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Calculation of Internal Radiation Dose due to Acute Ingestion of 60Co by Adopting HATM Model

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Abstract

Activity of radionuclide, absorbed dose, committed equivalent dose, committed effective dose due to acute intake of 1 Bq of 60Co through ingestion have been calculated by using locally developed software that has been prepared basing on the human alimentary tract model. Due to ingestion, maximum radiation dose is deposited in the alimentary tract, which consists of seven tissue compartments, e.g., OC, OP, ST, SI, LC, RC, and RSC. Tissue masses of alimentary tract for Bangladeshi people have been considered to calculate the abovementioned quantities for different age groups such as newborn, 1 yr, 5 yrs, 10 yrs, 15 yrs (male and female) and adult (male and female). Regarding age the variation of absorbed dose, committed equivalent dose and committed effective dose follows the sequence: newborn >1 yr> 5 yr> 10yrs > 15 yrs> adult female > adult male.

Index terms— absorbed dose, committed equivalent, and committed effective dose, human alimentary tract model (HATM

radioisotope production laboratory and research facility or during routine work at the workplaces with an unsealed radioisotope. That's why the authorities such as UNSCEAR [2], IAEA [3], and ICRP [4] develop radiation safety standards. Internal radiation dose cannot be measured directly; of course, some models are there. This can be used for assessment of internal radiation dose, based on the radioactivity by bioassay measurement and whole-body counting.

The present study describes a generic methodology for the calculation of internal radiation doses due to the acute intake of beta-emitting radionuclides through ingestion. Visual Basic language software has been developed. The software is userfriendly and is found to work well as desired. This software can comfortably be used for calculation of internal radiation doses due to the intake of radioisotopes through ingestion by radiation workers and the public at large.

The activity of radionuclide, absorbed dose, committed equivalent dose, committed effective dose due to acute intake of 1 Bq of 60 Co through ingestion have been calculated by using the software that has been prepared based on the HATM. Due to ingestion maximum radiation dose is deposited in the alimentary tract, which consists of seven tissue compartments, (RC) and Rectosigmoid Colon (RSC). Tissue masses of alimentary tract for Bangladeshi people have been considered to calculate the above-mentioned quantities for different age groups such as newborn, 1 yr, 5 yrs, 10 yrs, 15 yrs (male and female) and adult (male and female).

1 a) The HATM

There are various ICRP, and MIRD models that are similar in terms of their assumption and defining equation. Contemporary internal dosimetry models began with the single compartment models of ICRP [5], and [6]. The MIRD methodology [7][8][9] and ICRP [10] and [11] developed the concept of source and target organs. ICRP [12] and ICRP [13] continue to refine to internal dosimetry model.

The new human alimentary tract model (HATM) [14] considers the movement of radionuclides Introduction adionuclides once entered into the body through different routes of entry [1] can't be eliminated. It gives out energy continuously as long as it remains inside the body. So it is necessary to assess internal radiation dose to measure the risk of human health. Occupational workers, and the public can be internally exposed by radiation due to the ingestion of contaminated food following nuclear reactor accident, accidental intake during the use of unsealed radioisotope in the field of nuclear medicine, throughout the tract from ingestion to elimination. The model (HATM) includes compartments representing the oral cavity (OC) and esophagus (OP) to account for doses received from transit or retention of activity in the upper regions of the tract. The model partitions the large intestine into three parts frequently addressed in colonic transit studies. It also includes compartments to account for nuclear transformations due to retention of a radionuclide in tissues of the tract in those cases where tissue retention is found by available information. The model includes pathways to account for absorption from the oral mucosa, stomach, or segments of the colon if specific information is available. HATM provides ageand gender-specific transit times for all of the tract depicted in the model and, for the upper (oral cavity, esophagus, and stomach), also provides materialspecific transit times.

The 1990 recommendations of ICRP introduced specific risk estimates and tissue weighting factors, w T , for radiation-induced cancer of the esophagus, stomach, and colon, requiring dose estimates for each of these regions. HATM takes account of sites of radionuclide absorption and retention in the tract and routes of excretion of absorbed radionuclides into the tract. Doses are calculated for sensitive cells in each region: mouth, esophagus, stomach, small intestine, and colon.

