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MONTE CARLO SIMULATION IN INTERNAL RADIOTHERAPY OF THYROID CANCER

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Abstract:
Thyroid radiotherapy is a cancer therapy that is treated by giving radioactive I-131 in Thyroid gland. This cancer is at the ninth from ten of common malignant cancer. A man has higher risk to get Thyroid cancer than a woman has. This organ is lain near human neck. This research aim was to simulate particle track of radiation I-131 and determine an absorbed dose and effective dose in Thyroid and other organs around Thyroid such as Brain, Lung and Cervical vertebrae. The simulation and calculation used Monte Carlo method operated by MCNPX software. Geometry of Thyroid and other organs used ORNL MIRD phantom geometry. From the results, it shown that particle track of radiation was distributed at Thyroid while several particles radiated other organs. The absorbed dose in Thyroid and other organs increased every rising activity of I-131 used, but the absorbed dose in other organs was less than in Thyroid. Radiation effect for damage cancer in Thyroid was shown by an effective dose which it increased every rising activity of I-131 used and the maximum effective dose was at 200 mCi activity of I-131. Although the effective dose in Thyroid increased, the effective dose in other organs like Brain, Lung and Cervical vertebrae was still less than in Thyroid so that the use of I-131 each activity did not really influence other organs around Thyroid.

Keywords:
Thyroid, Radioactive I-131, MCNPX, ORNL MIRD phantom.

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1. INTRODUCTION

Thyroid cancer is at the ninth from ten of common malignant cancer. A man has higher risk to get Thyroid cancer than a woman has. This organ is lain near human neck. It adheres on trachea and fascia pretrachealis. There are many way to diagnose Thyroid cancer; laboratory inquest, radiologis inquest, ultrasonography and thyroid uptake. To heal thyroid cancer can use radiotherapy technique (Sjamsuhidajat, 2005; Lukitto, 2004; Tjindarbumi, 1995).

Thyroid radiotherapy is a cancer therapy that is treated by giving radioactive I-131 in Thyroid gland. This radioactive will react in thyroid gland the same as common iodine so that it can be used to damage a thyroid cancer. The radioactive also will go out from body by urine and sweat (American Thyroid Association, 2005).

The radioactive of I-131 is implanted into the cancerous tissue by injection. I-131 is a gamma and beta emitting radioisotope with a high energy that is equal to 365 keV for gamma and 606 keV for beta. Activities that are used in implants in thyroid cancer are 5-30 mCi for hyperthyroid, 25-75 mCi for turning down thyroid size which is big previously but function normally, and 30-200 mCi to damage cancer cell. The half-life of I-131 is 8.06 days. (American Thyroid Association, 2005).

The use of radioactive I-131 for treatment of thyroid cancer has a risk where other organs around Thyroid will accept dose of radiation. One of the risks is large dose which is accepted by brain, lung, heart and cervical vertebrae. Large dose accepted those organs will make a high defect at those organs. To reduce that problem, we have to know the probable dose which is accepted by cell cancer and the organs. One of ways is to make a simulation of interaction of radiation particle with organ.

The simulation used to determine the interaction of radiation particles and matter is a Monte Carlo method. One of Monte Carlo software is MCNPX (Monte Carlo N-Particle) made by a team from Los Alamos National Laboratory. It can simulate particles interaction with real situation. The use of Monte Carlo in radiation transport is an effective way to predict absorbed dose in an organ. According to Krstic, MCNP can be used to simulate dose in organs by modelling a phantom geometry. Another simulation by Agita which calculated absorbed dose in Prostate Brachytherapy showed that MCNP calculation can determine dose in organ. The use of a well-supported radiation transport code such as MCNP with knowledge of patient anatomy will result in a significant improvement in the accuracy of dose calculations. This study simulates Thyroid cancer with Male ORNL MIRD phantom and uses I-131 radioactive which are distributed with MCNPX program. (Monte Carlo Team, 2000; Cecen, 2013; Krstic, 2014; Agita, 2011).

