Statistical Design of Final Status Surveys

Professional Training Programs

Lecture Overview

• Final status survey and DQOs

• WRS test sample size and example

• Sign test sample size and example

• Determine measurement locations

• Hot spots
Final Status Survey and DQOs

Final Status Survey

• Objective: Demonstrate that residual radioactivity in each survey unit satisfies release criteria

• Builds on data from HSA and survey results from scoping and characterization

• Survey design includes:
  – Scans to identify hot spots
  – Random (statistical) samples for determining average contamination levels in survey unit
Final Status Survey

• Null hypothesis (H₀): Residual radioactivity exceeds the release criteria
  – H₀ is treated like a baseline condition
  – Assumed to be true in the absence of strong evidence to the contrary

• Decision errors occur when:
  – H₀ is rejected when it is true (Type I)
  – H₀ is accepted when it is false (Type II)

Final Status Survey — Statistical Tests

Wilcoxon Rank Sum test
(two-sample test)

• Contaminant is in background

Sign test
(one-sample test)

• Contaminant is NOT in background, or is present at small fraction of the DCGL
• When surface activity assessment is performed with background subtracted from each measurement
Data Quality Objectives Process

- Uses a graded approach to (survey) data quality requirements
- Ensures that the type, quantity, and quality of data are appropriate for the intended application
- **Flexible** approach for planning and conducting surveys

Final Status Survey DQOs

- State Type I and Type II decision errors associated with $H_0$
- Specify a gray region ($\Delta = DCGL - LBGR$)
  - LBGR is commonly set at the expected mean concentration in the survey unit
  - Setting LBGR requires sufficient characterization data from the survey unit
- Survey instrument MDCs and scan MDCs (could drive sample size in Class 1 survey unit)
WRS Test: Sample Size and Example

WRS Test — FSS Design Steps

Step 1 • Estimate standard deviations in the reference area and survey unit and use larger of the two values

Step 2 • Calculate relative shift

Step 3 • Determine $P_r$ and decision error percentiles based on selection of decision errors ($\alpha$ and $\beta$ errors)

Step 4 • Calculate sample size
WRS Test — Step 1

• Estimate standard deviation of contaminant in both reference area ($\sigma_r$) and survey unit ($\sigma_s$)

• Use scoping/characterization survey data, or collect limited number of measurements

• Use the larger value of $\sigma_r$ or $\sigma_s$

WRS Test — Step 2 and 3

• Calculate the relative shift — ratio of $\Delta/\sigma$
  
  ($\Delta = $ DCGL - LBGR)

• Determine $P_r$ — tabulated probability based on relative shift ($\Delta/\sigma$) (MARSSIM Table 5.1)

• Determine decision error percentiles, $Z_{1-\alpha}$ and $Z_{1-\beta}$, based on decision errors (MARSSIM Table 5.2)
**WRS Test — Step 4**

- Calculate sample size (N) for each reference area/survey unit pair (MARSSIM Equation 5-1):

\[ N = \frac{(Z_{1-\alpha} + Z_{1-\beta})^2}{3(p - 0.5)^2} \]

- Increase number of data points by 20% to allow for lost or unusable data (MARSSIM Table 5.3 provides sample sizes—already includes 20% increase)

**WRS Test Example**

- Site conducted operations with processed U

- Parcel of land on site has been characterized
  - Class 2 area—12,000 m²
  - Divided into two survey units

- Background reference area selected
WRS Test Example

- DCGL\textsubscript{w} for U-238 is 8 pCi/g  (0.30 Bq/g)

- Expected mean concentration above background (LBGR) is 4 pCi/g  (0.15 Bq/g)

- Type I (\(\alpha\)) is 0.025, Type II (\(\beta\)) is 0.10

- \(\sigma_r = 0.5\) pCi/g U-238  (0.02 Bq/g U-238)

- \(\sigma_s = 2.9\) pCi/g U-238  (0.11 Bq/g U-238)

WRS Test Example — Step 1

- Estimate standard deviation of contaminant in both reference area (\(\sigma_r\)) and survey unit (\(\sigma_s\))

