still below 60%.

1. Introduction

The American Association of Physicists in Medicine (AAPM) recommends that the doses given in brachytherapy for patients have inaccuracies that are allowed to reach $\pm 5\%$ [1]. The radiation dose can be calculated using the Monte Carlo method, which is one of the software, namely Monte Carlo N-Particle Version 5 (MCNP5). MCNP5 is a software created by the Monte Carlo team from the Los Alamos National Laboratory, USA and applied to simulate the journey of neutron particles, photons and electrons in three-dimensional material starting from particles or photons "born" than interacting with the material until it ends in the area "dead". And this software is very good to use in dosimetry calculations. Research on dose analysis in prostate cancer Brachytherapy with 103-Pd using the Monte Carlo method by Setiawati et al. resulted in an association between effective doses and activity of 103-Pd [2]. Monte Carlo was also used to investigate the influence of tissue inhomogeneity on dose calculations in water media such as in the Treatment Planning System (TPS) of Brachytherapy using 192-Ir sources [3]. MCNP is also used to validate the high dose rate (HDR) calculation of Brachytherapy TPS (Treatment Planning System), there are only small differences at points outside
the source end so that this result is biased for clinical use [4]. Simulation of the determination of absorption dose in prostate Brachytherapy using MCNP5 software produced a linear relationship between the absorption dose and the number of seeds used [5]. Simulation of determination of radiation absorption dose-γ of 103-Pd on breast Brachytherapy using MCNP5 software with PBSI technique produces absorbent dose value in the sternum; the left lung is smaller than the absorption dose in the breast which means the chest and lung organs are relatively safe [6]. In this study, the goal to be achieved is to determine the value of the absorption dose using MCNP5 from the left lung organ and organs near the left lung and compare the value of the absorbent dose when the activity of 131-Cs is different.

2. Methods
Geometry and definition of material used in ORNL-MIRD phantom modeling are very important in the simulation of lung brachytherapy. In making geometry, it is always necessary to have input data which includes the density, material-compiler, surface shape and size, and cell. In the phantom geometry, an ORNL-MIRD model is a geometric form of the human body which consists of 3 main body parts, namely the head, body, and legs.

In this simulation, the radiation source is modeled in the form of the position of the beam of particles emitted to the lungs. The definition of the source required as an input for MCNP5 is the type of particle emitted, the energy and abundance of particles, and the direction of the particle beam. The radiation sources used in this study are presented in Table 1.

| Source       | Information                        |
|--------------|------------------------------------|
| Nuclide      | 131Cs                              |
| Form         | Point                              |
| Number of Seed | 10, 20, 30, 40, 50, and 60         |
| Activity     | 1.7 mCi; 2 mCi; and 2.3 mCi        |
| Energy       | 30, 4 KeV                          |
| Type of Particle | Photon and Electron               |
| Source Placement | Inside the left lung randomly     |

This study makes a left lung geometry with a density of 0.296 g / cm3 and is located in the position of Cartesian coordinates, namely (8.5; 0; 43.5). Figure 1 shows human right and left lung organs and organs around the lungs. The lung organ in the phantom is made in an ellipsoid-shaped cell that is formed to resemble the original lung.

The numbers in figure 1 show the phantom geometry cell number. Cell 2301 number is the left lung cell while the right lung is indicated by cell number 2300. Cell number 2000, 2001, 2004, 2005 respectively are wall cells and left ventricular contents, left the atrial wall and left atrial contents. The number of seeds inserted into the organs in this simulation is 10, 20, 30, 40, 50, and 60. The implanted seeds in the lungs are positioned in a randomly distributed left-hand part of the lungs. In addition to the number of seeds, the activity of 131Cs is 1.7 mCi, two mCi, and 2.3 mCi.

3. Results and Discussion
The results of running visual editor are presented in Figure 1 and Figure 2
Figure 1 shows the human right and left lung organs and organs around the lungs. The lung organs in phantom are made in ellipsoid-shaped cells that are formed to resemble real lungs. The numbers in figure 1 show the cell number of the phantom geometry. Cell number 2301 is the left lung cell while the right lung is cell number 2300. Number cell 2000, 2001, 2004, and 2005 respectively are left ventricular wall cells, left ventricular contents, left atrial wall and contents of the left atrium.

Based on the results of the calculation, obtained data on absorbed doses on the left lung organ which is the object of research as well as the organs around it, namely the right lung of the left atrial wall, left atrial contents, left ventricular wall and left ventricular contents with variations in the number of seeds — the results of the calculation of absorbed doses using activities of 131-Cs that are different, namely 1.7 mCi, two mCi and 2.3 mCi as in figure 3, 4 and 5.

