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Measurement uncertainty estimation of health risk from exposure to natural radionuclides in soil

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ABSTRACT

Cancer mortality risk were estimated due to external exposure to ^{40}K in soil. Uncertainty estimation was performed for the risk considered as a measurand. It was presented uncertainty estimation using two methods. One method is based on the Guide to the Expression of Uncertainty in Measurement Framework (GUF) and other represents Monte Carlo method. For the Monte Carlo method, the mean of the obtained distribution that represents mortality cancer risk estimation, due to one year exposure to ^{40}K with mean activity concentration of 708 Bq/kg in soil, is 12.9×10^{-6} with 90% confidential interval ($k \approx 1.64$) of $(4.7–25.5) \times 10^{-6}$. According to GUF the mean value is estimated as 10.9×10^{-6}, with 90% confidential interval of $(0.9–20.8) \times 10^{-6}$. Uncertainty of assessed risk obtained by numerical simulation is slightly different with asymmetrical boundaries related to the mean value, comparing to the uncertainty estimated using GUF.

1. Introduction

Ionizing radiation can cause cells damage, which in turn may lead to cancer. Natural radiation sources contribute to irradiation of the population via various exposure pathways like inhalation, ingestion, dermal or external exposure [1]. Health risk assessment should be integral part in every radiation protection program.

Data on radionuclides content in soil may be used to estimate the limitations and potentials of soils for many specific uses [2]. Surveys like these are important in areas where the demand on soil resources is high. Determination of trace elements in soils, especially of radionuclides, should be related to health impact assessment from the environment as essential component of the radiation protection program. Procedures for health risk assessment incorporated into QA radiation protection programs should obtain routine risk assessment that would help professional planers and decision makers to make workable plans about land use.

Risk of stochastic effects, like cancer development from exposure to ionizing radiation, can be related to various quantities like dose equivalent, effective dose, cancer mortality and morbidity risk [3–8]. Dosimetry is important step in health risk assessment regarding exposure to ionizing radiation. The Monte Carlo techniques are used for accurate prediction of dose distributions [9]. They represent statistical sampling technique that enables solving of mathematical model in the form of probabilistic approximation of the solution [10–12]. Monte Carlo techniques are basis for a number of numerical experiments, which are dealing with transport of radiation particles.

Dose equivalent can be measured using ionization chambers and thermoluminescent dosimeters based on CaF_2:Mg. Also, it could be used Monte Carlo simulations of radiation transport from the source in the soil through air till it reaches a simulated virtual detector 1 m above the ground [13]. Numerical experiments are convenient for exploring of the influence quantities and variation of processes parameters under the well controlled conditions. Correct mathematical model, which provides reliable

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description and connections between all processes that are relevant, enables obtaining correct output from the simulation processes. Ionization chambers and thermoluminescent dosimeters cannot measure contribution to the total dose from the different radionuclides. Using numerical experiments, it is possible to determine contribution of the various sources to the total dose under the various simulation conditions. If there was low radionuclide content in soil, measurement of the dose would be impossible because it would be under detection level of the detector, so numerical experiment would be more convenient solution. It was reported that, in dosimetry, results obtained with simulation process often demonstrate lower uncertainty then results from direct measurements. Monte Carlo simulation increases number of events by introducing more then million histories (number of repeated numerical simulations). It is estimated that relative expanded uncertainty ($k = 2$) of results obtained with direct measurement are within 20% with assigned Normal distribution [14], while measurement uncertainty of results obtained with Monte Carlo simulation is mainly within 10%. Lack of sufficient knowledge about the model increases uncertainty of the output estimate. For Monte Carlo simulation used in dosimetry, well defined input parameters, such as material characterization, geometry, and the source distribution, are of the crucial importance.

Purpose of this study was to estimate uncertainty of the quantities that are related to health risk due to external exposure to radionuclide ^{40}K in soil as integral part of the radiation protection program. Dose equivalent quantity and cancer mortality risk were estimated. A special emphasize was put on the estimation of measurement uncertainty related to cancer risk assessment using Monte Carlo method (MC) and comparison with results obtained with Guide to the expression of Uncertainty in Measurement Framework (GUF).

1.1. Measurement uncertainty of the assessed risk

All results of the measurements are approximation of the value of the measurand. Risk can be considered as the measurand. The uncertainty of the result of measurement arises from the existence of various random effects as well as from the lack of knowledge about the systematic effects. According to GUF, all results of the measurement should be accompanied by a statement of the uncertainty of that estimate in order to be completed [15].

There are two approaches for the propagation of the uncertainty of the measurand: (i) approach using GUF and (ii) Monte Carlo approach. The main difference is the way that these two methods treat propagation of uncertainty. GUF approach is based on the estimation of the standard uncertainty of the output quantity combining the standard uncertainties of the input quantities through process of propagation of standard uncertainties. It is used "law of propagation of uncertainty" which is expression of the standard deviation of a linear combination of random variables [16]. For the general model represented as Eq. (1)

$$y = f(x_1, x_2, \ldots, x_n) \tag{1}$$

where $x_1,\ldots x_n$ are input estimates of the input quantities $X_1,\ldots, X_n$, and the y is estimate of the measured Y, combined standard uncertainty of the estimate y is given by Eq. (2)

$$u(y) = \sqrt{\sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i}\right)^2 u^2(x_i)} \tag{2}$$

where $u(x_i)$ is a standard uncertainty of the estimates of input quantities and f is function given in Eq. (1). Calculated combined standard uncertainty is standard deviation of distributions that are accompanied to the measurand. In GUF approach, these distributions are Gaussian or t-distribution.

While GUF model propagates standard uncertainties of input estimates, the Monte Carlo approach propagates probability distributions of input quantities [17]. Such PDFs include asymmetric densities such as Poisson (counting rates) and Gamma (special cases of which are exponential and the chi-squared). The use of Monte Carlo method requires (i) generators (algorithms) to sample from all PDFs for the input quantities and (ii) consideration of the number of Monte Carlo trials needed to deliver certain correct digits in the standard uncertainty associated with the estimate of the output quantity. Briefly, from each input PDF draw at random value x_i for the random variable X_i than we evaluate corresponding y_i (possible value for the measurand Y) using the resulting vector x_j ($j = 1, 2\ldots M$). All steps are iterated M times and M values of y_j for Y are sorted in non-decreasing order. Sorted values are used to obtain numerical approximation for the output distribution. Using Monte Carlo approach we avoided application of degrees of freedom, actually this approach is intrinsically Bayesian. Some authors stated that it is better to use Monte Carlo approach because classical GUM framework slightly overestimates the overall uncertainty by 10% [18].

Monte Carlo simulations have become increasingly common in environmental health and safety risk assessments. It is strongly suggested that the uncertainty related to the assessed risk should be estimated using Monte Carlo method [19]. Monte Carlo methods generate a probability density function for the output so they are to be contrasted with the deterministic methods used to generate specific single number or point estimates of risk. Uncertainty could be assigned to point risk estimate using GUF, and it is expected that probability distribution should be Gaussian. If it is suspected that probability distribution of output quantity deviates from Gaussian, it is recommended to use Monte Carlo techniques for propagation of uncertainty [15,17]. Also, it is recommended that the uncertainty should be estimated using Monte Carlo methods if the model is expected to be significantly nonlinear, or if the uncertainty is in the range of the estimated value.

2. Estimation of health risk

According to procedure for the estimation of health risk presented in the paper, dose equivalent quantity and cancer mortality risk were estimated due to external irradia-