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2. MATERIALS AND METHODS

Materials used in this research were ORNL MIRD database geometry. The exterior of phantom has approximately the form of the human body. The phantom consists of skeletal, lung, and other soft tissue. The exterior of the phantom is depicted in Figure 1. The arms are not separated from the trunk, and minor appendages such as fingers, feet, chin, and nose are omitted.

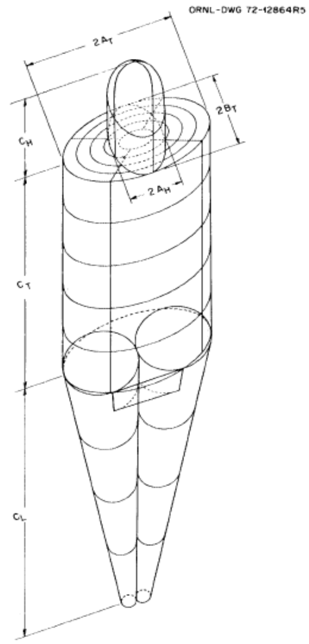

Figure 1: Dimensions of adult phantom. The subscripts H, T, and L refer to head, trunk and legs, respectively (M. Cristy, 1980)

In the phantom, there has been no attempt to introduce small variations which would be presumed to have only a small effect on the scattering of photons. Similarly, the description of the interior organs, while approximately correct as to size, shape, position, composition and density, are simplified to provide formulas which are readily calculated on a digital computer. The exact specifications of the phantom and the internal organs are given in Figure 2.

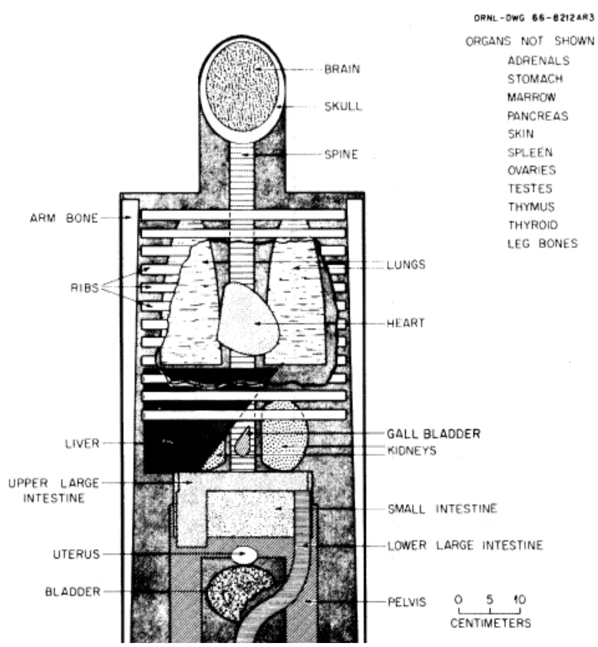

Figure 2: Anterior view of the principal organs in the head and trunk (M. Cristy, 1980)

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Phantom geometry is created using MCNP visual editor like in Figure 3. Figure 4 shown MCNP model around Thyroid organ. Tissue density in MCNP is divided into three parts, namely the density of soft tissue, bone tissue and cardiac tissue. Thyroid geometry is modelled with a volume of 19.9 cm^3 and is located near neck.