From the graph, it can be seen that the absorbed dose in the left lung organ is larger than the other two organs. This is because the radiation source is placed in the left lung as for the value of the smallest absorbed dose in the right lung caused by its location far from the left lung so that it is relatively safe against the side effects of brachytherapy. Atrium consists of walls and contents. The left atrial wall is located in the outer part of the atrium and is closer to the left lung. For absorbed doses, the left atrial wall is relatively larger than other organs than the left lung such as left atrial contents, left ventricular wall and contents, and right lung and approaches the absorbed dose in the left lung. This is due to the location of the left atrial wall adjacent to the left lung, but the left atrial wall is relatively at risk of side effects from brachytherapy. The contents of the left atrium are protected by the layers of the left atrial wall so that before radiation γ reaches the left atrial contents, radiation will be absorbed by the left lung and left atrial wall first so that the absorbed dose in the left atrial contents
is much smaller. As for the absorbed dose on the left ventricular contents is greater than the left ventricular wall due to the mass of the left ventricular wall is greater than its contents.

![Figure 3](image1.png)

**Figure 3.** The relationship between the amount of seed and the absorbed dose
Activity 1.7 mCi

![Figure 4](image2.png)

**Figure 4.** The relationship between the amount of seed and the absorbed dose
Activity 2 mCi
Figure 5. The relationship between the amount of seed and the absorbed dose Activity 2.3 mCi

This result is by several studies that have been conducted, among others, by Agita R which states that there is a linear relationship between absorption dose with the number of seeds used and research from Gusmativa that the absorption dose in the organ at risk of breast cancer is still relatively safe [5,6].

Based on figure 3, 4 and 5, the organ closest to the left lung is the left atrial wall where the left atrial wall will be relatively safe if the percentage of the dose is less than 75%. Furthermore, the left atrial contents left the ventricular wall and left ventricular contents percentage of the dose should be less than 50%, while the right lung located far from the left lung the percentage of absorption dose must be less than 25% [7].

This activity variation is done to find out the relationship between the absorption dose with the activity used. The activities used vary from 1.7 mCi, two mCi, and 2.3 mCi. Based on the results of calculations, graphs have obtained the relationship between absorption dose and activity used in the left lung, can be seen in Figure 6.

Figure 6. The relationship between absorbed dose and activity in the left lung
From Figure 6 it can also be seen that for all seeds, 10, 20, 30, 40, 50, and 60 seeds show a linear graph, which means the amount of activity is directly proportional to the value of the absorbent dose. The greater the activity used, the greater the absorption dose is given, and vice versa. The smaller the activity used, the smaller the absorption dose given. From the graph, the equation of the line is obtained

\[ D = MA + C \]  

(1)

D is the absorbed dose, M is the gradient of the line equation, A is the activity used, and C is the constant

From the calculation above, a graph of the relationship between the number of seeds and the gradient can be seen in Figure 7.

From Figure 7, the equation of the line is as follows:

\[ B = 0.35s + 0.49 \]  

(2)

B is the line equation gradient, and s is the number of seeds. By substituting equation two into equation 1, a general equation is obtained to determine the number of absorbent doses, activities, and number of seeds as equation 3.

\[ D = (0.35s + 0.49)A \]  

(3)

D is the absorbed dose, s is the number of seeds, A is the activity used. With this equation, interpolation and extrapolation methods can be used to determine the value of absorbed doses.

4. Conclusion

Based on the research conducted it can be concluded that the ORNL-MIRD human body phantom geometry can be made with Monte Carlo simulation. From the graph between absorbance dose (Ds)
and the number of seed (s) for the activity of 1.7 mCi, two mCi and 2.3 mCi it is strongly related that the more seed implanted, the greater the absorbed dose received by the organ. Furthermore, from the organ at risk that was relativized to the left lung by 100%, the percentage of doses obtained on the left wall and atrial contents, the wall and left ventricular contents, and the lungs were 59.58%, 14.32%, 11.62%, 15.5% and 0.17% which are relatively safe from radiation risk. And there is a relationship between activity (A), and the number of seed (s) used based on the equation of absorption dose, namely $D_s = (0.35 \times s + 0.49) \times A$ so that the interpolation and extrapolation methods can be used to determine the absorption dose based on this equation. Seed number and activity.

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