2 II.

3 Methodology

The proposed work is calculation based. An expression has been derived in work for the committed equivalent dose to some regions of the human body due to intake of some beta-emitting radionuclides through ingestion considering physiological parameters for different age groups of Bangladeshi population. The viewpoints of HATM [14] have been adopted to formulate mathematical equations for retention and the number of radioactive disintegrations that take place in different compartments of the digestive tract at a given time after intake of radionuclides. Subsequently, the equivalent dose, committed equivalent dose, and committed effective dose in each tissue or organ of interest have been formulated. A database library has been generated in Microsoft Access to store relevant data for assessment of retention and cumulated activity and equivalent doses in each of the compartments for different age groups of Bangladeshi population and ICRP reference subjects. Software has been developed to calculate the above-mentioned quantities rapidly. a) Mathematical Formalism H. Bateman's general equation [15] of activity can be written as (1) Here i A is the activity in organ i (i=1,2,3???????7) i ? is the transfer rate of the radionuclide from the organi? = ? = n i t i o i i e C N A( ) ? ? = = ? = n i m i n i i m C 1 1 ? ? ? ( )( )( ) ( ) m n m m m n ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? = ... 3 2 1 3 2 1 (2)

For materials deposited into first, second, 3 rd , 4 th , 5 th , 6 th , and 7 th compartment can be obtained by putting i=2, 3, 4, 5, 6, and 7 respectively into Eqn. (**??**) t o e N A 1 1 ? ? = (3) ( ) ( ) ? ? ? ? ? ? ? ? ? ? + ? = ? ? 2 1 1 2 2 1 2 2 1 ? ? ? ? ? ? ? ? t e t e N A O (4) Volume XIX Issue II Version I Year 2019 (D D D D) ( ) ( ) ( ) ? ? ? ? ? ? ? ? ? ? ? + ? ? + ? ? = ? ? ? 3 2 3 1 2 3 2 1 1 3 1 2 3 2 1 0 3) ( ) ( ) (3 2 1 ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? t t t e e e N A (5) ( )( ) ( ) ( )( ) ( )( ) ? + ? ? ? + ? ? ? + ? ? ? = ? ? ? ? 4 3 4 2 4 1 3 4 3 2 3 1 2 4 2 3 2 1 1 4 1 3 1 2 4 3 2 1 0 4) ( ) ( ) ( ) ( ) (( )()( ) ( ) ( )( )( ) ( )( )( ) ( )( )( )? + ? ? ? ? + ? ? ? ? + ? ? ? ? + ? ? ? ? = ? ? ? ? ? 5 4 5 3 5 2 5 1 4 5 4 3 4 2 4 1 3 5 3 4 3 2 3 1 2 5 2 4 2 3 2 1 1 5 1 4 1 3 1 2 5 4 3 2 1 0 5) ( ) ( ) ( ))(( ) ( ) (5 4 3 2 1 ?( )( )( )( ) ( ) ( ) ( )( )( )( ) ( )( )( )( ) ( )( )( )( ) ( )( )( )( ) ? + ? ? ? ? ? + ? ? ? ? ? + ? ? ? ? ? + ? ? ? ? ? + ? ? ? ? ? = ? ? ? ? ? ? 6 5 6 4 6 3 6 2 6 1 5 6 5 4 5 3 5 2 5 1 4 6 4 5 4 3 4 2 4 1 3 6 3 5 3 4 3 2 3 1 2 6 2 5 2 4 2 3 2 1 1 6 1 5 1 4 1 3 1 2 6 5 4 3 2 1 0 6) ( ) ( ) ( ) ( ))(( ) ( ) (6 5 4 3 2 1 ?( )( )( )( )( ) ( )( )( )( )( ) ? + ? ? ? ? ? ? + ? ? ? ? ? ? + ? ? ? ? ? ? + ? ? ? ? ? ? + ? ? ? ? ? ? + ? ? ? ? ? ? = ? ? ? ? ? ? ? ?)( )( )( )( ) ( ) ( )( ) ( )( )( )( ) ( )( )( )( ) ( )( )( )( )( )) ( ) ( ) ( ) ( ) ( ))(( ) ( ) (7 6 5 4 3 2 1 ? t t? ? ? × × × = ? mSv (10)

Where, A(t) is the activity at any organ after a time t from ingestion.T R i i i i M w S T AF E Y S T SEE) ( ) (? = ? MeV 1 ?

