Designing a Computer Code to Estimate the Committed Dose Equivalent to Internal Organs Following the Injection of a Radiopharmaceutical

***Z. Keldani, R. Roman and S. Saadi**
University of Ontario Institute of Technology, Ontario, Canada
zaid.keldani@uoit.net

An Undergraduate Level Submission

Summary

Radiopharmaceuticals are drugs that contain radioactive isotopes and are used within the nuclear medicine field for diagnostic procedures. There is a demand for an effective software to calculate the Committed Dose Equivalent (CDE) to patients. The designed software would be a useful tool for medical professionals in the nuclear medicine field and for any patient interested in knowing the dose received following the injection of a radiopharmaceutical. The aim is to design an affordable and easy to learn tool to estimate the Committed Dose Equivalent to various organs of interest as well as the total body.

1.0 Introduction

Radiopharmaceuticals are radioactive agents used to diagnose and treat specific medical problems. They may be administered to the patient in various ways such as injection, ingestion, or placed into the eye [1]; the type of radiopharmaceutical used and the way it is introduced into the patient's body determine the targeted organ. The radioactivity is then detected by dedicated imaging equipment and scans are generated. These scans are images of the targeted organs enabling the observation and examination of how the organs are functioning. Moreover, these images enable the detection of cancer or tumors that may be present within an organ. Currently, Iodine-131 (I-131) and Technetium-99m (Tc-99m) are the most commonly used radiopharmaceuticals, in Canada Tc-99m is used in over 80% of all nuclear medicine scans [2]. With numerous scans and diagnostic procedures being widely conducted, a demand is present for an effective software to estimate a patient's Committed Dose Equivalent (CDE).

2.0 Methodology

To develop the software, the scope was set to include modelling the bio-distribution of the radioactive material, calculating the activity in regions of interest of the human body (source organs), as well as computing the dose based on the distribution of the injected radiopharmaceutical. In order to model the distribution of the radioactive material and determine the localization in each organ, a multi-compartment bio-kinetic model was studied and analyzed. A multi-compartment model, which consists of blocks, each representing one or a group of organs, provides information on the bio-distribution of the radioactive material as well as its concentrations. The multi-compartment model can be mathematically be represented as a system of differential equations which can then be used to calculate the activity in source organs and the dose received by target organs. As a result, a multi-compartment model of I-131 was adopted and chosen as a pilot study to perform dose calculations due to its reasonable complexity.

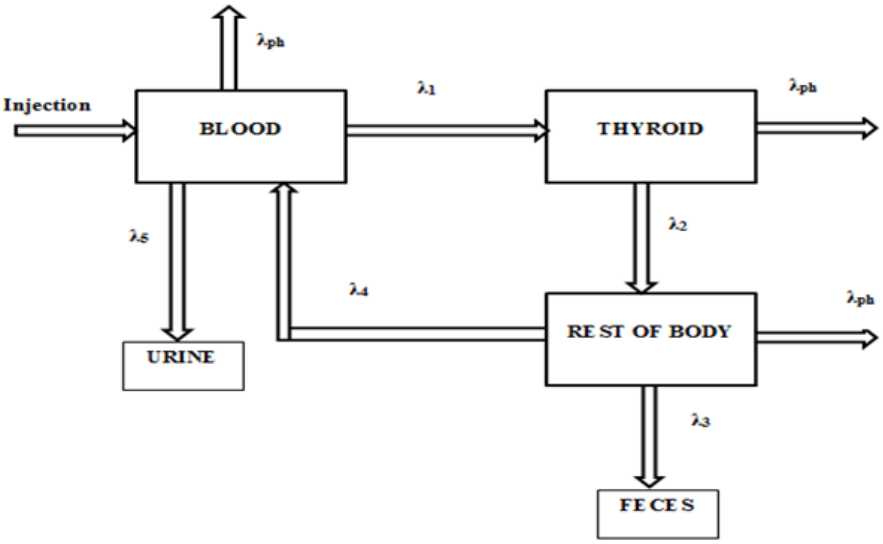

Figure 1 - I-131 Bio-kinetic Model [3]

