14 – Search Procedures

SAND2011-2084P

Defense Nuclear Nonproliferation

Search and Secure Workshop

14.1 – Search Planning

Preparation

- Determine search team membership
- Prioritize search sites based on
  - Verified inventory
  - Information received about the presence of Category 1 – 3 sources at a site (even if it’s not in the verified inventory)
- Identify or develop source recovery procedures
- Identify equipment or other resource needs
- Determine storage or disposal options
- Obtain approvals for searches and source movements

Preparing for the search

- Training
  - Equipment
  - Search Procedures
  - Actions to take for identified sources
  - Procedures for leaking source
  - Contamination control

- Safety
  - Dose limits
  - Fall back dose rates
  - Integrating dosimeters

Preparing for the Search

- Search Information
  - Develop a generic site search map
    - with approximate dimensions
    - based on presumed boundaries
  - Site history
  - Radionuclides likely to encounter

- Communication equipment
  - Cell or satellite phone
  - Radios
  - Call-in times
  - Stop time

Preparing for the search

- Materials
  - Health physics references
  - Consumables
    - Batteries
    - Contamination control materials
    - Packaging materials

- Equipment
  - Detection
    - Calibrated
    - Pre-operational checks
    - Efficiencies for radionuclides
    - Backup instruments
  - Source packaging
  - Transportation

Evaluation of Equipment Sensitivity

- Ability of a detector to distinguish between background radiation and radiation from a source
- Influenced by:
  - Detector geometry and efficiency
  - Energy and type
  - Counting time
  - Background fluctuations
  - User technique!

Sensitivity Worsens with Increasing Background Radiation Levels

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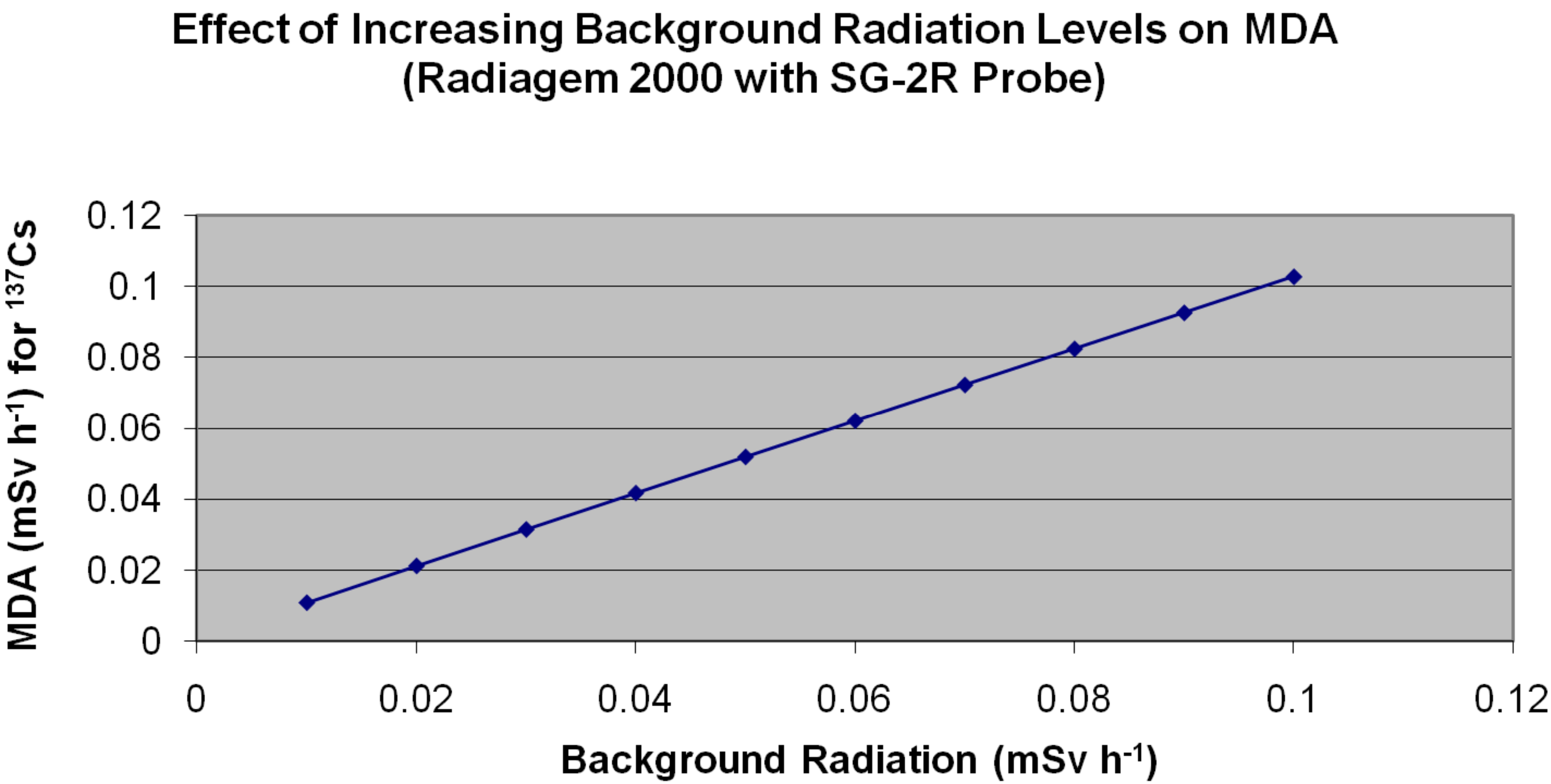