4 Kg per transformation

Where, Y i is the yield of radiations of type i per transformation E i is the average, or unique energy of radiation i in MeV AF(T ? S) is the absorbed fraction that is the average fraction of energy in T from radiation arising in S; W R, the radiation weighting factor and M T is the mass of the target organ in kg.

5 c) Committed Equivalent Dose

The committed equivalent dose for each type of radiation is given byi s i S T SEE U S T H) (10 6 . 1) (13 ? × × × = ? ? Sv (**11**)

Where s U is the number of the transformation of j in S over the lifetime following intake of the radionuclide. This is the expression for the number of transformations in the various organs in the tract following ingestion of 1 Bq of activity.

Oral cavity:R OC OC U ? ? + = 1 Esophagus:))((1 R EP R OC EP U ? ? ? ? + + = Stomach:))( )((1 R ST R EP R OC ST U ? ? ? ? ? ? + + + = Small intestine:))( )( )((1 B R SI R ST R EP R OC ST U ? ? ? ? ? ? ? ? ? + + + + + = Left colon:))( )( )( )((1 R LC B R SI R ST R EP R OC LC U ? ? ? ? ? ? ? ? ? ? ? + + + + + + = Right colon:))( )( )( )( )((1 R RC R LC B R SI R ST R EP R OC RC U ? ? ? ? ? ? ? ? ? ? ? ? ? ? + + + + + + + = Rectosigmoid colon:))( )( )( )( )( )((1 R RSC R RC R LC B R SI R ST R EP R OC RSC U ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? + + + + + + + + = d) Committed Effective Dose

Committed effective dose for any organ of alimentary tract is the product of committed equivalent dose and tissue weighting factori i W H E × ? =) (? mSv (**12**)

Where W i is the tissue weighting factor.

6 Global Journal of Medical Research

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7 Results and Discussion

Activity, absorbed dose, committed equivalent dose, and committed effective doses due to acute ingestion of 1 Bq of 60 Co. Tissue masses of alimentary tract for Bangladeshi people have been considered to calculate the above-mentioned quantities for different age groups such as newborn, 1 yr, 5 yrs, 10 yrs, 15 yrs (male and female) and adult (male and female).

8 a) Activity

Activity has been calculated at different compartments of HAT of the subjects of age groups: newborn, 1 yr, 5 yrs, 10 yrs, 15 yrs (male), 15 yrs (female) and adult (both male and female) and time elapsed as considered in the work is mostly 0.5 hr, 1 hr, 2 hrs, 4 hrs, 8 hrs, 12 hrs, 24 hrs and 48 hrs after the ingestion of the radionuclide.

Figs. **??**-7 show the variation of activity in OC, OP, ST, SI, LC, RC, and RSC for all age groups. By studying the nature of the graphs, it is found that the tissues of all the seven organs (excepting oral cavity) show a tendency of rising of activity initially and subsequent falling. The radionuclide 60 Co is absorbed in one organ, which is caused after the release of it from the previous organ. The significant aspects of the absorption in and release from these organs are described below:

The activity-time graph for 60 Co has been constructed for the above-mentioned seven tissues of the alimentary tract. By studying the nature of the graphs it is found that the tissues of all the seven organs (excepting oral cavity) show a tendency of the rise of activity initially and subsequent falling.

Activity-versus-time graphs are plotted for OC (Fig. **??**), OP (Fig. **??**), and ST (Fig. **??**). Fig. **??** shows that for OC, at around 0.001 hr after ingestion of the radionuclide, the activity reaches 0.97 Bq, and at 0.2hr after ingestion, it reaches to around 2.47x10 -3 Bq. The observation (a sharp fall) can be accepted because OC is the first organ, and its transit time is very short.