The bio-kinetic model that is shown above comprises three main compartments which are the blood, the thyroid and the rest of the body. Following the injection, the radioactive material starts its path from the first compartment (the blood), which is then absorbed by the thyroid and lastly by the rest of the body. Each of the arrows represents the decay that the radioactive material undergoes; the λ value associated with each arrow signifies the decay constant. Lambdas from λ_1 to λ_5 represent the biological decay constants of I-131 from one compartment to another. Additionally, the radioactive material undergoes physical decay by emitting gamma rays and other types of ionizing radiation. The decay constant associated with this process is Lambda physical (λ_{ph}). The bio-kinetic model also considers urine and feces as means of excretion. In order to find the activity in each of the compartments and the dose to other body organs, the number of radioactive nuclides in each compartment had to be found. For this purpose, a system of differential equations that describes the dynamics of the multi-compartmental system was developed and numerically solved. In the following differential equations, N values represent the number of radioactive nuclides in that specific compartment:

$$\frac{dN_{Blood}}{dt} = -(\lambda_1 + \lambda_5 + \lambda_{ph})\, N_{Blood} + \lambda_4 N_{Body} \quad (1)$$

$$\frac{dN_{Thyroid}}{dt} = -(\lambda_2 + \lambda_{ph})\, N_{Thyroid} + \lambda_1 N_{Blood} \quad (2)$$

$$\frac{dN_{Body}}{dt} = -(\lambda_3 + \lambda_4 + \lambda_{ph})\, N_{Body} + \lambda_2 N_{Thyroid} \quad (3)$$

2.1 Dose Calculations

Two dose calculating methods were identified and examined. The first method was the Medical Internal Radiation Dose (MIRD) technique. The second method was introduced by the International Commission on Radiological Protection (ICRP). Both approaches were studied and found to be similar in the way of calculating the dose. However, it was decided that the MIRD technique would be used. The CDE is the effective dose to organs or tissues after introducing radioactive material into the body, integrated over a 50-year period for adults and a 70-year

period for children [4]. In order to reduce the complexity of the dose calculations, the MIRD technique assumes that the radioactive material is evenly distributed within an organ. Besides, it neglects any dose received by ionizing radiation other than gamma rays. The CDE ($H_{T,\,t}$) is computed by first calculating the absorbed dose using the following equation [5]:

$$D = S\,(T \leftarrow S) * \int_0^t A.\,dt \tag{4}$$

Where:

- D is the absorbed dose in the target organ in units of Gray (Gy).
- $S(T \leftarrow S)$ is the absorbed dose per activity in units of Gy; the T and S between brackets symbolize the Target and Source organs, respectively.
- $\int_0^t A.\,dt$ is the cumulated activity of the radioactive material in the source organ.

In order to calculate the activity in the source organ, the number of radioactive nuclides in that organ has to be found by solving the system of differential equations that was developed for the bio-kinetic model as well as using the following equation [5]:

$$A(t) = \lambda_{ph} * N(t) \tag{5}$$

Where:

- $N(t)$: is the number of radioactive nuclides in the source organ at time t.
- λ_{ph}: is the physical decay constant of the radioactive nuclides per unit time.

