Calculation of Measurement Uncertainty for The Scan Minimum Detectable Concentrations

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1. Introduction

Early in a decommissioning process, a scoping survey is performed to identify the potential radioactive contaminants [1, 2]. Appropriate survey instruments are selected, and measurements are conducted at suspect locations. The selection of appropriate instruments is likely to be the most critical factors in assuring that the survey determines the radiological status of a site. Above all, the instrument must be capable of measuring levels which are less than the guideline values. In this study, a scan minimum detectable concentration(MDC) for a soil and its measurement uncertainty has been calculated, and the results are presented.

2. Methods and Results

2.1 Overview of Method for Calculating Scan MDC

The scanning instrument being considered in this study is a 2"x 2" NaI scintillation detector [GSP-2, Johnson & Associates Inc., PO Box 472, Ronceverte, WV24970]. The background for this detector is 1,800 cpm, and the sensitivity is 200 cpm per μR/hr at the ^{137}Cs energy of 662 keV.

Steps for calculating the scan MDC for a soil is as follows[3,4]:

(1) Calculate the minimum detectable count rate(MDCR) for a given level of performance, scan speed, and background level of the detector.
(2) Translate MDCR to the minimum detectable exposure rate using the relationship of net count rate to net exposure rate.
(3) Translate minimum detectable exposure rate(MDER) to scan MDC

The MDCR is calculated using

$$MDCR = \frac{d'\sqrt{b_i}}{i\sqrt{p}} \tag{1}$$

where b_i is background counts(counts), i is observation interval length(sec), d' is detectability index [3,5], and p is surveyor efficiency relative to ideal surveyor[3,5].

The MDER is calculated using

$$MDER = \frac{MDCR}{W_T} \tag{2}$$

where w_T is total energy-weighted sensitivity(cpm per μR/hr) and is given by

$$W_T = \sum_i \frac{R_i S_i}{R_T} \tag{3}$$

where R_T is total exposure rate with buildup(μR/hr), and R_i is exposure rate with buildup(μR/hr) for each decay energy. S_i is sensitivity(cpm per μR/hr) for each decay energy and is given by

$$S_i = S_{Cs}\frac{RDR_i}{RDR_{Cs}} \tag{4}$$

where S_{Cs} and RDR_{Cs} are the sensitivity and the relative detector response for ^{137}Cs energy of 662 keV, respectively. RDR_i is the relative detector response for each decay energy and is determined by multiplying the relative fluence rate to exposure rate by the probability of an interaction at the energy of an interest.

The scan MDC is given by

$$scan\ MDC = C \times \frac{MDER}{R_T} \tag{5}$$

where C is the concentration of input source term for a radionuclide of interest. Upon substituting *MDER*, the formula becomes

$$scan\ \mathrm{MDC} = \frac{Cd'\sqrt{b_i}}{W_T R_T i\sqrt{p}} \tag{6}$$

Modeling using Microshield [Grove Engineering, 3416 Olandwood Ct., Suite 211, Olney, MD 20832] was used to determine the exposure rate produced by a radionuclide concentration at a source-to-detector separation distance. The following factors were considered in the modeling:

- radionuclide of interest: depleted and natural uranium, 3 % enriched uranium
- radionuclide concentration of input source term : 1.85 Bq/g
- areal dimensions of the cylindrical hot spot : 0.25 m^2 (radius of about 0.28 m)
- dose point : 10 cm above the surface
- depth of the hot spot : 15 cm, uniform contamination
- density of soil : 1.6 g/cm^3 [6]

2.2 Combined Standard Uncertainty of a Scan MDC

It was assumed that there are no correlations among the input variables used to determine the scan MDCs. Therefore, the combined standard uncertainty, $u_c(y)$ of a scan MDC, y, is the positive square root of the combined variance $u_c^2(y)$, which is given by[7]

$$u_C^2(y) = \sum_{i=1}^{N}\left(\frac{\partial y}{\partial x_i}\right)u^2(x_i) = \sum_{i=1}^{N} c_i^2 u^2(x_i) \tag{7}$$

where y is the function given in Equation (6). $u(x_i)$ and c_i is a standard uncertainty and sensitivity coefficient of input variables x_i, respectively. The concentration of the input source term, C, and the detectability index, d' are treated as constants with no associated uncertainty, so Equation (7) becomes

$$u_c^2(y)=\left(\frac{\partial y}{\partial b_i}\right)^2 u^2(b_i)+\left(\frac{\partial y}{\partial i}\right)^2 u^2(i)+\left(\frac{\partial y}{\partial p}\right)^2 u^2(p)+\left(\frac{\partial y}{\partial R_T}\right)^2 u^2(R_T)+\left(\frac{\partial y}{\partial W_T}\right)^2 u^2(W_T) \quad (8)$$

b_i is assumed to have a triangular distribution with a half-width of 30 %. i is assumed to have a triangular distribution with a half-width of 0.5. p is ranged to be between 0.5 and 0.75[3]. A value of 0.5 was chosen as a conservative value in this study. p is assumed to have a rectangular distribution with a half-width of 0.125. R_T and W_T were assumed to have rectangular distribution. Therefore, Microshield calculations for the two extreme cases were made to obtain the upper bound and the lower bound for R_T and W_T values. In each calculation total activity was the same, only the distribution with depth and source-to-detector distance were changed. The extreme cases were for a source-to-detector distance of 8 cm with the activity uniformly distributed within the top 7.5 cm of the soil versus a source-to-detector distance of 12 cm with activity uniformly distributed within the bottom 7.5 cm of the soil.

Table 1 shows the values used to calculate the scan MDC and its uncertainty. Table 1 shows the scan MDCs for a soil and its expanded measurement uncertainty for depleted and natural uranium, 3 % enriched uranium.

Table 1. The values used to calculate the scan MDC, standard uncertainty for each source of uncertainty, and uncertainty contribution

parameters		Values	Type	Probability distribution	$u_i(x_i)$	$u_i(y)$ [3)]
b_i (counts)		30	B	Triangular	3.674	0.242
i (sec)		1.0	B	Triangular	0.200	0.806
p		0.5	B	Rectangular	0.072	0.285
d'		1.90	-	-	-	-
W_T [1)]	Dep. U	860	B	Rectangular	113.36	0.521
	Nat. U	956	B	Rectangular	94.397	0.461
	3% U	974	B	Rectangular	59.467	0.364
R_T [2)]	Dep. U	0.350	B	Rectangular	0.121	1.365
	Nat. U	0.264	B	Rectangular	0.099	1.767
	3% U	0.204	B	Rectangular	0.070	2.055
C (Bq/g)		1.85	-	-	-	-

[1]cpm per μR/hr
[2]μR/hr
[3] $u_i(y)=|c_i|u(x_i)$

Table 2. 2" x 2" NaI scintillation detector scan MDCs for a soil and its expanded measurement uncertainty

Radioactive material	Scan MDC(Bq/g)
Deplete uranium	3.95±3.42[1)]
Natural uranium	4.71±4.22[1)]
3 % enriched uranium	5.97±4.96[1)]

[1]a coverage factor of 2 and an estimated coverage probability of 95 %.

3. Conclusions

This paper evaluated the uncertainty for the scan MDC. The method to determine the uncertainty for the scan MDC and results can be useful for a survey design at the early stage of a decommissioning process.

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