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Research on the activity and doses of radionuclides for different ages people through biokinetic modeling in HATM method

M. Kamal Hossain [1], M. Sazzad Hossain [2], Haron-Or-Rashid [3], Md. Nurul Islam [2,*] and A.H.M. R. Quddus [4]

[1] *Department of Physics, Sreenagar Govt. College, Bangladesh.*
[2] *Department of Physics, Bangladesh Army University of Engineering & Technology, Qadirabad Cantonment, Natore, Bangladesh.*
[3] *Department of Physics, Govt. Anondo Mohon College, Bangladesh.*
[4] *Department of Physics, National University, Bangladesh.*

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Abstract

Based on the Human Alimentary Tract Model (HATM), the activity and doses of radionuclides due to acute intake of 1 Bq of few radionuclides such as 60Co, 134Cs (long lived) and 131I (short lived) are calculated. A software has been developed in Visual Basic language for the calculation of the doses due to intake of radioisotopes by radiation workers and public at large. Radiation doses that are deposited at the most through ingestion in the alimentary tract which (HATM) is made of seven tissue compartments: Esophagus (OP), Left Colon (LC), Oral Cavity (OC),Right Colon (RC), Rectosigmoid Colon (RSC), Stomach (ST) and Small Intestine (SI). Nine (9) organs of the tract out of which 4 organs are deposited by radiation doses within the tract such as ST, SI, LC and RC and 5 other organs are deposited by radiation doses outside of the tract, e.g. liver, right kidney (RK), left kidney (LK), right lung (RL) and left lung (LL) have been taken into account here. The different tissue masses of the tract of various age-groups of Bangladeshi people were considered for calculation. The considered age groups of the people are like as new born, 1 yr, 10 yrs, adult male, adult female for within the tract 4 organs and <20 yrs male, 21-40 yrs male, 41-60 yrs male, > 60 yrs male, <20 yrs female, 21-40 yrs female, 41-60 yrs female foroutside of the tract 5 organs. In each tissue compartment retention variation follows the serial: 60Co >134Cs>134I.

Keywords: Activity of a radionuclide; Internal radiation exposure; Biokinetic model; Radioactive contamination; HATM

1. Introduction

Radiation is a form of energy which closely entangles the universe all around us. This kind of energy is spread as particles or rays that are emitted by excited radioactive atoms or nuclei. There are three kinds of ionizing radiations such as alpha particles, beta particles and gamma rays. This study deals with one (1) from these three (3) radiations, particularly the gamma radiations that can hold sufficient energy and is taken on to have room inside our body. Gamma rays can ionize atoms in tissue directly or cause what are known as "secondary ionization". Ionizations are caused when energy is transferred from gamma rays to atomic particles such as electrons. These energized particles then interact with tissue to form ions through secondary ionizations and can cover 100 m to 1000 m in air before spending their energy. Garnma ray's ionizing ability is measured in terms of its radiation exposure. The organs or tissues of an individual may also be irradiated by the radiation emitted within any internally deposited radionuclide; the corresponding exposure is termed internal radiation exposure.

*Corresponding author: Nurul Islam

Radioactive contamination can be ingested into the body if it is airborne or is taken in contamination of food or drink, and irradiates the body internally. For internal exposures, committed effective doses are generally determined from an assessment of the intakes of radionuclides from bioassay measurements. Overexposure of an ionizing radiation can lead to effects such as birth defects, illness, cancer, and death, depending on the degree of exposure and the period of time over which it is received. Internally deposited radionuclides are the potential sources of internal exposure; these can emit alpha particles, beta particles and gamma rays. Gamma emitters like Cobalt-60, Iodine-131 and Cesium-137 are used in the present study.

Most people's primary source of gamma exposure is naturally occurring radionuclides, particularly potassium-40, which is found in soil and water, as well as meats and high-potassium foods such as bananas. Radium is also a prominent source of gamma exposure. However, the increasing use of nuclear medicine (e.g., bone, thyroid, and lung scans) contributes an increasing proportion of the total for many people. Gamma rays can easily travel great distances through air and penetrate several centimeters in tissue. Most have enough energy to pass through the body, exposing all organs. Although they are generally classified as an external hazard; gamma emitting radionuclides can also be inhaled, or ingested with water or food, and cause exposures to organs inside the body. Because of the gamma ray's high penetrating power and ability to travel great distances, it is proved to be a primary hazard to the general population during most radiological emergencies. In fact, when the term "radiation sickness" is used to describe the effects of large exposures in short time periods, the most severe damage almost certainly results from gamma radiation.

The biokinetic model needed for more specific estimates of doses to individuals, to be used in the case of accidents or incidents, or when operations could result in doses approaching regulatory limits, is also needed. Technical details and advice on the assessment of internal contamination by direct methods has been published by the IAEA [1]. Recommendations have been made by the ICRP on methods for assessing intakes of radionuclides, and the resulting doses, from monitoring data [2, 3]. The ICRP advices in the various parts and supplements of its Publication 30 [4-7], which describes the biokinetic model used for calculating dose equivalents to organs and tissues from intake by inhalation and ingestion of a wide range of radionuclides in different chemical forms. The fraction of an intake that remains in the body (for direct methods) or that is being excreted from the body (for indirect methods) at time 't' after an intake depends on the radionuclide, its chemical and physical form and the route of intake, as well as t.

It is worth noting that internal doses cannot be measured directly; they can only be inferred from measured quantities such as body activity content, excretion rates or airborne concentrations of radioactive material. Intakes of radionuclides can be determined by either direct or indirect measurement methods. Direct measurements of gamma or x-ray photons (including bremsstrahlung) emitted from internally deposited radionuclides are frequently referred to as body activity measurements, whole body monitoring or whole body counting. Indirect measurements are measurements of activity in samples which may be either biological (e.g. excreta) or physical (e.g. air filters). Biokinetic modeling of retention and biophysical modeling of energy deposition may still be needed to calculate the intake and the committed effective dose. Direct measurements are useful in qualitative as well as quantitative determinations of radionuclides in a mixture that might have been inhaled, ingested or injected. Direct measurements can assist in identifying the mode of intake by determining the distribution of activity in the body [8, 9]. In this work calculations have been done to have idea about redistribution of activity, gathering information about the total body retention, and the biokineticbehaviour of radionuclides in the body. Various types of reference level are described in the related Safety Guide [10]. Biokinetic models for most radionuclides in their commonly encountered forms, with reference parameter values, have been published by the ICRP. These models are based on Reference Man [11].

