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# Calculation of Absorbed Dose Distribution for Breast Brachytherapy Simulation By CS-1 $^{131}$Cs Seed and ADVANTAGE™ $^{103}$Pd Seed Using Monte Carlo N Particle Extended Simulator

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**Abstract** Simulation using Monte Carlo code has been conducted to determine the distribution of absorbed dose to the breast brachytherapy with $^{131}$Cs and $^{103}$Pd radionuclide sources. Simulations performed on stage I breast cancer with cancer diameter is 2 cm. Sources of radionuclides simulated in the form of seed is modeled with CS-1 which is made by IsoRay $^{131}$Cs and seed ADVANTAGE™ $^{103}$Pd which is made by IsoAID, LLC. Seed was planted in breast cancer cells. Calculation of absorbed dose distribution was performed by varying the distance from the seed. Variations of the distance started from a radius of 0.3 cm to 2 cm with a range of 0.1 cm respectively. In this simulation will also be reviewed the value of absorbed dose for healthy cell like breast, sternum, and lung. The relation between the absorbed dose and the distance from the seed can be described in the form of power law. The results of the calculation show that the maximum absorbed dose is in the target site of the cancer cells (5.791 ± 0.002) Gy per 5 MBq of $^{131}$Cs and (2.755 ± 0.009) Gy per 5 MBq for $^{103}$Pd. The absorbed dose at sternum (1.514 ± 0.011) x 10-4 Gy per 5 MBq of $^{131}$Cs and (7.515 ± 0.633) x $10^{-7}$ Gy per 5 MBq for $^{103}$Pd. While the absorbed dose in the lungs is and (3.615 ± 0.082) x $10^{-5}$ Gy per 5 MBq for $^{131}$Cs and (3.972 ± 0.591) x $10^{-8}$ Gy per 5 MBq for $^{103}$Pd.

**Keywords** brachytherapy, absorbed dose, $^{131}$Cs, $^{103}$Pd, monte carlo

## INTRODUCTION

### *A. Background*

One of malignant disease that often affects women is breast cancer. There are several choices of breast cancer treatment, and of course this choice depends on the size and location of the tumor [1].

Breast cancer is defined as a disease of malignant neoplasms that originate from the parenchyma [2]. If breast cancer is still in stage I and II, then one of the early stages of overcoming breast cancer is surgery or called lumpectomy. Cancer cells are composed of abnormal cells that grow in certain tissues and cells remain roots can continue to grow uncontrolled [3]. To that end, after surgery patients are encouraged to do radiation therapy that aims weeks to kill cancer cells in the removal of the tumor and the surrounding area.

Brachytherapy an alternative therapy treatment of cancer through electromagnetic radiation from a radioactive substance placed near the cancer cells [4]. This method is an effective procedure to kill cancer cells and to prevent tumor coming back. Type of radionuclides commonly used in breast Brachytherapy is 192Ir, $^{103}$Pd and $^{131}$Cs [5].

One method is a method of breast Brachytherapy MHDR (Mammosite High Dose Rate Brachytherapy System). This method uses the type of radionuclide iridium (192Ir) which is inserted into the balloon catheter. Treatment with

MHDR method is limited in patients who already had a lumpectomy space as a balloon catheter, so that patients with early stage can not be taken care of by methods MHDR. To overcome this, other methods that can be used is a method PBSI (Permanent Seed Implant Breast). PBSI method uses a radioactive substance that shaped capsule (seed) which is implanted in cancer cells permanently until the maximum dose is reached. Patients in the early stages can be treated with metoe PBSI without surgical removal of tissue [6].

Determination of safe dose to specific organs in Brachytherapy very important to note. During this time of dosing implants using a simple way by using the approach in tumor shape and form of radionuclide sources. The approach is often done, tumor volume is assumed to be a block or ball, and radionuclide sources is assumed as the point form so that the absorbed dose obtained is not right. Possibility to put detectors and radioactive substances in the body simultaneously extremely unlikely that the necessary simulations to calculate the absorbed dose as precisely as possible. Monte Carlo method is one program that can be used to define the function of dose distributions, dose variation and dose calculations for Brachytherapy [7].

