Internal Radiation Dose Assessment in Nuclear Medicine Practices by Using Locally Developed IRDE Software

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ABSTRACT

In nuclear medicine practices, internal radiation dosimetry offers methods for calculation of radiation absorbed dose and risks from radionuclides incorporated inside the body. To manually perform internal radiation dosimetry is time-consuming and errors can occur in each step leading to developing software tools to ease users. There are many software packages available; however, many of them have limited functions. Locally developed IRDE software has been used to calculate the absorbed dose per unit of radioactivity in the target organ. The dose calculation methodology in nuclear medicine practices is described in this study along with a preliminary result on dose calculation for Bangladeshi population due to ingestion of ^{131}I radioisotope in nuclear medicine practices. IRDE is user-friendly, graphic user interface-based software. It can be performed all steps of internal dosimetry within single environment lead to reducing calculation time and reducing possibility of error. IRDE also provides fast and accurate results which may be useful for a routine work in nuclear medicine facilities.

Key words: **Nuclear medicine, internal dosimetry, IRDE software, ICRP model, biokinetics**

INTRODUCTION

In nuclear medicine, medical radioisotopes are used in variety of diagnostic and therapeutic procedures. Internal radiation dosimetry is essential to evaluate the risk and benefit of any procedures. It is also used to optimize imaging techniques and develop new radiopharmaceuticals. Internal radiation dosimetry in nuclear medicine is usually performed using MIRD (Medical Internal Radiation Dose) method, which is based on measurement of the biokinetics data of serial image scans. Radiation dose assessment for internal emitters in nuclear medicine has risen from its humble beginnings in the1940s, when researchers used a single 3-factor equation to estimate organ dose, to its current practice, in which researchers are using complex and sophisticated models to calculate organ doses and dose distributions in nuclear medicine patients and radiation workers. Standardized dose estimates are needed for basic risk/benefit decision-making for diagnostic agents, which continue to be used and to proliferate at a rapid rate. Reliable estimates of radiation-absorbed dose from the use of diagnostic or therapeutic radiopharmaceuticals in nuclear medicine are essential to the evaluation of the risks and benefits of their use. To estimate absorbed dose for all significant tissues, one must determine the quantity for each tissue. In addition, internal dosimetry is a tool for radiation protection of the patient in nuclear medicine (1, 2).Generally, internal absorbed radiation doses are being calculated by using commercially available software package like MIRDOSE (3),RADAR (4),OLINDA/EXM (5), MONDAL(6), LUDEP (7) and but they are complex and costly for routine use in rapid dose calculation in nuclear medicine practices. The MIRDOSE software has been popular for a number of years for calculating internal radiation dose estimates for radionuclides used in nuclear medicine. In 2000, the MIRDOSE code was withdrawn from circulation by Oak Ridge Associated Universities (8).The personal computer code OLINDA/EXM (5), which is an acronym standing for Organ Level INternal Dose Assessment/EXponential Modeling, was designed as an update to MIRDOSE. The software called “IRDE”

has been developed for easy and fast calculation of patient-specific internal radiation doses based on the ICRP biokinetics and dosimetry model (9, 10). Different medical radioisotopes (such as, ^{131}I, ^{99m}Tc, ^{18}F, ^{125}I etc.) are being widely used in nuclear medicine practices for diagnostic and therapeutic purposes in Bangladesh. This study was undertaken to calculate the internal radiation doses due to ^{131}I for Bangladeshi population by using IRDE software. This paper will provide the concepts and techniques of quantitative nuclear medicine imaging for patient specific dosimetry and how gradually they are heading towards a successful approach to patient-specific quantification which holds tremendous potential for the internal dosimetry to be more precise by recognizing the difference among individuals. This allows the patients to be exposed to appropriate dosage of radionuclides and also reduces the damage to healthy tissues during treatment.

COMPUTATIONAL METHOD

A series of biokinetic and dosimetric models has been developed for calculating radiation doses from intake of radionuclides in the body. Of these Human Respiratory Tract (HRT) and Human Alimentary Tract (HAT) models are worth mentioning (11-15). The function describing uptake and retention of a radionuclide in a body tissue following its ingestion is described considering an organ to consist of a number of separate compartments. Loss of radionuclide from one compartment is taken to be governed by the first order kinetics. The retention of an element in any organ or tissue will usually be described by either single exponential term or the sum of a number of exponential terms. These new models are considerably more complex as compared to earlier ones and as a consequence they present considerable difficulties in their implementation.