- \(\sigma_r = 0.5\) pCi/g U-238  (0.02 Bq/g U-238)

- \(\sigma_s = 2.9\) pCi/g U-238  (0.11 Bq/g U-238)

- Use the larger value: 2.9 pCi/g U-238  (0.11 Bq/g U-238)
WRS Test Example — Step 2 and 3

• Calculate the relative shift
  \[ \Delta/\sigma = (8-4)/2.9 \quad \text{or} \quad \Delta/\sigma = (0.3-0.15)/0.11 \]
  \[ = 1.3 \quad \text{(rounded)} \]

• Determine \( P_r \) — (MARSSIM Table 5.1)
  – Type I (\( \alpha \)) is 0.025, Type II (\( \beta \)) is 0.10
  – \( P_r = 0.82 \)

• Determine decision error percentiles — (MARSSIM Table 5.2)
  – \( Z_{1-\alpha} = 1.96 \)
  – \( Z_{1-\beta} = 1.28 \)

WRS Test Example — Step 4

• Calculate sample size (\( N \)) for each reference area/survey unit pair (MARSSIM Equation 5-1):

• Substituting into sample size equation:

\[
N = \frac{(Z_{1-\alpha}+Z_{1-\beta})^2}{3(P_r-0.5)^2} = \frac{(1.96+1.28)^2}{3(0.82-0.5)^2} = 34.2
\]

• Increase by 20% and round up—42 samples (Confirm in MARSSIM Table 5.3: \( N/2 = 21 \))
### WRS Test Example — Summary

**Step 1**
- $\sigma_s = 2.9$ pCi/g $\text{U-238}$ (0.11 Bq/g $\text{U-238}$)

**Step 2**
- $\Delta/\sigma = (8-4)/2.9 = 1.38$  
- $\Delta/\sigma = (0.296 - 0.148)/0.1073 = 1.38$  
  (round down to 1.3)

**Step 3**
- $P_r = 0.82$, $Z_{1-\alpha} = 1.96$, $Z_{1-\beta} = 1.28$

**Step 4**
- $N = \frac{(Z_{1-\alpha} + Z_{1-\beta})^2}{3(P_r - 0.5)^2} = \frac{(1.96 + 1.28)^2}{3(0.82 - 0.5)^2} = 34.2$

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### Sign Test: Sample Size and Example
### Sign Test — FSS Design Steps

<table>
<thead>
<tr>
<th>Step 1</th>
<th>Estimate standard deviation in survey unit measurements (and in background measurements if applicable)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 2</td>
<td>Calculate relative shift</td>
</tr>
<tr>
<td>Step 3</td>
<td>Determine Sign p and decision error percentiles based on selection of decision errors ($\alpha$ and $\beta$ errors)</td>
</tr>
<tr>
<td>Step 4</td>
<td>Calculate sample size</td>
</tr>
</tbody>
</table>

### Sign Test — Step 1

- Estimate standard deviation of contaminant in survey unit, $\sigma_s$

- When using Sign test for net measurements on building surfaces, incorporate reference area $\sigma_r$ as well (propagate error)

$$\sigma_{total} = \sqrt{\sigma_s^2 + \sigma_r^2}$$
Sign Test — Step 2 and 3

- Calculate the relative shift — ratio of $\Delta/\sigma$
  
  $\Delta = \text{DCGL} - \text{LBGR}$

- Determine Sign $p$ — tabulated probability based on relative shift ($\Delta/\sigma$) (MARSSIM Table 5.4)

- Determine decision error percentiles, $Z_{1-\alpha}$ and $Z_{1-\beta}$, based on decision errors (MARSSIM Table 5.2)

Sign Test — Step 4

- Calculate sample size ($N$) for survey unit (MARSSIM Equation 5-2):

  $$N = \frac{(Z_{1-\alpha} + Z_{1-\beta})^2}{4(Sign p - 0.5)^2}$$

- Increase number of data points by 20% to allow for lost or unusable data (MARSSIM Table 5.5 provides sample sizes - already includes 20% increase)
MARSSIM Recommendation for Surface Activity Assessment