Information dose distribution in the tumor needs to be known by a medical physicist to do so when therapy healthy tissue around the tumor dose is minimal. Departing from the background of the writer wanted to know the distribution of micro-capsule dose radionuclide $^{131}$Cs source and $^{103}$Pd on breast cells and the surrounding healthy tissue.

*B. Review of Literature*

Brachy derived from the Greek "brachios" which means close, linguistically Brachytherapy can be interpreted as a therapeutic range. The term was later used for the application of radiation therapy from close range to Brachytherapy of the term is radiation therapy with radiation sources close to the source of the disease. This treatment method is often also called the closed-source radiation therapy (internal) or sealed source [8].

Application of the method Brachytherapy need to pay attention to the distribution of radiation dose at close range as interstitial, intracavitary or intravascular. The amount of radiation dose used carefully arranged so that the tumor and surrounding normal tissue to get the planned dose [4].

Interstitial Brachytherapy is one technique Brachytherapy by inserting a radiation source in cancer tissue. Implantation in an organ using a needle or catheter applicator [8]. Intracavitary Brachytherapy a radiation therapy by inserting a contact applicator through the lumen (cavity of the body) which will then be filled with sources of radionuclides for example 192Ir [9].

Mammosite High Dose Rate Brachytherapy System (MHDR) is one of the techniques intracavitary Brachytherapy. Patients with the application of techniques MHDR first undergo surgical removal of the cancerous tissue (lumpectomy). The next stage is inserting a balloon catheter into a chamber containing 192Ir lumpectomy. The use of this method is limited to patients who have cancer tissue removed and can not be used for cancer in its early stages.

Obstacles faced with MHDR methods can be overcome using a technique interstitial Brachytherapy by planting a seed that already contains the source of radionuclides into the organs of the body through a catheter. One of the methods of the technique known as Permanent Seed Implant Breast (PBSI) [10].

PBSI treatment process with this method takes ± 60 minutes and not only done one time treatment but is done according to the level of damage as a result of breast cancer cells. Planting seed will be guided using CT-Scan and ultrasound.

Implant Brachytherapy effective only if all parts of the visible tumor. Tumors can be accessed and the limit is clear enough. Tumors were great and boundless invisible Brachytherapy usually not done because it is difficult to reach the edges of the tumor [10].

Application of Brachytherapy technique can overcome weaknesses in radiotherapy that do not focus on targets who are at risk of surrounding healthy tissue. Implementation is done by first estimating quantitative biological effects on patients. The biological effects of Brachytherapy can be known accurately in terms of physical quantity which is the energy absorbed by each unit mass of tissue.

Studies have been conducted PBSI adapting the method using Monte Carlo software to calculate the absorbed dose to the breast Brachytherapy. The first study using 125I source as a seed planted in the breast. The distribution of the absorbed dose is obtained an effect on other organs such as the heart and spine. The experts then look for other sources of radioanuklida more appropriate to replace 125I [5].

Other studies using $^{103}$Pd which has a lower energy than 125I and a shorter half-life. Based on the research that has been done, use $^{103}$Pd relatively safe because the distribution of absorbed dose in organs other than the breast is relatively small compared to the use of 125I. Organ breast scores absorbed dose of 90 Gy, other organs such as the lungs, sternum and heart are affected only by ± 5 Gy [11]. In 2011 also has simulated determination of γ-radiation absorbed dose using radionuclide sources $^{103}$Pd to know the effect of absorbed dose to the breast tissue, lung and chest bone. Seed implant assumed as dots that spreads the breast tissue. The Pengasumsian less relevant because in fact the seed implant shaped capsule with a radioactive substance in it [6]. Additionally absorbed dose is measured on average around breast cells regardless of the absorbed dose distribution around the seed.

In the year 2012 has made the development of research preceding year with seed implants made previously in the form of a point into a capsule shape with a cylindrical geometry as a cover source coupled with the base and lid hemispherical corresponding to the shape of seed ADVANTAGE™ $^{103}$Pd. Capsule seed ADVANTAGE™ $^{103}$Pd created by isoAID LLC [6]. Pengasumsian form of seed, pendefisian source of radionuclides in seed and seed position in the breast cells are less precise so that the modeling does not meet the reality.