Equipment Sensitivity

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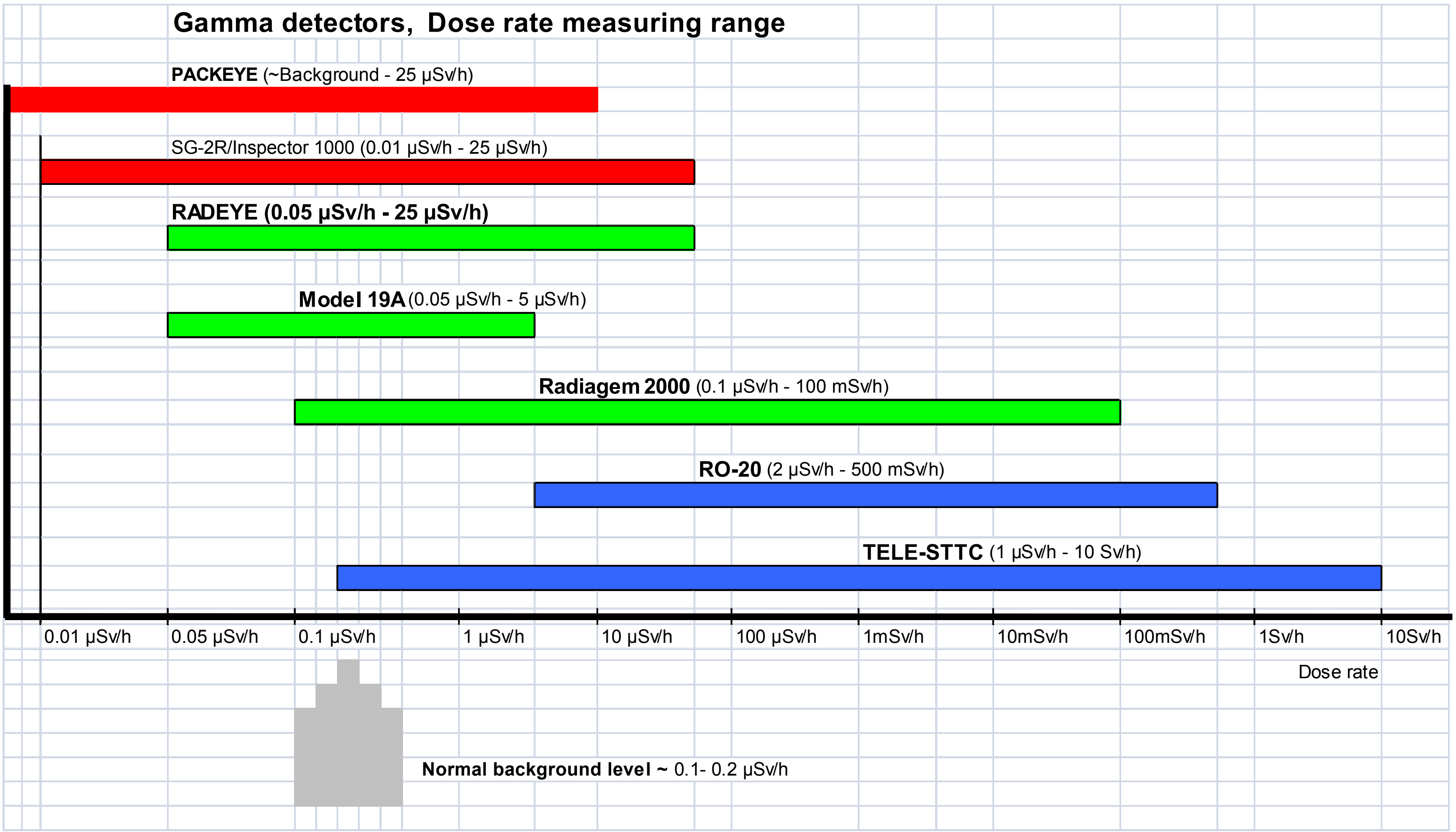
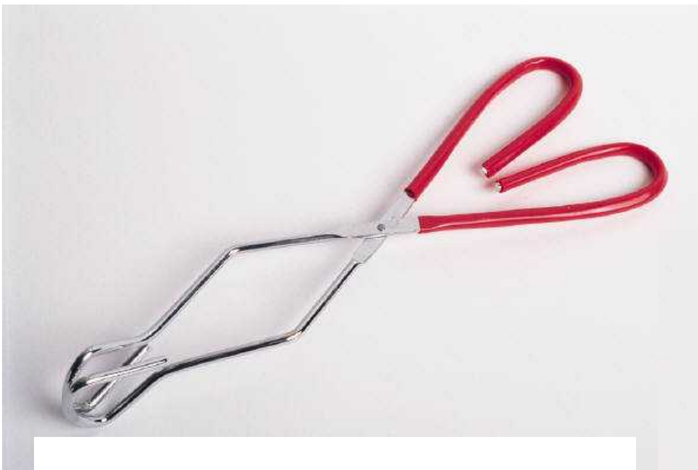
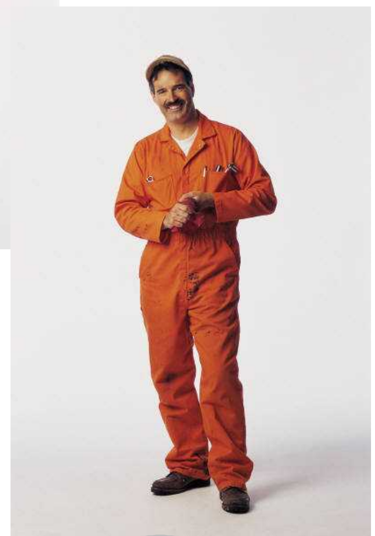
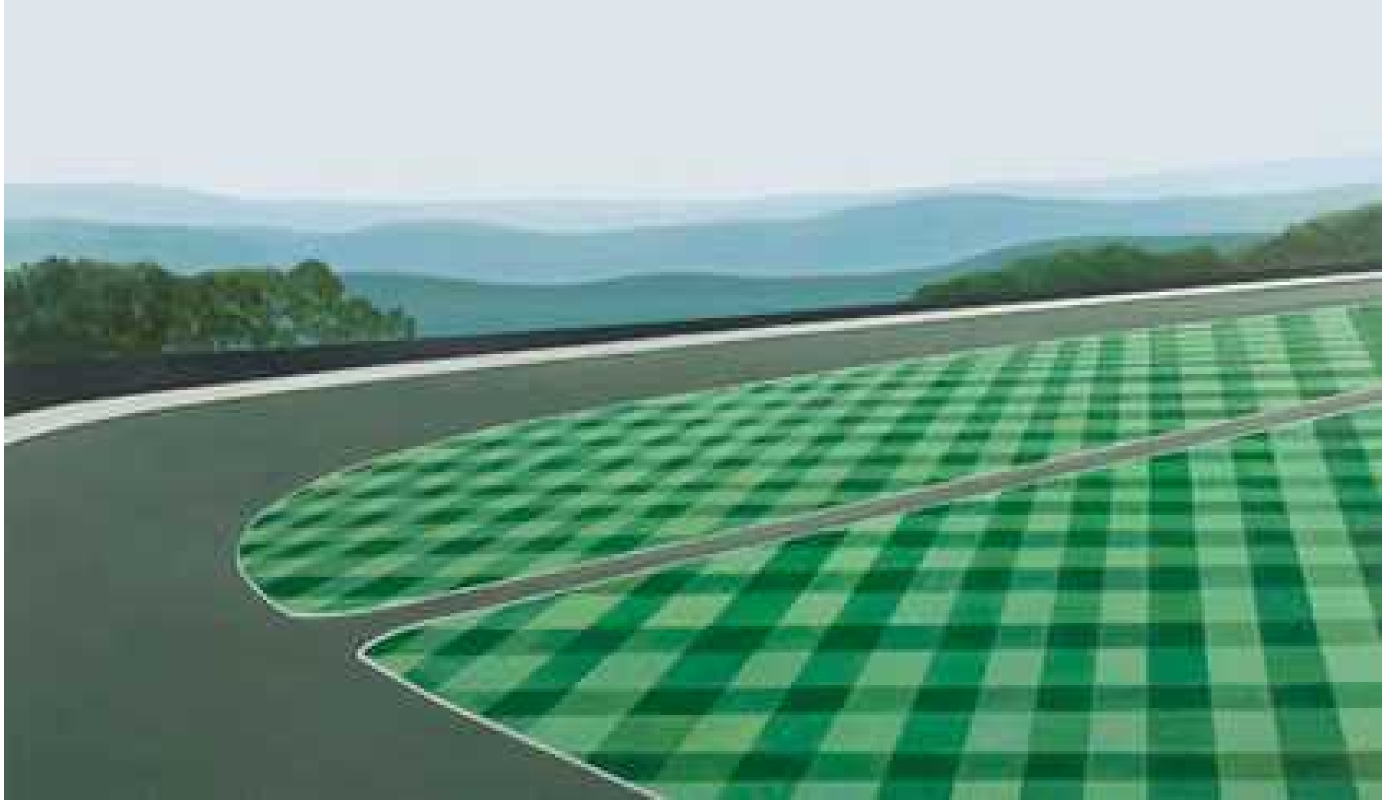


