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# ESTIMATION OF PATIENT EFFECTIVE DOSE FROM $^{131}$I USING MONTE CARLO CALCULATION

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**Abstract** – During the oral application of radionuclide therapy it is from the vital importance to measure effective dose in stomach in which the $Na^{131}I$ therapeutic capsule stays during the 15 minutes which is long enough to make risky exposure. As it is not possible to determine it by direct measurements there is a strong recommendation to estimate the dose by calculation. The main goal is to calculate effective dose and risk as a result of $^{131}I$ capsules remaining in stomach before the absorption starts. Monte Carlo code MCNP4b was used to model the transport of gamma and beta particles emitted by radionuclide $^{131}I$ treated as a point source at the bottom of the stomach. Absorbed energy per unit transformation in stomach and surrounding organs has been calculated. The dose equivalents in these organs have been calculated in aim to determine the effective doses using appropriate tissue weighting factor values. The local doses in stomach wall reached the values in order of several hundreds of grays in a very short time. In such case the traditional concept of risk is not applicable, so it becomes necessary to create the very new concept which is able to cover higher risks under presented circumstances.

Keywords: effective dose, risk estimates, Monte Carlo

## 1. INTRODUCTION

Capsules or solutions containing $Na^{131}I$ are indicated for the therapy of some thyroid carcinomas, such as functional metastatic papillary or follicular carcinoma of the thyroid and for the treatment of hyperthyroidism (diffuse toxic goiter and single or multiple toxic nodular goiter). They are also used for the treatment of recurrent hyperthyroidism after surgery.

The administration of $Na^{131}I$ capsules or solutions is oral. We presume that the absorption in gastrointestinal tract starts immediately if the solution is used while for the case of capsule therapy we estimate that radioactivity of $^{131}I$ stay in stomach for 15 minutes in average before the absorption starts. Institute of nuclear sciences VINCA is a manufacturer for $Na^{131}I$ capsules and it is experimentally obtained that the capsule dissolving time is 15 minutes. In this time interval a large amount of radioactivity needlessly expose a part of stomach and several surrounding organs. Comparing to the solution treatment of patients this is the additional risk. The longer remaining of capsule in stomach increase the real risk. The aim of this paper is to show one of the possible way how the additional risk can be estimated.

The recommended activities for $Na^{131}I$ capsules or solution for the therapy, delivered to the average patient (70 kg), are between 3.7 GBq and 7.4 GBq for ablation of normal thyroid tissue and for subsequent treatments, and between 148 MBq and 370 MBq for hyperthyroidism. For the purpose of this paper the nominal dose of 3.7 GBq has been chosen [1]

## 2. MATERIALS AND METHODS

The general method for solving the mentioned problem is presented in three steps as follows:

(1) *Dose equivalents* in tissues or organs are calculated by appropriate radiation transport codes using a suitable mathematical anthropomorphic phantom;

(2) *The effective doses*, E, on the basis of tissue weighting factors, has been calculated and

(3) *Additional risks* of lifetime mortality can be easily determined.

### *2.1. Phantom*

The calculations were performed using a few various anthropomorphic phantoms. The oldest one was MIRD anthropomorphic model started in 1980's, but still in use. [2] From 1990's to nowdays a few models were in use as image-based rigid and stationary models [3] and deformable and moving models. [4]. The novel MIRD anthropomorphic models are very suitable for presented calculation because they are representative for broad population and easy to use in Monte Carlo calculation. These models were developed for calculations of doses absorbed in specific organs due to a source in some other organ. A later report gave a complete mathematical description of all important organs in humane body.[5] In this paper we gave our results only for the new MIRD model.

The phantom consists of three major sections:

(a) an elliptical cylinder representing the trunk and arms;

(b) two truncated circular cones representing the legs and feet; and

(c) a circular cylinder on which sits an elliptical cylinder capped by half an ellipsoid representing the neck and head.

The other organs are modelled by appropriate geometrical figures. The stomach wall is represented by the volume between two concentric ellipsoids and the contents by the volume within the inner ellipsoid.