In addition $^{103}$Pd radionuclide sources, in 2004 the source of the radionuclide $^{131}$Cs was also introduced to the medical world, especially for Brachytherapy. Radionuclide $^{131}$Cs higher energy and has a shorter half-life than the average of other isotopes commonly used in breast Brachytherapy like $^{103}$Pd and 125I [12]. Monte Carlo simulations using software to radionuclide $^{131}$Cs source is still limited. The study uses micro-capsules $^{131}$Cs (model Cs-1) was conducted to determine the distribution of dose on the prostate organs and surrounding healthy tissue [13]. Measurements of dose distributions with MCNP program showed satisfactory results with accuracy error of less than 5%.

Based on the insights and background libraries that have been previously described, it will be absorbed dose distribution measurement on Brachytherapy breast, lung and breast bone with $^{131}$Cs seed sources and $^{103}$Pd. It is intended to determine the pattern of Distribution of the dose, so that could be a reference to the treatment of breast Brachytherapy so that treatment can be run safely.

## RESEARCH METHODS

This study begins by gathering information and data related to the issues to be discussed are searching for the study of geometry ORNL-MIRD, characteristic of $^{131}$Cs and $^{103}$Pd through library of papers, theses, books, diktat and from the internet.

In solving the problems, this study is divided into several sections, namely;

*A. Modeling Geometry*

The first step in this research is the geometry modeling ADVANTAGE™ $^{103}$Pd seed, seed CS-1 $^{131}$Cs, cancer cells using a variation of the distance, breast tissue, lung and breast bone of the data previously collected. Geometry modeling begins with making the card surface which is the surface appearance of the model geometry. Making the card followed by cell surface card that contains specifications covering the space between the surface density of the material, material definitions, and the name of each cell. Afterwards, cell importance is to be calculated and defined sources of radiation used and continued to command the election tally.

Modelling distance variation performed in the range of 0.3 cm to 2 cm from seed, phantom geometry modeling geometry adapted to the shape, density and volume of adult female phantom models ORNL-MIRD while modeling Radionuclide Sources indicated by Table I as follows:

**Table. 1.** Radionuclide sources Input

| Description | Radionuklida Sources | |
|---|---|---|
| | $^{103}$Pd | $^{131}$Cs |
| Shape | *Capsule* ADVANTAGE™ models | *Capsule* CS-1 models |
| Total *seed* | 1 piece | 1 piece |
| Half-life | 16,99 days | 9,6 days |
| Energiy | 0,021 MeV | 0,0304 MeV |
| emission of particles | Photon | Photon |
| Placement source | In breast cancer cells | In breast cancer cells |

Definition of resources required to simulate a trip particles. In this simulation the radiation source in the form of micro capsules implanted in breast cancer cells. Definition of resources needed as input MCNPX execution is kind of the emitted particles, energy, abundance of particles, particle beam direction, and geometry in the form of radionuclide source shape position.

*B. Verification Modeling Results*

Verification is done by displaying the geometry created in a two-dimensional look and can also be displayed in three dimensions. Seed modeling results, variations in distance and phantom shown in Figure 1, Figure 2, Figure 3, Figure 4 and Figure 5 as follows.

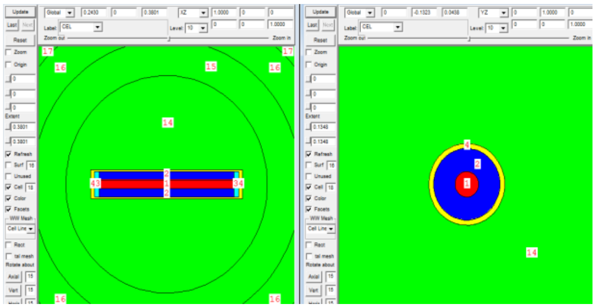

Figure 1. Seed $^{131}$Cs

Model Cs-1 capsule $^{131}$Cs has received permission from the FDA in 2003. The capsule diameter of 0.8 mm with a length of 4.5 mm. Figure 1 shows a model of Cs-1 capsule from IsoRay $^{131}$Cs.

