DOSE CALCULATION IN NUCLEAR MEDICINE FOR INTERNAL ORGANS USING GAMOS NMGUI SOFTWARE

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Accurately calculating the dose for patients in cancer treatment is a crucial task. Currently, there are many methods as well as simulation software for dose calculation, most of which have certain limitations in terms of flexibility, ease of use, and error in organ's borders when calculating the dose at voxel level using the traditional Monte Carlo method. However, GAMOS developers have implemented an application specifically for nuclear medicine dosimetry - Gamos NMGUI. This software simplifies the dose calculation process with just a few buttons. The addition of the "parallel geometry" utility eliminates error at the boundaries, resulting in more optimal dosesfor patients. The results of the S values for the ICRP phantoms with Gamos NMGUI show a good agreement with the results calculated by Stephanie Lamart et al. The doses for the boundaries of some organs (Gallbladder Wall, Stomach Wall, Heart Wall, Urinary Bladder Wall) calculated by the "parallel geometry" method has deviations of up to 26% (heart wall) when compared with the traditional MC method. This shows the need to improve the dose calculation by using the parallel geometry technique. In summary, Gamos NMGUI is a convenient, simple but highly effective dose software.

I. INTRODUCTION

Nowadays, cancer is one of the most concerning diseases not only in Vietnam but also worldwide. Nuclear medicine (NM) is one of the leading specializations in cancer treatment. However, it is important to minimize the risks caused by radiation to body and ensure the effectiveness of treatment.[1] To do this, the dose distribution in the body must be calculated accurately. Among the many dose calculation methods applied globally, the Monte Carlo (MC) method is strongly backed by experts due to its flexibility and reliability.[2]

Nevertheless, this method is quite complex because it requires good knowledge of the MC principle and the ability to utilize simulation code. Many MC simulation software has been developed to serve calculation purposes. Among them, the GAMOS/Geant4 software is considered to be the most simplified compared to others since calculations can be executed via command line packets.[3] A general limitation of the MC method in dosing for phantom voxels or computed tomography images is the error at the organs' boundaries. For voxels at the boundary with only a fraction of their volume in the organ, the traditional MC method takes the center of the voxel into consideration. If the voxel center is inside the structure, the volume of the whole voxel is considered to be in the structure. Otherwise, the voxel will be omitted.

At this time, there are new advancements based on the parallel geometry method, enabling the possibility to accurately calculate the fraction of volume and the energy deposited in the volume fraction of the voxel contained within the structure.[4]

However, without a comprehensive knowledge of the MC method, using the code is not a simple task, especially when the application of the parallel geometry method also requires many complicated steps. Recently, the GAMOS developers has implemented an sub-application for GAMOS, dedicated to Nuclear Medicine - GAMOS Nuclear Medicine Dosimetry Graphical User Interface (GAMOS NMGUI).[3] In this version, the dose calculation is designed to be highly simplified yet highly effective. The cancellation of the marginal effect caused by the specifics of the tomography is also added as an "option" to improve the accuracy of the results. The sophisticated and powerful algorithm can automatically convert the geometries of the patient's organs into Geant4 geometries, so that the exact dose for each structure can be calculated using the parallel geometry method. User can adjust the number of decays to get the desired error. In addition, phantoms can be used to replace a patient, or the tomography of a specific patient can be used. This innovation is crucial for treatment since the structure information along with the distribution of radiopharmaceuticals in the patient's body can be included into the calculation. Dose calculations can be done effortlessly and quickly with just the click of a few buttons.