Useful Tools





14.2 – Search Design



Define the Search Limitations

- Geographic boundaries
- Weather constraints
  - No rain or snow
    - Possible with PackEye
  - No water puddles
- Practical constraints
  - Equipment limitations
  - Site access restrictions
  - When do you stop? (We'll discuss this)

Onsite Preparations

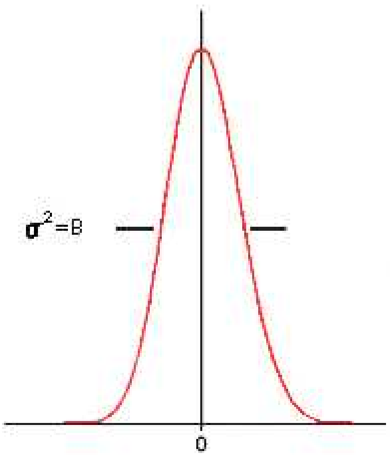
- Determine if previously gathered information was accurate
  - Do boundaries need to be changed?
  - Are the conditions what were expected?
- Select background reference area
- Determine the reference background count rate (R_b)
- Discuss
  - Search methods
  - Contamination control
  - Leaking source issues
  - Actions to take if a source is discovered

Background Counting is an Important Part of Determining Sensitivity

- Background radiation fluctuates

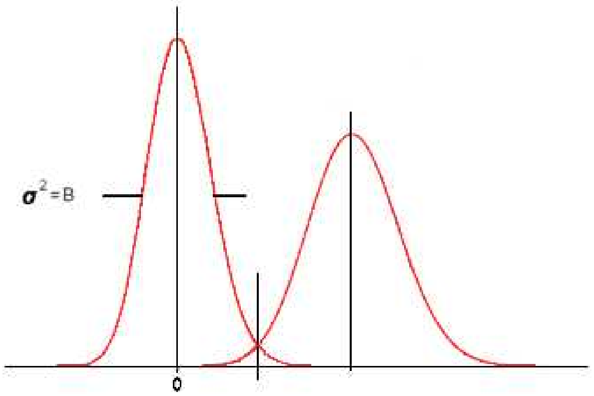
- By calculating an average Background Count Rate and standard deviation of the rate, you can begin to determine whether a measurement is greater than background.

- More detailed information is in Appendix 14-A.



Examples

- Example 1
  - One background measurement with R_b = 35 counts per minute (cpm).
  - During your search, an area yields 45 cpm
  - Is there a source?
- Example 2 (same area)
  - 10 background measurements
  - R_b varies from 26-55 cpm
  - 45 cpm measurement was not significant!