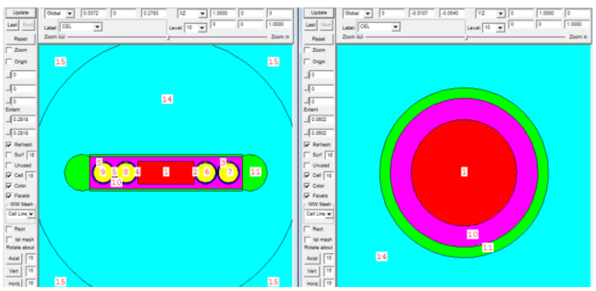

Figure 2. Seed $^{103}$Pd

Figure 2 is a geometry Seed $^{103}$Pd ADVANTAGE™ models which refers to the model geometry belongs isoAID LLC. The outside diameter of the capsule of 0.8 mm with a length of 4.5 mm.

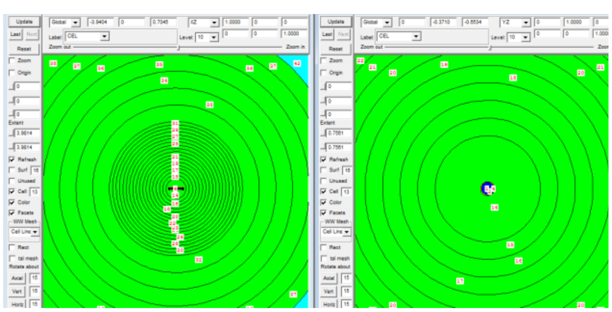

Figure 3. Distance Variations from Seed

Figure 3 shows the variation of the distance spherical cell cancer of the seed planted in the breast. In this simulation modeling is also conducted to review the value of healthy tissue around the breast absorbed dose in order to get value of absorbed dose to a minimum. Modeling healthy tissue can be seen in Figure 3 below:

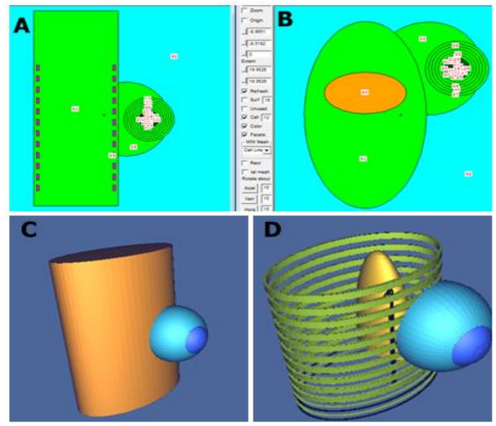


Figure 4. Geometry Phantom body.

In this study, the radionuclide source modeling cylindrical form of micro capsules. Modeling adapted to the shape and size of the originals and not assumed to be a point so that the information absorbed dose in the radius direction adjacent to the seed also needs to be known. The modeling is done by dividing cancer cells that are close to the seed into four pieces at a radius of 0.3 cm to 0.6 cm from seed as shown in Figure 5 below:

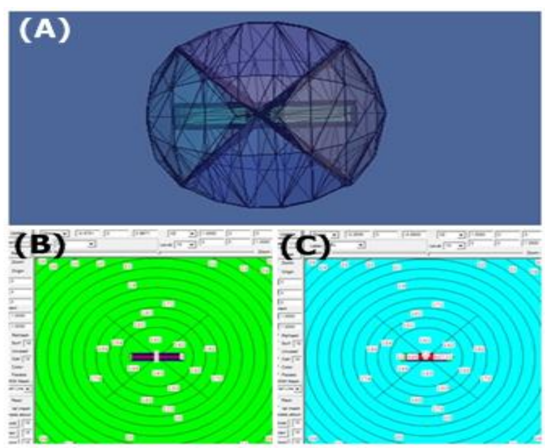


Figure 5. Geometry Cell Cancer in Four Parts

Also shown the results of plot and plot tracks the source to determine the position of the particle source of radionuclides in cell geometry seed that has been made and the direction of the particle distribution.

*C. Determine Source of Variation Activities*

NPS card (Number of Photon per Secon) is the input source of the radionuclide activity. Variations NPS is 1 x 106 NPS; 2 x 106 NPS; 3 x 106 NPS; 4 x 106 NPS; 5 x 106 NPS. The amount of NPS will set a specific number of particles that live right on the number of NPS is entered.

*D. Execution Program*

Execution is to get the value of Energy Deposition (Mev/Trans) which would then be converted to the value of absorbed dose. In this simulation running time is stopped using the NPS card which is a variation of the source activity. The whole treatment is applied to all the variations and the circuit has been modeled.