The S-factor, which is the absorbed dose per activity, is calculated using the following equation [5]:

$$S(T \leftarrow S) = \Delta * \sum_{n=1}^{i} \phi\,(T \leftarrow S) \tag{6}$$

Where:

- $\phi\,(T \leftarrow S)$: is the Specific Absorbed Fraction (kg^{-1}), obtained from MIRD pamphlet 05 tables [5].
- Δ: is the product of photon energy (E) and its yield (n)

The final step of calculating the CDE is to multiply the absorbed dose that was found earlier by the radiation weighing factor (W_R) and the tissue weighing factor (W_T) for each of the target organs [5]. Both the radiation and tissue weighing factors are found in ICRP publication 103 [6].

$$H_{T_t} = D * W_R * W_T \tag{7}$$

2.2 Code

Several programming languages were examined and evaluated based on a predefined criterion. After the evaluation process was completed, it was concluded that C# will serve as the most efficient in meeting the objectives. Once the software is executed, the user has to select a radiopharmaceutical from the drop list. The user then has to input the initial activity being injected. Finally, the user has to select patient's legal gender.

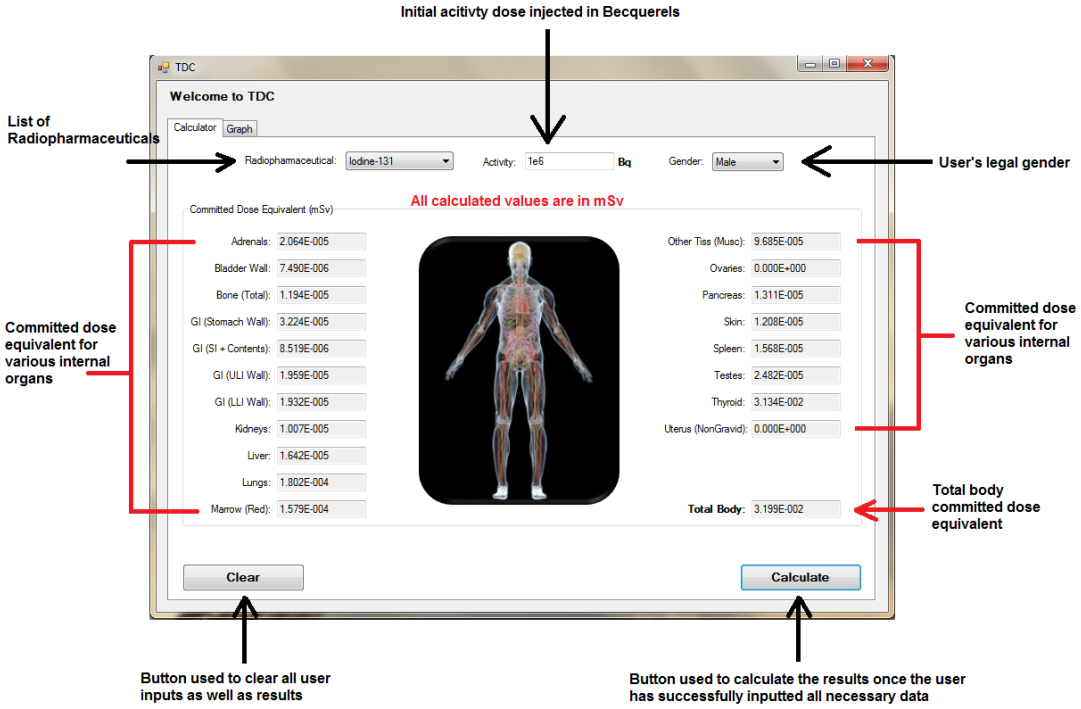

Figure 2 - Software user interface (Tab 1)

Once all required data have been successfully and correctly inputted by the user, the user will then press the "Calculate" button located at the bottom right corner of the software to obtain the generated results. Figure 2 above shows a test run of the software as well as the user interface once the program executable has been run. Since the software is still in beta version, the only available radiopharmaceutical is Iodine-131, which was used as a starting point due to the reasonable complexity of its bio-kinetic model. The inputted activity is then used by the software to calculate the initial number of radionuclides (N_0), which is then used through the system of differential equations shown in section 2.1. The software then utilizes the system of differential equations and various specific absorption factors (from the MIRD pamphlet no.5) to trace the activity throughout the compartments shown in the bio-kinetic model in section 2.1. The software performs 438,000 steps; each step is considered an hour, and collectively are equvalent to 50 years. Once all calculations have been performed, results are then displayed in the 20 textboxes allocated in Tab 1 for various internal organs, as well as the total body. This then allows the user to switch to the second tab by clicking the "Graph" button. This action generates a line graph that displays the patient's cumulative dose (in mSv) with respect to time.