Calculating the Average Background Count Rate

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- Determining R_b
  - Suggest at least 10 one-minute measurements
  - Use the same count time for all measurements
  - Use the applicable formula below:

$$R_b = \frac{\sum_{i=1}^{n} \frac{C_b}{T_b}}{n}$$

$$R_b = \frac{\sum_{i=1}^{n} R_n}{n}$$

Note:

$\mathbf{C_b}$ – counts (for equipped instruments)

R_n – count rate (for equipment not capable of recording counts)

$\mathbf{T_b}$ – count time for each measurement

n – number of measurements taken

Example: Calculating the Average Background Count Rate

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Ten 1-minute counts were taken to determine the background count rate in the reference area. The net counts observed are provided in the table below. What is the average background count rate?

n	Number of Counts	n	Number of Counts
1	27	6	25
2	31	7	22
3	20	8	36
4	26	9	27
5	29	10	24

Calculating the Average Background Count Rate

- Using the formula provided earlier:

$$R_b = \frac{27/1\min + 31/1\min + \ldots + 27/1\min + 24/1\min}{10}$$

$$R_b = 26.7cpm$$

General Equipment Application

- Use primary search tools to find sources
  - PackEye
  - Inspector 1000
  - Radiagem 2000 with NaI probe
- Use secondary or support tools to localize the source (prefer audio response)
  - RadEye
  - MicroSievert
  - Radiagem 2000 base alone or with TELE-STTC
- Attempt identification with Inspector 1000

Conducting Site Searches

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- Broad Area
  - Quick check of entire site
  - Not sufficient for shielded or buried sources!
    - Large or small bare sources are easy to find
    - Orphan sources are not typically found in a bare condition
- Local Area
  - Conducted after the broad-area search
  - Use grid pattern to ensure full coverage
  - Ensures you find all sources regardless of condition

Broad Area Searches

Primary search tools can be used in a slow-moving vehicle (5 – 7 km h^{-1} max) …

Broad Area Searches

A large area can be covered quickly with few people……..

Decision Rules
(When have we found something?)

- For the PackEye or RadEye investigate all artificial source alarms (due to NBR)
- For all other instruments rule can be based on the background count rate (R_b), counts (B), or radiation level.
- We propose using the following combination
  - 2 x R_b = assessment level
  - 3 x R_b = action level

Use of Assessment and Action Levels

- **Assessment Level ($\geq 2 \times R_b$)**
  - Stop where you are
  - Let the meter stabilize
  - Resume survey if action level criteria not met

- **Action Level ($\geq 3 \times R_b$)**
  - Source exists
  - Investigate
    - Localize
    - Attempt to identify

Broad-Area Search

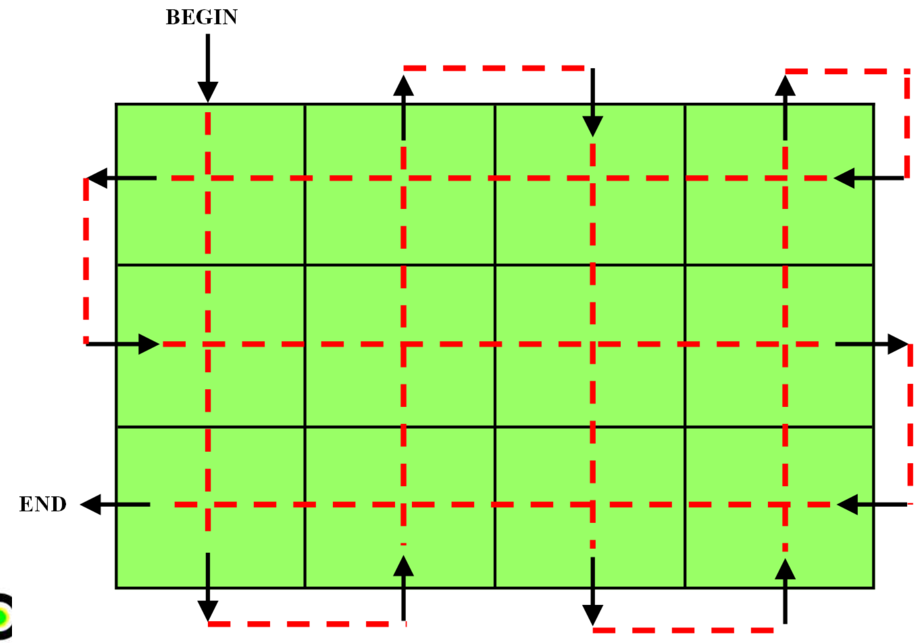
- Use most-sensitive detectors
  - Audible-equipped units are preferred
  - If audible response not available
    - Pay close attention to meter face
    - Be very careful when walking and doing this!
- Investigate all suspicious items or areas
- Remove sources and resurvey to check for multiple sources and/or contamination
- Conduct local-area search when completed