The rate constants (λ_B) for the different compartments in the gastrointestinal tract system and the radioactive decay constant (λ_R) of the radionuclide determine the rate of translocation to the body fluids after the radionuclide has been ingested.For the present purpose the GI tract is represented by four sections (Figure 1); and each of these sections is considered as a single compartment.

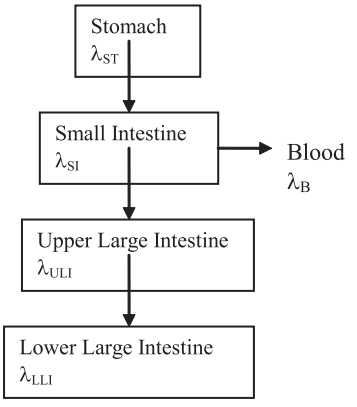

Figure 1: Different parts of GI tract and biological transfer routes of radionuclides.

The translocation from one compartment to the next is expressed by first order kinematics; and thus q(t), the activity of ingested radionuclide in a compartment at time t is described by the following equations

$$\frac{d}{dq}q_{ST}(t) = -\lambda_{ST}q_{ST}(t) - \lambda_R q_{ST}(t) + \dot{I}(t) \quad (1)$$

$$\frac{d}{dq}q_{SI}(t) = -\lambda_{SI}q_{SI}(t) - \lambda_R q_{SI}(t) - \lambda_B q_{SI}(t) + \lambda_{ST}q_{ST}(t) \quad (2)$$

$$\frac{d}{dq}q_{ULI}(t) = -\lambda_{ULI}q_{ULI}(t) - \lambda_R q_{ULI}(t) + \lambda_{SI}q_{SI}(t) \quad (3)$$

$$\frac{d}{dq}q_{LLI}(t) = -\lambda_{LLI}q_{LLI}(t) - \lambda_R q_{LLI}(t) + \lambda_{ULI}q_{ULI}(t) \quad (4)$$

where, λ_R is the radioactive decay constant of the radioactive nuclide λ_{ST}, λ_{SI}, λ_{ULI}, λ_{LLI} are are the rate constants for loss of material from stomach, small intestine, upper large intestine and lower large intestine respectively, $I(t)$ is the rate of intake of activity from outside the system into stomach at time t. is the rate of transfer of activity to body fluids from the small intestine, which is assumed to be the only site of absorption from the GI tract to body fluids, and is the rate of ingestion of activity of the radionuclide at time $\lambda_B q_{SI}(t)$ t. The value of can be estimated from f1, the fraction of a stable element reaching the body fluids following ingestion.

$\lambda_B = \frac{f_1\lambda_{SI}}{1-f_1}$, values of f_1 are given (12) in the metabolic data for a number of classes of compounds of each individual element. For f_1=1 it is assumed that the

radionuclides pass directly from small intestine to body fluids and does not pass through other sections of the gastrointestinal tract. $I(t)$ may be set equal to zero for all radionuclides considering time t to be zero at the time of single instantaneous intake, $q_1(0)$ may be set equal to zero for all i from 2 to n, i.e. for all other compartments of the chain. Under these boundary conditions Skrable et al. (15) have shown that

$$q_i(t) = \left[\left(\prod_{k=1}^{i=-1} \lambda_{(k,k+1)} \right) \sum_{k=1}^{i} \left(\frac{q_1(0) e^{-\lambda_k t}}{\prod_{p=1, p\neq k}^{i} \Pi(\lambda_p - \lambda_k)} \right) \right] \quad (5)$$

Where,

$$\prod_{i=m}^{n} a_i = a_m \times a_{m+1} \times \ldots . a_n \; if \; \mathrm{n} \geq \mathrm{m}$$

$$\prod_{i=m}^{n} = 1 \; \text{if m}\rangle\text{n}$$

$q_i(t)$ is the activity of a radionuclide in compartment i at time t. If $q_1(0)$ is considered to be equal to Q, the amount of activity initially introduced. $q_1(t) = q_{st}(t)$ is the activity in the transfer compartment stomach (ST) at any time t, $q_2(t) = q_{SI}(t)$ is the activity in the tissue compartment small intestine (SI), $q_3(t) = q_{ULI}(t)$ is the activity in the tissue compartment upper large intestine (ULI), $q_4(t) = q_{LLI}(t)$ is the activity in the tissue compartment lower large intestine (LLI).