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The wall is defined by equation 1.

$$\left(\frac{x-x_0}{a}\right)^2+\left(\frac{y-y_0}{b}\right)^2+\left(\frac{z-z_0}{c}\right)^2\le 1 \qquad (1)$$
$$\left(\frac{x-x_0}{a-d}\right)^2+\left(\frac{y-y_0}{b-d}\right)^2+\left(\frac{z-z_0}{c-d}\right)^2\ge 1$$

In the case of adult male the parameters in former equation have the next values: a=4.00, b=3.00, c=8.00, d=0.613, $x_0$=8.00, $y_0$=-4.00, $z_0$=35.00 [5]

For the purpose of this investigation we consider the worst case that the stomach is "empty". This consideration is based upon clinical practice in our hospitals that all therapy procedures are given "at the empty stomach". According to this presumption the iodine capsule is at the bottom of the stomach lying at the stomach wall. The highest doses are delivered to the empty stomach because beta particles are absorbed (neutralized) in stomach content if present.

Three phantom tissue types are recognized as skeletal, lung and all other tissue (soft tissue). The densities of those tissues are: 1.4 $gcm^{-3}$; 0.296 $gcm^{-3}$ and 1.04 $gcm^{-3}$ respectively. The exact compositions of each tissue type are given in ICRP 70, ICRP 89 and ICRU 46 (ICRP 1996, ICRP 2002, ICRU 1992). In this phase of research it is not necessary to specify the gender of the patient.

The soft tissue composition used in this paper is presented as 10.6 % H + 11.5 % C + 2.2 % N + 75.1 % O + 0.1 % Na + 0.1 % P + 0.1 % S + 0.2 % Cl + 0.1 % K

### *2.2. Application of MCNP software package*

We used the radiation transport code MCNP4b, a general Monte Carlo N-Particle transport code (MCNP), developed at the Los Alamos National Laboratory. This is a multipurpose computational code appropriate for various complex geometries. MCNP provides seven standard neutron tallies, six standard photon tallies, and four standard electron tallies. These basic tallies can be modifed by the user in many ways. [9,10]. In the case of $^{131}$I beta particles and gamma rays transport should be taken into account. As input data for both particles we used beta particles spectra of radionuclide iodine-131 shown in figure 1 which is converted in the form of histogram. Our calculated data are given in figure 2. As $^{131}$I emits a lot of gamma photons with discrete energies we used only several energies of significant importance.

Proper tally specification is very important in MCNP calculations. In the case of dose distribution calculation in different organs for gamma rays the tallies *F8 and F6 are applicable and therefore used. And for beta rays only *F8 tally can be used. These tallies give the absorbed energy in organs in units $MeVg^{-1}$ per disintegration.

In the case of calculation of local dose distribution in stomach wall beside F6 and *F8 tallies, just for gamma rays F2 tally has been used to. Because this tally represents flux averaged over a surface, flux-dose rate conversion coefficients have been used [11].

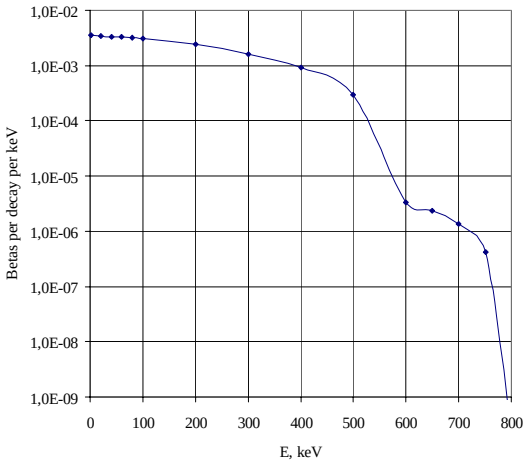


Fig. 1. Beta spectra of $^{131}$I

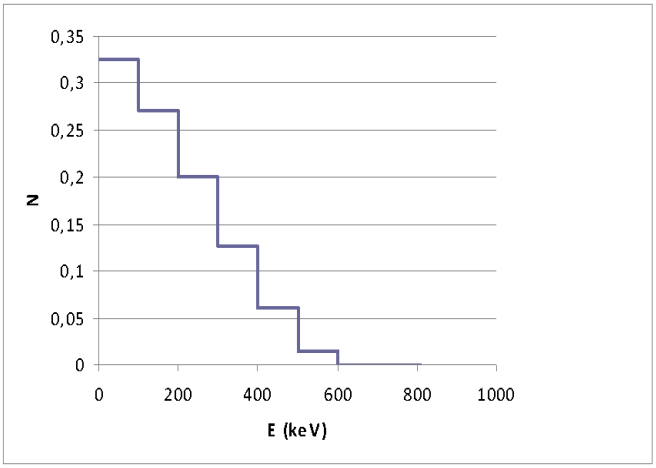


Fig. 2. Calculated histogram

## 3. RESULTS

### *3.1. Effective dose and cancer risk*

By application of MCNP4b software the absorbed energy in the most exposed organs as a consequence of $^{131}$I capsule staying in stomach has been calculated. For the capsule activity of 3.7 GBq its 15 minutes remaining in stomach, the dose equivalent (radiation weighting factor equal unity) in different organs are calculated. The relative uncertainty was not higher than 5%.

