NUKLEONIKA 2016;61(1):45–47
doi: 10.1515/nuka-2016-0010

ORIGINAL PAPER

DE GRUYTER
OPEN

Numerical model of thyroid counter

Maciej Szuchta,
Jakub Ośko

Abstract. The aim of this study was to develop a numerical model of spectrometric thyroid counter, which is used for the measurements of internal contamination by *in vivo* method. The modeled detector is used for a routine internal exposure monitoring procedure in the Radiation Protection Measurements Laboratory of National Centre for Nuclear Research (NCBJ). This procedure may also be used for monitoring of occupationally exposed nuclear medicine personnel. The developed model was prepared using Monte Carlo code FLUKA 2011 ver. 2b.6 Apr-14 and FLAIR ver. 1.2-5 interface. It contains a scintillation NaI(Tl) detector, the collimator and the thyroid water phantom with a reference source of iodine ^{131}I. The geometry of the model was designed and a gamma energy spectrum of iodine ^{131}I deposited in the detector was calculated.

Key words: iodine • Monte Carlo • FLUKA • gamma spectrometry • thyroid phantom

M. Szuchta✉
Faculty of Physics,
Warsaw University,
5a Pasteura Str., 02-093 Warsaw, Poland,
Tel.: +48 22 553 2000, Fax: +48 22 553 2999,
E-mail: maciej.szuchta@student.uw.edu.pl

J. Ośko
National Centre for Nuclear Research,
7 Andrzeja Sołtana Str., 05-400 Otwock/Świerk, Poland

Received: 31 July 2014
Accepted: 17 August 2015

Introduction

The measurement of iodine gathered in thyroid gland activity is one of the most commonly used *in vivo* routine individual internal exposure monitoring method. The knowledge of iodine activity in thyroid together with scenario of contamination allows to assess the contamination with iodine and committed effective dose which is, according to Polish law, a dose limit for internal exposure. This measurement technique is also used in nuclear medicine for diagnostic of thyroid diseases and determining of thyroid iodine uptake.

The most often used with *in vivo* measurements dosimetric equipment are spectrometry detectors – NaI scintillators or high-purity germanium (HPGe) detectors. All of them need to be calibrated with the radioactive reference sources. Though calibration must be performed with physical source (according to the accreditation authorities requirements). Although Monte Carlo calculation is not considered by accreditation authorities, it is often used for the preliminary calibration, for example, for choosing appropriate measurements geometry [1], material for phantoms or for interlaboratory comparison purposes [2, 3].

The gamma radiation spectrum registered by thyroid counter used for routine internal exposure monitoring in National Centre for Nuclear Research was calculated using FLUKA Monte Carlo code.

Method

Calculations were based on FLUKA ver. 1.2-5 software used to track particle interactions with matter and particle transport calculations.

FLUKA is a general purpose tool for calculations of particle transport and interactions with matter, covering an extended range of applications spanning from proton and electron accelerator shielding to target design, calorimetry, activation, dosimetry, detector design, accelerator-driven systems, cosmic rays, neutrino physics, radiotherapy, etc. FLUKA can simulate with high accuracy the interaction and propagation in matter of about 60 different particles, including photons and electrons from 1 keV to thousands of TeV, neutrinos, muons of any energy, hadrons of energies up to 20 TeV (up to 10 PeV by linking FLUKA with the DPMJET code) and all the corresponding antiparticles, neutrons down to thermal energies and heavy ions. The program can also transport polarized photons (e.g. synchrotron radiation) and optical photons. Time evolution and tracking of emitted radiation from unstable residual nuclei can be performed online. FLUKA can handle even very complex geometries [4, 5].

The developed model includes the thyroid counter used in NCBJ and thyroid water phantom with the iodine ^{131}I radioactive source. The thyroid counter consists of the Canberra-Packard NaI(Tl) (thallium-activated sodium iodide) detector, model 802-2x2, and multichannel analyzer Tukan8k produced by NCBJ [6].

The thyroid water phantom is a cylinder Lucite (PMMA) vessel (128 mm in diameter, 165 mm high), with a cover and two small (13 cm^3) cylinder vessels inside. During the measurements, the bigger vessel is filled with distilled water and the small ones, which simulate the thyroid lobes, are filled with the reference solution of radioisotopes. Construction of the phantom makes it possible to move the small vessels in two directions (horizontal and vertical). The whole phantom can rotate on its base and a certain angle of rotation can be fixed. There is also a possibility to use the vessels of different volume [7, 8]. The water phantom is presented in Fig. 1.

