FC-18-006
Revision 0
Soil Minimum Detectable Concentrations for 2x2 NaI Probes

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1.0 PURPOSE

The purpose of this document is to establish a standard methodology for determining the minimum detectable concentration of radioactive contaminants in soil using a standard 2-inch by 2-inch NaI scintillation detector.

2.0 METHODOLOGY

The general methodology is described in detail in Section 6.8.2 of NUREG-1507, "Minimum Detectable Concentrations With Typical Radiation Survey Instruments for Various Contaminants and Field Conditions."

The Derived Concentration Guideline Levels (DGCLs) used as target values were obtained from FC 18 004, "Soil DCGLs for Fort Calhoun Station Outside the Protected Area Identified for Partial Site Release."

MicroShield 11.21 was used to model the soil dose rates that would result from contamination at the DGCLs. See Attachment 1.

3.0 ASSUMPTIONS

3.1 The calculations are based on the Cs-137 DGCL determined in FC-18-004. The other radionuclides are accounted for by scaling them into consideration based on their relative concentrations listed in FC-18-002, "Potential Radionuclides of Concern During the Decommissioning of Fort Calhoun Station."

3.2 The calculations in this document are based on a Ludlum 44-10 (2-in x 2-in NaI) probe connected to a Ludlum 4404-4 data logger. The count rate to dose rate conversion used is the vendor-recommended 900 cpm/μR/hr for Cs-137.

3.3 The sample time is assumed to be 1 second for the scanning Minimum Detectable Count Rate calculations. For field measurement purposes, this will require the probe be over any given 28cm area for one second – an approximate scan speed of 11 inch/sec.

3.4 The background count time is assumed to be 1-minute for the scanning Minimum Detectable Count Rate calculations.

3.5 The instrument MDCR is calculated based on the Stapleton Approximation (see NUREG-1575, Figure 20.54).

3.6 The probability of Type I and II errors is assumed to be 0.05% (95% confidence) for the scanning Minimum Detectable Count Rate calculations.

4.0 CALCULATIONS

4.1 Instrument Minimum Detectable Count Rate (MDCR)

Equation 1 - MDCR

$$MDCR = \frac{\frac{(z_{1-\alpha}+z_{1-\beta})^2}{4}\left(1+\frac{t_s}{t_b}\right)+(z_{1-\alpha}+z_{1-\beta})\sqrt{R_b t_s\left(1+\frac{t_s}{t_b}\right)}}{t_s}$$

Where:

$MDCR$ = minimum detectable count rate (cpm)

α = probability of a Type I (false positive) error

β = probability of a Type II (false negative) error

$z_{1-\alpha}$ = $(1-\alpha)$ quantile of the standard normal distribution (1)

$z_{1-\beta}$ = $(1-\beta)$ quantile of the standard normal distribution (1)

t_s = sample count time (min)

t_b = background count time (min)

R_b = background count rate (cpm).

(1) The "quantile of the standard normal distribution" is calculated using the Excel NORMSINV() function.

Substituting the values into Equation 1 the listed in the assumptions and the measured background count rate of 6,000 CPM:

$$MDCR = \frac{\frac{(1.64485+1.64485)^2}{4}\left(1+\frac{0.0166}{1}\right)+(1.64485+1.64485)\sqrt{(6{,}000)(0.0166)\left(1+\frac{0.0166}{1}\right)}}{0.0166}$$

= 2,155 CPM

Converting the result into a dose rate:

$$\text{MDCR in } \mu R/hr = \frac{MDCR}{900\ \frac{\mu R/hr}{cpm}} = \frac{2155\ cpm}{900\ \frac{\mu R/hr}{cpm}} = 1.13\ \mu R/hr$$

4.2 Soil Activity Model

The MicroShield model is included as Attachment 1. The model uses Cs-137 (and the known equilibrium energies & radionuclides) as the primary radionuclide. The model assumed 5 pCi/g of Cs-137.

The assumed dimensions of the soil area surveyed were a 28cm in diameter and 15cm thick disc of soil with a density of 1.6 g/cm^3.

The calculated dose rate for 5 pCi/g Cs-137 in soil is 1.25 μR/hr.

