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Characterisation of radioactive waste using Monte Carlo simulations

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ABSTRACT

The characterisation of radioactive waste is one of crucial steps in waste management. One of possible methods includes combination of Monte Carlo simulations and gamma spectrometry measurements. Such sophisticated methods have been broadly used in commercial installations for characterisation of radioactive waste. This paper deals with the problem of radiation shielding optimisation in case of storing of radioactive lighting roads. In this paper Monte Carlo codes FOTELP (Vinča Institute, Serbia and Montenegro) and EGSnrc (NRCC, Canada) were applied for shielding calculation, in case of radioactive waste put in standard 200 litre drum, and filled with concrete and lead.

1 INTRODUCTION

Radioactive waste from entire operational reactor's time as well institutional radioactive waste from medical and other institutions, have been deposited for a long time in the temporary waste storage at the Vinča Institute. Project for solving accumulated problems with radioactive waste in the Institute is established, supported by the Serbian government and IAEA. Some of related problems are discussed in another article at this conference [1].

One of the important steps is to adopt some routine methodologies for characterisation of different waste parameters [2]. The most important among them are parameters related to radioactivity. It is desirable to use non-destructive methodologies as much as possible - to minimise expenses and optimise shielding.

Monte Carlo methods are widely used for shielding calculation, so they can be used in non-destructive characterisation of waste radioactive properties. On the other side, increasing availability of inexpensive computer power makes them interesting even for routine procedures. The aim of this paper is to compare code results in treating specific problem type.

1 MONTE CARLO CODES

Several Monte Carlo codes treating photon, electron and positron transport, are available today. We investigate here applicability of code FOTELP [3], for waste characterisation purpose comparing their results with results of well known code EGSnrc. Both programs are available from Radiation Safety Information Computation Centre (RSICC), but also freely available for download from Internet.

In this paper, basic code features are reviewed, as well the factors that could contribute to the discrepancy of calculation results significantly. These are for example, interaction cross sections and electron (positron) transport algorithms, since they can cause uncertainties of up to few percents each.

2.1 Cross-sections

At the moment, the most accurate (available) library for photon interactions is Evaluated Photon Data Library (EPDL97)[4]. It describes interactions of photons with matter as well as the direct production of secondary photons and electrons, and is made to be used together with Evaluated Electron Data Library (EEDL) and Evaluated Atomic Data Library (EADL). They are developed in the Lawrence Livermore National Library. Unfortunately, there are significant uncertainties even in those libraries, especially for low energies below few keV[5]. In shielding, we encounter so-called deep penetration problems, where scattered radiation is more important than direct. As a consequence, those uncertainties can influence calculation results.

2.2 FOTELP

FOTELP is a general purpose Monte Carlo code developed at Vinča Institute by R.Ilić [3] for the coupled transport of photons, electrons and positrons. It performs calculations in 3D geometry for particle energies in range 1 keV to 100 MeV. Two program modules can describe the particles transport geometry: original – using R-functions, and module PENGEOM from PENELOPE code of Barcelona University. In this paper, the R-functions approach is used. Simulation of electron transport in FOTELP follows Berger's condensed history method and approach as in ITS codes, with some numerical improvements.

Further on, FOTELP uses XCOM photon cross sections library developed by National Institute of Standards and Technology (NIST). This library is a little bit different from EPDL97 (especially for coherent scattering).

The variance reduction method used by FOTELP is electron range rejection.

2.3 EGSnrc

EGSnrc [6] is a new, enhanced version of Electron-Gamma-Shower (EGS) system of computer codes for Monte Carlo simulation of the coupled transport of electrons and photons for energies above a few keV up to several hundreds of GeV, developed by *National Research Council of Canada*.

EGSnrc code involves new algorithm for electron transport. This algorithm - called PRESTA-II, uses different scheme for determining the position of the endpoint of a transport step in the condensed history method. It uses cross sections in accordance with EPDL97, and also EEDL and EADL.

A variety of variance reduction methods have been built in EGSnrc.

3 MODEL AND RESULTS

As mentioned above, the aim of this paper is to compare results of two different codes, FOTELP and EGSnrc, in treating the same specific shielding problem. In order to do that, a shielding model is designed and implemented to both codes, preserving input control parameters similar, as much as possible.

As a convenient example for this study, existing radioactive waste container from the interim storage at the "Vinca" Institute was chosen. This container is used for storing the radioactive lighting roads.