## RESULTS AND DISCUSSION

Execution of the program has been successfully carried out and the results of running the data obtained by the transformation of energy deposition (MeV/Trans). These results are then converted into units of absorbed dose to get the value of each cell. The result of the calculation of absorbed dose distribution is shown in Table II and Table III as follows:

Table II Absorbed Dose Distribution of $^{131}$Cs 5 MBq

| Radionuclides Sources $^{131}$Cs | | |
|---|---|---|
| R (cm) | Absorbed Dose (Gy) | Information |
| 0,3 | 5,791 ± 0,002 | cancer cells |
| 0,4 | 1,756 ± 0,008 | cancer cells |
| 0,5 | 1,051 ± 0,005 | cancer cells |
| 0,6 | (6,939 ± 0,039) x $10^{-1}$ | cancer cells |
| 0,7 | (4,913 ± 0,024) x $10^{-1}$ | cancer cells |
| 0,8 | (3,650 ± 0,012) x $10^{-1}$ | cancer cells |
| 0,9 | (2,840 ± 0,011) x $10^{-1}$ | cancer cells |
| 1 | (2,235 ± 0,017) x $10^{-1}$ | cancer cells |
| - | (1,514 ± 0,011) x $10^{-4}$ | Sternum |
| - | (3,615 ± 0,082) x $10^{-5}$ | Lungs |

Tabel III Absorbed Dose Distribution of $^{103}$Pd 5 MBq

| Radionuclides Sources $^{103}$Pd | | |
|---|---|---|
| R (cm) | Absorbed Dose (Gy) | Information |
| 0,3 | 2,755 ± 0,009 | cancer cells |
| 0,4 | (7,967 ± 0,044) x$10^{-1}$ | cancer cells |
| 0,5 | (4,437 ± 0,034) x $10^{-1}$ | cancer cells |
| 0,6 | (2,813 ± 0,021) x $10^{-1}$ | cancer cells |
| 0,7 | (1,885 ± 0,016) x $10^{-1}$ | cancer cells |
| 0,8 | (1,345 ± 0,013) x $10^{-1}$ | cancer cells |
| 0,9 | (9,759 ± 0,066) x $10^{-2}$ | cancer cells |
| 1 | (7,286 ± 0,058) x $10^{-2}$ | cancer cells |
| - | (7,515 ± 0,633) x $10^{-7}$ | Sternum |
| - | (3,972 ± 0,591) x $10^{-8}$ | Lungs |

From Table II and Table III can be graphed the relationship between the dose absorbed by variations in the distance from the source shown in Figure 6.

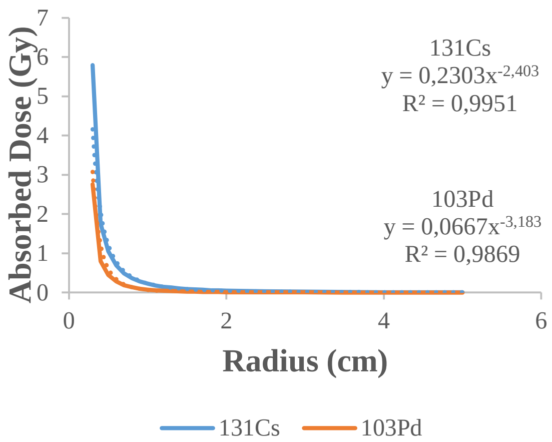


**Figure 6.** Relationship Between the distance with Absorbed Dose.

From Figure 6 it can be seen that the magnitude of the dose absorbed decreasing power law of the distance from the source. This happens because the photon energy generated is reduced or absorbed by the material through which it passes i.e. cancer cells. Due to the absorption of energy by the cancer cells, the intensity of the photon will be reduced after passing the cancer cells. The energy that is absorbed is called the absorbed dose. Based on the results obtained, the distribution of absorbed dose to the maximum dose contained in a radius of 0.3 cm from the seed to the absorbed dose of (5.791 ± 0.002) Gy per 5 MBq of $^{131}$Cs and (2.755 ± 0.009) Gy per 5 MBq for $^{103}$Pd while the minimum dose contained in the organ around the breast that is to be reviewed on the sternum of (1.514 ± 0.011) x 10-4 Gy per 5 MBq of $^{131}$Cs and (7.515 ± 0.633) x 10-7 Gy per 5 MBq for $^{103}$Pd. As for lung $^{131}$Cs absorbed dose obtained by (3.615 ± 0.082) x 10-5 Gy per 5 MBq and (3.97 ± 0.5) x 10-8 Gy per 5 MBq for $^{103}$Pd. Value relative error at the output MCNPX tally refers to the type of one sigma confidence level (1σ) with the correct percentage of 68.5%. From the simulation results can be concluded that the risk Brachytherapy to injure other organs is very small.