In this study, the authors used the GAMOS NMGUI (a sub-application of GAMOS) on a case of a patient with thyroid disease and using the isotope I-131. The S value is calculated for the thyroid gland and certain organs of the circulatory, respiratory, reproductive and digestive systems. The results calculated on the ICRP phantoms are compared with the ones calculated by Stephanie Lamart et al.[5] Then, the results of a particular patient were calculated for thin organs, with complex shapes and structures such as the Gallbladder Wall, Stomach Wall, Heart Wall, Urinary Bladder Wall. We executed the calculations by cancelling out the marginal effect by paralleo geometry method and compared the results with the traditional MC method. Calculation using the LiverMore Physics model with error under 1%. 'GmEMExtendedPhysics' is the selected physics. The threshold (CUT) for production of electron by ionisation and gammas by bremsstrahlung is 0.1mm.[6]

II. METHODS

1. Study setting

In this study, we calculate the absorbed dose at voxel level, using the MC method with a novel and advanced tool, GAMOS NMGUI. Calculations are done on male and female ICRP phantoms, and on an specific patient in some organ boundary regions (Gallbladder Wall, Stomach Wall, Heart Wall and Urinary Bladder Wall). The male patient is prescribed I-131 with the activity of 5.55×10^{14} Bq. The voxel dimensions of the CT and NM images of the patient are: $0.978 \times 0.978 \times 2.5$mm and $4.79 \times 4.79 \times 4.79$mm, respectively.[5] The results on the organ boundary are compared between the traditional MC method and parallel geometry method by GAMOS NMGUI.

We calculated only the average dose per decay for the purpose of comparing the two methods. From these values, if users want to furthermore calculate the cumulative dose for the body, it is necessary to combine with the kinetic information of the radiopharmaceuticals.

2. Materials and methods

Dose calculation by Monte Carlo method

When applied to the simulation of the transport of radiation in matter, the MC method models the phenomena through direct simulation of experiments and theoretical formulas describing the interaction and energy deposits of radiation in matter.

The solution is randomly sampling the initial parameters of the particle until the result converges. A summary of the simulation process is shown in Figure 1. The history of tracking a particle starts from the time it is created until it is discarded. The next section presents the dose calculation principle for the phantom voxel.
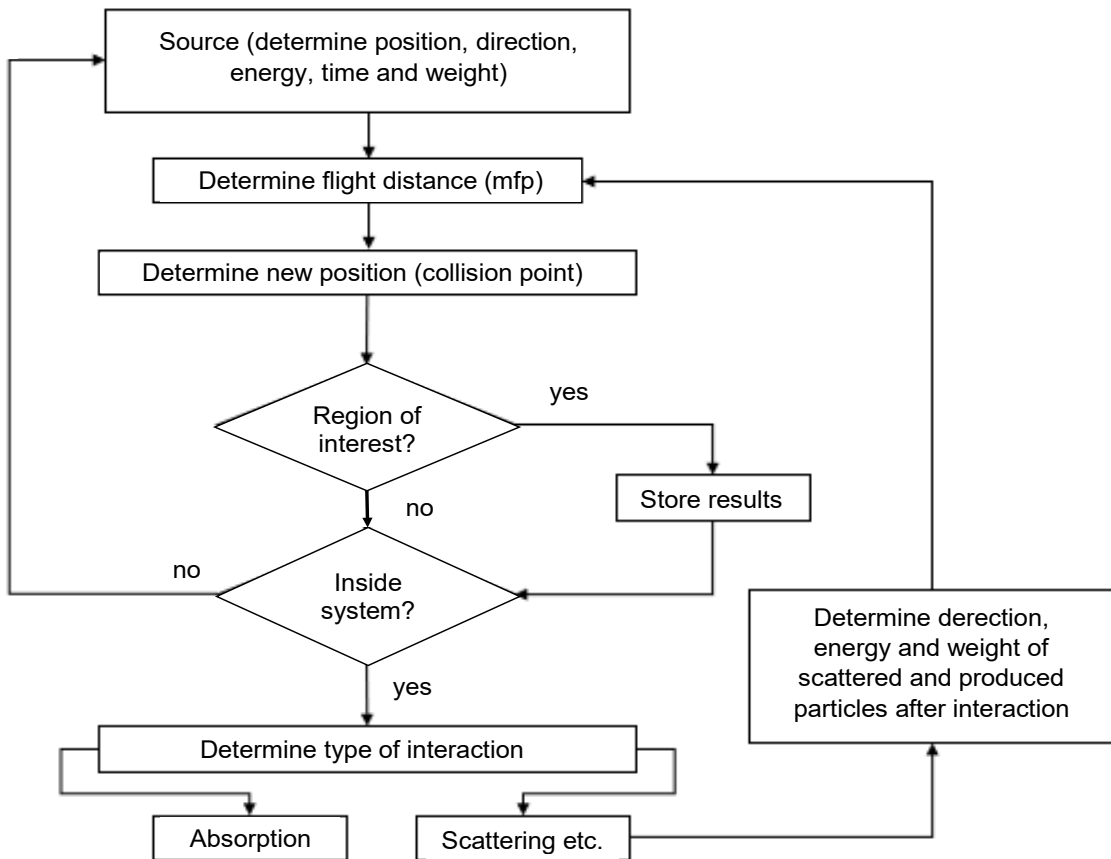
Figure 1. Summary of the simulation process

