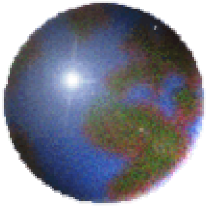

Delaware Valley Society for Radiation Safety MARSSIM Workshop

FIELD INSTRUMENTATION AND FINAL STATUS SURVEYS

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OUTLINE

- Field Survey Instruments
- ISO-7503 Approach
- Surface Activity Assessment for Decay Series
- Hot Spot Considerations
- Scan MDC and Related Discussion

MARSSIM FSS Instrumentation

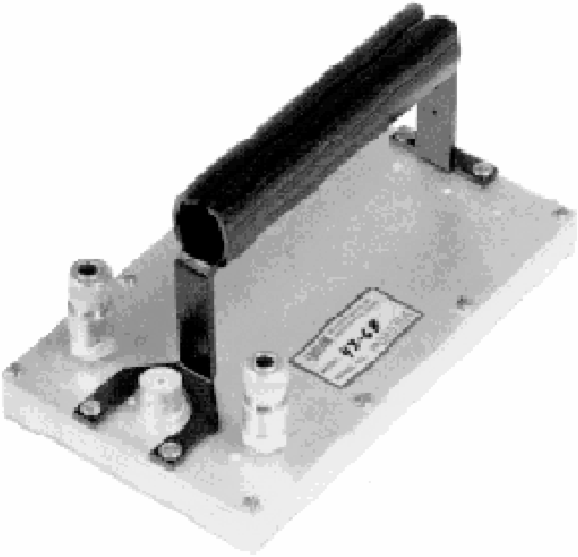
- Field survey instruments used to perform scanning in buildings and land areas, and to make surface activity measurements
- Laboratory instruments to determine radionuclide concentrations in soil – depending on radionuclides includes gamma spec, alpha spec and wet chemistry

Survey Instrumentation

- Field survey instruments described in MARSSIM Appendix H:
  - Gas proportional
    - Alpha-only (using voltage setting)
    - Beta-only (using Mylar thickness)
    - Alpha plus Beta
  - GM (measures primarily beta)
  - ZnS (alpha measurements)
  - Dual phosphor (alpha and beta, cross talk)

Gas Flow Proportional Counters

- Can distinguish alphas and betas
- P-10 gas needed
- connected or disconnected
- large windows
- very thin window
- problems with gas

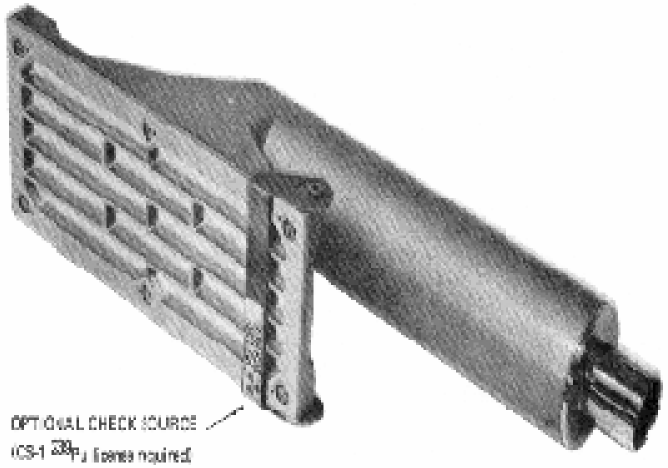


Combined Alpha –Beta Scintillators

- can distinguish alphas and betas
- no gas supply required
- large window areas
- beta efficiency can be relatively poor
- light leaks

Alpha Scintillators - ZnS

- only responds to alphas
- no gas supply
- large window areas
- light leaks

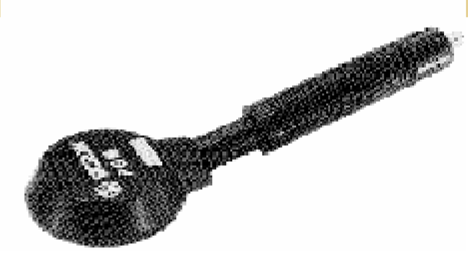


Windowless Gas Flow Proportional Counter

- for H-3
- needs continuous source of gas
- fixed measurements not scans
- flat surfaces
- interference from dust and static charges—very “finicky”