Radioactive lighting roads are stored in specially designed containers, made on the basis from the standard 200-liter drum. Total activity in these drums can be considerably high; therefore drum shield should have some additional layers, such as lead for example. For this purpose we made a rather simplified model, and implemented it with identical dimensions and materials for both codes. For calculating with EGSnrc, we used user code DOSnrc, made

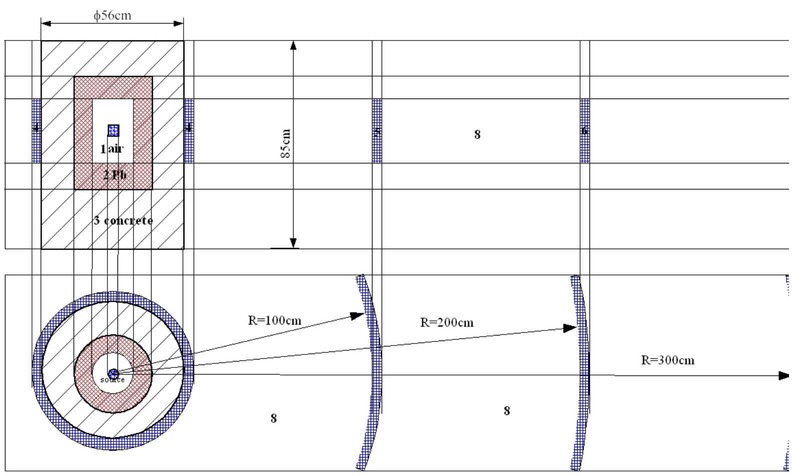

Figure 1 Simplified model of drum used for storing radioactive lighting roads – vertical and horizontal cross-sections

for calculating deposited doses in cylindrical geometries. Figure 1 presents cross sections of used cylindrical model. Adopted dimensions are similar to real dimensions.

Small homogenous cylindrical gamma source is positioned in the centre of the drum. In contrast to real situation, where we have Eu sources, the mono-energetic source with photons of 1 MeV is used, with self-absorption neglected. Lead thickness is 5 centimetres. Rings, signed 4 to 7, are made from ICRU 4-component tissue, and are used to roughly assess doses radial dependency. The calculations are made with 10^7 particles with both codes. Results are presented in Table 1. and Figure 1.

Table 1. Fractions of deposited energy calculated by FOTELP and EGSnrc

Code	***Air (1)***	***Pb (2)***	***Concrete (3)***	***Exterior (4+5+6+7+8)***
FOTELP	0.0001123 ±4.2%	0.964 ± 0.03%	0.0307 ± 4.03%	0.000877 ± 9.23%
EGSnrc	0.0001681 ±0.8%	0.976 ± 0.2%	0.0210 ± 0.9%	0.000265 ± ~7.0%

Generally smaller statistical uncertainties obtained by the EGSnrc code, probably stem from the built in variance reduction methods (Russian roulette for charged particles and photon forcing) used during calculations. Figure 2 presents radial distribution of absorbed dose, obtained by two codes, FOTELP and EGSnrc. Doses were calculated as deposited energy in rings filled with ICRU tissue (2cm thickness).

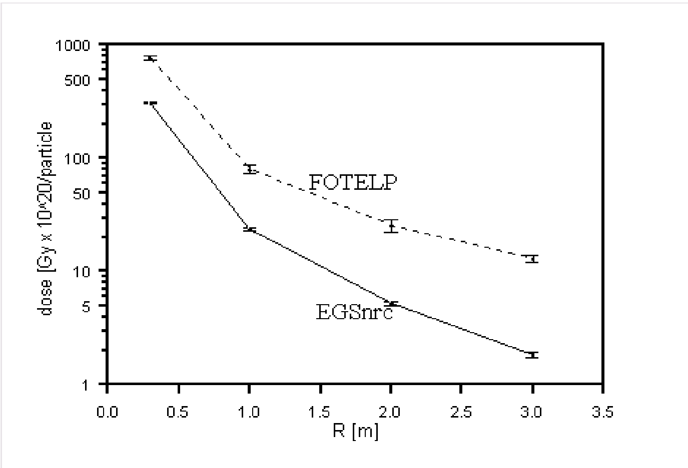

Figure 2. Comparison of approximative doses calculated by FOTELP and EGSnrc

Doses obtained by FOTELP are slightly higher from those ones obtained by the EGSnrc, as presented on Figure 2. The difference obtained slightly increases with distance. However, one should take into account the very small magnitude of doses calculated. Although the number of histories in the Monte Carlo calculations could be greater, discrepancies in results cannot be explained completely by statistical uncertainties. One can say that the main source of discrepancies stems from different algorithms in FOTELP and EGSnrc, as well as different cross sections libraries.

4 CONCLUSIONS

In this article, we compared calculations of simplified model of a radioactive waste container with shielding made from lead and concrete. Calculations are made with Monte Carlo codes FOTELP and EGSnrc. Results achieved with both codes are reasonable, and discrepancies are as expected. It is concluded that discrepancies could originate mainly from differences in used transport algorithms, and secondly from the cross sections differences and statistical errors. It is clear that careful use of algorithms and cross sections is necessary for all applications concerning shielding and in connection with that - characterisation of radioactive waste. According to results obtained, one could say that FOTELP gave valuable results, but further investigation of algorithms and cross sections influences on its results will be very useful. Using of EPDL97 cross sections within the FOTELP code is to be considered for future calculations. Also, it would be useful to include some additional variance reduction algorithms to achieve more efficient calculation.

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