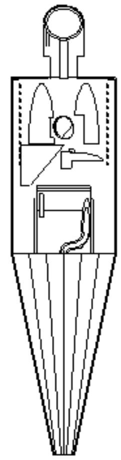

Figure 3: Model phantom in MCNP viewed from the front

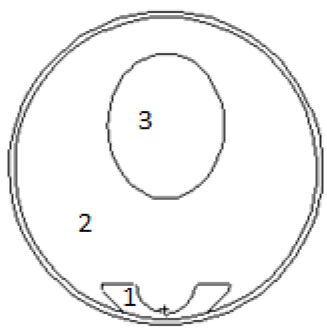

Figure 4: MCNP model of Thyroid (1), Tissue of neck (2), and Spine (3) is viewed from top

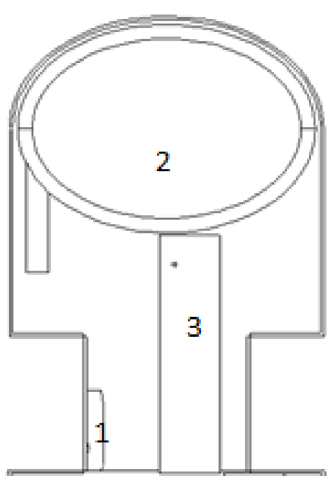

Figure 5: MCNP model of Thyroid (1), Brain (2), and Neck Spine (3) is viewed from left side

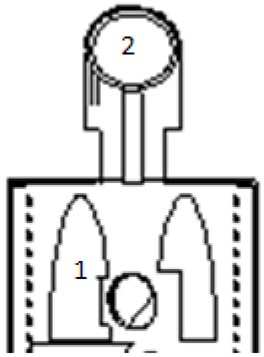

Figure 6: MCNP model of organs around Thyroid; Lung (1) and Brain () is viewed from the front

After creating phantom geometry, the second step is to simulate radiation trip by defining the first radiation source. Radiation source is defined by SDEF cards with Gamma energy of I-131, and calculating uses Tally 8 to obtain organ absorbed dose value (D (T←S)). Tally 8 is MCNP input which will accumulate energy absorbing by a cell in MCNP model of phantom geometry. Radiation source of I-131 is distributed in Thyroid, and uses radiation activity variation of 5, 15, 25, 35, 45, 55, 65, 75 and 200 mCi.

The energy values obtained from simulation are absorbed dose in target organ (D (T←S)). This states that if there is a source of radiation on the organ (S), and there is a target organ (T) which receives radiation from a radiation source, then the average dose rate in organ of T that receives irradiation of organ of S is:

$$\dot{D} = \frac{1{,}6\times10^{-13}\times A_0\times D(T\leftarrow S)}{m} \qquad (1)$$

$\dot{D}$ is an average dose rate (Gy/s), A_0 is radioactive activity (Bq), and *m* is the mass of the organ affected by radiation exposure (kg). Total dose received by the T organ over an infinite period of time since the radioactive treated in S organ can be obtained by integrating the dose rate with respect to time, ie:

$$D_{st} = 1{,}6\times10^{-13}\times\frac{D(T\leftarrow S)}{m}\times\frac{A_0}{\lambda} \qquad (2)$$

To demonstrate the effectiveness of radiation in a specific effect on organ needed a new scale called the effective dose is obtained by multiplying total absorbed dose to the tissue weighting factor (w_t) as in equation 3 (S. Wiryosimin, 1995).

$$D_e = w_t \times D_{st} \qquad (3)$$

D_e is the effective dose (Sv). The value of tissue weighting factor for each organ is different, as shown in Table 1.

Table 1: Tissue weighting factor of various organs R. H. Clarke, 2011)

Tissue	w_t
Bone-marrow (red), colon, lung, stomach, breast, remainder tissues	0,12
Gonads (Testes)	0,08
Bladder, esophagus, liver, thyroid	0,04
Bone surface, brain, salivary glands, skin	0,01

Remainder tissues are adrenals, extrathoracic (ET) region, gall bladder, heart, kidneys, lymphatic nodes, muscle, oral mucosa, pancreas, prostate, small intestine, spleen, thymus and uterus or cervix.