Imparted energies per transformation for different organs are presented on table 1.

Table 1. Imparted energy per transformation for different organs.

| Organ | Imparted energy per transformation (MeV) | | |
|---|---|---|---|
| | Gamma | Beta | Gamma +Beta |
| Bone surface | 3.65E-03 | 0 | 3.65E-03 |
| Stomach | 6.96E-05 | 1.57E-01 | 1.57E-01 |
| Colon | 5.06E-03 | 3.79E-06 | 5.06E-03 |
| Kidneys | 1.37E-04 | 0 | 1.37E-04 |
| Liver | 3.60E-04 | 5.38E-07 | 3.61E-04 |
| Lungs | 3.96E-05 | 1.50E-07 | 3.98E-05 |
| Testes | 1.22E-04 | 0 | 1.22E-04 |
| Bladder | 7.77E-04 | 0 | 7.77E-04 |
| Skin | 2.74E-04 | 0 | 2.74E-04 |

Using calculated imparted energies per transformation as well as radiation quality factors we have calculated dose equivalent rates in different organs as a base for effective dose estimation. Calculated values of dose equivalent rate for different organs are presented in table 2.

Table 2. Calculated values of dose equivalent rate in different organs.

| Organ | [Gy/s] | [Gy/15 min] |
|---|---|---|
| Bone surface | 6.17E-07 | 5.56E-04 |
| Stomach | 6.88E-04 | 6.19E-01 |
| Colon | 8.71E-06 | 7.84E-03 |
| Kidneys | 3.00E-07 | 2.70E-04 |
| Liver | 1.28E-07 | 1.15E-04 |
| Lungs | 2.80E-08 | 2.52E-05 |
| Testes | 2.67E-06 | 2.40E-03 |
| Bladder | 1.11E-05 | 9.95E-03 |
| Skin | 1.47E-07 | 1.33E-04 |

Considering the number of histories obtained uncertainties of Monte Carlo calculations of energy imparted in organs (MeV per disintegration) are acceptable. By means of tissue weighting factors [13] and dose equivalent in different organs the effective dose has been calculated and presented in table 3.

Table 3. Calculated values of effective dose in different organs.

| Organ | Tissue weighting factor | *E* [Sv] |
|---|---|---|
| Bladder | 0.05 | 4.98E-04 |
| Bone surface | 0.01 | 5.56E-09 |
| Colon | 0.12 | 9.41E-04 |
| Liver | 0.05 | 5.75E-06 |
| Lungs | 0.12 | 3.03E-06 |
| Ovary,gonads | 0.20 | 4.81E-04 |
| Skin | 0.01 | 1.33E-06 |
| Stomach | 0.12 | 7.43E-02 |

### *3.2. Local dose in stomach wall*

As MIRD is used for the calculation of average organ doses and is not capable to recognize the local doses we applied Monte Carlo code. These calculations have been performed by MCNP4b package for the point source iodine-131 in the soft tissue. For beta dose *F8 tally and for gamma dose both *F8 and F2 tallies have been used. Due to the sphere symmetry, estimated uncertainties are less than 0.01 %, and they are not significant. The dose-distance profile is presented in figure 3.

In the vicinity of the capsules we obtained high dose values in order of several thousand grays. Space dose fractionation has to be taken into account. These results indicate that the concept of average organ or tissue dose must be recruited by additional calculations.

The following example could serves as a good illustration of organ fractionation dose. Point source of $^{131}$I is in the middle of the soft tissue sphere. The average dose in the sphere of radius *r* has been calculated by MCNP4b code. The average doses in a function of sphere mass for the point source activity of 3.7 GBq are presented in figure 4. It was reasonable to presume the point source geometry as the small dried drop deposited on the capsule holder. Selfabsorption in such source should not be significant.