Then the solution of these equations for retention can be obtained as(13):

$$q_{ST}(t) = Qe^{-(\lambda_{ST}+\lambda_R)t} \quad (6)$$

$$q_{SI}(t) = \frac{Q \times \lambda_{ST}}{(\lambda_{ST} - \lambda_{SI} - \lambda_B)} \times \left\{ e^{-(\lambda_{SI}+\lambda_B+\lambda_R)t} - e^{-(\lambda_{ST}+\lambda_R)t} \right\} \quad (7)$$

$$q_{ULI}(t) = \frac{Q \times \lambda_{ST} \times \lambda_{SI}}{(\lambda_{ST} - \lambda_{SI} - \lambda_B)} \left[\frac{e^{-(\lambda_{ST}+\lambda_R)t}}{(\lambda_{SI}+\lambda_B-\lambda_{ST})(\lambda_{ULI}-\lambda_{ST})} + \frac{e^{-(\lambda_{SI}+\lambda_B+\lambda_R)t}}{(\lambda_{ST}-\lambda_B-\lambda_{SI})(\lambda_{ULI}-\lambda_{SI}-\lambda_B)} + \frac{e^{-(\lambda_{ULI}+\lambda_R)t}}{(\lambda_{ST}-\lambda_{ULI})(\lambda_{SI}+\lambda_B-\lambda_{ULI})} \right] \quad (8)$$

$$q_{LLI}(t) = \frac{Q \times \lambda_{ST} \times \lambda_{SI} \times \lambda_{ULI}}{(\lambda_{ST} - \lambda_{SI} - \lambda_B)} \left[\frac{e^{-(\lambda_{ST}+\lambda_R)t}}{(\lambda_{SI}+\lambda_B-\lambda_{ST})(\lambda_{ULI}-\lambda_{ST})(\lambda_{LLI}-\lambda_{ST})} + \frac{e^{-(\lambda_{SI}+\lambda_B+\lambda_R)t}}{(\lambda_{ST}-\lambda_B-\lambda_{SI})(\lambda_{ULI}-\lambda_{SI}-\lambda_B)(\lambda_{LLI}-\lambda_{SI}-\lambda_B)} + \frac{e^{-(\lambda_{LLI}+\lambda_R)t}}{(\lambda_{ST}-\lambda_{LLI})(\lambda_{SI}+\lambda_B-\lambda_{LLI})(\lambda_{LLI}-\lambda_{ULI})} + \frac{e^{-(\lambda_{ULI}+\lambda_R)t}}{(\lambda_{ST}-\lambda_{ULI})(\lambda_{SI}+\lambda_B-\lambda_{ULI})(\lambda_{LLI}-\lambda_{ULI})} \right] \quad (9)$$

The dose absorbed per unit time to a particular organ or tissue after a certain time of acute intake is now given by

$$\mathrm{D(t)} = = 1.6 \times 10^{-10} \sum_{s} \left[q_S(t) \sum SEE(T \leftarrow S)_i \right]_j \text{ in mSv} \quad (10)$$

Here, $q_S(t)$ is the retention at particular compartment S, after a certain time of a particular radionuclide j, from the acute intake.Summation in S is due to irradiation of target organ T by radiations arising in several different sources S.

$\mathrm{SEE}(\mathrm{T}\leftarrow\mathrm{S})_i$ is the specific effective energy from radiation of type i originating in S.

$\mathrm{SEE}(\mathrm{T}\leftarrow\mathrm{S})_i$ for a particular radionuclide j, is given by

$$\mathrm{SEE}(\mathrm{T}\leftarrow\mathrm{S})\mathrm{i} = \frac{Y_i E_i AF(T \leftarrow S)_i Q_i}{M_T} \text{ MeV kg}^{-1} \text{ per transformation} \quad (11)$$

Here, Y_i is the yield of radiations of type i per transformation of radionuclide j;Ei (in MeV) is the average, or unique energy of radiation i;AF(T←S is the average fraction of energy absorbed in T from radiation arising in S;Q_i is the quality factor appropriate for radiation i, and MT (in g) is the mass of the target organ. The values of these parameters for Bangladeshi population have been used (16).

