# Monte Carlo estimation of patient effective dose in diagnostics procedures using $^{131}I$

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# Monte Carlo Estimation of Patient Effective Dose in Diagnostics Procedures Using $^{131}$I

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**Abstract**. Therapeutic or diagnostic radiopharmaceutical capsule containing Na$^{131}$I stays in stomach for 15 minutes before the absorption starts, long enough to make possible risky exposure. During the oral application it is reasonable to measure effective dose in stomach. Direct measurements of organ doses are not possible so there is a strong recommendation to estimate them by calculation. The main goal is the $^{131}$I risk assessment. Monte Carlo code MCNP4b was used to model the transport of gamma and beta particles emitted by radionuclide $^{131}$I considered 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. Obtained results had not significant importance for radiation protection but they were important for establishment of new calibration procedures as a part of QA and QC programs in radiopharmaceuticals production and control.

## 1. Introduction

Capsules containing Na$^{131}$I are indicated for the therapy of some thyroid carcinomas, for the treatment of recurrent hyperthyroidism after surgery but also in nuclear medicine diagnostic techniques.

The recommended activities 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, between 148 MBq and 370 MBq for hyperthyroidism and up to 100 MBq in diagnostics. [1] For the purpose of this paper the nominal dose of 74 MBq has been chosen

The administration of Na$^{131}$I capsules or solutions is oral. In the case of solution absorption in gastrointestinal tract starts immediately but in the case of capsules the dissolving time of capsule material is 15 minutes. This time is obtained experimentally at VINCA Institute of Nuclear Sciences, the manufacturer of the capsules and radiopharmaceuticals based upon $^{131}$I. In this time interval some amount of radioactivity needlessly expose a part of stomach wall and several surrounding organs. These doses are not measurable but could be easily estimated using numerical experiment. Monte Carlo technique, also gives a good and reliable tool for risk assessment. The aim of this paper is to show one of the possible way how the additional risk can be estimated.

 

## 2. Materials and Methods

General method for determination of effective dose in different organs and for estimation of additional risks is presented as three steps procedure: (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 were assessed.

### 2.1. Phantom

The calculations were performed using a few various anthropomorphic phantoms. [2,3,4,5]. In this paper we considered 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. 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]

As input parameters the three phantom tissue types were recognized: skeletal, lung, and all other tissue (soft tissue). The densities of these tissues were: 1.4 $gcm^{-3}$; 1.04 $gcm^{-3}$ and 0.296 $gcm^{-3}$ respectively. The exact composition of each tissue type is given in ICRP 70, ICRP 89 and ICRU 46 [6,7,8] 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 code developed at the Los Alamos National Laboratory [9]. In the case of $^{131}I$ it is necessary to take gamma rays transport into consideration beside beta particles. Proper tally specification is very important in MCNP simulation. For the calculation of gamma dose distribution in different organs *F8 and F6 tallies are applicable and therefore used. For beta rays only we used *F8 tally. These tallies give the absorbed energy in organs in units MeV/g per disintegration. For the estimation of local dose distribution in stomach wall we used F6 and *F8 tallies as well as F2 tally applicable only for gammas. [10, 11]. The total number of histories was $10^6$. The estimated relative uncertainty of simulation was not higher than 5 %. Due to the sphere symmetry estimated uncertainties for calculation of local stomach doses are less than 0.01 %, and they are negligible. Considering the number of histories obtained uncertainties of Monte Carlo calculations of energy imparted in organs are acceptable.

In the case of $^{131}I$ beta particles as well as 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 (ICRP 1983 and Chul 1999). 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, presented in table 1.

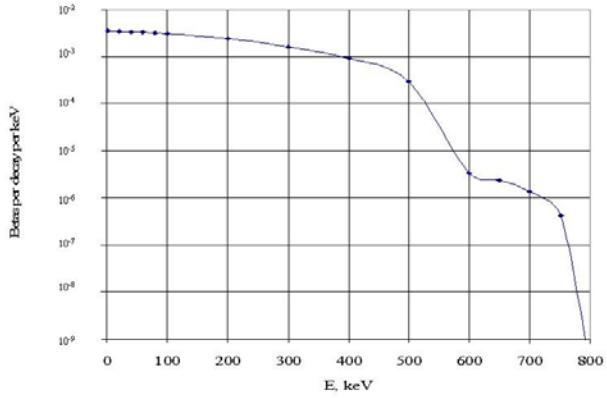


**Figure 1.** Beta spectra of $^{131}$I

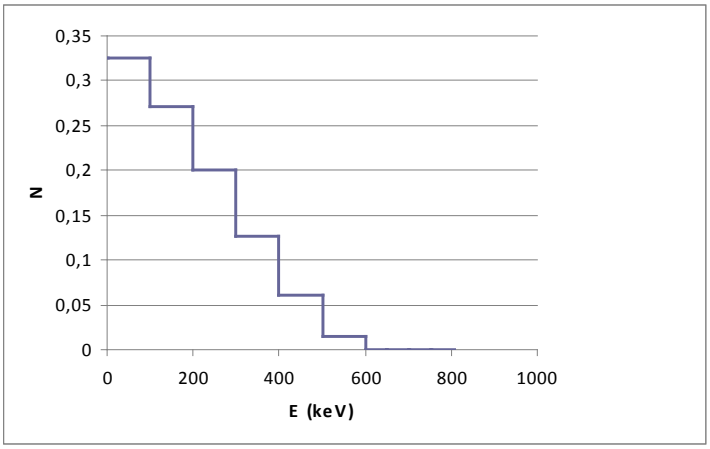


**Figure 2.** Beta spectra of $^{131}$I (histogram version)

Table 1. $^{131}$I photon emission.