Pancake GM

- responds to alphas, betas and gammas
- small window
- shielded versions available
- rugged



Selection of Instrumentation

- Selection based on contaminants, their associated radiations, media surveyed and MDCs (sensitivity)
- MARSSIM Guidance: MDCs less than 10% of the $DCGL_W$ are preferable—while MDCs up to 50% of the $DCGL_W$ are acceptable (this does **not** apply to scan MDCs)

ISO-7503 Methodology

- ISO-7503-1 “Evaluation of Surface Contamination-Part 1: Beta Emitters and Alpha Emitters”
- Separate total efficiency into instrument and surface efficiency components:

$$A_S = \frac{R_{S+B} - R_B}{(\varepsilon_i)(\varepsilon_S)(W)},$$

where:

ε_i is the instrument or detector efficiency,

ε_s is surface or source efficiency,

W is the physical probe area

ISO-7503 Methodology (cont.)

- Distinguishes between instrument efficiency (ε_i) and surface efficiency (ε_s)
- Our conventional total efficiency is simply: (ε_i)(ε_s)
- ε_i is the ratio between the net count rate and 2π surface emission rate (includes absorption in detector window, source-detector geometry)—maximum ε_i is 1.0

ISO-7503 Methodology (cont.)

- ε_s is the ratio between the number of particles emerging from surface and the total number of particles released within the source—accounts for self-absorption and backscatter

- ε_s is nominally 0.5 (no self-absorption, no backscatter)–backscatter increases value, self-absorption decreases value

ISO-7503 Efficiency Components

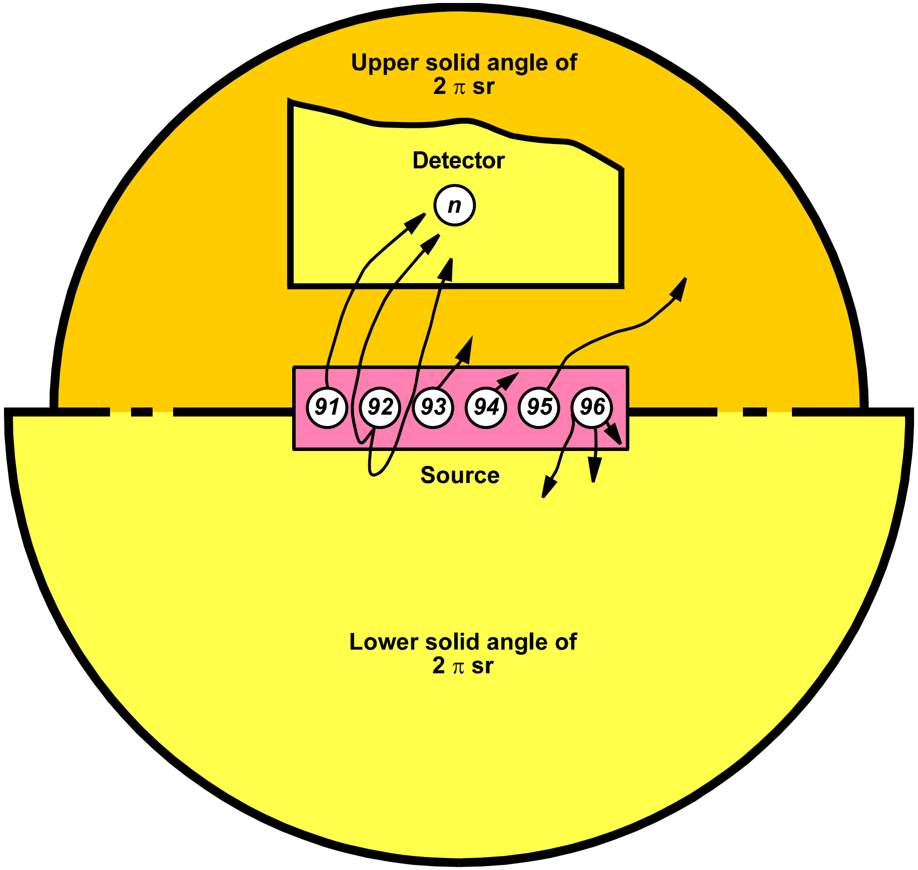
- Definition of terms for ISO-7503 approach
  - Activity of source (A): $A = q_1 + q_2 + q_3 + q_4 + q_5 + q_6$
  - Surface emission rate (q_{2B}): $q_{2B} = q_1 + q_2 + q_3 + q_5$
  - Surface efficiency (ε_s):