Dose calculation for voxel phantom

To use the MC method for dose calculation, description of the anatomical structure and activity distribution is required. Calculations on a specific patient requires the CT image, nuclear medicine (NM) image and patient's structure file. Among these, CT images gives information about the patient's anatomical information. It is necessary to convert information from the Hounsfield Unit (HU) number to density as well as material.[7] Structural images help to determine the geometry of each organ. Combined with the NM images, the distribution of activity in the body is shown, which, along with the number of events set up, helps calculate the dose distribution in the body at the voxel level.[8]

Dose calculation with GAMOS NMGUI

With this very simple interface, calculating dose with GAMOS NMGUI is done easily through buttons, which will trigger GAMOS code to be run in the background and produce results. Calculation steps include:

- Step 1: Convert CT/NM images to GAMOS format.

To convert CT/NM images to GAMOS format, select the folder containing these images via the "DICOM CT" or "DICOM PET/SPECT" buttons. When converting CT images to GAMOS format, it is necessary to include converted information from HU regarding the density and material through the "Hounsfield Unit to Material" button.

- Step 2: Defining the structure file for the calculation.

Users can flexibly choose whether to use structure files for calculation or not. If there is a structure file, users will know the limit of the organ and classify the voxels for each different organ. From there, the dose for each organ can be calculated. Otherwise, there will be no information about each organ's border, so only the dose distribution per voxel will be seen. In this study, the authors segmented the structures using the Carimas software (Figure 2).
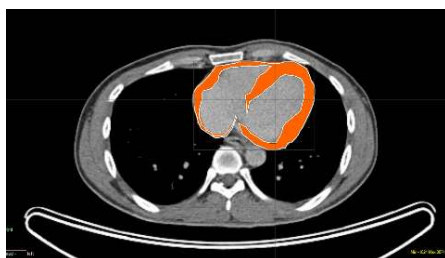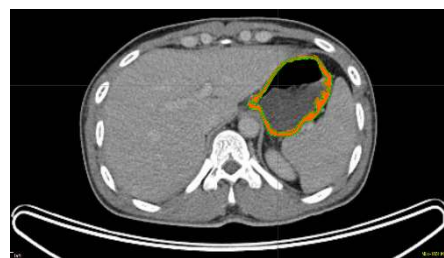
Hearth Wall

Gallbladder Wall

Urinary Bladder Wall

Stomach Wall

Figure 2. Boundaries of a few organs

The segmented structures are saved as point sets and converted to Geant4 geometry and then declared as "parallel geometry" in the next step.

- Step 3: Calculate dose using parallel geometry to eliminate marginal effects

To eliminate the marginal effect, GAMOS will base on the structure geometry to create Geant4 geometries that best reflect the geometry of the structure. These geometries are declared as parallel geometries, and then attached to them with a filter to properly extract the energy deposited in the structure, so that the dose of the structure can be calculated accurately without the impact of marginal effects, caused by the geometrical characteristics of the computed

tomography images.

