Calculation of Scan Minimum Detectable Concentrations for a 2" x 2" NaI Scintillation Detector in Soil

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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) has been calculated. The method to determine the scan MDC is described herein.

2. Methods and Results

The scan MDCs for a 2"x 2" NaI scintillation detector [GSP-2, Johnson & Associates Inc., PO Box 472, Ronceverte, WV24970] in soil have been calculated. The methodology used to determine the scan MDCs is based on NUREG-1507 approach [3]. An overview of the approach has the following three calculational steps. Step 1 : Calculation of the MDCR(Minimum Detectable Count Rate) that can be detected for a given background level. The MDCR is calculated:

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

where b_i is background counts in observation interval i, d' is detectability index [4], based on acceptable correct detection rate and false positives, p is surveyor efficiency relative to ideal surveyor [4]. The calculation has been performed for a background level of 1,800 cpm, a desired level of a performance of 95% correct detections, and a 60% false positive rate, which yields a d' of 1.38, and an observation interval of 1-second. The MDCR for these conditions is 641 cpm.

Step 2 : Calculation of the corresponding minimum detectable exposure rate(MDER) for the detector and radionuclide. The MDER is calculated:

$$MDER = \frac{MDCR}{w_T}$$

where w_T is total weighted instrument sensitivity(cpm per μR/hr). Weighted instrument sensitivity(WS_i) for each energy is calculated:

$$WS_i = \frac{R_i S_i}{R_T}$$

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 instrument sensitivity(cpm per μR/hr) for each energy. S_i is calculated:

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

where S_{Cs} is instrument sensitivity to ^{137}Cs. The manufacturer of a 2" x 2" NaI scintillation detector quotes a counting rate to exposure rate ratio for ^{137}Cs of 200 cpm per μR/hr. RDR_{Cs} is the relative detector response for ^{137}Cs, RDR_i is the instrument sensitivity at the energy of interest. RDR_i is determined by multiplying the relative fluence rate to exposure rate($FRER_i$) by the probability of an interaction(P_i) at the energy of an interest with a detector. The FRER is calculated:

$$FRER_i \approx X \frac{1}{E_i(\mu_{en}/\rho)_{air}}$$

where X is the exposure rate(set equal to 1 μR/hr for this calculation), E_i is the energy of the gamma photon of concern(keV), and $(\mu/\rho)_{air}$ is the mass energy absorption coefficient in the air at the gamma photon energy of concern(cm^2/g). The probability of a interaction(P) for a gamma is calculated:

$$P_i = 1 - e^{-(\mu/\rho)_{NaI} x_{NaI} \rho_{NaI}}$$

where $(\mu/\rho)_{NaI}$ is the mass attenuation coefficient of NaI crystal at the energy of interest(cm^2/g). x is thickness of NaI crystal(Tl)(cm), and ρ is density of the NaI crystal(g/cm^3). The calculated $FRER_i$, P_i, RDR_i, and S_i for each of energies of interest are presented in Table 1.

Table 1 : The calculated $FRER_i$, P_i, RDR_i, and S_i for each of energies of interest

Energy (keV)	$FRER_i$	P_i	RDR_i	S_i (cpm per μR/hr)
15	0.0500	1.0000	0.0500	255
30	0.2169	1.0000	0.2169	1,107
50	0.4880	1.0000	0.4880	2,491
60	0.5481	1.0000	0.5481	2,798
80	0.5193	1.0000	0.5193	2,651
100	0.4301	1.0000	0.4301	2,195
150	0.2671	1.0000	0.2671	1,363
200	0.1871	0.9978	0.1867	953
662	0.0515	0.7602	0.0392	200
800	0.0434	0.7159	0.0311	158
1000	0.0359	0.6659	0.0239	122

R_T and R_i was determined analytically using Microshield [Grove Engineering, 3416 Olandwood Ct., Suite 211, Olney, MD 20832]. The factors in the Microshield modeling include:

- radionuclide of interest(considering all gamma emitters for decay chain) : depleted and natural uranium, 3 %, and 20 % enriched uranium
- expected concentration of the radionuclide of interest : 50 pCi/g for total uranium
- areal dimensions of the area of elevated activity : 0.25 m^2(radius of 28 cm)
- location of dose point(NaI(Tl) scintillation detector height above the surface) : 10 cm
- depth of the hot spot : 15 cm
- density of soil : 1.6 g/cm^3 [5]

Modeling analyses were conducted for the above conditions. Energy grouping method for decay energies emitted from radioactive materials which were considered in this study was used in the Microshield calculation. The source activity was selected based on a concentration of 50 pCi/g for total uranium, divided between the uranium isotopes according to their activity fractions and converted to appropriate units for the modeling code. The modeling code determined the exposure rate. The calculated exposure rate from modeling code, weighted instrument sensitivity, and total weighted instrument sensitivity for 3 % enriched uranium are listed in Table 2

Table 2 : The calculated exposure rate, weighted instrument sensitivity, and total weighted instrument sensitivity for 3 % enriched uranium

Energy (keV)	Expsoure rate (μR/hr)	S_i (cpm/μR/hr)	WS_i (weighted cpm/μR/hr)
15	$8.55x10^{-6}$	255	0.01
30	$1.33x10^{-3}$	1,107	8.01
50	$4.62x10^{-4}$	2,491	6.24
60	$4.76x10^{-3}$	2,798	72.32
80	$4.75x10^{-3}$	2,651	68.28
100	$2.33x10^{-2}$	2,195	277.92
150	$1.58x10^{-2}$	1,363	117.18
200	$9.11x10^{-2}$	953	471.11
800	$6.42x10^{-3}$	158	5.52
1000	$3.63x10^{-2}$	122	24.00
Total	$1.84x10^{-1}$	-	1051

It is interesting to note that about 82 % of a 2" x 2" NaI scintillation detector's response to 3 % enriched uranium is from gamma energies in the 100 to 200 keV range.

Step 3: Calculation of the scan MDC for a given MDER. The scan MDC is calculated:

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

where C is the concentration of a radionuclide of interest(set equal to 50 pCi/g for this calculation), R_T is total exposure rate with buildup(μR/hr). The scan MDCs for depleted and natural uranium, 3 %, and 20 % enriched uranium in the soil are listed in Table 3.

Table 3 : 2" x 2" NaI scintillation detector scan MDCs

Radioactive material	Scan MDC Bq/g (pCi/g)
Deplete uranium	1.62 ($4.39x10^1$)
Natural uranium	4.71 ($1.27x10^2$)
3 % enriched uranium	6.13 ($1.66x10^2$)
20 % enriched uranium	7.99 ($2.16x10^2$)

3. Conclusions

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

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