The excreted radionuclide will then appear in the next tissue, e.g., OP. After the lapse of the time at OC, the activity in OP should show growth, and this is observed in work; the peak is found to appear at around 0.02 hrs after ingestion. The value in the OP attains the maximum value at this time, the calculated result and the rising rate being 0.19Bq and 9.5Bq/hr, respectively. The activity change with time shows a sharp fall. After 0.4hrs, the activity level reduces to 3.07x10 -6 Bq. This time is also short, again possibly due to the low transit time of the organ.

The excreted radionuclide is then deposited in the later tissue, e.g., ST. Fig. **??** shows that for ST, the activity level reaches to the maximum value (=0.89Bq) at 0.15hrs after ingestion. The rising-rate is 5.9Bq/hr. Then the activity level decreases exponentially. Finally, it reduces to a value of approximately 1.97x10 -4 Bq at a time 10hrs after ingestion.

The excreted radionuclide from ST is then deposited in the later tissue, e.g., SI. Fig. **??** shows the pattern of change. In the case of SI, the maximum value of activity appears at about 1.2hrafter the ingestion; the maximum significance being 0.36 Bq. Then it falls, and in doing so, it takes a time of about 15hrs in total to reach the value of 2.29x10 -5 Bq.

The radionuclide then goes to the next tissue, e.g., LC, and the pattern of retention in the organ is shown in Fig. **??** In LC, activity level rises to 5hrs after ingestion, which is remarkably different from that of the other organs. The maximum value attained is 0.73 Bq. During the falling down process, this organ takes a very long time, e.g., approximately 96 hrs to reach it of approximately 4.2x10 -4 Bq.

Fig. **??** shows the variation of the activity with time for the organ RC. One may observe from the figure that in the case of RC, it rises up to attain the maximum value (=0.36) in 15hrs of duration; the rising rate being 0.024Bq approximately. The activity value then continuously decreases, and after an elapse of 150 hrs, the organ retains approximately 6.31x10 -5 Bq of activity in total. The falling rate is guided by an approximately exponential function.

The RSC graph (Fig. **??**) shows that up to around 27 hrs after ingestion, the activity rises, being significantly different from that of the other ones. The peak value is about 0.27Bq, the rising rate being 0.01Bq/hr. Then the activity level decreases exponentially. Around 180hrs, duration is necessary for the activity level to fall to the value of 5.09 x 10 -5 Bq.

9 b) Absorbed Dose

Figs. 8-13 show the variation of absorbed dose in 0 to 48 hrs by OP, ST, SI, LC and RC organs for a new-born baby who is supposed to have ingested 1 Bq of the radionuclide 60 Co. The absorbed dose in OP decreases very rapidly, its value becoming practically insignificant after around 0.4 hours. The absorbed dose in OP, ST, SI, LC, RC, and RSC increases exponentially (approximately) and then decreases. This pattern of variation is expected mainly because of the biological excretion phenomenon. Of course, the effect of radioactive half-life is also active in these cases.

The maximum absorbed dose per Bq intake of 60

Co is found to be 1.4x10 -11 , 1.95x10 -11 , 1.84x10 -12 , 1.60x10 -11 , 7.89x10 -12 , and 1.38x10 -11 mSv in the compartments of OP, ST, SI, LC, RC, and RSC respectively. The maximum absorbed dose in OP occurs quickly after the process of intake. Similar results are found for all the other age groups: 1 yr, 5 yrs, 10 yrs, 15 yrs (male), 15 yrs (female), adult (male) and adult (female). The absorbed dose in different parts of the human alimentary tract for the adult (male) is found to be the lowest because of the relatively larger tissue

10 c) Committed Equivalent Dose

Figs. [14][15][16] show the variation of committed equivalent dose in OP, LC, ST, SI, RC, and RSC for eight different age groups of people due to ingestion of the radionuclide 60 Co. The equivalent dose is the maximum in the case of subjects of new-born age group. Then it decreases as age increases; its value is becoming almost the same for 15 yrs (male), 15 yrs (female), adult (male), and adult (female) because of their having approximately similar body mass [16].