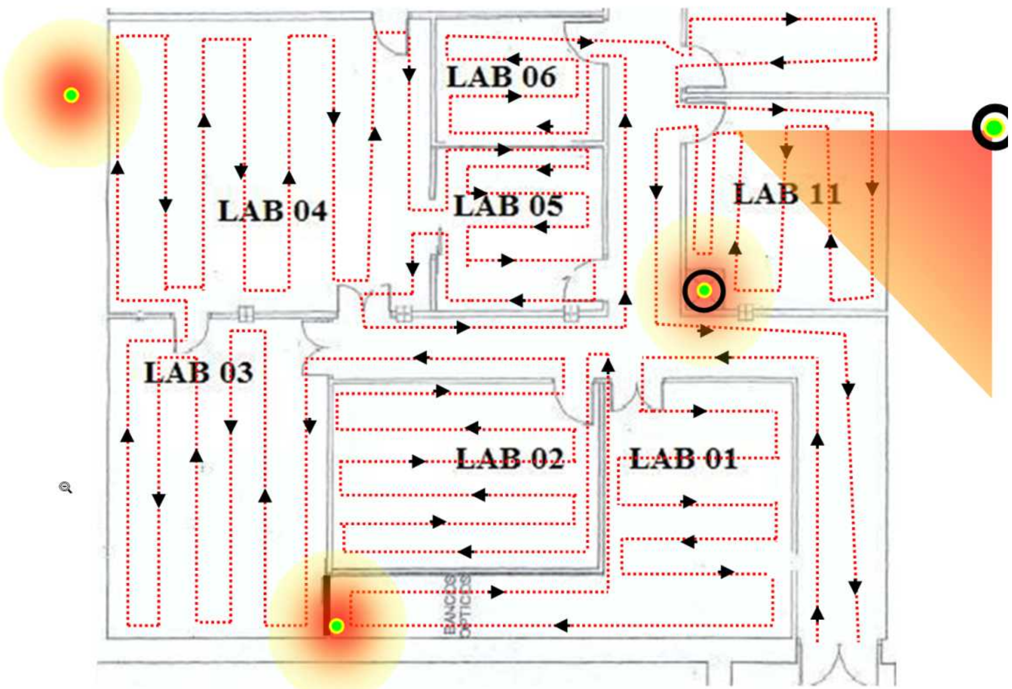
Local-Area Search

- Follow a grid pattern
  - Use 2 m spacing for photons/neutrons
    - Each 2 m point is a grid point
    - More details are available in Appendix 14-B
  - Pause at each grid point and allow meter to stabilize
    - Let instrument stabilize
    - Continue toward next grid point if count rate doesn't exceed the assessment or action levels
  - Listen for increase in audible count rate at any location of the survey (not just grid points)
    - $\geq 2 \times R_b$ (assessment level)
    - $\geq 3 \times R_b$ (action level)
- Survey is complete when the grid has been covered

Following the grid helps to assure that the survey is complete

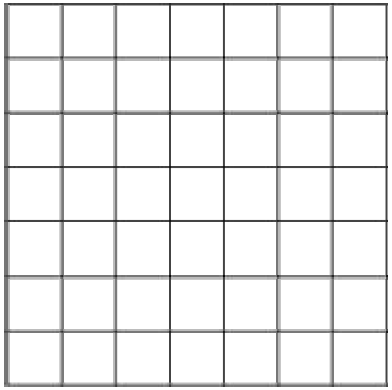
Following a grid can be helpful both during the outdoor and indoor searches



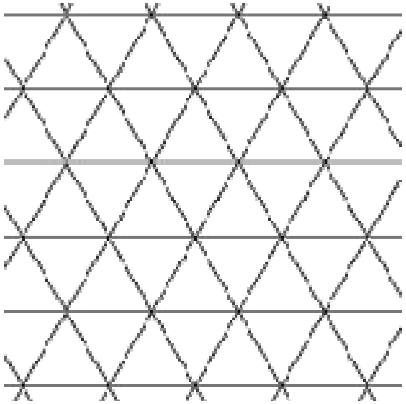


Grid Patterns

- Square
  - 2 m sides
  - Easy to use
  - Requires more points for a given confidence level



- Triangular
  - Equilateral triangles with 2 m sides
  - More difficult to use
  - Requires less points



Telescoping Probe (TELE-STTC)

Used for approaching high radiation fields once a source is located…

Building Searches

- Search buildings first
- Visit all floors
- Search rooms with the following items first:
  - Attic or basement areas
  - Suspicious looking items
  - Nuclear-related signs
  - Garbage containers
  - Industrial shop areas
  - Floor drains
  - Sewer lines
- Building Surveys
  - Search plan for photons and neutrons
  - Pause for increased counts
  - Perform static 1 minute count if count rate $\geq 2 \times R_b$
  - $\geq 3 \times R_b$ is a source

Field Searches

- Search after buildings
- Pay particular attention to:
  - ditches, sheds, or trailers
  - suspicious looking items
  - radiation-related signs
  - garbage containers
  - above-ground tanks
  - septic or sewer areas
  - earthen mounds
  - underground tanks

- Site surveys
  - Search plan for gamma and neutron emitting sources
  - Pause for increased counts
  - Perform static 1 minute count if count rate $\geq 2 \times R_b$
  - $\geq 3 \times R_b$ is hot spot flag

Possible Actions Resulting from the Search

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- No sources found
  - Document the search
  - No other action is necessary
- Sources Found
  - Localize the source
    - Using appropriate equipment
    - Approach slowly
    - Use body as simple method to determine directionality
    - Use of tools, such as a shovel may assist
  - Estimate activity
    - RO-20 ion chamber
    - 1 m distance

Possible Actions Resulting from the Search (continued)

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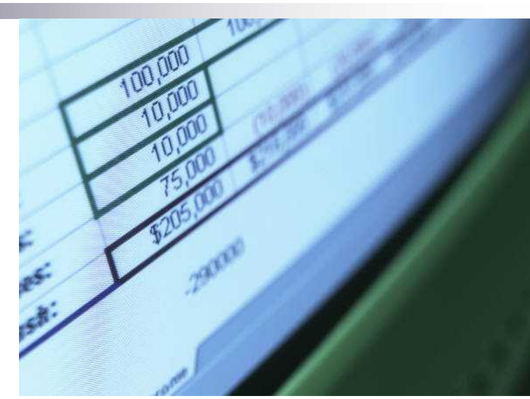
- Sources found (continued)
  - Assess need for shielding
  - Control access to the area and post trefoil sign
  - Identify the radionuclide (if possible)
  - Assess contamination
  - Evaluate the best follow up actions
    - Prepare for transfer (see Packaging and Transportation)
      - Lab for analyses (take other action afterward)
      - Recycle or reuse
      - Interim storage
      - Disposal
    - Secure in place
    - GTRI and/or the IAEA may be able to provide assistance with transportation and physical protection.