In the area of the ball is close to the seed occurs absorbed dose distribution is uneven due to the cylindrical shape of the seed. Subsequent research carried out for the calculation of the direction distribution of dose distributions by dividing the area into four sections ball. Quadrant 1 shows the upper region of the seed, quadrant 2 shows the right-side area of the seed, third quadrant shows the lower region of the seed, and quadrant 4 shows left side area of the seed. The result of the calculation of dose distributions obtained are shown in Table 5.3 as follows,

**Tabel IV.** Distribution Dosage in close distance from Seed.

| $^{103}$Cs Source | | $^{103}$Pd Source | |
|---|---|---|---|
| Radius 0,3 cm | | Radius 0,3 cm | |
| Information | dose (%) | Information | dose (%) |
| Quadrant 1 | 20,67% | Quadrant 1 | 19,57% |
| Quadrant 2 | 29,30% | Quadrant 2 | 30,76% |
| Quadrant 3 | 20,79% | Quadrant 3 | 20,16% |
| Quadrant 4 | 29,24% | Quadrant 4 | 29,51% |
| total | 100% | total | 100% |

The data in Table IV shows that the percentage distribution of absorbed dose distribution direction at a radius of 0.3 cm highest one is in quadrant 2 and quadrant 4 which is the right and left of the seed. This is because the area in quadrant 2 and 4 closer to the source.

In this study, the absorbed dose distribution calculation with five variations of activity for each radionuclide sources shown in Figure 7 and Figure 8 as follows:

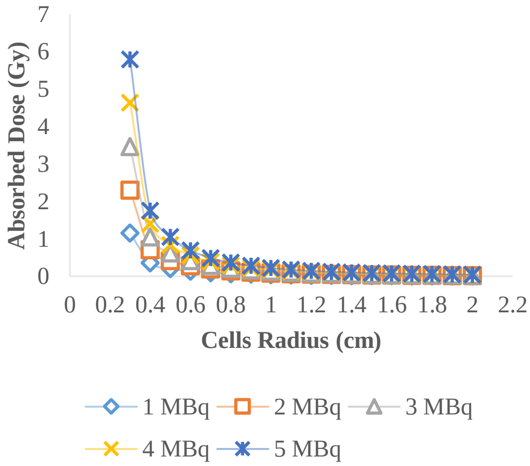


Figure 7. $^{131}$Cs Source

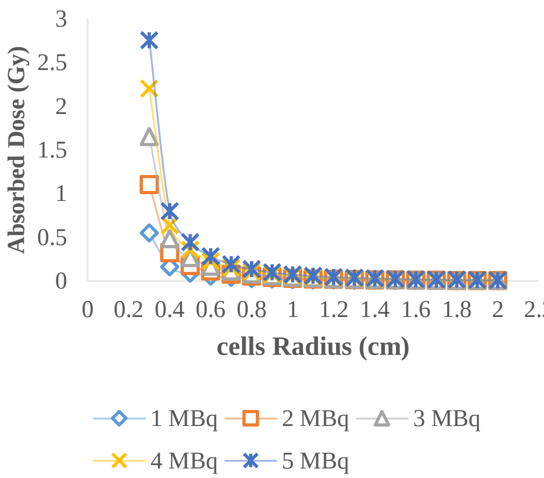


Figure 8. $^{103}$Pd Source

The results showed that the absorbed dose increases with the increase given activity. The relationship between the activity of the absorbed dose can be used to obtain the optimal dose. The maximum optimal dosing in breast Brachytherapy note to kill cancer cells. The maximum dose calculations will be discussed further in the next section.