$$\varepsilon_s = \frac{q_1 + q_2 + q_3 + q_5}{q_1 + q_2 + q_3 + q_4 + q_5 + q_6} = \frac{q_{2\pi}}{A}$$

  - Instrument efficiency (ε_i): $\varepsilon_i = \dfrac{n}{q_1 + q_2 + q_3 + q_5}$

(n is the instrument net count rate)

Definition of Terms for ISO-7503 Approach



Determination of ε_i

- ε_i is determined similarly to current practice, except that detector response, in cpm, is divided by the 2π surface emission rate of the calibration source (not source activity in dpm)
- ε_i is calculated from the 2π surface emission rate of the calibration source, that is subtended by the physical probe area of the detector ($q_{2\pi,sc}$):

$$\varepsilon_i = \frac{R_{S+B} - R_B}{q_{2\pi,sc}}$$

Determination of ε_i (cont.)

- ε_i should be "determined by means of reference radiations provided by reference sources of known emission rate per unit area in accordance with ISO-8769"
- ISO-8769 recommends calibration source areas of at least 150 cm^2 (want calibration source larger than detector physical probe area)
- If you only have smaller calibration sources, then just cal with source in multiple locations

Example Certificate of Calibration

- 150 cm^2,Tc-99 source on stainless steel
- Calibration source certificate:
  - 2π emission rate is 14,400 cpm
  - 4π activity is 23,100 dpm
- Backscatter provided as 25%
- The 2π emission rate provides the NIST-traceability, the dpm value is calculated (using the backscatter value)

Radionuclide Sources For Calibration

- Select calibration source based on type and radiation energy of contamination
- ε_i increases with increases in beta energy (data for gas proportional detector):

	ave energy	ε_i
C-14	49.4 keV	0.254
Tc-99	84.6 keV	0.364
Tl-204	244 keV	0.450
SrY-90	563 keV	0.537

Determination of ε_s

- ε_s is determined either by experimentation, or by simply selecting appropriate values based on the radiation type and energy

- Recommendations of ISO-7503:
  - ε_s equals 0.5 for maximum beta energies, $E_\beta > 0.4$ MeV (e.g., Tl-204, SrY-90)
  - ε_s equals 0.25 for 0.15 MeV $< E_\beta < 0.4$ MeV and alphas (e.g. C-14, Pu-239)

Example Using the ISO-7503 Approach

- Gas proportional detector conventionally calibrated to Th-230 alpha source: total efficiency is about 0.20 c/dis
- Determine ε_i from NIST certificate for Th-230
  - 2π emission rate is 23,855 alphas/min, assume detector background is 1 cpm and the gross count on the calibration source is 11,077 cpm:

$$\varepsilon_i = \frac{11{,}077 - 1}{23{,}855} = 0.46$$

- Note: This is 2π value! Multiply by ε_s is to get total efficiency (4π) of 0.115

Example Using the ISO-7503 Approach

- Determine ε_s for surface types for Th-230 alpha source:
- Scabbled concrete: $\varepsilon_s = 0.276$; $\varepsilon_{tot} = (0.46)(0.276)$
  = **0.13 c/dis**
- Stainless steel: $\varepsilon_s = 0.499$; $\varepsilon_{tot} = (0.46)\ (0.499)$
  = **0.23 c/dis**
- Untreated wood: $\varepsilon_s = 0.194$; $\varepsilon_{tot} = (0.46)(0.194)$
  = **0.09 c/dis**