Based on these algorithms, IRDE software has been developed (9,10). Basic layout of the IRDE software is shown in Fig. 2. There are four result boxes: retention, cumulated activity, absorbed dose and equivalent dose, each giving the calculated value for which the program is designed.

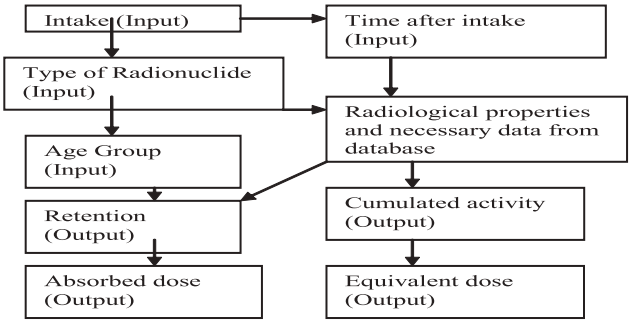

Figure 2: The logic lying behind preparation of the software.

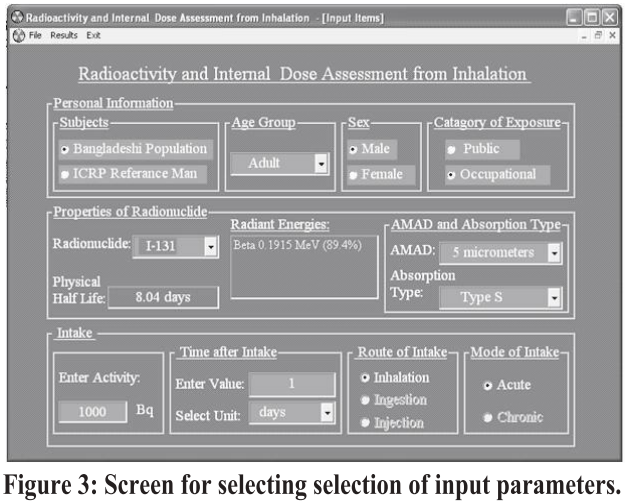

Figure 3: Screen for selecting selection of input parameters.

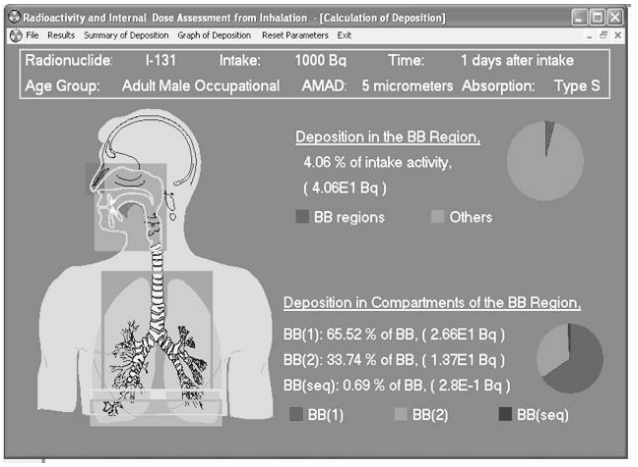

Figure 4: Deposition of radioactivity in different regions in graphic form.

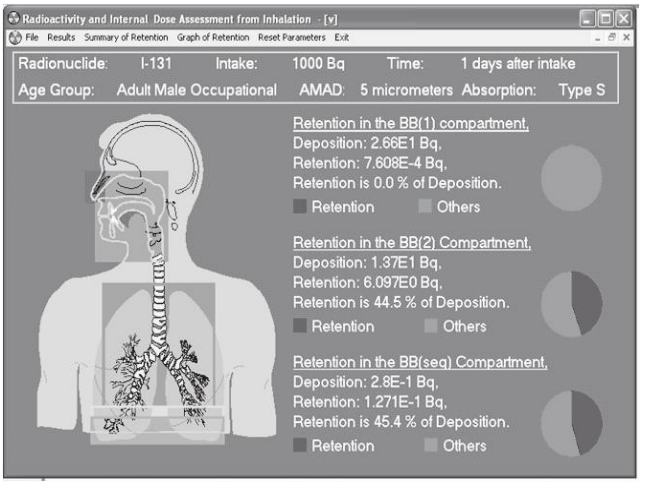

Figure 5: Retention of radioactivity in different regions in graphic form.