Various measures have been taken to ensure all human errors are eliminated. For instance, in the absence of one of the three required inputs, if the user presses "Calculate", an error message will appear notifying the user of that missing variable. All the textboxes used to display results have been set to read-only to prevent the user from tampering with the output. The activity textbox shown in Figure 2 above will only allow numbers and a single input of 'e' (for scientific notation), '.' (for decimals), and '+' / '-'.

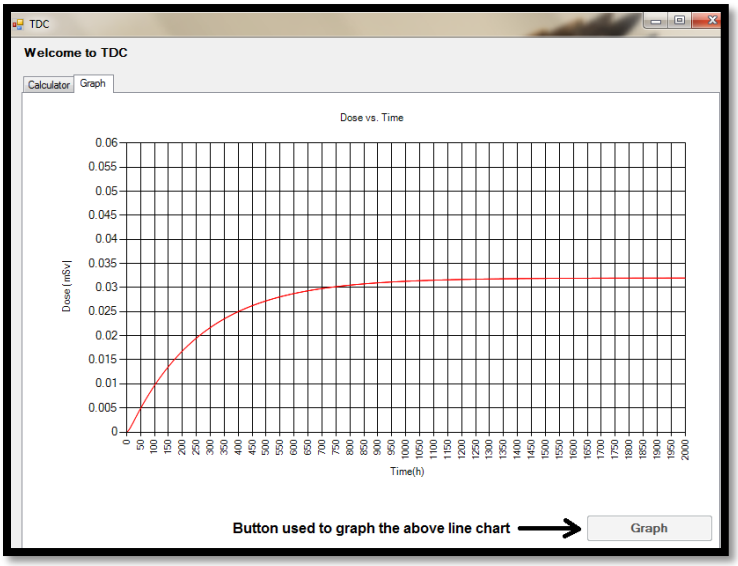

Figure 3- User interface (Tab 2) displaying info graphic

3.0 Conclusion and Future Work

A software to estimate the Committed Dose Equivalent (CDE) was designed and developed in C# programming language and using the MIRD technique as a method of calculating the dose. A bio-kinetic model of I-131 was used to build the preliminary version and as a pilot study in order to calculate the activity in different body regions which was then used to perform the dosimetry. The future work of this research will focus on enhancing the software and include other radiopharmaceuticals such as Tc-99m based radiopharmaceuticals.

4.0 References

[1] Chetan D. M., Dinesh K. P., “Health and Pharmaceutical Biotechnology”, 2006, p. 13.

[2] Health Canada, "Medical Isotopes - Frequently Asked Questions," 31 08 2009. [Online]. Available: http://hc-sc.gc.ca/dhp-mps/brgtherap/activit/fs-fi/isotopes-med-faq-eng.php.

[3] V. Berkovskyy, "Assessment of Doses to the Thyroid Gland," [Online]. Available: http://www-pub.iaea.org/iaeameetings/cn224p/Session12/Berkovskyy.pdf.

[4] ICRP, “Compendium of Dose Coefficients based on ICRP Publication 60”, Volume 41, 2012.

[5] W. S. Snyder, M. R. Ford and G. G. Warner, "Estimates of Specific Absorbed Fractions for Photons Sources Uniformly Distributed in Various Organs of A Heterogeneous Phantom," Society of Nuclear Medicine, 1978.

[6] European Nuclear Society, "Radiation Weighting Factors," 1996. [Online]. Available: http://www.euronuclear.org/info/encyclopedia/r/radiation-weight-factor.htm. [Accessed 19 12 2014].