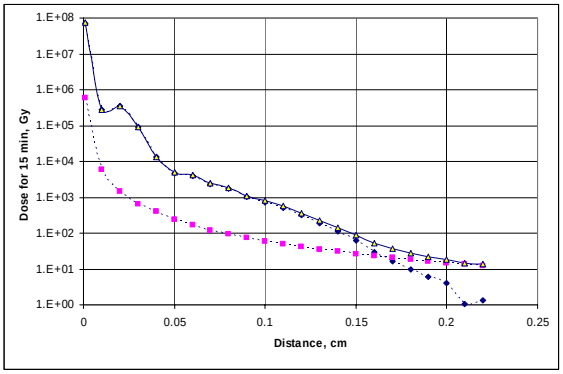


Fig. 3. The dose - distance profile, betas are marked by pink, gammas are marked by blue and total dose is marked by yellow

It is evident that a middle dose is less than 1 Gy for an organ like stomach (130 g), about 10 Gy in an organ like thyroid (10 g) and higher than 100 Gy in the most exposed part of the stomach (less than 1 g). If the mass of the soft tissue is ten times smaller, the average dose is approximately ten times higher.

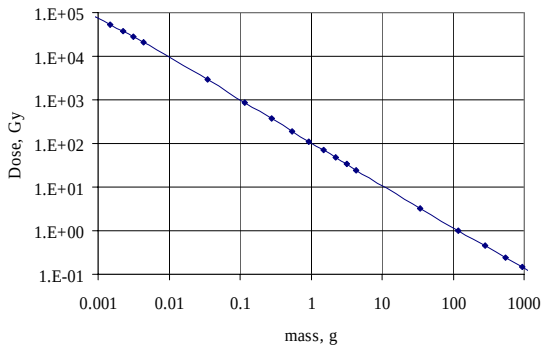


Fig 4. The average doses in function of sphere mass for point source activity 3.7 GBq

### *3.3. Calculation of risks*

Effective dose at the whole body level is 76.2 mSv. As expected, this value is relatively small. The additional risk of cancer death with the value of 0.6e-3 is negligible. The same situation comes from the calculation of Summary of the Lifetime Mortality in the Whole Population from Specific Fatal Cancers after Exposure at Low Radiation Dose and Dose Rates[12]. The risk coefficients and calculated risk are presented in table 4.

These results do not point out to higher risk to patient because of the 15 minutes capsule staying in stomach. But because of high activity of capsule local doses and dose rates could be very large and the presented model for risk calculation could not be appropriate. Therefore it is necessary to know dose distance relation in stomach wall.

Table 4. The risk coefficients and calculated risks for different organs.

| Organ | Risk coefficient ($10^{-2}Sv^{-1}$) | Risk |
|---|---|---|
| Bladder | 0.30 | 2.99E-05 |
| Bone surface | 0.05 | 2.78E-10 |
| Colon | 0.80 | 2.27E-05 |
| Liver | 0.15 | 1.73E-07 |
| Lungs | 0.85 | 2.014-07 |
| Ovary,gonads | 0.10 | 2.40E-06 |
| Skin | 0.02 | 2.65E-08 |
| Stomach | 1.10 | 6.81E-03 |
| Kidney | 0.5 | 1.35E-06 |
| Total risk | | 6.917E-03 |

## 4. CONCLUSION

The investigations and calculations were started with assumption that the values of additional effective doses or risks during the 15 minutes of $^{131}I$ capsules retaining in the stomach before their absorption are not neglectable. Application of solution has some advantages as the absorption in stomach wall is immediate but also has a lot of disadvantages. Capsules containing $Na^{131}I$ are widely used as they are more comfortable for administration and there is less possibility for local contamination of patient and medical staff.

The recommended doses for the therapy of average patient (70 kg) are in the range from 148 MBq to 7.4 GBq, depending of disease which has to be treated. As the administration of $Na^{131}I$ capsules is oral they retain in stomach for at least 15 minutes before absorption starts. During that time a large amount of radioactivity needlessly expose a part of stomach and several surrounding organs. This fact was the main reason for our prediction about the necessity of additional risk estimation. Obtained results indicate that values of local doses in stomach wall could not be ignored.

According to the obtained results we recommended some corrections of the traditional concept of risk estimation in our hospitals and we emphasized the necessity to create the concept which is able to cover higher risks under presented circumstances. We strongly recommend the estimation of additional risks for each type of the procedure as a part of QA programs for $Na^{131}I$ capsules application.

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