1.1. The HATM

The Human Alimentary Tract Model (HATM) is an alternative one for dose calculation. This is a new model for the human alimentary tract that replaces the model for the gastrointestinal tract adopted by ICRP in Publication 30. The Publication 30 model was developed specifically to calculate doses to workers, either from the direct ingestion of radionuclides or following their inhalation as particles with subsequent escalation from the lungs to the alimentary tract. It takes account of transit of ingested materials through 4 regions of the alimentary tract. These are the stomach, small intestine, upper large intestine, and lower large intestine. The absorption of radionuclides to blood was specified by values of fractional uptake (f1) from the small intestine.

The Publication 30 model, although intended for the calculation of doses for the occupational exposure of adults, has been applied to calculate dose coefficients for members of the public, including children. Increased intestinal absorption of radionuclides by infants was also taken into account but age-dependent differences in transit times were not included. The new human alimentary tract model (HATM) considers the movement of radionuclides throughout the alimentary tract from ingestion to elimination, taking accounts of sites of radionuclide absorption and retention in the alimentary tract and routes of excretion of absorbed radionuclides into the alimentary tract.

The main objective of the present study is to calculate the internal radiation doses for different age groups of Bangladeshi population subjects from an acute intake of gamma emitting radionuclides through ingestion. The study is extended to determine the internal radiation dose parameters for performing necessary calculations and to modify the mathematical formulae, to develop computer software for easy calculation of internal radiation doses based on the HATM mathematical algorithm.

2. Methodology

The proposed work is calculation based. A software package has been developed to incorporate compartmental analysis of deposition and retention of radionuclides including resulting dose levels. It has been incorporated with the compartmentalized form of the HATM. The software is suitable to calculate the amount of radioactivity at a time t after the first intake of radionuclides through ingestion and the total number of disintegrations over any time interval of interest in a region of human digestive tract. This software has been used to calculate the desired activity at a time after intake.

The program information will be presented in a standard form. Visual Basic (VB) has been chosen in the work because it is a high level language widely used for mathematical and scientific calculations. Using Microsoft Access 7.0 a data library with some databases is prepared for providing necessary radiological and biological data for the calculations. Radioisotopes and their decay constant, half-life and such other information are recorded in this library.

In the current study activity of the target tissues for different radionuclides in different organs are calculated. For the calculation the total alimentary tract is divided into seven different organs. Radionuclides injected into the tract are passed through oral cavity which is the first organ in the tract and then it passes through the other organs gradually. The retention or transit time of radionuclides is different in various organs. So finally we can say that the above mentioned quantities are functions of transit time, nature of radionuclides and the nature of target tissues as well.

The strength of a radioactive source is called its activity, which is defined as the rate at which the isotope decays. Specifically, it is the number of atoms that decay and emit radiation in one second. Radioactivity may be thought of as the amount of radiation produced in a given amount of time.

If $A_i(t)$ is the activity of any injected radionuclide in a compartment (i) after time t, then the rate of activity is given by,

$$\frac{d}{dt}A_i(t) = - \lambda_i A_i(t) - \lambda_R A_R(t) + I(t) \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Here, A_i is the activity in organ i (i = 1,2,3,……7)

λ_i is the transfer rate of the radionuclide from the organ i.

λ_R is the decay constant of the radionuclide.

$I(t)$ is the initial activity of the radionuclide.

Now we may get seven different equations for seven organs respectively from Eqn. (1). These are shown below.

For oral cavity

$$\frac{d}{dt}A_{OC}(t) = -\lambda_{OC}A_{OC}(t) - \lambda_R A(t) + I(t). \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

For esophagus

$$\frac{d}{dt}A_{OP}(t) = -\lambda_{OP}A_{OP}(t) - \lambda_R A_{OP}(t) + \lambda_{OC}A_{OC}(t) \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

For stomach

$$\frac{d}{dt}A_{ST}(t) = -\lambda_{ST}A_{ST}(t) - \lambda_R A_{ST}(t) + \lambda_{OP}A_{OP}(t) \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

For small intestine

$$\frac{d}{dt}A_{SI}(t) = -\lambda_{SI}A_{SI}(t) - \lambda_R A_{SI}(t) - \lambda_B A_{SI}(t) + \lambda_{ST}A_{ST}(t) \quad \text{.....................(5)}$$

For left colon

$$\frac{d}{dt}A_{LC}(t) = -\lambda_{LC}A_{LC}(t) - \lambda_R A_{LC}(t) + \lambda_{RC}A_{RC}(t) \quad \text{.............(6)}$$

For right colon

$$\frac{d}{dt}A_{RC}(t) = -\lambda_{RC}A_{RC}(t) - \lambda_R A_{RC}(t) + \lambda_{SI}A_{SI}(t) \quad \text{..................(7)}$$

For rectosigmoid colon

$$\frac{d}{dt}A_{RSC}(t) = -\lambda_{RSC}A_{RSC}(t) - \lambda_R A_{RSC}(t) + \lambda_{LC}A_{LC}(t) \quad \text{.............. (8)}$$

Where,

λ_R = the radioactive decay constant for the radioactive nuclide,

λ_{OC} = the rate constant for the loss of the material from oral cavity,

λ_{EP} = the rate constant for the loss of the material from esophagus,

λ_{ST} = the rate constant for the loss of the material from stomach,

λ_{SI} = The rate constant for the loss of the material from small intestine,

λ_{LC} = The rate constant for the loss of the material from left colon,

λ_{RC} = The rate constant for the loss of the material from right colon,

λ_{RSC} = The rate constant for the loss of the material from rectosigmoid colon.

The values of λ_{OC}, λ_{EP}, λ_{ST}, λ_{SI}, λ_{LC}, λ_{RC}, λ_{RSC} are given in Table 1 [12].

Table 1 Mean residence time and the rate constants of different parts of HAT

Name of the Organs	Mean residence time	Rate Constant (/d)
Oral Cavity	12 sec	7200
Esophgus	40 sec	2160
Stomach	70 min	20.57
Small intestine	4 hrs	6
Left colon	12 hrs	2
Right colon	12 hrs	2
Rectosigmoid colon	12 hrs	2

A_{OC}, A_{EP}, A_{ST}, A_{SI}, A_{lc}, A_{RC}, A_{RSC} are the activity of radionuclide in OC, EP, ST, SI, LC, RC, RSC respectively.