(from Table 5.5 in NUREG-1507)

Surface Activity Assessment for Decay Series

- Decay series emit a complex scheme of alpha, beta and gamma emissions
- Calibration to a single radionuclide may not be representative of the detector's response to U or Th decay series
- One approach is to make beta measurements in place of alpha measurements, considering alpha to beta ratio, and calibrate detector to a single radionuclide (e.g. SrY-90 for Pa-234m in U series)

Surface Activity Assessment for Decay Series (cont.)

- Alternative approach using NUREG-1507 (Section 5.5): Considers detector's response to each of the alpha and beta emissions in decay series, and then weight individual efficiencies based on the isotopic ratio
- Technique requires that decay scheme be completely described in terms of radiation type, energy and abundance, as well as instrument and surface characteristics (3% enriched U example)

Surface Activity Assessment for Decay Series (cont.)

- NUREG-1507 Table 5.32

	Avg Energy	Alpha Fraction	Yield	Efficiency	Weighted Efficiency
^{238}U	Alpha/4.2	0.167	100%	0.01	1.67×10^{-3}
^{234}Th	Beta/0.0435	0.167	100%	0.038	6.36×10^{-3}
^{234m}Pa	Beta/0.819	0.167	100%	0.453	7.58×10^{-2}
^{234}U	Alpha/4.7	0.799	100%	0.01	7.99×10^{-3}
^{235}U	Alpha/4.4	0.033	100%	0.01	3.33×10^{-4}
^{231}Th	Beta/0.0764	0.033	100%	0.118	3.93×10^{-3}
	Total Weighted Efficiency				**0.096**

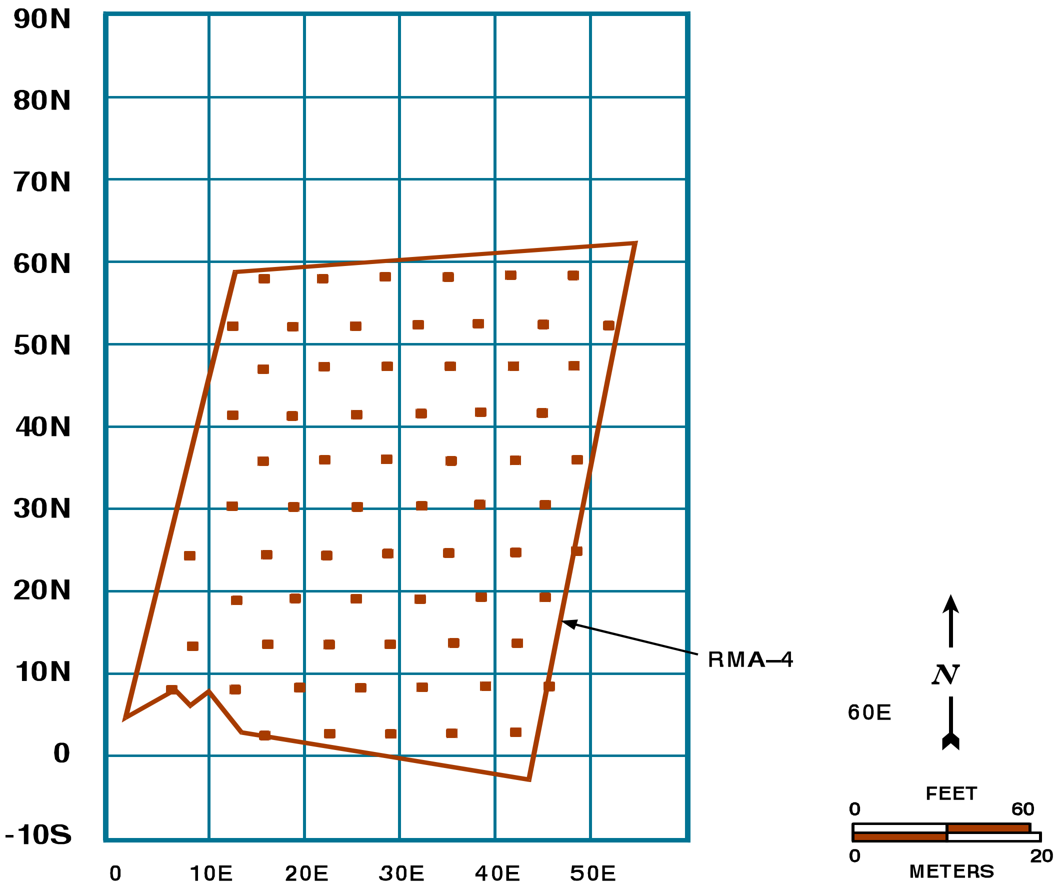
Surface Activity Assessment for Decay Series (cont.)