- Gross measurements use the WRS Test—which requires a background reference area for each different surface material type

- This is impractical for gross surface activity measurements—results in building surfaces divided into survey units based on contamination potential and surface type; would result in multiple survey units in a single room

Using Sign Test for Surface Activity Assessment

- Statistical power between WRS and Sign tests for this application is similar

- Facilitates determination of surface activity for shielded and unshielded measurements

- The EMC test for hot spots requires the subtraction of an average background anyway to facilitate comparison to DCGL_{EMC}

- Decommissioning Health Physics 2nd edition, Section 13.3 discusses option in detail
Surface Material Backgrounds

- Background beta and/or alpha count rates are determined for each surface material encountered in the survey unit (natural radioactivity from Th, U, K-40)

- Group surface types with like background levels (e.g., drywall, steel, wood)—as opposed to individual backgrounds for each

- Obtain 10–20 measurements of background across the surface material to determine mean and standard deviation

- May need shielded as well as unshielded measurements at each location in the survey unit in order to account for a variable ambient (gamma) background

Sign Test Example — Surface Activity Assessments

<table>
<thead>
<tr>
<th>Class 1 survey unit area 320 m² – concrete floor</th>
<th>Contaminant</th>
<th>DCGL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Am-241</td>
<td>130 dpm/100 cm²</td>
</tr>
<tr>
<td></td>
<td>Co-60</td>
<td>11,400 dpm/100 cm²</td>
</tr>
<tr>
<td></td>
<td>SrY-90</td>
<td>34,400 dpm/100 cm²</td>
</tr>
<tr>
<td></td>
<td>Cs-137</td>
<td>44,000 dpm/100 cm²</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Class 1 survey unit area 320 m² – concrete floor</th>
<th>Contaminant</th>
<th>DCGL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Am-241</td>
<td>0.02 Bq/cm²</td>
</tr>
<tr>
<td></td>
<td>Co-60</td>
<td>1.9 Bq/cm²</td>
</tr>
<tr>
<td></td>
<td>SrY-90</td>
<td>5.7 Bq/cm²</td>
</tr>
<tr>
<td></td>
<td>Cs-137</td>
<td>7.3 Bq/cm²</td>
</tr>
</tbody>
</table>
Sign Test Example — Surface Activity Assessments

- Separate alpha and beta measurements will be taken with a gas proportional detector

- Decision errors chosen and decision error percentiles determined (MARSSIM Table 5.2)
  - Type I (α) is 0.025, so $Z_{1-\alpha} = 1.96$
  - Type II (β) is 0.10, so $Z_{1-\beta} = 1.28$

Sign Test Example — Gross Activity DCGLs

- Gross alpha DCGL same as Am-241

- Gross beta DCGL must consider relationship of Co-60, SrY-90 and Cs-137 (MARSSIM Equation 4-4, Step 2 MARSSIM Cheat Sheet)

- Results of characterization provides relative ratios: 0.3 Co-60, 0.2 SrY-90 and 0.5 Cs-137
Sign Test Example — Gross Activity DCGLs

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>DCGL $\text{dpm/100cm}^2$ ($\text{Bq/cm}^2$)</th>
<th>Relative Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-60</td>
<td>11,400 (1.9)</td>
<td>0.3</td>
</tr>
<tr>
<td>SrY-90</td>
<td>34,400 (5.7)</td>
<td>0.2</td>
</tr>
<tr>
<td>Cs-137</td>
<td>44,000 (7.3)</td>
<td>0.5</td>
</tr>
</tbody>
</table>

$DCGL_{\text{gross}}$ is the gross alpha or beta activity DCGL for the specified mix of nuclides.

$f_1, f_2, \text{ etc.} –$ are the fractions of the total alpha or beta activity contributed by Nuclide 1, Nuclide 2, etc.

$DCGL_{\text{f1}}, DCGL_{\text{f2}}, \text{ etc.} –$ are the individual DCGLs for Nuclide 1, Nuclide 2, etc.