Equations (1) – (8) are first order differential equations with constant coefficients. These equations can be compared with the differential equation of series nuclear transformation. Thus the solution of the equation can be written in the form of H. Bateman's equation [13] as $A_i = N_o \sum_{i=1}^{n} C_i e^{-\lambda_i t}$

$$= N_o [C_1 \exp(-\lambda_1 t) + C_2 \exp(-\lambda_2 t) + \ldots\ldots + C_n \exp(-\lambda_n t)] \ldots\ldots\ldots\ldots(9)$$

Where,

$$C_m = \frac{\prod_{i=1}^{n} \lambda_i}{\prod_{i=1}^{n} (\lambda_i - \lambda_m)}$$

$$= \frac{\lambda_1 \lambda_2 \lambda_3 \ldots\ldots\ldots \lambda_n}{(\lambda_1 - \lambda_m)(\lambda_2 - \lambda_m)(\lambda_3 - \lambda_m) \ldots\ldots\ldots (\lambda_n - \lambda_m)} \ldots\ldots\ldots(10)$$

For oral cavity, the first compartment, the value of activity A_1 (t) is obtained by putting i = 1 into Eqn. (9) as

$$A_1 = N_o e^{-\lambda_1 t} \ldots\ldots\ldots\ldots\ldots\ldots (11)$$

For material deposited into second compartment from the first one the value of activity can be obtained by putting i=2 into Eqn. (9)

$$A_i = N_o \sum_{i=1}^{n} C_i e^{-\lambda_i t} \quad A_2 = N_o \left(C_1 e^{-\lambda_1 t} + C_2 e^{-\lambda_2 t} \right);$$

And from Eqn. (10) we get

$$C_m = \frac{\prod_{i=1}^{n} \lambda_i}{\prod_{i=1}^{n} (\lambda_i - \lambda_m)}$$

$$C_m = \frac{\lambda_1 \lambda_2}{(\lambda_1 - \lambda_m)(\lambda_2 - \lambda_m)} \text{ [i = 2]}$$

$$C_1 = \frac{\lambda_1 \lambda_2}{(\lambda_2 - \lambda_1)} \text{ [m = 1]}$$

$$C_2 = \frac{\lambda_1 \lambda_2}{(\lambda_1 - \lambda_2)} \text{ [m = 2]}$$

Now putting the values of C_1 C_2 finally we get

$$A_2 = N_O \lambda_1 \lambda_2 \left(\frac{e^{-\lambda_1} t}{(\lambda_2 - \lambda_1)} + \frac{e^{-\lambda_2} t}{(\lambda_1 - \lambda_2)} \right) \ldots\ldots\ldots\ldots (12)$$

For material deposited into the third compartment from the second one, value of activity can be obtained by putting i=3 into Eqn. (9):

$$A_i = N_o \sum_{i=1}^{n} C_i e^{-\lambda_i t}$$

$$A_3 = N_0\left(C_1 e^{-\lambda t_1} + C_2 e^{-\lambda_2 t} + C3 e^{-\lambda_3 t_1}\right)\text{[i=3]}$$

And from Eqn. (10) we get

$$C_m = \frac{\prod_{i=1}^{n} \lambda_i}{\prod_{i=1}^{n} (\lambda_i - \lambda_m)}$$

$$C_m = \frac{\lambda_1\lambda_2\lambda_3}{(\lambda_1-\lambda_m)(\lambda_2-\lambda_m)(\lambda_3-\lambda_m)} \quad C_1 = \frac{\lambda_1\lambda_2\lambda_3}{(\lambda_2-\lambda_1)(\lambda_3-\lambda_1)} \text{ [m = 1]}$$

$$C_2 = \frac{\lambda_1\lambda_2\lambda_3}{(\lambda_1-\lambda_2)(\lambda_3-\lambda_2)} \text{ [m = 2]}$$

$$C_3 = \frac{\lambda_1\lambda_2\lambda_3}{(\lambda_1-\lambda_3)(\lambda_2-\lambda_3)} \text{ [m = 3]}$$

Putting the value of C_1 C_2 C_3 finally we get

$$A_3 = N_0\lambda_1\lambda_2\lambda_3\left(\frac{e^{-\lambda_1 t}}{(\lambda_2-\lambda_1)(\lambda_3-\lambda_1)} + \frac{e^{-\lambda_2 t}}{(\lambda_1-\lambda_2)(\lambda_3-\lambda_2)} + \frac{e^{-\lambda_3 t}}{(\lambda_1-\lambda_3)(\lambda_2-\lambda_3)}\right) \text{………………….(13)}$$

Similarly, for the seventh compartment we get

$$A_7 = N_0\lambda_1\lambda_2\lambda_3\lambda_4\lambda_5\lambda_6\lambda_7\left(\begin{array}{l} \frac{e^{-\lambda_1 t}}{(\lambda_2-\lambda_1)(\lambda_3-\lambda_1)(\lambda_4-\lambda_1)(\lambda_5-\lambda_1)(\lambda_6-\lambda_1)(\lambda_7-\lambda_1)} + \\ \frac{e^{-\lambda_2 t}}{(\lambda_1-\lambda_2)(\lambda_3-\lambda_2)(\lambda_4-\lambda_2)(\lambda_5-\lambda_2)(\lambda_6-\lambda_2)(\lambda_7-\lambda_2)} + \\ \frac{e^{-\lambda_3 t}}{(\lambda_1-\lambda_3)(\lambda_2-\lambda_3)(\lambda_4-\lambda_3)(\lambda_5-\lambda_3)(\lambda_6-\lambda_3)(\lambda_7-\lambda_3)} + \\ \frac{e^{-\lambda_4 t}}{(\lambda_1-\lambda_4)(\lambda_2-\lambda_4)(\lambda_3-\lambda_4)(\lambda_5-\lambda_4)(\lambda_6-\lambda_4)(\lambda_7-\lambda_4)} + \\ \frac{e^{-\lambda_5 t}}{(\lambda_1-\lambda_5)(\lambda_2-\lambda_5)(\lambda_3-\lambda_5)(\lambda_4-\lambda_5)(\lambda_6-\lambda_5)(\lambda_7-\lambda_5)} + \\ \frac{e^{-\lambda_6 t}}{(\lambda_1-\lambda_6)(\lambda_2-\lambda_6)(\lambda_3-\lambda_6)(\lambda_4-\lambda_6)(\lambda_5-\lambda_6)(\lambda_7-\lambda_6)} + \\ \frac{e^{-\lambda_7 t}}{(\lambda_1-\lambda_7)(\lambda_2-\lambda_7)(\lambda_3-\lambda_7)(\lambda_4-\lambda_7)(\lambda_5-\lambda_7)(\lambda_6-\lambda_7)} \end{array}\right) \text{……………………….(14)}$$

2.1. The Computer Program for Activity Calculations

Equation (1) is the general equation for activity calculation. In particular equations (2)-(8) give activity values of the organs oral cavity, esophagus, stomach, small intestine, left colon, right colon and rectosigmoid colon respectively. The solution is given in Eqns. (9) to (14).