FLUKA model consists both thyroid water phantom and Canberra-Packard NaI(Tl) detector. The modeled thyroid water phantom has the same dimensions and materials as the real phantom. Detector was modeled as a probe with the 2 × 2 inches

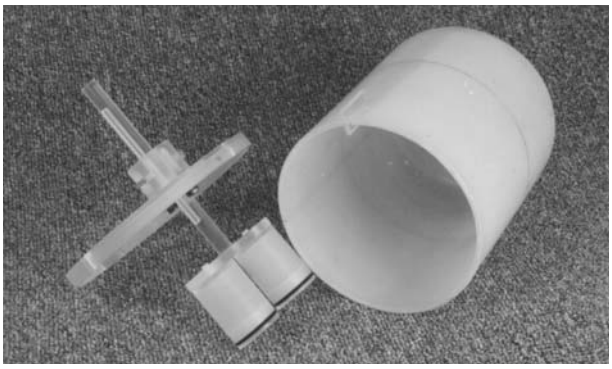

Fig. 1. Thyroid water phantom [7].

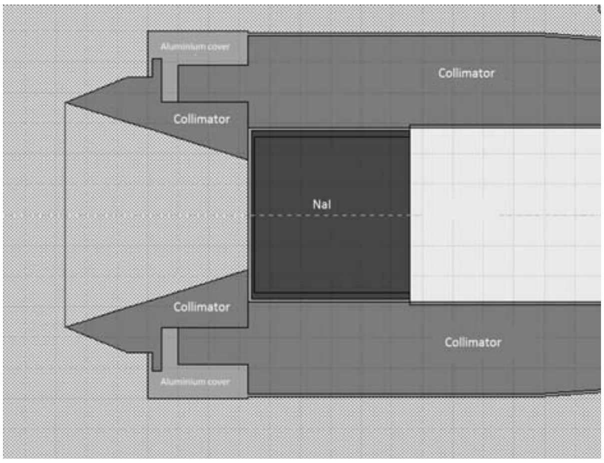

Fig. 2. Monte Carlo model of thyroid counter detector.

NaI(Tl) crystal surrounded by Al_2O_3 and aluminum cover. The probe is mounted inside the lead collimator with aluminum cover. The second collimator is placed on the front probe surface. The model does not contain the photomultiplier and electronic parts of the detector. The modeled geometry is presented in Fig. 2 (detector) and Fig. 3 (thyroid water phantom).

The created model allows the calibration of the counter and the examination of the compatibility of experimental spectra and spectra obtained by simulation.

The developed model was used to calculate the gamma energy spectrum emitted from the source and registered in the detector. The source was modeled as the solution of iodine ^{131}I in form of two cylinders. Iodine is filling both thyroid phantom vessels. Its energy lines and efficiencies were modeled according to FLUKA libraries and emitted isotopically.

PRECISIO defaults card suitable for precision simulations was declared for presented simulations. The calculation was carried out for 10 million histories. Photons emitted from iodine source were registered in the NaI(Tl) detector described earlier, using USRBDX card with two-way scoring and linear binning in energy. Simulations were performed for energy range 0.2–464 keV and 2048 energy intervals.

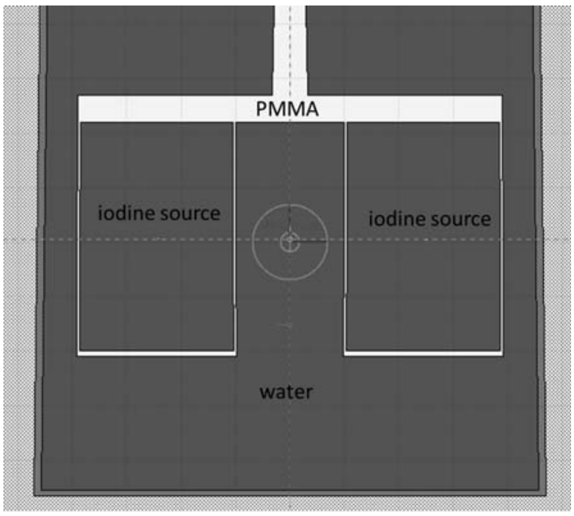

Fig. 3. Monte Carlo model of water thyroid phantom.

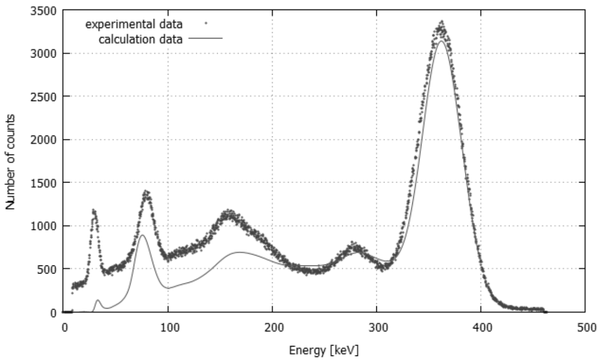

Fig. 4. Calculated and experimental iodine ^{131}I gamma spectrum registered by scintillation detector.