$DCGL_{\text{f1}} = \frac{1}{DCGL_{1}} = \frac{1}{11,400}$

$DCGL_{\text{f2}} = \frac{1}{DCGL_{2}} = \frac{1}{34,400}$

$DCGL_{\text{f3}} = \frac{1}{DCGL_{3}} = \frac{1}{44,000}$

$DCGL_{\text{f1}} = \frac{f_1}{DCGL_{\text{f1}}} = \frac{0.3}{11,400}$

$DCGL_{\text{f2}} = \frac{f_2}{DCGL_{\text{f2}}} = \frac{0.2}{34,400}$

$DCGL_{\text{f3}} = \frac{f_3}{DCGL_{\text{f3}}} = \frac{0.5}{44,000}$

$dcpm = 23,000 \frac{dpm}{100 \text{cm}^2}$

$Bq = 3.8 \frac{Bq}{cm^2}$

Survey Instrument DQOs

- Gas proportional detector used for surface activity measurements
- Need a weighted efficiency for the gross beta measurements

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Relative Ratio</th>
<th>$\varepsilon_1$</th>
<th>$\varepsilon_2$</th>
<th>Weighted $\varepsilon_{\text{total}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-60</td>
<td>0.3</td>
<td>0.41</td>
<td>0.25</td>
<td>0.031</td>
</tr>
<tr>
<td>SrY-90</td>
<td>0.2</td>
<td>0.59</td>
<td>0.5</td>
<td>0.059</td>
</tr>
<tr>
<td>Cs-137</td>
<td>0.5</td>
<td>0.46</td>
<td>0.5</td>
<td>0.115</td>
</tr>
<tr>
<td>Total Efficiency</td>
<td></td>
<td></td>
<td></td>
<td>0.205</td>
</tr>
</tbody>
</table>
**Survey Instrument DQOs**

Static MDC (in dpm/100 cm² or Bq/cm²) should be less than 50% DCGL (MARSSIM Cheat Sheet)

\[
MDC = \frac{3 + 4.65 \sqrt{\frac{C}{B}}}{t \varepsilon_i \varepsilon_s \frac{A}{100}} \quad \text{or} \quad A
\]

- \( MDC \) – minimum detectable concentration
- \( C_B \) – background count(s)
- \( t \) – count time
- \( \varepsilon_i \) – instrument 2 pi efficiency
- \( \varepsilon_s \) – surface efficiency
- \( A \) – physical probe area

**Survey Instrument DQOs**

- Assume average background count rate on concrete floor is 360 cpm (6 cps)

- Calculate beta MDC for a 1-min count:

\[
MDC = \frac{3+4.65\sqrt{360}}{(1)(0.205)(126/100)} = 350 \text{dpm/100cm}^2 \quad \text{or} \quad 0.06 \frac{\text{Bq}}{\text{cm}^2}
\]

- Is this MDC less than 50% of DCGL\(_W\)?

(Yes, gross DCGL was 23,000 dpm/100 cm\(^2\) or 3.8 Bq/cm\(^2\))
Survey Instrument DQOs

• Assume $\varepsilon_i$ for alpha measurements calibrated to Th-230 is 0.44, and background is 2 cpm (0.033 cps)

• Calculate alpha MDC for a 1-min count:

$$MDC = \frac{3 + 4.65\sqrt{2}}{(1)(0.44)(0.25)(126/100)} = 69 \text{ dpm/100 cm}^2 \text{ or } 1.15 \times 10^{-2} \frac{\text{Bq}}{\text{cm}^2}$$

• Alpha MDC is just slightly greater than 50% of DCGL for 1-min count—is that OK? (Gross DCGL was 130 dpm/100 cm$^2$ or 2.17 x 10$^{-2}$ Bq/cm$^2$)