The Visual Basic is one of the most popular high-level language programs.It is easy to design and also very easy to use. This program has been used to solve the equations. The input description and the output of the program along with labeling are shown in the following sections. The extracted information from the program is presented in a standard form. The basic information of this program includes: Interface labeling, Coding for the labeling program, and Program running.

2.1.1. Interface Labeling

Interface labeling of the designed program for the calculation of any of the desired quantities in case of any of the 9 organs under study is done following the previously mentioned procedure. The input values of the program calculations are shown by the blank boxes represented by A, B, C, and D where the meaning of the terms at the left side of the boxes.

Command buttons for the program running; new calculation and shutting down of the calculation are all represented in figure 3. Of all these three command buttons the 'Result' button gives the calculated values for which the program is designed, 'New' button takes new values for further calculation of the values, and the 'End' command button finally shuts down the program after calculation.

Absorbed dose, Committed equivalent dose, Committed effective dose

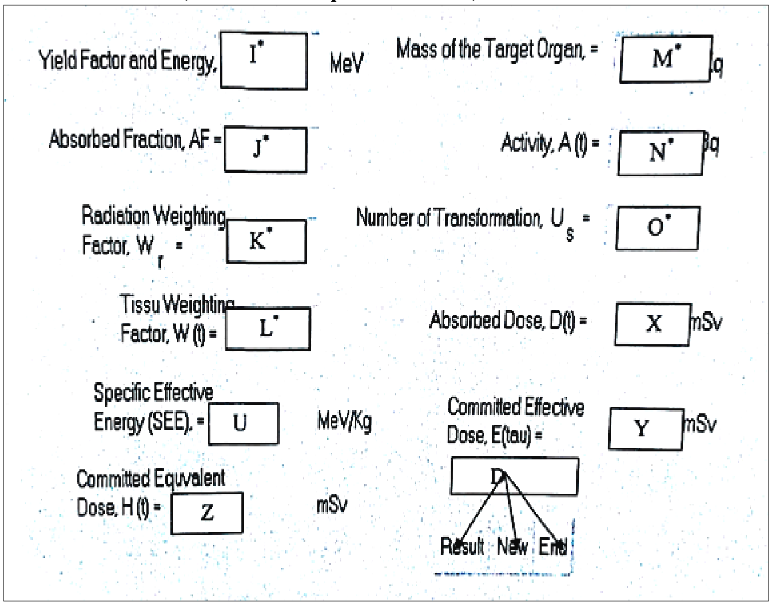

Figure 1 Program for the calculation of absorbed dose, committed equivalent dose and committed effective dose

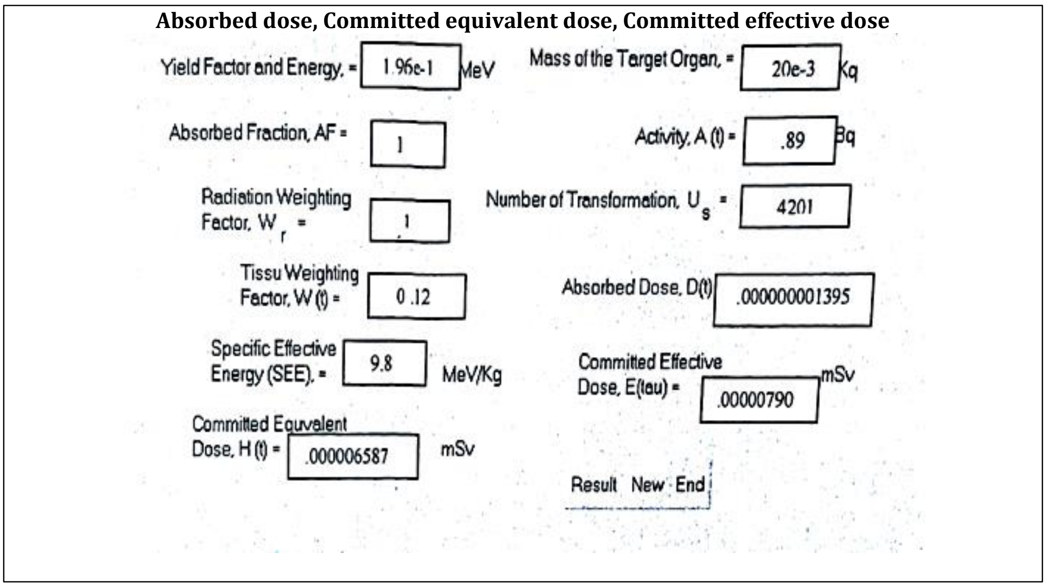

Figure 2 Calculated values of absorbed dose, committed equivalent dose and committed effective dose

In the present work calculations have been done for activity, absorbed dose for all the 9 organs mentioned before. Figure 1 shows the designed program for the calculations of the dose values. Calculated output values from the program may be observed in figure 2.