Site Search Report



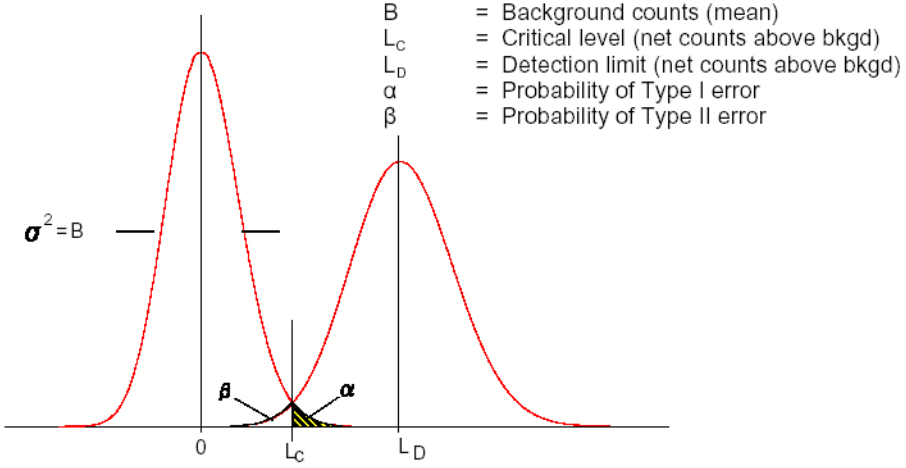
- Radioactive sources located during search
  - Physical form
  - Radioactivity level
  - Volume and weight measurements
- Actions taken to secure the source
- Options being considered for securing the source
- Copy of all survey documentation
- Discussion of problems encountered during searches
- Digital photographs of the site, buildings, and important features that are correlated to the search maps
- Source recovery begins after location (and possible identification) and will be discussed in a separate presentation

Appendix 14-A

- Evaluation of equipment sensitivity
- Calculating critical level (L_c), detection level (L_d) and minimum detectable activity (MDA) using equipment parameters
- Specify tolerable decision errors

Evaluation of Equipment Sensitivity

- Critical Level (L_c)
  - Response is above background
- Detection Level (L_d)
  - Response can be seen with a fixed certainty
- Minimum Detectable Activity (MDA)
  - Convert L_d to units of activity
- Evaluate each piece of equipment



Critical Level (L_c) – Response is "Above Background"

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- Background Count Rates

$$L_c = k\sqrt{\frac{\overline{R}_b}{T_b} + \frac{\overline{R}_b}{T_s}}$$

Where:

- k = 1-sided confidence level
- = 2.32 (99% confidence)
- = 1.645 (95% confidence)
- = 1.2816 (90% confidence)
- R_b = average background count rate (counts per minute – CPM)
- T_b = background count time (minutes)
- T_s = sample count time (minutes)

- Static Background Counts

$$L_c = k\sqrt{2\overline{B}} = 2.33\sqrt{\overline{B}}$$

(@ 95% Confidence)

Where:

- k = 1-sided confidence level
- = 2.32 (99% confidence)
- = 1.645 (95% confidence)
- = 1.2816 (90% confidence)
- B = average number of background counts

Detection Level (L_d) – Response is "Above Background" with a Fixed Certainty

- Background Count Rates

$$L_d = \frac{k^2 + 2k\sqrt{\bar{R}_b T_s (1 + \frac{T_s}{T_b})}}{T_s}$$

Where:

- k = 1-sided confidence level
-   = 2.32 (99% confidence)
-   = 1.645 (95% confidence)
-   = 1.2816 (90% confidence)
- R_b = average background count rate (counts per minute – CPM)
- T_b = background count time (minutes)
- T_s = sample count time (minutes)

- Static Background Counts

$$L_d = k^2 + 2k\sqrt{2\bar{B}} = 3 + 4.65\sqrt{\bar{B}}$$

(@ 95% Confidence)

Where:

- k = 1-sided confidence level
-   = 2.32 (99% confidence)
-   = 1.645 (95% confidence)
-   = 1.2816 (90% confidence)
- B = average number of background counts

Minimum Detectable Activity (MDA) – Converts L_d to Units of Activity or Dose

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- Background Count Rate

$$MDA = \frac{k^2 + 2k\sqrt{\overline{R_b}T_s(1+\frac{T_s}{T_b})}}{C \cdot \varepsilon \cdot T_s} = \frac{L_d}{C \cdot \varepsilon}$$

Where:

- L_d = detection level
- C = unit conversion factor
- ε = detector efficiency (counts per disintegration, counts per μSv, etc.)
- T_s = sample count time (minutes)
- T_b = background count time (minutes)

- Static Background Counts

$$MDA = \frac{k^2 + 2k\sqrt{2\overline{B}}}{C \cdot \varepsilon} = \frac{L_d}{C \cdot \varepsilon}$$

Where:

- L_d = detection level
- C = unit conversion factor
- ε = detector efficiency (counts per disintegration, counts per μSv, etc.)