The maximum committed equivalent dose per Bq intake of 60 Co is found to be 3.07x10 -9 ,9.21x10 -8 , 2.08x10 -8 , 2.59x10 -7 , 2.59x10 -7 , and 6.05x10 -7 mSv for OP, ST, SI, LC, RC, and RSC respectively. Fig. **??**7 shows the variation of committed equivalent dose in OP, LC, ST, SI, RC, and RSC for a particular age group of subjects, e.g., newborn child. The committed equivalent dose has a minimum value in OP due to a very tiny number of transformations (only 40) occurring there. In the next organ, e.g., ST, this value rises due to its larger number of transformations. In SI, this value is again decreasing due to its larger mass. In LC and RC, this value is almost the same because of their equal mass and transformation number. In RSC committed equivalent dose is maximum due to its lowest mass. For age groups: 1 yr, 5 yrs, 10 yrs, 15 yrs (male), 15yrs (female), adult (male), and adult (female) similar results are found.

The variation of committed effective dose in the organs OP, ST, SI, LC, RC, and RSC for the different age groups of people due to the ingestion of the radionuclide 60 Co is shown in Figs. 18-20. As expected, the committed effective dose is the maximum in case of a subject of new-born age group. Then it decreases as age increases; its value is becoming almost the same for 15 yrs (male), 15 yrs (female), adult (male) and adult (female) subjects because of their having close body mass.

The maximum committed effective dose per gram intake of 60 Co is found to be 1.22x10 -10 , 1.10x10 -8 , 2.41x10 -9 , 3.11x10 -8 , 3.11x10 -8 , and 7.26x10 -8 mSv for OP, ST, SI, LC, RC, and RSC respectively. In the case of a new-born baby, the variation of committed effective dose in the organs OP, ST, SI, LC, RC, and RSC is given in Fig. **??**1.

Committed Effective dose has a minimum value in OP due to a very tiny number of transformations. In the next organ e.g., ST this value is rising due to its greater number of transformations. In SI, this value is again decreasing due to its larger mass. In LC and RC this value is almost the same because of their equal mass and transformation number. In RSC, committed equivalent dose is the maximum due its lowest mass.

Similar results are found for subjects of age groups: 1 yr, 5 yrs, 10 yrs, 15 yrs (male), 15yrs (female), adult (male), and adult (female).

11 IV.

12 Conclusion

Due to ingestion, maximum radiation dose is deposited in the alimentary tract, which consists of seven tissue compartments, e.g., OC, OP, ST, SI, LC, RC, and RSC. The transfer of radionuclides from the oral cavity to the esophagus has been considered an instantaneous process that gives less retention but activity in the entry route.

Regarding age, the variation of absorbed dose, committed equivalent dose, and committed effective dose follows the sequence: Newborn >1 yr> 5 yr> 10yrs > 15 yrs> adult female > adult male.
c. Absorbed dose for an alpha-emitting radionuclide is higher than beta-emitting radionuclides due to higher radiation weighting factor (w R).
d. The absorbed dose, committed equivalent, and committed effective dose show a common tendency that these values are maximum for a subject of newly born age group; then, it decreases as the age increases for all the radionuclides of interest.
e. Regarding compartment the trends of variation of maximum absorbed dose are: ST > LC > OP > RSC > RC >SI
f. Regarding tissue compartments the variation pattern of committed equivalent dose is: RSC> LC > RC > ST > SI > OP
g. The highest committed effective dose per Bq intake for each radionuclide is found in the alimentary tract of a newborn baby. These values for stomach are 3.72 x10 -6 mSv/Bq, 2.16x10 -6 mSv/Bq, 8.64x 10 -

Figure 1:

12 CONCLUSION

The following important observations could be made from the study: a. [1] [2] [3]

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[2] © 2019 Global Journals

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