2.1.2. Program Design

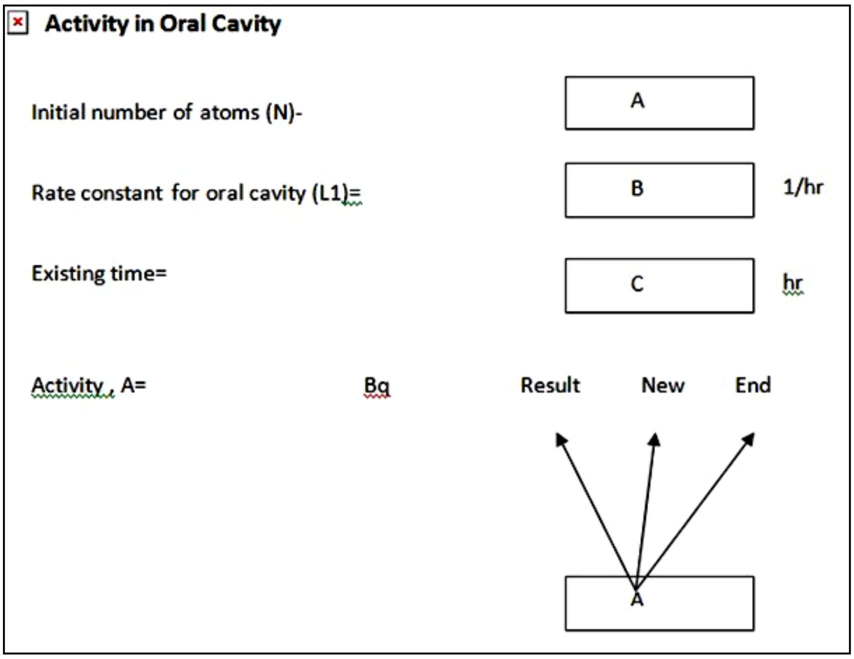

Figure 3 Program labelling for the calculation of activity

2.1.3. Program Running

To get the output result three input values as shown in the design text of the program are given. The system is same everywhere. Among the three command buttons 'Result' button gives the results of calculation shown in Fig. 4. 'New' command button enters next new set of values and gives results of calculation accordingly. 'End' command button ends the program of calculation.

Only gamma dose is calculated for the above mentioned three organs, as only gamma rays can penetrate these. Four tissue compartments within the GI tract are considered in the present work. In the case of gamma dose calculation for any organ of the GI tract, one tissue compartment is considered as a target, while the rest three as a whole the source. But in the case of beta dose calculation this concept is not used. In this case, every organ at a time acts as a source and target. Both beta and gamma dose are calculated within GI tract.

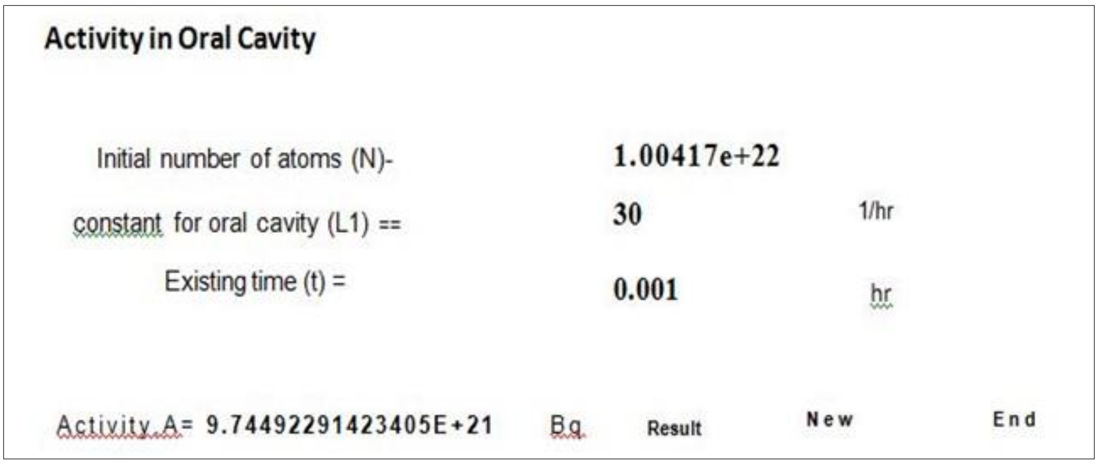

Figure 4 Calculated values for activity in oral cavity

3. Results and Discussion

Calculations have been done for the radionuclides: 60Co, 131I and 134Cs. These radionuclides are all gamma and beta emitting ones. Discussion has been made on radioactivity calculations done due to gamma emitting radionuclides separately, Beta emitting radionuclides separately and Gamma & beta emitting radionuclides together.

In total 9 organs were taken into consideration. In GI Tract Model the number of division is 4 against 9 in the HATM. Number of divisions in the later case is more and thus more precise results can be obtained. This is one of the reasons for which the later one is superior to the former.

3.1. Activity Calculations Due to Ingestion of the Radionuclides

3.1.1. Activity of 60Co in the Tissues

For activity calculations done in this work the initial intake has been assumed to be 1 Bq of the radionuclide; the assumption has been made for all the radionuclides under consideration. Activity at different compartments of HAT has been calculated. As mentioned before in total 9 organs, e.g., stomach (ST), small intestine (SI), left colon (LC), right colon (RC), left lung (LL), right lung (RL), left kidney (LK), right kidney (RK) and liver are taken into consideration. Some relevant points of the organs are discussed below:

Out of the 9 organs in total of HATM, 4 organs are considered as sources of radionuclides, because radionuclides pass through these organs directly during the alimentation process. The other organs, e.g., left lung, right lung, left kidney, right kidney and liver are considered as the targets. On the other hand in the case of dose distribution to the earlier mentioned 4 organs in the alimentary tract one organ is considered as a target while the rest 3 organs are considered as the sources. This process is similar for all the 4 organs. Thus the total number of targets, e.g., organs considered in the calculations is 9.

Calculations have been performed for the subjects of age groups: 1 yr, 10 yrs, adult (male) and adult (female) for the first 2 organs. For other organs, e.g., left kidney, right kidney and liver the age groups considered are <20 yrs (male), 21-40 yrs (male), 41-60 yrs (male),>60 yrs (male) and <20 yrs (female), 21-40 yrs (female) and 41-60 yrs (female). Time elapsed after the ingestion of the radionuclide has been considered basing on the half lives of the radionuclides.

Since a radionuclide is ingested through mouth, it travels along the digestive tract and hence the activity in different compartments due to it rises in accordance to its position in the tract. As time passes the latter compartments get its share - one after another, and hence the activity gradually increases systematically in these compartments depending on its location in the tract.

Figs. 5- 8 are the graphs showing time variation of activity arising due to the radionuclide 60Co in the compartments ST, SI, LC and RC.

