CALCULATION OF THE RADIONUCLIDES CONCENTRATIONS FROM IN-SITU SPECTROMETRY DATA MEASURED BY SEMICONDUCTOR SPECTROMETER

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Introduction
Semiconductor detectors provide very high energy resolution (comparing with scintillation counters) that enables one to distinguish and identify all radionuclides (natural ones as well as man-made contaminants) carrying out in-situ environmental measurements (typically in the reference point 1 meter above ground). While data from the scintillation detector can be processed (and radionuclides concentrations calculated) by deconvolution technique (preparing detection system response matrix for corresponding experimental arrangement), the unacceptably large matrixes should be necessary (to preserve high resolution) for the spectra from semiconductor detectors processing. By this reason, another method of semiconductor spectra processing and calculation of radionuclides concentration in the soil surface layer was designed. The method is based on the two steps:

1. experimental calibration of the detection efficiency angular-energy dependence for individual detector and mathematical fit of this dependence for desired energy interval (usually up to 3 MeV for environmental measurements) and full spatial angle
2. definition and calculation of the conversion factors (independent on the detector and detector parameters) that describe (for given experimental arrangement and source energy) relation between the source emission concentration and photon radiance

Detection system calibration
Experimental calibration of the detection efficiency angular-energy dependence for individual detector can be done using set calibration sources covering desired energy interval. Example of such calibration for the real detector (geometry of broad parallel beam perpendicular to the detector enface) is in Fig. 1 that shows also polynomial fit (two continuously joined fits for two energy sub-regions). Fits of relative angular and energy dependence of detection effi-
ciency can be also done from experimental data. Example of such polynomial fit of angular dependence for the same detector and energy line 344.3 keV is in Fig. 2. Fits of angular dependence for all experimental energies and vice versa enable very good description of detection system parameters using cross interpolation.

Calculation of conversion factors

The conversion factors can be obtained (by numerical integration) from photon fluence rate angular-energy distribution, calculated by Monte Carlo model of desired experimental arrangement. Example of such distribution calculated for U-series radionuclides is in Fig. 3, for $^{137}$Cs in Fig. 4. These factors generally depend on soil density (composition, humidity), radionuclides depth distribution model, etc. Taking into account such parameters, we can calculate the individual radionuclides concentrations in the soil surface layer (saturated thickness of this layer depends on the source energy) from peak areas of the corresponding source energy lines. Calculated conversion factors for

Fig. 1: Example of detection efficiency fit

Fig. 2: Example of angular dependence fit

Fig. 3: Calculated photon flux density energy-angular distribution in reference height 1 meter for U-series radionuclides homogeneously dispersed in the saturated soil surface layer (normalised to volume activity 1 Bq m$^{-3}$)
the most significant energy lines of natural radionuclides (homogeneously dispersed in the soil surface layer) and $^{137}$Cs, $^{134}$Cs sources (dispersed exponentially in the soil surface layer) are in Figs. 5 and 6. Calculations were done for three soil densities, which enable interpolation for real density if known. Dependence on the soil density is almost negligible for exponential source distribution (see Fig. 6).

**Conversion factors for user defined depth distribution models**

While homogeneous depth distribution can be considered for the natural radionuclides (U and Th series and $^{40}$K), the depth distribution of man-made contaminants can depend on many parameters (physical and chemical form, time after deposition, weather conditions, vegetation cover, territory exploitation, etc.). To solve this problem, the conversion factors for the set of

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**Fig. 4:** Calculated photon flux density energy-angular distribution in reference height 1 meter for $^{137}$Cs with exponential depth distribution (relaxation length 3 cm) in the soil surface layer (normalised to effective superficial activity 1 Bq m$^{-2}$)

**Fig. 5:** Calculated conversion factors for most significant energy lines of natural radionuclides (homogeneously dispersed in the soil surface layer), reference height 1 meter and three soil densities

**Fig. 6:** Calculated conversion factors for the energy lines of $^{134}$Cs and $^{137}$Cs radionuclides dispersed exponentially in the soil surface layer (with relaxation length 3 cm), reference height 1 meter and three soil densities
sub-layers of saturated soil surface layer (each set for given energy line) and most significant contaminants were calculated by Monte Carlo simulation. The conversion factors for the user defined depth distribution models can be derived from this data to improve the data processing and interpretation. Example of calculated dependence of conversion factors on mean depth of layer for $^{137}\text{Cs}$ source and three different soil densities is in Fig. 7.

Possibility of corrections for the soil density based on the differences of the different photon energies attenuation was studied, but this effect proved to be very small for practical use.

**Conclusion**

The computer code based on the described method was designed including calculation of conversion factors for user defined depth distribution models. Inputs of the code are peak areas of the considered radionuclides energy lines (measured in the given arrangement and calculated by any spectra analysis software), known or expected depth distribution models for individual radionuclides (including user defined models) and soil density. The activity concentrations of considered radionuclides and depth distribution models are calculated by the code. Described method was successfully tested and is used for processing of in-situ gamma spectrometry data measured by the spectrometer with semiconductor detector.