The radiation dose depends on the amount of energy deposited or absorbed by materials, activities, duration of radiation, and the distance of the source to the target. The maximum dose to kill cancer cells in the breast Brachytherapy is equal to 90 Gy [10]. Before calculating the maximum dose, the first known absorbed dose relationship with the activity of the radionuclide. The relationship between the dose absorbed by the activity shown in Figure 9 as follows:

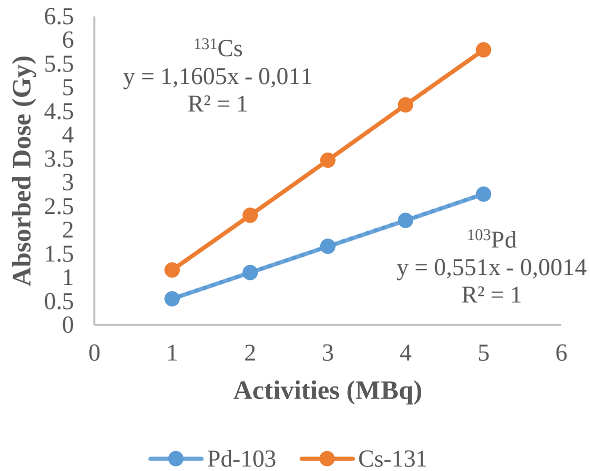


Figure 9. The relationship between dose Absorbed with Activities.

Activities seed source is an activity that is used in units of the NPS (Number of photons per second). The amount of resources activity can be increased by increasing the NPS at the input. NPS is defined as the number of particles $\gamma$ decay per second (Bq). In Figure 9 is shown that the greater the activity that is used, the greater the value of absorbed dose. Can be concluded that the dose absorbed is linearly related to the total activity of each radionuclide is implanted. Linear relationship occurs because of radiation used is homogeneous. Homogeneous means that the radiation source used is the same that $^{131}$Cs with 0.0304 MeV energy and to $^{103}$Pd at 0.021 MeV.

With the equation in Figure 9 it is to achieve the optimum dose can be done by raising activities. If y is a function of absorbed dose, x is the activity of seed used and y = 90 Gy, then the value obtained for x amounted to 77.56 MBq

$^{131}$Cs and x for 103Pd amounted to 163.34 MBq for single capsule. The result of the calculation of the maximum activity data obtained can then be used to review the maximum absorbed dose received by healthy tissue sternum and lungs. The review was conducted by program execution back and enter the appropriate value in the input NPS activity data in order to obtain the maximum value of absorbed dose to healthy tissue sternum and lungs. The results obtained from the calculation, the value of absorbed dose to the sternum of 2.35 × 10-3 Gy and the lungs of 5.49 × 10-4 Gy of $^{131}$Cs, while the absorbed dose to $^{103}$Pd obtained on the sternum by 2, Gy and 45 × 10-5 and in the lungs of 1.29 × 10-6 Gy. Values absorbed dose received by healthy tissue is relatively small and are under the tolerance dose TD5/5 17.5 Gy to the lung, whereas tolerated dose to the breast bone is not presented yet absorbed dose obtained relatively very small even when compared with the dose tolerance for society. From the calculation of the maximum activity showed that the $^{131}$Cs to have a better role than the $^{103}$Pd in killing cancer cells, this is due to the maximum activity required by $^{131}$Cs to provide the same biological effect on tumor cells smaller than the $^{103}$Pd.

## CONCLUSION

In this study it can be concluded on the dose distribution in the breast Brachytherapy including;

1. Distribution of absorbed dose from seed centers around breast cancer decreased power law with increasing radius of cancer cells. From the resulting distribution of absorbed dose obtained maximum dose contained in a radius of 0.3 cm from the seed to the absorbed dose of (5.791 ± 0.002) Gy per 5 MBq of $^{131}$Cs and (2.755 ± 0.009) Gy per 5 MBq for $^{103}$Pd. The minimum dose contained in the sternum was (1.514 ± 0.011) x 10-4 Gy per 5 MBq of $^{131}$Cs and and (7.515 ± 0.633) x 10-7 Gy per 5 MBq for $^{103}$Pd. As for lung $^{131}$Cs absorbed dose obtained by (3.615 ± 0.082) x 10-5 Gy per 5 MBq and (3.972 ± 0.591) x 10-8 Gy per 5 MBq for $^{103}$Pd.

2. There was an absorbed dose distribution is uneven in cancer cells closest to the seed with the greatest percentage of doses are in quadrant 2 and quadrant 4 which is the right side and the left side of the seed.

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