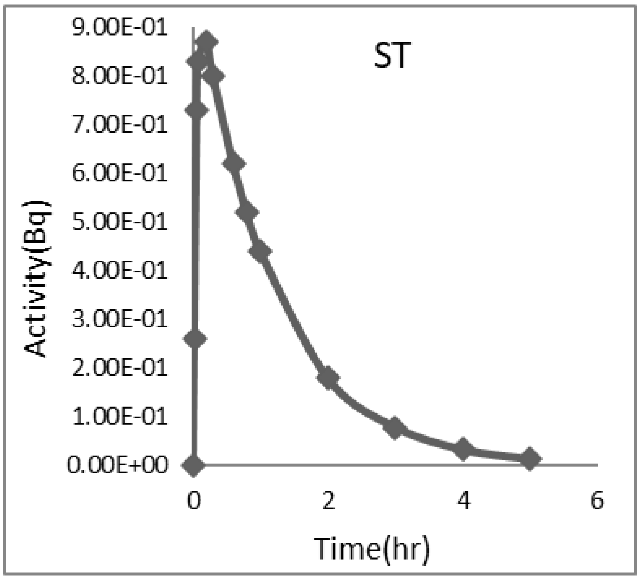

Figure 5 Time variation of activityin ST arising due to ^{60}Co

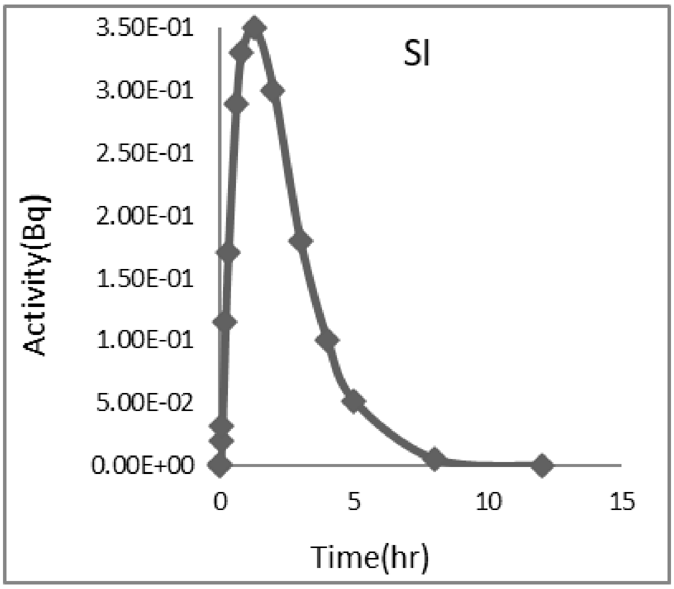

Figure 6 Time variation of activityin SI arising due to ^{60}Co

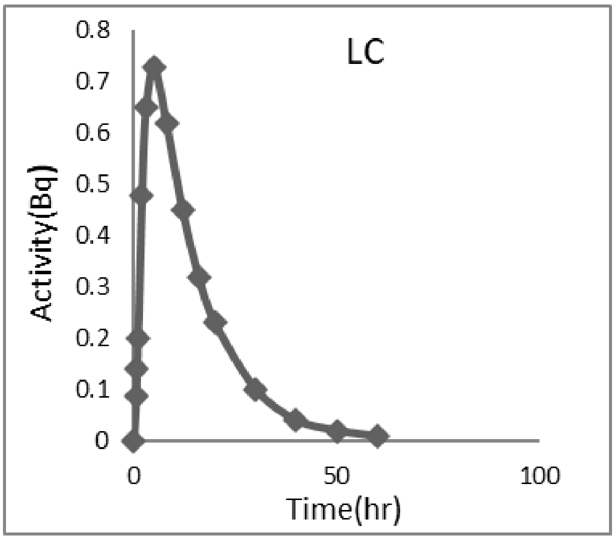

Figure 7 Time variation of activityin LC arising due to ^{60}Co

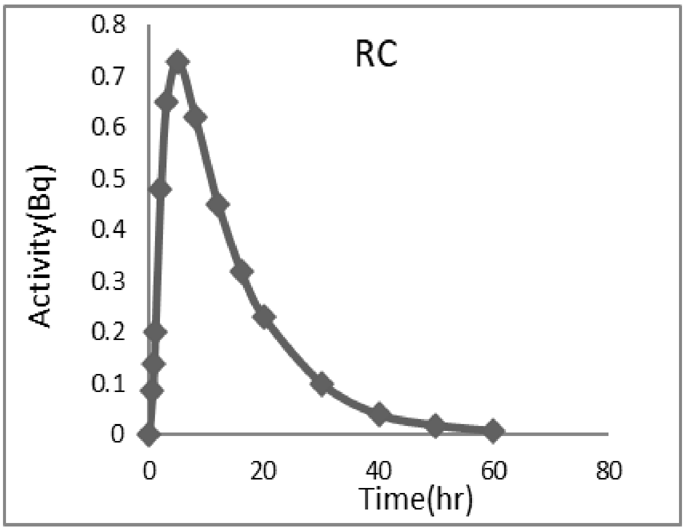

Figure 8 Time variation of activityin RC arising due to ^{60}Co

Calculations have been done in the work to find out the average rates of rise and fall. This is done for the cases of all the radionuclides. Because of the simplicity in the calculations average values were chosen for the purpose. These values were calculated identifying a clear zone of rise and fall; in each case the portion of the graph showed a straight line. The maximum value of the activity along with the rates of rise and fall for all the 4 organs are recorded in Table 2. The 'time span of measurements' shown in 2 of the columns of the table mentions the starting and ending time of each incident, counting being started (time = 0) from the time of accumulation of the radionuclide in the compartment mentioned. Thus the starting time of rise is taken as 0 hr (for every case); this is the start of the time counting as well.Starting time of falling is counted from this starting time. It is worth mentioning that this time is again not the actual starting time of falling; rather it is a bit after that, and is the time which starts showing a sharp fall maintaining the same rate of falling for considerable time duration.

The falling rate thereafter is lower than this value quoted in the table. The same consideration is maintained for other similar tables.

Table 2 Information on activity values arising due to 60Co

Name of the compartments	**Maximum values**	**Rising Rate**		**Falling rate**	
		Magnitude (Bq/hr)	**Time span of measurements**	**Magnitude (Bq/hr)**	**Time span of measurements**
ST	0.87	10.375	0 hr - 0.08 hr	0.51	0.3 hr – 1 hr
SI	0.35	0.48	0 hr - 0.6 hr	0.08	2 hrs – 5 hrs
LC	0.73	0.24	0 hr – 2 hr	0.03	8 hrs – 20 hrs
RC	0.36	0.32	0 hr – 3 hr	0.03	8 hrs – 20 hrs

3.1.2. Activity of 131I in the Tissues

The pattern of variation of activity with time for the radionuclide 131I has been shown in Figs. 9 to 12.