3. RESULTS AND DISCUSSIONS

Radioactive Iodine-131 is injected to thyroid gland with some activities which depend on type of thyroid cancer. The radioactive will radiate some high energies that can damage a cancer cell. This radiation energy is accepted not only by target organ but also some organs around it. Simulating this radiotherapy can determine how much dose will be accepted by organs (Thyroid, Brain, lung and cervical vertebrae) before the treatment is given.

MCNP simulation simulates radiation process to obtain dose in organ. Radioactive Iodine-131 is put in thyroid geometry. In Figure 7 and 8, it showed MCNP simulation particle track of radiation from Iodine.

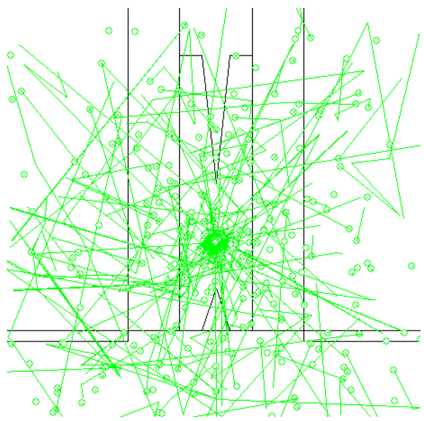

Figure 7: Particle track of Iodine radiation around Thyroid gland from front side of Thyroid

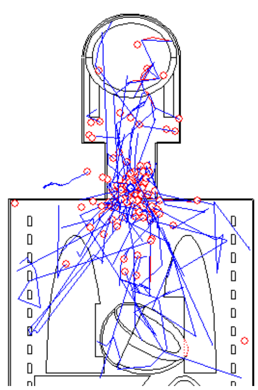

Figure 8: Particle track of Iodine radiation in Thyroid radioterapy form front side of phantom; electron (blue line) and Photon (red line)

From Figure 7 and 8, the particles of radiation concentrated at Thyroid area whereas several particles radiated other organs like Lung, Heart and Brain. Photon track was less than electron track due to photon energy was able to be absorbed by electron to move next electron state. From the MCNP calculation of absorbed dose that it was shown in Figure 9 and 10.