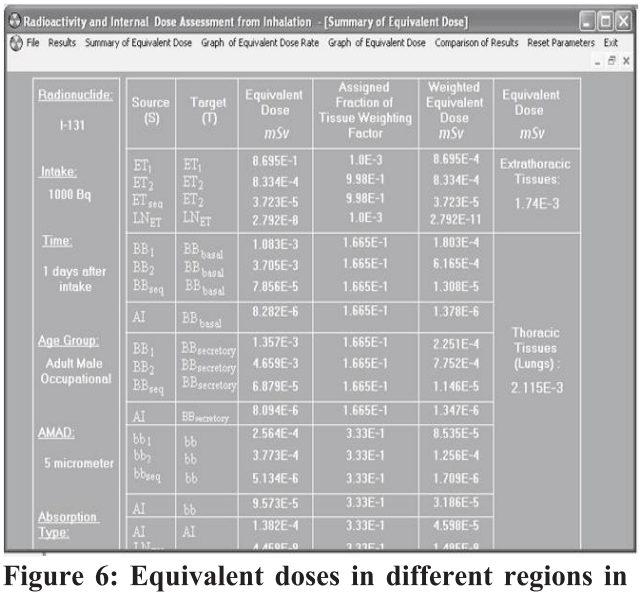

Figure 6: Equivalent doses in different regions in tabular form.

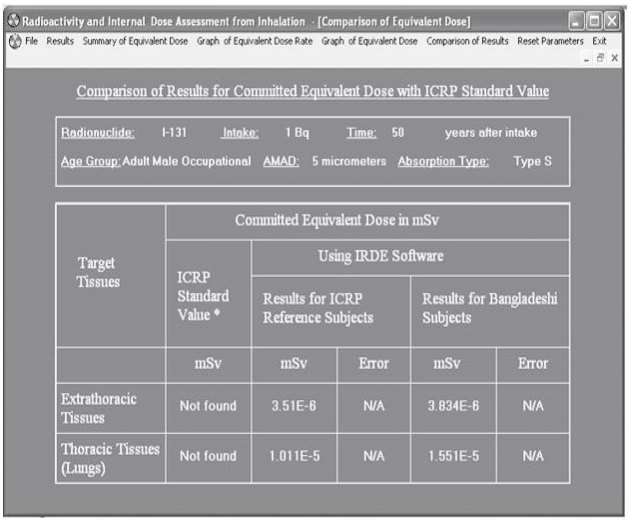

Figure 7: Comparison of committed equivalent dose levels in different regions.

RESULTS

Figure 3 shows the form for entering input parameters in the IRDE software. Typical results from IRDE software are shown in Figures 4-6. Figure 7 shows a comparison of committed dose values between ICRP reference man and Bangladeshi population for generic intake of 1 Bq activity of ^{131}I. The results from IRDE software (3.83×10^{-6} mSv for extrathoracic tissues and 1.055×10^{-5} mSv for thoracic tissue) are well comparable with those of ICRP values (3.51×10^{-6} mSv for extrathoracic tissues and 1.01×10^{-5} mSv for thoracic tissue). This confirms that the IRDE software works well, as desired. Table 1 shows the typical results of retention and absorbed dose in different parts of GI tract through ingestion of generic value of 1000 Bq for 131I radionuclide for Bangladeshi adult man.

Table 1: Typical results of retention and dose absorbed by IRDE software.

Parts of GI tract	Retention 1 hr after ingestion	Absorbed dose (Gy) 1 hr after ingestion
ST	0.4215	7.8074×10^{-9}
SI	0.3287	1.3431×10^{-9}
ULI	0.0672	4.1629×10^{-9}
LLI	0.0014	2.2170×10^{-9}

CONCLUSION

Internal radiation doses in different parts of GI tract have been calculated by using locally developed IRDE software. It is simple and easy to handle. This can comfortably be used for the purposes of calculation of internal radiation doses due to intake of radioisotopes through ingestion by radiation workers and public at large during administration of it in the nuclear medicine practices. The study provides persons charged with the responsibility for monitoring internal exposures of workers with comprehensive methods for assessing committed effective doses from estimated intakes of radioactive material. Further works are in progress for validation of IRDE software with other commercial software.

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