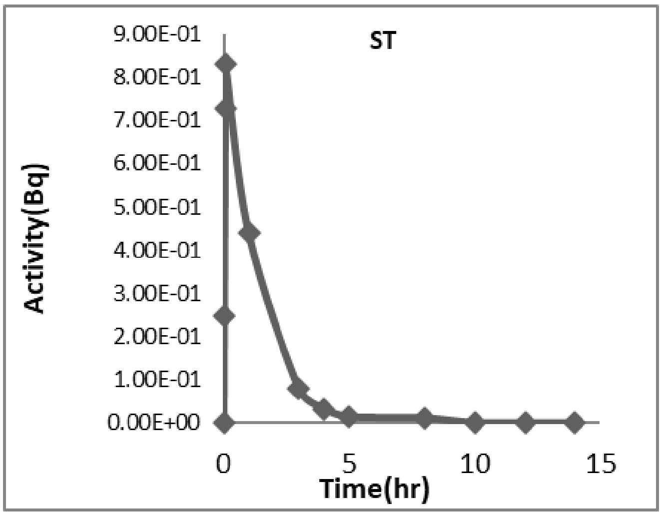

Figure 9 Time variation of activityin ST arising due to 131I

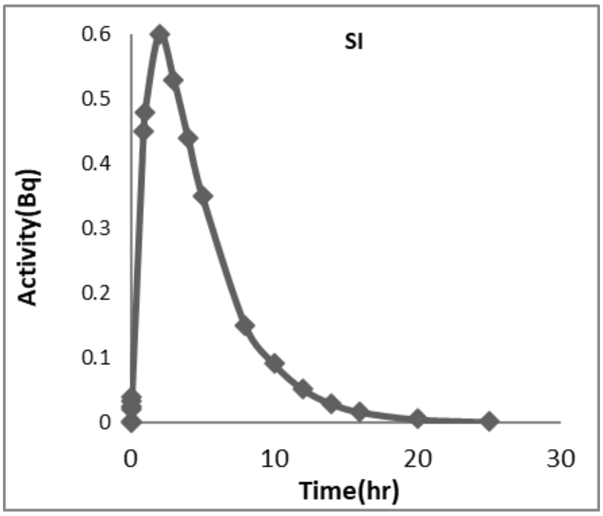

Figure 10 Time variation of activityin SI arising due to 131I

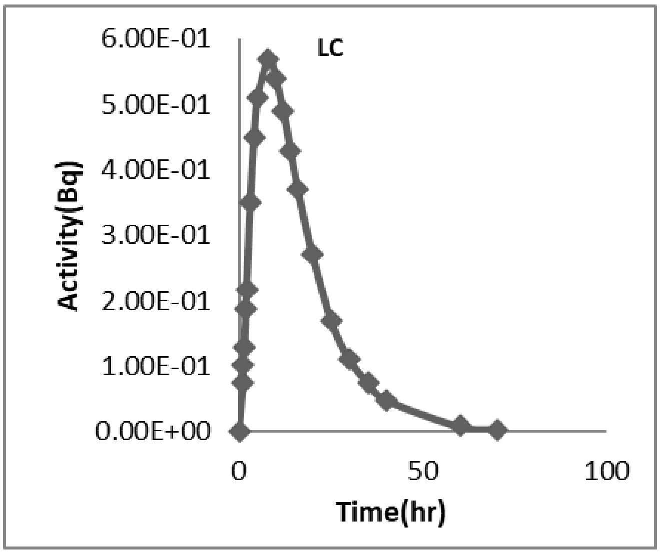

Figure 11 Time variation of activityin LC arising due to 131I

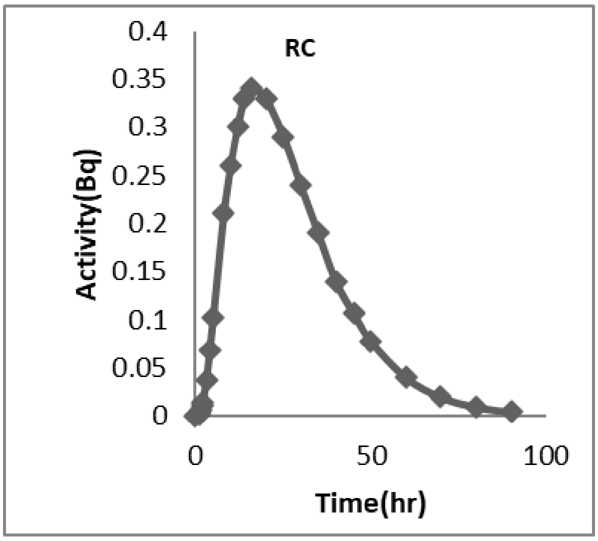

Figure 12 Time variation of activityin RC arising due to 131I

As of the previous cases the maximum value of activity and its rising and falling rates for the radionuclide are calculated in the work. These values are given in Table 3.

Table 3 Information on activity values due to 131I

Name of the compartments	**Maximum values**	**Rising Rate**		**Falling rate**	
		Magnitude (Bq/hr)	**Time span of measurements**	**Magnitude (Bq/hr)**	**Time span of measurements**
ST	0.83	10.375	0 hr - 0.08 hr	0.22	0.6 hr – 3 hrs
SI	0.60	0.48	0 hr – 1 hr	0.08	3 hrs – 8 hrs
LC	0.57	0.11	0 hr – 4 hrs	0.03	10 hrs – 20 hrs
RC	0.34	0.02	0 hr – 12 hrs	0.01	25 hrs –50 hrs

3.1.3. Activity of 134Cs in the Tissues

The pattern of variation of activity with time due to the radionuclide 134Cs in the 4 tissues mentioned before is shown in Figs. 13 to 16.