- Step 4: Select the required isotope

This can be done by selecting the "Isotope" button.

- Step 5: Select the decay number

The larger the number of events, the smaller the error and the longer it takes to calculate. Therefore, the selection of the number of events will help us control the calculation time as well as the statistical error in dose calculation. After executing the above declarations, the dose calculation is performed when the "Execute" button is selected. In short, calculating the dose with GAMOS NMGUI is simplified to 5 steps and is much simpler than the old GAMOS version (Figure 3).
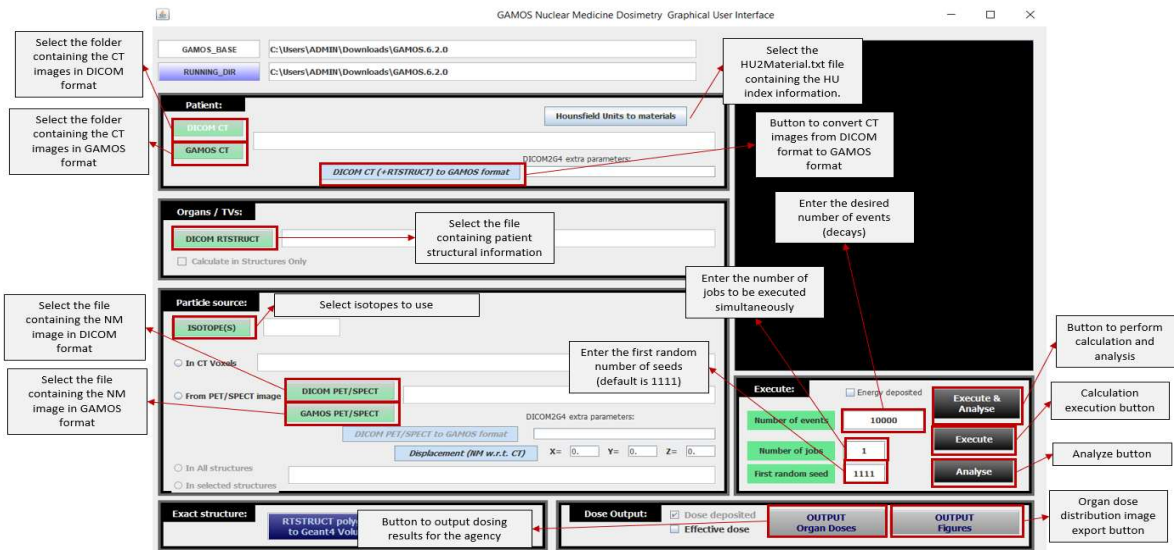

Figure 3. Annotate buttons in GAMOS

3. Research ethics

Following the research ethics, the research has no effect on patients' health and patient information is kept strictly confidential.

III. RESULTS

1. S value calculation results for female ICRP phantom, with thyroid as the source organ (mGy/Bq.s)

Table 1. S value calculation results for female ICRP phantom, with thyroid as the source organ (mGy/Bq.s)

Target organ	Stephanie Lamart	Calculated with GAMOS	Deviation
Thyroid	1.87E-09	1.89E-09	1.1%
Digestive system			
Stomach	8.62E-14	8.85E-14	2.6%
Liver	1.46E-13	1.41E-13	-3.5%
Small intestine	1.96E-14	1.88E-14	-4.3%
Pancreas	5.45E-14	5.32E-14	-2.4%
Gallbladder	9.15E-14	9.00E-14	-1.7%