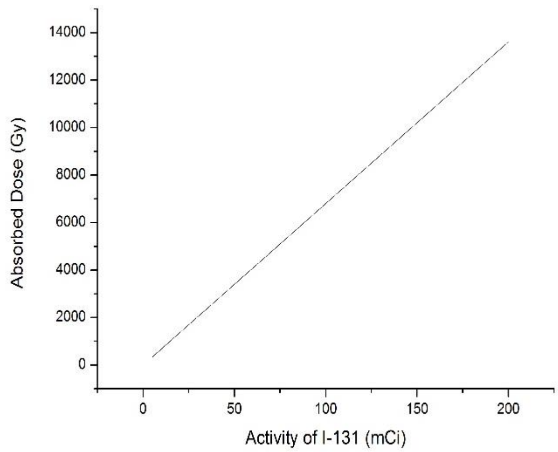

Figure 9: Absorbed dose in Thyroid each of activities

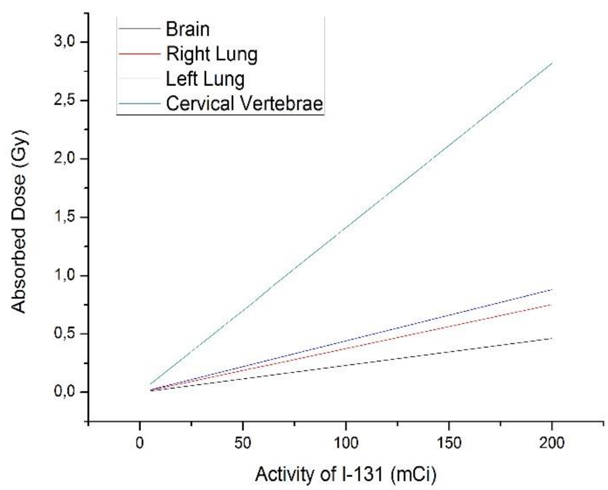

Figure 10: Absorbed dose in other organ around thyroid each of activities

The calculation showed that the larger activity of I-131 was used, the higher the absorbed dose was. The highest absorbed dose was in Thyroid where Brain got the least absorbed dose that other organs around Thyroid. Absorbed dose in Brain was the least due to photon or particle radiation from I-131 experienced many physics phenomena like Compton scattering, bremsstrahlung, electron collusion and so on. This happened due to the density of skull was higher than soft tissue so that the particle composing skull got more interaction with particle radiation of I-131. The calculation of effective dose in Thyroid and other organs was shown in Figure 11 and 12.

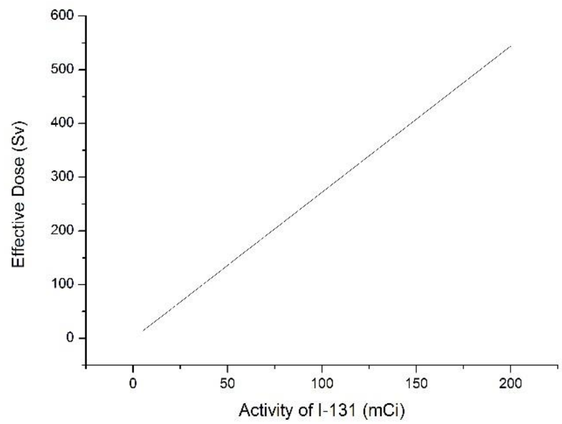

Figure 11: Effective dose in Thyroid each of activities

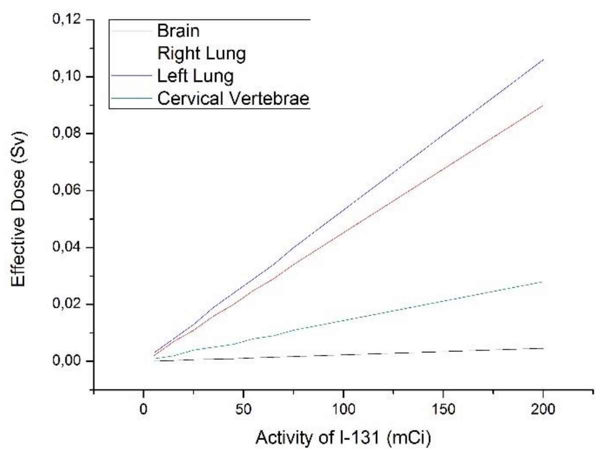

Figure 12: Effective dose in other organs around Thyroid each of activities

The effective dose shows the large of radiation effect to an organ. The calculation in Figure 10 showed that the larger activity of I-131 was used, the larger radiation effect was. For other organs around Thyroid in Figure 11, Lung had larger effective dose due to it was near Thyroid but the effective dose was less than effective dose in Thyroid. The large effective dose was able to show that cancer cell was able to be destroyed more effective. The use of 200 mCi I-131 was not significant effect for other organs around Thyroid which it was able to be looked from effective dose around 0.0001-0.003 Sv for Brain, Cervical Vertebrae and Lung in Figure 11.

4. CONCLUSIONS & RECOMMENDATIONS

From the results, it could have been concluded that Monte Carlo Simulation was able to show not only dose calculation but also particle track of radiation from source of I-131. It had also been able to predict how large dose in cancer cell (Thyroid) and other organs around cancer cell was before real treatment did. The calculation results was obtained that absorbed dose in Thyroid would increase by rise of I-131 activity but absorbed dose in other organs around Thyroid such as Brain, Lung and Cervical vertebrae was less than in Thyroid. The effect of radiation in an organ was shown by an effective dose where the effective dose in Thyroid increased each rise of activity. The maximum of effective dose in Thyroid was at 200 mCi activity of I-131. However, the effect of 200 mCi in other organs around Thyroid was still less so that it was not really influential for the organs.

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