- Detector’s efficiency for each radiation emission was determined experimentally by selecting radionuclides with similar energies, or empirically
- Note that about 80% (0.0758 of 0.096) of detector’s response is from Pa-234m, and not likely to be affected much by field conditions
- To evaluate this technique, 3% EU was deposited on SS and surface activity measurements made resulted in **0.09 c/dis**

Hot Spot Considerations

- Hot Spot Survey Design
  - For Class 1 areas, determine if sample size is sufficient for hot spots that may be present
  - Based on sample size (n), the average area bounded by sample points represents largest hot spot that could exist, and not be sampled
  - The average area (a’) is determined by dividing the survey unit area by the sample size (n)

Hot Spot Considerations—Area Bounded By Sampling Locations



Hot Spot Considerations (cont.)

- Hot Spot Survey Design (cont.)
  - Area Factor—factor by which this area may exceed $DCGL_W$ (area factor is based on dose modeling)
  - Determine required Scan MDC:

    $= DCGL_W * \text{Area Factor}$
  - Determine actual Scan MDC

Hot Spot Considerations (cont.)

- Hot Spot Survey Design (cont.)
  - If Actual Scan MDC < Required Scan MDC—then initial data point spacing sufficient
  - If Actual Scan MDC > Required Scan MDC—then calculate Area Factor that corresponds to actual Scan MDC:

$$Area\,Factor = \frac{Scan\,MDC(actual)}{DCGL_W}$$

Hot Spot Considerations (cont.)

- Hot Spot Survey Design (cont.)
  - Determine hot spot area that corresponds to the calculated area factor (using actual scan MDC)
  - The new sample size, n_{EA}, is calculated by dividing the hot spot area of concern into the survey unit area

Scan Survey Instrumentation

- NaI Detectors (2″x2″; FIDLERs)
- Gas Proportional Detectors
  - Floor monitor (570 cm^2 probe area)
  - Hand-held detectors
- GM and ZnS Detectors
  - For scanning difficult to access locations
- New technologies—GPS-based detectors; SRA SCM

NaI Gamma Scintillators

- most sensitive gamma detector
- easily measures background
- cpm or µR/h
- limited size, heavy, fragile

Plastic Scintillators

- easily measures background (µR/h or µrem/h)
- lighter and more rugged than NaI
- energy independent

Low Energy Gamma Detectors

- thin (1 mm) NaI crystals
- primarily used for I-125
- light leaks

FIDLER

- large area thin NaI crystal
- primarily used for Am-241
- window settings critical
- heavy – more suited to fixed measurements than scanning

Pre-MARSSIM Scan Experiences

- Don't ask/Don't tell - Many D&D projects never even considered the question/issue of scan MDC
- NUREG/CR-5849 - 3 times background level for low count rates could be detected with scan
- Empirical evaluations - Technicians asked to scan surfaces with hidden sources; scan MDCs based on activity level that some specified percentage of technicians could detect