Sign Test Example — DQO Inputs

Unity rule is used for survey design

<table>
<thead>
<tr>
<th>Characterization data used for planning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survey Unit (1σ )</td>
</tr>
<tr>
<td>-------------------</td>
</tr>
<tr>
<td>Gross $\alpha$</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Gross $\beta$</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
Sign Test Example — Convert gross activity DCGLs to cpm or cps using efficiencies

- Gross alpha DCGL:
  \[(130 \text{ dpm/100 cm}^2)(0.44)(0.25)(126/100) = 18 \text{ cpm}\]
  \[SI = (2.17 \times 10^{-2} \text{ Bq/cm}^2)(0.44)(0.25)(126 \text{ cm}^2) = 0.301 \text{ cps}\]

- Gross beta DCGL:
  \[(23,000 \text{ dpm/100 cm}^2)(0.205)(126/100) = 5,940 \text{ cpm}\]
  \[SI = (3.8 \text{ Bq/cm}^2)(0.205)(126 \text{ cm}^2) = 98.2 \text{ cps}\]
- Since unity rule is used: DCGL = 1

Sign Test — FSS Design Steps

Step 1 • Estimate standard deviation in survey unit (and in background measurements if applicable)

Step 2 • Calculate relative shift

Step 3 • Determine Sign p and decision error percentiles based on selection of decision errors (α and β errors)

Step 4 • Calculate sample size
Sign Test Example — Step 1

Variability for measurements should consider that Sign test involves subtracting mean background from gross measurement so total variability must be propagated.

\[ \sigma_{total} = \sqrt{\sigma_s^2 + \sigma_r^2} \]

**Characterization Data Used for Planning**

<table>
<thead>
<tr>
<th></th>
<th>Survey unit (cpm)</th>
<th>Reference area (cpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gross ( \alpha )</strong></td>
<td>8 ± 5 (cpm)</td>
<td>2 ± 0.4 (cpm)</td>
</tr>
<tr>
<td></td>
<td>0.13 ± 0.08 (cps)</td>
<td>0.03 ± 0.007 (cps)</td>
</tr>
<tr>
<td><strong>Gross ( \beta )</strong></td>
<td>1544 ± 562 (cpm)</td>
<td>360 ± 45 (cpm)</td>
</tr>
<tr>
<td></td>
<td>26 ± 9.4 (cps)</td>
<td>6 ± 0.75 (cps)</td>
</tr>
</tbody>
</table>

\[ \sigma_{total \ \alpha} = \sqrt{5^2 + 0.4^2} = 5 \text{ cpm} \quad (0.083 \text{ cps}) \]

\[ \sigma_{total \ \beta} = \sqrt{562^2 + 45^2} = 564 \text{ cpm} \quad (9.4 \text{ cps}) \]
Sign Test Example — Step 1

Variability in terms of unity (Step 15 – MARSSIM Cheat Sheet):

\[
\sigma = \sqrt{\left(\frac{\sigma}{DCGL_{NUCLIDE\ 1(\alpha)}}\right)^2 + \left(\frac{\sigma}{DCGL_{NUCLIDE\ 2(\beta)}}\right)^2}
\]

\[
\sigma = \sqrt{\left(\frac{5}{18}\right)^2 + \left(\frac{564}{5940}\right)^2} = 0.29
\]

Sign Test Example — Step 2 and 3

<table>
<thead>
<tr>
<th>Characterization Data Used for Planning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survey unit (cpm)</td>
</tr>
<tr>
<td>Gross α</td>
</tr>
<tr>
<td>Gross β</td>
</tr>
</tbody>
</table>

LBGR in terms of unity (Step 15 – MARSSIM Cheat Sheet):

\[
LBGR = \frac{Exp\ conc\ alpha_{DCGL\ 1}}{DCGL\ 1} + \frac{Exp\ conc\ beta_{DCGL\ 2}}{DCGL\ 2}
\]

\[
LBGR = \frac{(8 - 2)}{18} + \frac{(1,544 - 360)}{5,940} = 0.53
\]

\[
LBGR = \frac{(0.13 - 0.03)}{0.301} + \frac{(26 - 6)}{98.2} = 0.53
\]
Sign Test Example — Step 2 and 3