4.3 Soil Activity that Corresponds to the Instrument MDCR

This value is calculated by scaling the dose rate from soil calculated at 5 pCi/g to the dose rate calculated to correspond to the MDCR:

$$\text{Scan MDC } \left(\frac{\text{pCi}}{\text{g}}\right) = 5\left(\frac{\text{MDCR in } \frac{\mu\text{R}}{\text{hr}}}{\frac{\text{dose rate}}{\frac{\text{pCi}}{\text{g}}}}\right) = 5\left(\frac{1.13}{1.25}\right) = 4.50 \ \frac{\text{pCi}}{\text{g}}$$

5.0 REFERENCES

5.1 FC 18 002, "Potential Radionuclides of Concern During the Decommissioning of Fort Calhoun Station," 2018

5.2 FC 18 004, "Soil DCGLs for Fort Calhoun Station Outside the Protected Area Identified for Partial Site Release," 2018

5.3 Fort Calhoun Nuclear Station Limited Site Radiological Characterization Survey Report, January 2017

5.4 Fort Calhoun Nuclear Station Limited Site Non-Radiological Characterization Survey Report, January 2017

5.5 NUREG-1507, "Minimum Detectable Concentrations With Typical Radiation Survey Instruments for Various Contaminants and Field Conditions," NRC, June 1998

5.6 NUREG-1575, "Multi-Agency Radiation and Site Investigation Manual (MARSSIM)," Rev. 1, August 2000.

5.7 NUREG-1576, "Multi-Agency Radiological Laboratory Analytical Protocols Manual (MARLAP)," July 2004

5.8 NUREG-1757, Volume 1, Revision 2, "Consolidated Decommissioning Guidance: Characterization, Survey and Determination of Radiological Criteria," U.S. Nuclear Regulatory Commission, September 2006.

5.9 NUREG-1757, Volume 2, Revision 1, "Consolidated Decommissioning Guidance: Characterization, Survey and Determination of Radiological Criteria," U.S. Nuclear Regulatory Commission, September 2006.

6.0 ATTACHMENTS

6.1 Attachment 1 – MicroShield Soil Activity Model

Attachment 1 – MicroShield Soil Activity Model

MicroShield 11.21
OPPD

File Name	Run Date	Run Time	Duration
X:\NucOperations\Low\RadProtection\Procedures\Rad Analysis\Rad Analysis 2018\FC-18-006 NaI Soil Scanning MDC\Soil DGCL.msd	March 21, 2018	12:13:39 PM	00:00:00

Project Info

Case Title	Soil DGCL
Description	Soil DGCL
Geometry	8 - Cylinder Volume - End Shields

Source Dimensions

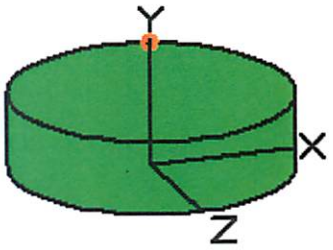
Height	15.0 cm (5.9 in)
Radius	28.0 cm (11.0 in)

Dose Points

A	X	Y	Z
#1	0.0 cm (0 in)	25.0 cm (9.8 in)	0.0 cm (0 in)

Shields

Shield N	Dimension	Material	Density (g/cm^3)
Source	3.69e+04 cm^3	Soil	1.6
Air Gap		Air	0.00122



Attachment 1 – MicroShield Soil Activity Model

Source Input: Grouping Method - Actual Photon Energies
Library: Grove

Nuclide	Ci	Bq	µCi/cm³	Bq/cm³
Ba-137m	2.7960e-007	1.0345e+004	7.5680e-006	2.8002e-001
Cs-137	2.9556e-007	1.0936e+004	8.0000e-006	2.9600e-001

Buildup

Buildup: The material reference is Source.

Integration Parameters

Radial	20
Circumferential	10
Y Direction (axial)	10

Results

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup	Absorbed Dose Rate mrad/hr No Buildup	Absorbed Dose Rate mrad/hr With Buildup	Absorbed Dose Rate mGy/hr No Buildup	Absorbed Dose Rate mGy/hr With Buildup
4.470e-03	1.074e+02	2.810e-07	2.921e-07	1.926e-07	2.002e-07	1.681e-07	1.748e-07	1.681e-09	1.748e-09
3.182e-02	2.142e+02	3.394e-05	4.377e-05	2.827e-07	3.646e-07	2.468e-07	3.183e-07	2.468e-09	3.183e-09
3.219e-02	3.952e+02	6.531e-05	8.481e-05	5.256e-07	6.825e-07	4.589e-07	5.959e-07	4.589e-09	5.959e-09
3.640e-02	1.438e+02	3.643e-05	5.141e-05	2.070e-07	2.921e-07	1.807e-07	2.550e-07	1.807e-09	2.550e-09
6.616e-01	9.309e+03	3.579e-01	6.440e-01	6.938e-04	1.248e-03	6.057e-04	1.090e-03	6.057e-06	1.090e-05
Total	**1.017e+04**	**3.580e-01**	**6.442e-01**	**6.950e-04**	**1.250e-03**	**6.067e-04**	**1.091e-03**	**6.067e-06**	**1.091e-05**