Calculating L_c, L_d and MDA using Equipment Parameters

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- Equipment-related values:
  - Time Constant (T_c)
  - Response Time (R_t)
- Examples:
  - Radiagem 2000 Base Unit (1 s)
  - Inspector 1000 (1 µs)
- Use the count rate equations, but make one of the following substitutions:

$$T_s = T_b = 2T_c$$

$$T_s = T_b = 0.88R_t$$

Equipment Sensitivity Exercise

- Calculate L_c and L_d using the count rate data provided by the instructor:
  - Use both count rate and static count equations
  - Assume sample count times and background count times are identical
  - State your confidence level
- Calculate L_c and L_d using the average count rate determined above:
  - Use time constant and response time
  - State your confidence level
- Compare and contrast the results.
- Keep in mind that your gross count rates at critical level and decision level are, respectively:

$$\overline{R}_{G_c} = \overline{R}_B + L_c$$

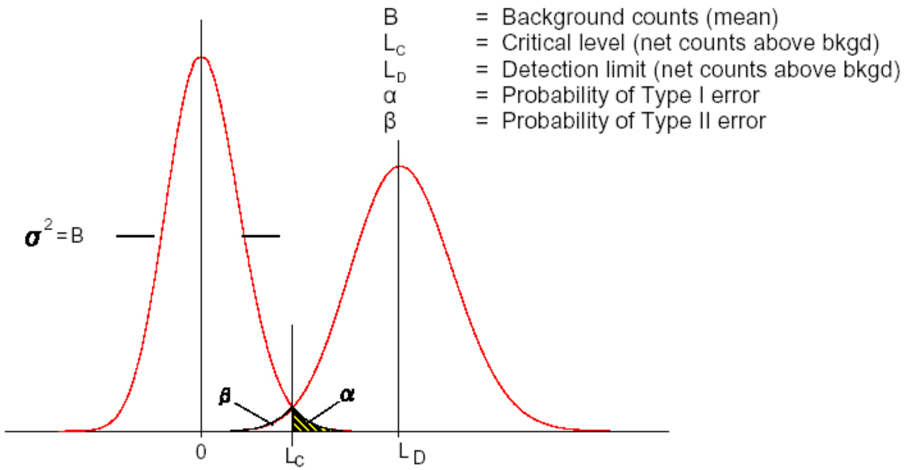
$$\overline{R}_{G_d} = \overline{R}_B + L_d$$

MDA Calculator Software

- Provided on your CD
- Developed by Ludlum
- Calculates L_c, L_d, MDA for all Ludlum models
- Also calculates L_c, L_d, and MDA using our equations
- Demo

Specify Tolerable Decision Errors

- State the Null Hypothesis
  - Radiation levels from orphan sources exceed the action level
- Decision Errors
  - False positive (α)
  - False negative (β)
- Minimal Concern for α
  - No indirect sampling costs
  - Several equipment types
  - Immediate verification



Appendix 14-B

- Optimize the Search Design
- Indirect Sampling Plan or Direct Radiation Measurements
- Determining Grid Spacing (γ and η only)

Optimize the Search Design

- Specify the sampling (measurement) plan
- Select the best data collection design
  - Direct measurements in our case
- Determine the number of samples (radiation measurements) to be taken
- Ensure the measurement methods will provide the required data

Assumptions

- Target hot spot is circular or elliptical
- Measurements are taken on a grid
  - Square
  - Rectangular
  - Triangular (we will use these)
- Only a small portion of the total area is sampled (measured)

Determining Grid Spacing (γ and η only)

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- Specify the shape factor (S) of the elliptical target
  - S = 1.0 is a circle
  - S < 1.0 is an ellipse (use for increased confidence)
- Specify L (radius of radiation pattern within which it can be detected)
  - L = 1 m acceptable for photons > 50 keV and all neutrons
  - Choose L < 1 m for increased confidence
- Specify an acceptable false negative rate (β)
  - Suggest 5 – 20 %
- Solve for G (grid spacing)
- Use G to specify the distance between static counting points during survey
- Take continuous measurements between grid points

Determining Grid Spacing Triangular Grid

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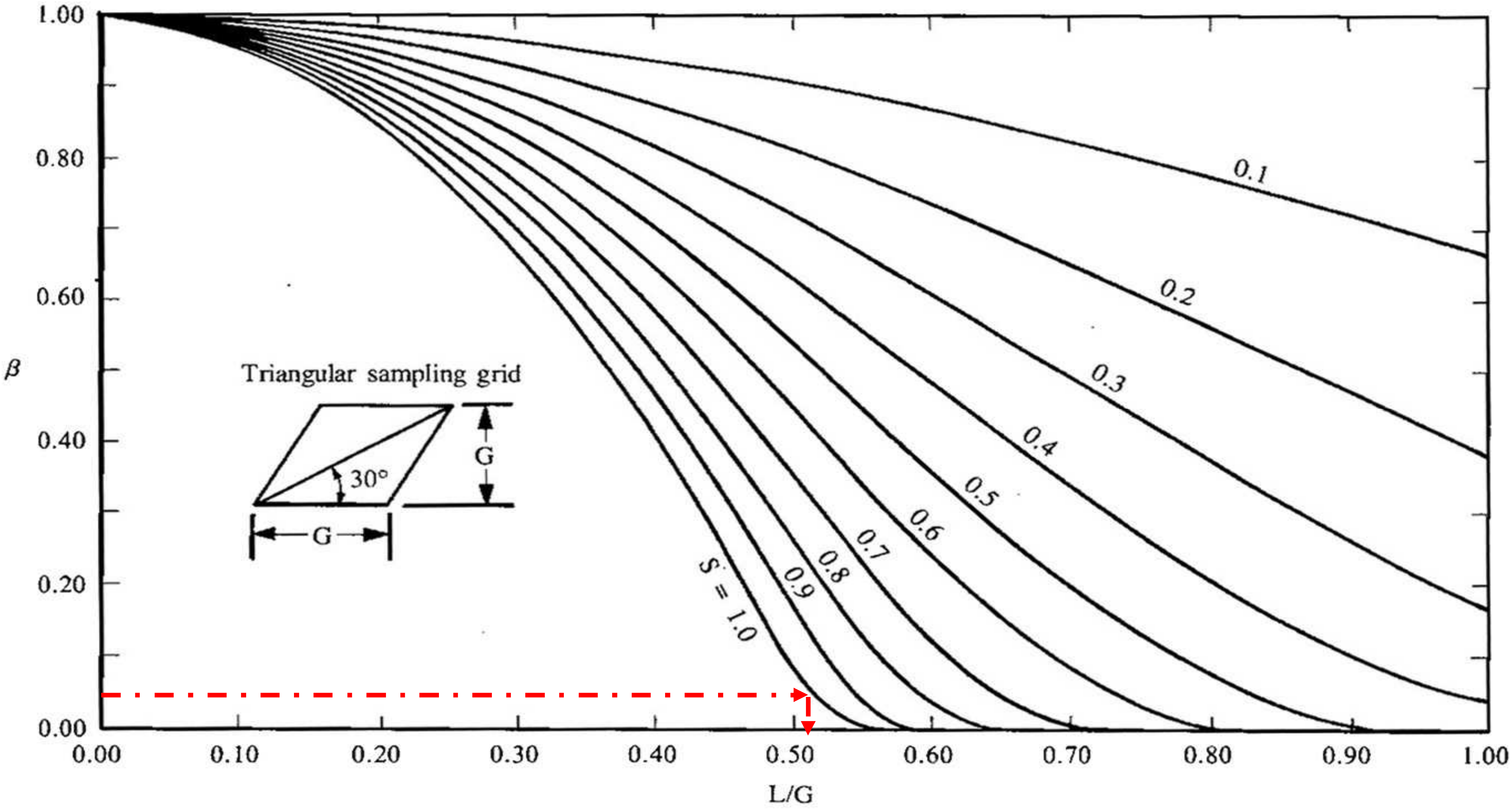