Target organ	Stephanie Lamart	Calculated with GAMOS	Deviation
Circulatory system			
Heart	6.76E-13	6.88E-13	1.7%
Brain	2.50E-13	2.60E-13	3.8%
Kidney (left)	5.44E-14	5.32E-14	-2.3%
Kidney (right)	5.23E-14	5.45E-14	4.0%
Respiratory system			
Lung (left)	9.96E-13	9.88E-13	-0.8%
Lung (right)	1.00E-12	1.02E-12	2.0%
Bronchi	1.08E-12	1.11E-12	2.7%
Windpipe	2.40E-11	2.39E-11	-0.4%
Reproductive system			
Bladder	2.26E-15	2.33E-15	3.0%
Ovary	2.46E-15	2.51E-15	2.0%
Uterus	2.24E-15	2.22E-15	-0.9%

2. S value calculation results (average dose per decay) for male ICRP phantom, with thyroid as source organ (mGy/Bq.s)

Table 2. S value calculation results (average dose per decay) for male ICRP phantom, with thyroid as source organ (mGy/Bq.s)

Target organ	Stephanie Lamart	Calculated with GAMOS	Deviation
Thyroid	1.59E-09	1.53E-09	-3.9%
Digestive system			
Stomach	1.18E-13	1.15E-13	-2.6%
Liver	1.44E-13	1.43E-13	-0.7%
Small intestine	2.39E-14	2.43E-14	1.6%
Pancreas	7.13E-14	7.22E-14	1.2%
Gallbladder	8.48E-14	8.61E-14	1.5%
Circulatory system			
Heart	6.47E-13	6.52E-13	0.8%
Brain	1.52E-13	1.51E-13	-0.7%
Kidney (left)	6.06E-14	6.12E-14	1.0%
Kidney (right)	5.62E-14	5.73E-14	1.9%

Target organ	Stephanie Lamart	Calculated with GAMOS	Deviation
Respiratory system			
Lung (left)	9.47E-13	9.54E-13	0.7%
Lung (right)	8.79E-13	8.83E-13	0.5%
Bronchi	9.30E-13	9.23E-13	-0.8%
Windpipe	2.03E-11	2.11E-11	3.8%
Reproductive system			
Testicular	3.14E-16	3.21E-16	2.2%
Bladder	2.73E-15	2.80E-15	2.5%

3. Dose calculated for the boundary of the organs of patients

Structures are the boundary regions of organs with complex anatomical and geometrical structures, with relatively thin thickness.

Table 3. Dose calculated for the boundary of the organs of patients (mGy/Bq.s)

Organ	Dose calculated with the traditional method	Dose calculated with the parallel geoemtry method	Deviation
Gallbladder Wall	1.92E-14	1.84E-14	-4%
Stomach Wall	2.83E-14	2.72E-14	-4%
Heart Wall	1.54E-13	1.22E-13	-26%
Urinary Bladder Wall	1.46E-15	1.51E-15	3%

IV. DISCUSSION

From the results on the ICRP phantom of two genders, using the I-131 isotope with the thyroid as the source organ, it is found that the results calculated with GAMOS are in good agreement with the calculation results of Stephanie Lamart et al.[5]

For the female phantom, the lowest deviation is of the windpipe (0.4%), the highest deviation is of the small intestine (4.3%). For the male phantom, the lowest deviation is of the right lung (0.5%) and the highest is of the thyroid gland (3.9%). The reason for the difference is statistical error, along with the CUT selection. However, since the deviations are small (all less than 5%), the results still prove that GAMOS is a reliable software.

The results on the organ boundaries with the traditional Monte Carlo method and with the parallel geometry method shown some differences. This deviation can be implied as the error of the traditional method. The error can be only a few percent (Gallbladder Wall, Stomach Wall and Urinary Bladder Wall), but can go up to 26% with the heart area. Many reasons can be attributed to this deviation: the number of voxels at the boundaries, the geometry of the structure, the density in the investigated area, the location of the voxel center, the fraction of the voxel volume in the organ, etc.[9] These factors simultaneously influence and complicate the

deviation between the two calculation methods. The considerable error in the Heart Wall shows the significance of the application of the parallel geometry method.