Results

The results of calculation were compared to different spectra obtained during experimental measurements using the thyroid counter. There was a good agreement in all cases, one of the analyzed spectra is presented in Fig. 4 and compared to calculation results.

The simulations were in a good agreement with calculation results and experimental spectrum in high energy range, including 364-keV energy peak. The area of this peak is used for detector efficiency calculation. The agreement in low energies is not as good as for high energies. The reason for this situation may be the simplification of the detector model and not including the photomultiplier and electronic parts that might be the source of scattering radiation. However, this is not considered a disadvantage of the model because the low energy range is irrelevant for efficiency calculation.

The net area of 364-keV energy peak was calculated for both spectra using the equation presented as follows:

$$\text{AREA} = N_{313\text{–}420} - \text{BACKGROUND}$$

where $N_{313\text{–}420}$ is the number of counts in the range of 313–420 keV; BACKROUND is the mean number of counts of the three channels on the left side and three channels on the right side multiplied by number of channels in the 364-keV energy peak area.

The calculated number of counts in the 364-keV peak area based on experimental data was 377 438 and based on simulation results was 389 849. The modeled value is 3.3% higher than experimental value.

Conclusions

The calculation obtained using the developed Monte Carlo model shows a good agreement with the experimental data. Even the simplified model (with worse agreement for low energies) may be used for further studies on the thyroid counter efficiency for various measurements geometries, for example, various thyroid dimensions. For studies that require the whole gamma radiation spectrum registered in the detector, the created model should be improved. It seems to be interesting to continue these studies and compare the obtained data to other Monte Carlo codes.

References

1. Koleska, M., Viererbl, L., & Marek, M. (2014). Development of the MCNPX model for the portable HPGe detector. *Radiat. Phys. Chem.*, *104*, 351–354.
2. Vrba, T., Nogueira, P., Broggio, D., Caldeira, M., Capello, K., Fantínová, K., Figueira, C., Hunt, J., Leone, D., Murugan, M., Marzocchi, O., Moraleda, M., Shutt, A., Suh, S., Takahashi, M., Tymińska, K., Lopez, M. A., & Tanner, R. (2014). EURADOS intercomparison exercise on MC modeling for the in-vivo monitoring of Am-241 in skull phantoms (Part I). *Radiat. Phys. Chem.*, *104*, 332–338.
3. Vrba, T., Broggio, D., Caldeira, M., Capello, K., Fantínová, K., Franck, D., Gómez-Ros, J. M., Hunt, J., Kinase, S., Leone, D., Lombardo, P. A., Manohari, M., Marzocchi, O., Moraleda, M., Nogueira, P., Ośko, J., Shutt, A., Suhl, S., Takahashi, M., Teles, P., Tremblay, M., Tymińska, K., Lopez, M. A., & Tanner, R. (2015). EURADOS intercomparison exercise on MC modeling for the in-vivo monitoring of Am-241 in skull phantoms (Part II and III). *Radiat. Phys. Chem.*, *113*, 59–71.
4. Battistoni, G., Cerutti, F., Fasso, A., Ferrari, A., Muraro, S., Ranft, J., Roesler, S., & Sala, P. R. (2007). The FLUKA code: Description and benchmarking. In M. Albrow, & R. Raja (Eds.), *Proceedings of the Hadronic Shower Simulation Workshop 2006, Fermilab 6–8 September 2006*. AIP Conference Proceeding, *896*, 31–49.
5. Ferrari, A., Sala, P. R., Fasso, A., & Ranft, J. (2005). FLUKA: a multi-particle transport code. CERN-2005-10. INFN/TC_05/11, SLAC-R-773.
6. Guzik, Z., Borsuk, S., Traczyk, K., & Płominski, M. (2006). TUKAN: An 8K pulse height analyzer and multi-channel scaler with a PCI or a USB interface. *IEEE Trans. Nucl. Sci.*, *53*(1), 231–235.
7. Ośko, J., Golnik, N., & Pliszczyński, T. (2007). Spectrometric measurements of iodine and technetium activity in thyroid. *Nucl. Instrum. Methods Phys. Res. Sect. A-Accel. Spectrom. Dect. Assoc. Equip.*, *580*, 578–581.
8. Pliszczyński, T., Ośko, J., Filipiak, B., Golnik, N., & Haratym, Z. (2002). Measurement of activity of ^{131}I deposited in human thyroid during the medical examination. *Współczesna Onkologia*, *6*(8), 530–553. (in Polish).