L = 1.0 and L/G = 0.51 therefore, G = 1.96 m or 2.0 m

Indirect Sampling Plan or Direct Radiation Measurements (sub-surface contamination or source)

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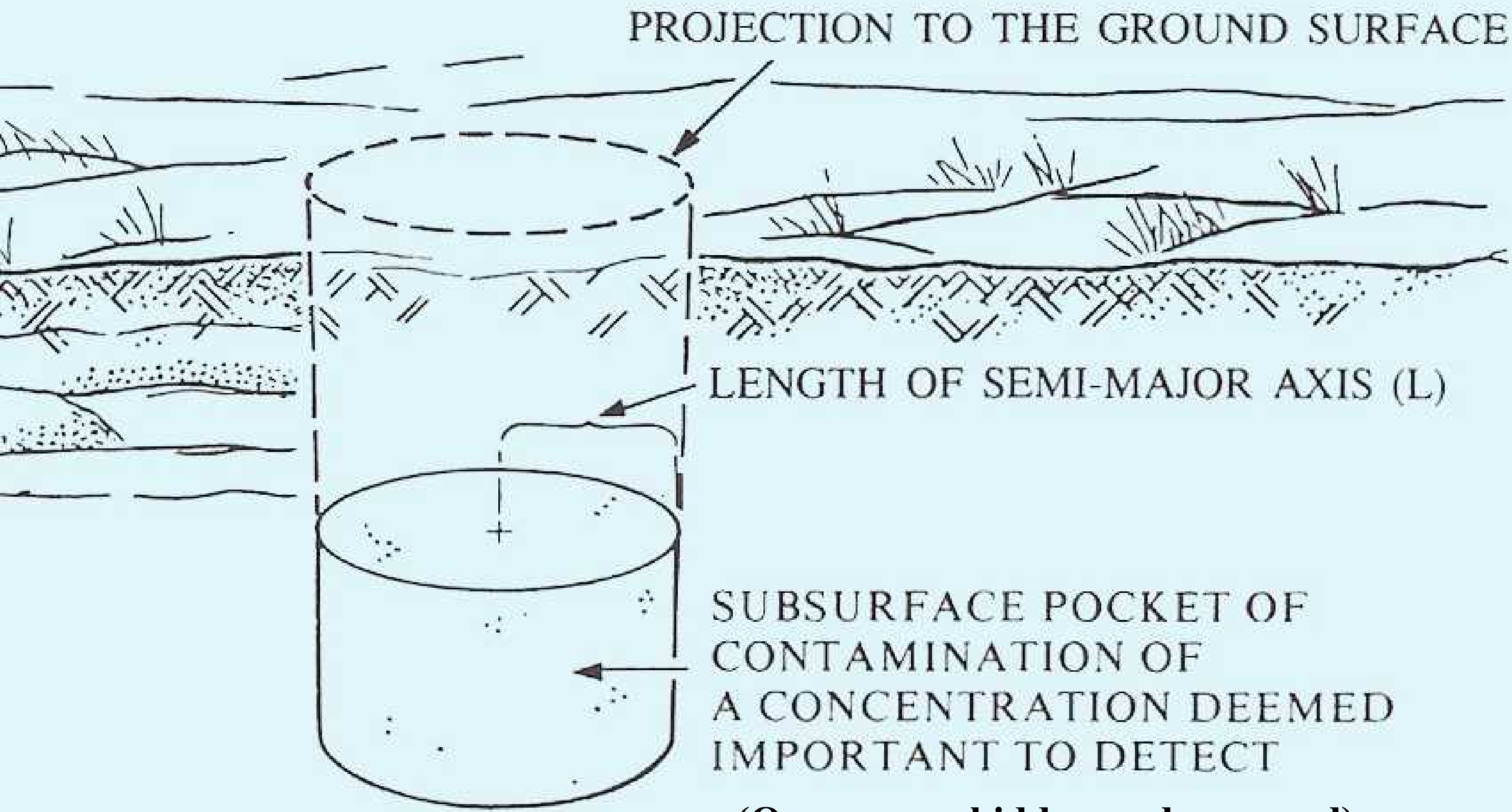

(Or a source hidden underground)

Visual Sample Plan (VSP) Software

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- Developed by Pacific Northwest National Laboratory (PNNL)
- Applications are for radiation site surveys and assessment and other decommissioning activities
- We are only using one small part of this code to optimize the search grid
- Free download at http://vsp.pnl.gov
- Current version is 6.0
- Provided on your CD
- Demo