There are also structural regions where deviations are small (only a few percent). However, when dose calculation for one or more organs is required, it is not possible to know in advance which structural region will have a large error in border (because many factors influence the margin error), so to calculate the dose for the structure of interest and always ensure optimal results, users should eliminate the marginal error by using parallel geometry. In the past this was quite complicated because it required the user to manually create the geometry file to convert all areas of the patient's structure to Geant4 geometry, having to use complex subtractions.[9] But now, this can be done easily with the "Calculate in Structures Only" button. For regions very far from the region of interest, where the received organ dose is very small relative to the region of interest, we need not use parallel geometry method to save the computation time. The parallel geometry option can be flexibly adjusted.

V. CONCLUSION

With the advent of many dose software, dose calculating nowadays can be step-by-step directed toward dosing for specific patients. MC is considered the mainstream method due to its reliability and flexibility. With the introduction of GAMOS NMGUI, dosing for patients can be performed with high reliability, yet very simply at the click of a few buttons. By applying an algorithm that converts patient structures to parallel geometry, it is possible to eliminate errors at the organ boundaries, thereby optimizing the dose when calculated for each patient's organs, enhancing the effectiveness of treatment for the patient.

For the purposes of dose comparison when calculating the dose for the organ boundary by two methods (traditional MC and parallel geometry), the authors therefore only calculated the average dose per decay. To derive the total dose received by the body, these results need to be combined with the kinetic information of the radiopharmaceuticals.

REFERENCES

1. Yi Y, Stabin MG, McKaskle MH, et al. Comparison of Measured and Calculated Dose Rates Near Nuclear Medicine Patients. *Health Phys*. 2013;105(2). https://journals.lww.com/health-physics/Fulltext/2013/08000/Comparison_of_Measured_and_Calculated_Dose_Rates.9.aspx

2. Besemer AE, Yang YM, Grudzinski JJ, et al. Development and Validation of RAPID: A Patient-Specific Monte Carlo Three-Dimensional Internal Dosimetry Platform. *Cancer Biother Radiopharm*. 2018;33(4):155-165. doi:10.1089/cbr.2018.2451

3. Nguyễn Thị Phương Thảo. Tính liều trong y học hạt nhân với Phantom Voxel bằng phần mềm GAMOS/GEANT4. Luận *Án* Tiến Sĩ. Viện năng lượng Nguyên tử Việt Nam; 2021.

4. Ebert MA, Haworth A, Kearvell R, et al. Comparison of DVH data from multiple radiotherapy treatment planning systems. *Phys Med Biol*. 2010;55(11):N337. doi:10.1088/0031-9155/55/11/N04

5. Lamart S, Simon SL, Bouville A, et al. S values for 131I based on the ICRP adult voxel phantoms. *Radiat Prot Dosimetry*. 2016;168(1):92-110. doi:10.1093/rpd/ncv016

6. Kyriakou I, Ivanchenko V, Sakata D, et al. Influence of track structure and condensed history physics models of Geant4 to nanoscale electron transport in liquid water. *Physica Medica*. 2019;58:149-154. doi:https://doi.org/10.1016/j.ejmp.2019.01.001

7. Bhattacharyya K. Godfrey Newbold Hounsfield (1919-2004): The man who revolutionized neuroimaging. *Ann Indian Acad Neurol*. 2016;19(4):448-450. doi:10.4103/0972-2327.194414

8. Ljungberg M, Sjögreen K, Liu Xiaowei, et al. A 3-Dimensional Absorbed Dose Calculation Method Based on Quantitative SPECT for Radionuclide Therapy: Evaluation for 131 I Using Monte Carlo Simulation. *J Nucl Med*. 2002;43(8):1101-9.

9. Dubois PA, Thao NTP, Trung NT, et al. A tool for precise calculation of organ doses in voxelised geometries using GAMOS/Geant4 with a graphical user interface. *Polish Journal of Medical Physics and Engineering*. 2021;27(1):31-40. doi:10.2478/PJMPE-2021-0005