Scan Sensitivity

- NUREG-1507 and NUREG/CR-6364 consider human factors involved with scanning
- Signal detection theory - Did signal arise from “Background Alone” or “Background Plus Source”?
- Evaluated scan sensitivity for ideal observer through computer simulation tests, and performed field tests to evaluate model

Estimation of Scan MDC

- The minimum detectable count rate (MDCR) in observation interval is determined:

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

- where:

  b_i = Background counts in observation interval

  d′ = Detectability index, based on acceptable correct detection rate and false positives

  p = Surveyor efficiency relative to ideal observer (based on experimentation)

Scan MDC for Structures

- Determine scan MDC for 10 cm x 10 cm hot spot of Tc-99 with gas proportional detector, scan rate is 5 cm/s (observation interval, i, is 2 sec)
- Detector parameters: Bkg = 300 cpm, ε_i = 0.36 and ε_s = 0.54

Scan MDC for Structures

- d′ = 2.48 for 95% true detection and 20% false positives, and surveyor efficiency (p) is 0.5:

$$MDCR = \frac{2.48\sqrt{10}}{\sqrt{0.5}\,(2\,\mathrm{sec})} = 5.5\,c/s \;or\; 330\,cpm$$

and

$$Scan\ MDC = \frac{MDCR}{\varepsilon_i \varepsilon_s} = \frac{330\ cpm}{(0.36)(0.54)} = 1{,}700\ dpm\ /100\,cm^2$$

Scan MDC for Soil

- Minimum detectable count rate (as before)
- Relate NaI cpm to exposure rate, using modeling code (e.g., MicroShield)
  - Radionuclide
  - Concentration
  - Hot spot dimensions (0.5 m x 0.5 m)
- Scan MDC as a function of parameters; consider value of empirical validation
- Scan MDCs are compared to $\mathrm{DCGL}_{\mathrm{EMC}}$ to assess need for additional samples

Example scan MDCs for 1.25"x1.5" NaI Detector

Radionuclide	**Scan MDC (pCi/g)**
Cs-137	10
Th-230	3,000
Th-232	3
Natural Thorium (daughters)	30
Processed Uranium	120
Enriched Uranium (3%)	140
Enriched Uranium (20%)	150

Empirical Assessment of Scan MDCs

- *A priori* experimentation of scan MDC
  - 305 net cpm detected in 50 cpm bkg, 310 cpm in 250 cpm bkg, and 450 cpm in 500 cpm bkg, for detection frequencies of 67% (Goles et al.)
  - 392 to 913 alpha dpm detectable 50% with Zns (Olsher)
  - Source levels of 700 cpm detectable in 482 cpm background 90% of time (Thelin)
- *A posteriori* assessment of scan MDC
  - Keep track of soil samples and surface activity measurements collected as a result of scans

A Posteriori Scan MDCs (validation of calculational approach)

- Co-60 site; NaI used to scan (bkg ~ 2 to 3 kcpm)

NaI reading	Co-60 concentration (pCi/g)
2.8 kcpm	0.1 (false positive)
25 kcpm	25.5
7 kcpm	9.2
18 kcpm	20.8
2.8 kcpm	2.1 (close to calculated value)

- Actual field conditions may differ from model

If Scan MDC Is NOT Sufficient – Reduce Scan MDC By:

- Slowing scan speed to increase observation interval; however, practical limit of several seconds on observation interval (can’t keep on scanning slower)
- Use more sensitive instrument (increase efficiency)
- Accept more false positives, which requires training technicians to pause and flag spots more frequently

If Scan MDC Is NOT Sufficient – Collect More Samples

- Simply collect the additional samples required
- If sample analyses not that expensive (e.g. direct measurements), perhaps the poor scan MDC not that burdensome

No Scan Capability At All

- Radionuclides include pure alpha and beta emitters (H-3, Ni-63, C-14, etc.) and low energy gamma and x-ray emitters (e.g., Fe-55)
- Perform systematic sampling in survey unit and analyze samples, and assess with posting plot
- Perform second stage sampling based on results of first sampling stage
  - at locations where samples exceed $DCGL_W$
  - results of posting plot that indicates potential locations for contamination