- Calculate the relative shift—
  \[ \Delta/\sigma = (1-0.53)/0.29 = 1.60 \]

- Determine Sign p — (MARSSIM Table 5.4)
  - Type I (\(\alpha\)) is 0.025, Type II (\(\beta\)) is 0.10
  - Sign p = 0.95

- Determine decision error percentiles—(MARSSIM Table 5.2)
  - \(Z_{1-\alpha} = 1.96\)
  - \(Z_{1-\beta} = 1.28\)

Sign Test Example — Step 4

- Decision errors chosen and decision error percentiles determined (MARSSIM Table 5.2)
  - Type I (\(\alpha\)) is 0.025, so \(Z_{1-\alpha} = 1.96\)
  - Type II (\(\beta\)) is 0.10, so \(Z_{1-\beta} = 1.28\)

- Substituting into sample size equation:
  \[ N = \frac{(Z_{1-\alpha}+Z_{1-\beta})^2}{4(Sign\ p-0.5)^2} = \frac{(1.96+1.28)^2}{4(0.95-0.5)^2} = 13 \]

- Increase by 20% and round up—17 samples (Confirm in MARSSIM Table 5.5: \(N = 17\))
Sign Test Example — Summary

Step 1
- \( \sigma \) (in terms of unity) = 0.29

Step 2
- \( \Delta/\sigma = (1-0.53)/0.29 = 1.60 \)

Step 3
- Sign \( p = 0.95 \), \( Z_{1-\alpha} = 1.96 \), \( Z_{1-\beta} = 1.28 \)

Step 4
- \( N = \frac{(Z_{1-\alpha} + Z_{1-\beta})^2}{4(\text{Sign } p - 0.5)^2} = \frac{(1.96 + 1.28)^2}{4(0.95 - 0.5)^2} = 13 \)

Determine Measurement Locations
Determining Survey Locations

• Class 1 and 2 area measurements located systematically on triangular/square pattern

• Class 3 measurements distributed randomly

• Spacing of triangular pattern, $L$ (MARSSIM Equation 5.5):

$$ L = \sqrt{\frac{A}{0.866 n_{EA}}} $$

where $A$ is survey unit area and $n_{EA}$ is survey unit sample size

Determining Survey Locations

• Random-start triangular grid pattern

• Beginning with random start location, identify a row of points parallel to x-axis at intervals of $L$

• A second row of points is then developed, parallel to the first row, at a distance of 0.866 $L$ from the first row

• MARSSIM Figure 5.5 provides an example of the triangular grid pattern
Determining Survey Locations — Example

- Class 1 unit area 100 m²
- Sign test, $n_{EA} = 17$
- Spacing of triangular pattern, $L$:

$$L = \sqrt{\frac{A}{n_{EA}}} = \sqrt{\frac{100}{0.866 (17)}} = 2.6m$$

Second Row $0.866 \times (2.6) = 2.25m$

where $A$ is survey unit area and $n_{EA}$ is survey unit sample size

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Hot Spots
Hot Spot Survey Design

• For Class 1 areas, determine if sample size \( (n) \) is sufficient for hot spots that may be present

\[
a' = \frac{\text{survey unit size}}{n}
\]

• Based on \( n \), average area bounded by four sample points \( (a') \) represents largest hot spot that could exist, and not be sampled:

- Area factors are generated via the RESRAD code based on postulated hot spots

<table>
<thead>
<tr>
<th>Area (m²)</th>
<th>Th-232 Area Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>3,000</td>
<td>1</td>
</tr>
<tr>
<td>300</td>
<td>1.19</td>
</tr>
<tr>
<td>100</td>
<td>1.36</td>
</tr>
<tr>
<td>30</td>
<td>1.78</td>
</tr>
<tr>
<td>10</td>
<td>2.63</td>
</tr>
<tr>
<td>3</td>
<td>5.49</td>
</tr>
<tr>
<td>1</td>
<td>12.4</td>
</tr>
</tbody>
</table>