| Energy (MeV) | Fraction |
|---|---|
| 0.0295 | 0.0474 |
| 0.0802 | 0.0262 |
| 0.2843 | 0.0605 |
| 0.3645 | 0.8116 |
| 0.6370 | 0.0748 |
| 0.7229 | 0.7229 |

## 3. Results

In the very first step of calculation MCNP4b software gave us the absorbed energy in the most exposed organs as a consequence of 74 MBq $^{131}I$ capsule staying in stomach for 15 minutes. Using calculated imparted energies per transformation as well as radiation quality factors we have calculated dose equivalent rates in different organs as input parameters for effective dose estimation. Calculated values of dose equivalent rate for different organs are presented in table 2. By means of tissue weighting factors and dose equivalent in different organs the effective dose has been calculated and presented in table 3.

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

| Organ | [nSv/s] | [μSv/15 min] |
|---|---|---|
| **Bladder** | 222 | 199 |
| **Bone surface** | 12.34 | 11.12 |
| **Colon** | 174.2 | 156.8 |
| **Liver** | 2.56 | 2.30 |
| **Lungs** | 0.56 | 0.504 |
| **Ovary, gonads** | 53.4 | 48.0 |
| **Skin** | 2.94 | 2.66 |

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

| Organ | Tissue weighting factor | $E$ [μSv] |
|---|---|---|
| **Bladder** | 0.05 | 9.96 |
| **Bone surface** | 0.01 | $11.12 \times 10^{-5}$ |
| **Colon** | 0.12 | 18.82 |
| **Liver** | 0.05 | $11.5 \times 10^{-2}$ |
| **Lungs** | 0.12 | $6.06 \times 10^{-2}$ |
| **Ovary, gonads** | 0.20 | 9.62 |
| **Skin** | 0.01 | $2.66 \times 10^{-2}$ |
| **Stomach** | 0.12 | 1486 |

Effective dose at the whole body level is 1.524 mSv. As expected, this value is relatively small. The risk coefficients and calculated risks are presented in table 4.

The additional risk of cancer death with the value of $13.834 \times 10^{-5}$ 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].

These results do not point out to higher risk to the patient but they emphasize the necessity of new metrological approach to QA an QC programs in radiopharmaceuticals manufacturing and control.

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 two 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.

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

| Organ | Risk coefficient ($10^{-2}Sv^{-1}$) | Risk ($x10^{-5}$) |
|---|---|---|
| **Bladder** | 0.30 | $5.98x10^{-2}$ |
| **Bone surface** | 0.05 | $5.56x10^{-7}$ |
| **Colon** | 0.80 | $4.54x10^{-2}$ |
| **Liver** | 0.15 | $3.46x10^{-4}$ |
| **Lungs** | 0.85 | $4.03x10^{-4}$ |
| **Ovary, gonads** | 0.10 | $4.80x10^{-3}$ |
| **Skin** | 0.02 | $5.30x10^{-5}$ |
| Stomach | 1.10 | 13.62 |
| **Total risk** | | 13.834 |

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. Self-absorption in such source should not be significant.

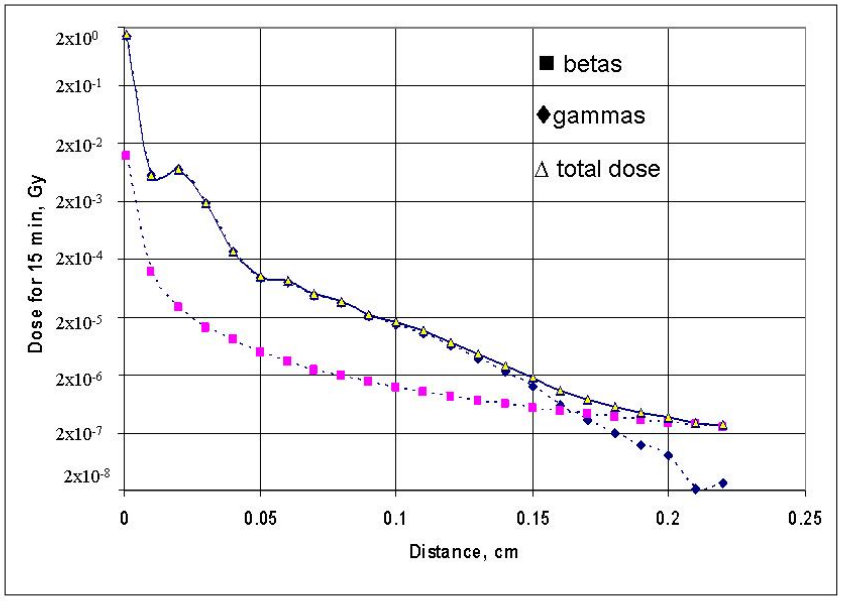


**Figure 3.** Dose-distance profile

## 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 negligible. 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 activities for the diagnostic purposes for an average patient (70 kg) are in the range from 50 MBq to 100 MBq depending of the thyroid mass. 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. As it is not possible to measure these doses directly Monte Carlo calculation seems to be good solution for this problem. 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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