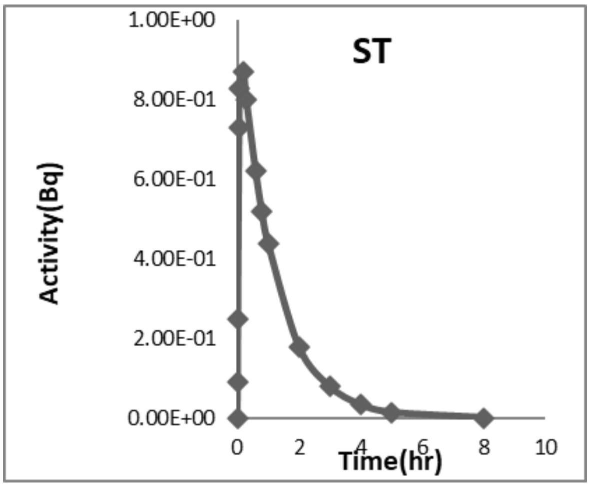

Figure 13 Time variation of activityin ST arising due to 134Cs

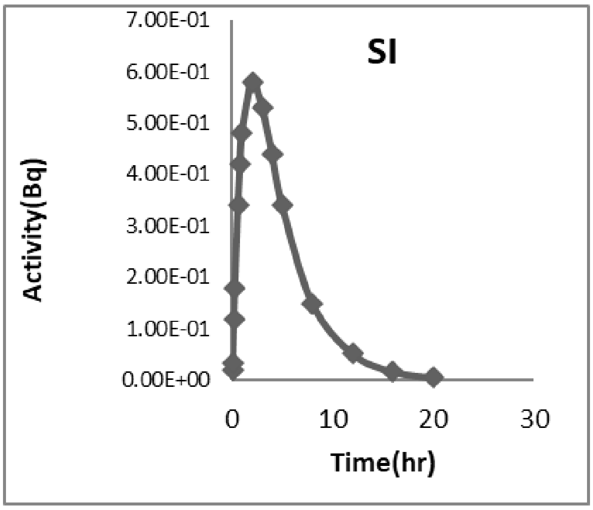

Figure 14 Time variation of activityin SI arising due to 134Cs

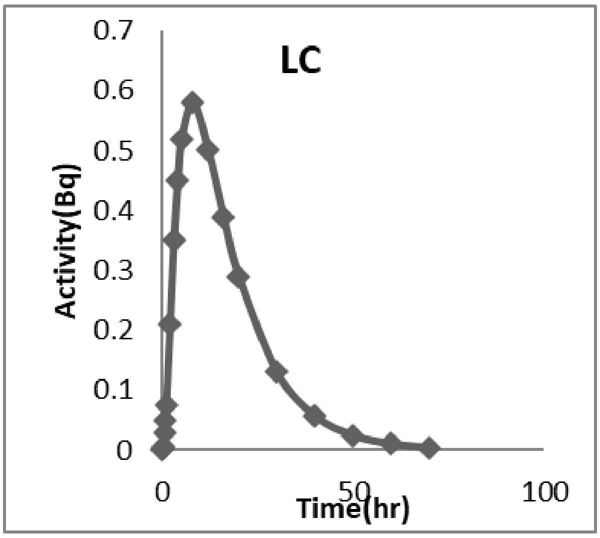

Figure 15 Time variation of activity in LC arising due to 134 Cs

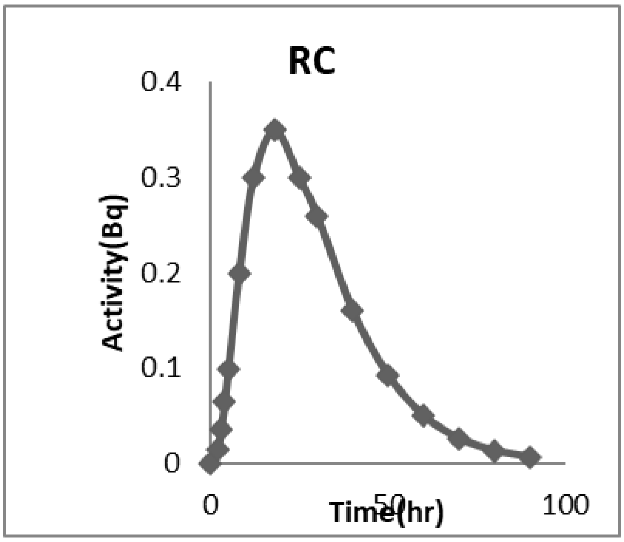

Figure 16 Time variation of activity in ST arising due to 134Cs

Information on the maximum value of activity, the rates of rising to it and falling there from for the radionuclide are given in Table 4.

Table 4 Information on activity values due to 134Cs

Name of the compartments	Maximum values	Rising Rate		Falling Rate	
		Magnitude (Bq/hr)	Time span of measurements	Magnitude (Bq/hr)	Time span of measurements
ST	0.87	10.375	0 hr - 0.08 hr	0.51	0.3 hr – 1 hr
SI	0.58	0.48	0 hr – 1 hr	0.08	3 hrs – 8 hrs
LC	0.58	0.10	0 hr – 5 hr	0.02	12 hrs – 30 hrs
RC	0.35	0.02	0 hr – 12 hr	0.01	25 hrs - 50 hrs

The time to attain the peak value of activity in the compartments can be serialized as:

RC > LC > SI > ST

The duration of stay is less in ST than that in SI. The retention time values for LC and RC are near to each other. For this radionuclide the time required to reach an insignificant value of activity is 7 hrs, 20 hrs, 60 hrs and 90 hrs respectively for the compartments ST, SI, LC and RC.

4. Conclusion

The following observations which are common for cases of all the radionuclide are worth mentioning:

- The organs accumulate the radionuclides at a quicker rate than that to release. Of course, the falling rate is guided by biological excretion process and the radiological half life of the concerned radionuclide.
- The duration of stay is less in ST than that in SI. The retention time values for LC and RC are near to each other.
- The retention time for the radionuclides in each organ follows the serial:
- ST < SI < LC < RC.
- Magnitude of the maximum activity in each compartment for ^{99m}Tc,^{131}I,^{134}Csfollows the serial:
- ST > SI > LC > RC.

The important observations could be made from the study. Time required to get an insignificant value of activity in the organs depends more on decay constant of radionuclides than the rate constant of the considered organ. The activity values became insignificant in the work approximately after 5 hrs in ST, 20 hrs in SI, 60 hrs in LC and 90 hrs in RC for long lived radionuclides (^{60}CO, ^{133}Ba, ^{134}Cs). These time span values are relatively shorter for short lived radionuclides (^{99m}Tc, ^{131}I) than those for the other radionuclides. Similar works have been done on these. [14]

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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