• Area factor—magnitude by which the concentration within the small area of elevated activity can exceed the DCGL\(_w\) while maintaining compliance with the release criterion
**Hot Spot Survey Design Steps**

1. **Step 1**
   - Determine required scan MDC

2. **Step 2**
   - Compare actual scan MDC to required scan MDC

3. **Step 3**
   - If actual scan MDC ≤ required scan MDC—sample size is sufficient

4. **Step 4**
   - If actual scan MDC > required scan MDC—increase sample size

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**Hot Spot Survey Design — Example**

- Sign test required 15 samples in Class 1 survey unit ($A = 1,800 \text{ m}^2$)
  
- $DCGL_{w} = 2.5 \text{ pCi/g for Th-232 (0.09 Bq/g)}$
  
- $a' = 1,800 \text{ m}^2 / 15 = 120 \text{ m}^2$
  
- Look up AF that corresponds to 120 m² (may need logarithmic interpolation)
  
- Actual scan MDC = 5 pCi/g (0.185 Bq/g)
Example Outdoor Area Factors

<table>
<thead>
<tr>
<th>Area (m²)</th>
<th>Th-232 Area Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>3,000</td>
<td>1</td>
</tr>
<tr>
<td>300</td>
<td>1.19</td>
</tr>
<tr>
<td><strong>120</strong></td>
<td>?</td>
</tr>
<tr>
<td>100</td>
<td>1.36</td>
</tr>
<tr>
<td>30</td>
<td>1.78</td>
</tr>
<tr>
<td>10</td>
<td>2.63</td>
</tr>
<tr>
<td>3</td>
<td>5.49</td>
</tr>
<tr>
<td>1</td>
<td>12.4</td>
</tr>
</tbody>
</table>

Area factor = 1.33 for $a'$ of 120 m²
Hot Spot Survey Design Steps

**Step 1**
- Required scan MDC = $(DCGL_W)(AF) = (2.5 \text{ pCi/g})(1.33) = 3.3 \text{ pCi/g}$ or $0.12 \text{ Bq/g}$

**Step 2**
- Actual scan MDC is $5 \text{ pCi/g}$ ($0.19 \text{ Bq/g}$)
- Required scan MDC is $3.3 \text{ pCi/g}$ ($0.12 \text{ Bq/g}$)

**Step 3**
- Is the actual scan MDC ≤ required scan MDC—NO

**Step 4**
- Actual scan MDC ($5 \text{ pCi/g}$ or $0.19 \text{ Bq/g}$) > required scan MDC ($3.3 \text{ pCi/g}$ or $0.12 \text{ Bq/g}$)—YES, increase sample size—HOW MUCH?

Hot Spot Survey Design — Example

- Determine the size of $a'$ the detector can scan sufficiently
- Calculate the area factor based on the actual scan MDC

$$AreaFactor = \frac{ScanMDC(actual)}{DCGL_W} = \frac{5 \text{ pCi/g}}{2.5 \text{ pCi/g}} = 2$$

$$AreaFactor = \frac{ScanMDC(actual)}{DCGL_W} = \frac{0.19 \text{ Bq/g}}{0.09 \text{ Bq/g}} = 2$$
Example Outdoor Area Factors

<table>
<thead>
<tr>
<th>Area (m²)</th>
<th>Th-232 Area Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>3,000</td>
<td>1</td>
</tr>
<tr>
<td>300</td>
<td>1.19</td>
</tr>
<tr>
<td>100</td>
<td>1.36</td>
</tr>
<tr>
<td>30</td>
<td>1.78</td>
</tr>
<tr>
<td>?</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>2.63</td>
</tr>
<tr>
<td>3</td>
<td>5.49</td>
</tr>
<tr>
<td>1</td>
<td>12.4</td>
</tr>
</tbody>
</table>

New a’ = 21.6 m² for area factor of 2

Example: Hot Spot Survey Design

- New sample size ($n_{EA}$): $1,800/21.6 = 83.3$
  
  Round up to 84 samples!

- This sample size has been driven by the potential for hot spots and an inadequate scan MDC