Decision-Making Requires Data

Instrumentation and analytical methods are the sources of data:

- “Real-time” versus more traditional methods
- Radionuclide-specific versus gross activity measurements
- In situ versus ex situ measurements
- “Cheap, fast, qualitative” versus “expensive, slow, definitive”
Ionizing Emissions Serve as the Basis for Most Radionuclide Measurement Systems

- Radioactive decay can involve a variety of emissions, including alpha particles, beta particles, and gamma rays.
- Gamma rays are typically the preferred emissions for measuring activity concentrations in soils because they are easiest to measure.
- Radionuclides that are not gamma emitters are often mixed with other radionuclides that are, and can be used as surrogates.
- For the decay of a particular radionuclide of concern, such as radium-226 or its daughter products, emissions are characterized by their specific energy and abundance.
Measurement Challenges

- **Alpha radiation (positively charged particle)**
  - Easily shielded, even by air
  - Place detector on or very near surface

- **Beta radiation (negatively charged particle)**
  - Shield/discriminate alpha, measure beta-gamma
  - Use at close range

- **Gamma radiation (photon, no mass)**
  - Field of view, collimators, shine, source geometry, self-shielding
  - 1-m height for dose rate measurements
Field of View

- “Field of View” refers to what a detector “sees”
- Field of view can vary dramatically from detector to detector
- Field of view is controlled by height of detector off ground, detector geometry, and collimation
- Shine refers to sources of radiation that affect a measurement without being in the presumed field of view
Energy Spectra

Co60

Characteristic photons

Resolution of energy peaks

Counts

Channels

Photon energy
Measurements Often Target Daughter Products or Progeny

Uranium-238 Decay Series

- U-238
  - $\alpha$ 4.5 x $10^4$ yrs
  - $\beta$ 1.2 mins
- Th-230
  - $\alpha$ 240,000 yrs
- Pa-234
  - $\beta$ 24 days
- Ra-226
  - $\alpha$ 1,600 yrs
- Ra-222
  - $\beta$ 3.8 days
- Po-214
  - $\beta$ 3.1 mins
- Po-218
  - $\alpha$ 20 mins
- Pb-214
  - $\beta$ 27 mins
- Pb-210

Thorium-232 Decay Series

- Th-232
  - $\alpha$ 14 x $10^9$ yrs
- Th-228
  - $\beta$ 6.1 hrs
- Ra-228
  - $\alpha$ 1.9 yrs
- Ra-224
  - $\beta$ 5.8 yrs
- Ra-220
  - $\alpha$ 3.6 days
- Rn-220
  - $\alpha$ 55 sec
- Po-212
  - $\beta$ 1.1 hrs
- Po-216
  - $\alpha$ 0.15 sec
- Bi-212
  - $\beta$ 11 hrs
- Pb-208
  - $\alpha$ 61 mins
- Pb-206
  - $\beta$ 3.1 mins
- Th-208
  - (stable)
Secular Equilibrium Assumptions Are Often Important

- Secular equilibrium: decay products are at the same activity concentration as parents
- Occurs when undisturbed in-growth has taken place over several half-lives for daughter products
- If assumption holds, allows one to measure a daughter and infer the activity concentration of the parent radionuclide
- A very common assumption made by laboratory gamma spec
- Can be an issue when daughters are mobile and samples are disturbed (e.g., Ra-226 decay chain)
- For data quality reviews, important to understand exactly what a lab is measuring
Basic Measurement Choices

- Soil samples with laboratory analyses
- Soil samples with field analyses
- Direct measurement techniques
- Scanning or survey techniques
Soil Sampling and Laboratory Analyses

- Typically ~400 grams of soil collected
- Laboratory uses alpha or gamma spectroscopy or beta scintillation for analysis with accurate activity concentrations returned
- Costs are on the order of $200 per sample or more
- Turn-around times usually weeks
Direct Measurements: In Situ HPGe/NaI Systems

- Works for gamma-emitting radionuclides (Ra-226, Th-232, Cs-137 and U-238)
- With proper geometry assumptions, provides activity concentration estimates
- Measurement times on order of 15 minutes with results immediately available
- Field of view considerations important
- Per measurement cost on order of $100
Field Analytical Methods: XRF

- Designed for inorganic analysis
- Measures total U and other metals (ppm)
- 2-minute count times or less
- Per measurement costs on order of $40 or less
Scanning/Screening Detectors

- Gas-filled (gas amplification of ion pairs)
  - Gas flow proportional counter (GPC)
  - Geiger-Mueller (GM) counter
  - Pressurized ionization chamber (PIC)

- Solid Scintillator (fluorescence)
  - NaI (TI)
  - ZnS (Ag)
Radiation and Detectors

- Alpha emitters
  - Gas Proportional
  - ZnS scintillator
  - Phoswich scintillator

- Beta-gamma
  - Gas Proportional
  - G-M
  - NaI (FIDLER, 1”×1”, 2” ×2”)

- Low-level gamma
  - G-M, PIC, NaI, plastic scintillator

- Higher-level beta-gamma
Quick Soil Screening: Geiger-Mueller Detector

- General-purpose detector
  - Beta-gamma surveys
  - Surface contamination
  - Exposure rate measurements (50 µR/h)
  - Health and Safety applications
  - Screening areas/materials
**Gross Activity Area Scans: NaI-Based Systems**

- Thin window mini-FIDLER with NaI crystal for gross counts
- Shielded housing to lower background and control field of view
- Rate meter for measuring output and interfacing with data logger
- Can be combined with GPS unit for locational control
- 2 second acquisition time
- Pennies per measurement
Example Output from Gross Gamma Scan and Sampling

- GPS-based NaI scans provide detailed information about spatial distribution of contamination in soils
- When coupled with mapping tools such as GIS, provide excellent means for characterizing soil surfaces
Dynamic Data Collection Strategies

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Presentation Focus

- Interpretation of gross gamma scans
- Use of incremental sampling approaches for improving mean estimates
Gross Gamma Scans Are Invaluable, But…

- Quickly and cheaply provide spatially complete coverage of exposed surfaces
- Data can be captured, tied to locations, and mapped to provide visual sense for where contamination is present
- Results (gross activity measured as cpm or cps) are not in same form as cleanup requirement definitions (e.g., radionuclide-specific activity concentrations)
- **Challenge:** How do we interpret gamma scan data to support decision-making?
How Do We Interpret These Results?
Interpreting Gamma Scans Requires Matching Physical Soil Sample Results

- Soil samples are collected from locations where stationary gross activity data are also available
- Locations are selected to target a range of activity likely to span our decision-making criteria
- Typically looking for at least 20 sample results
- Samples are collected in a manner that mirrors the field of view of the detectors, to the extent possible
- The products are paired results that can be evaluated (i.e., locations with both gross activity data and a sample-based activity concentration)
For Single Radionuclide Sites, Linear Regression Can Be Used to Derive Relationship

- When just one gamma-emitting radionuclide is present, one expects a linear relationship between gross activity and activity concentrations.
- Linear regression can convert cps or cpm to an equivalent activity concentration that can be compared to cleanup criteria.

\[
y = 0.0047x - 44.846
\]

\[R^2 = 0.9015\]
Example Data Transformation…
Sometimes the Relationship is Not so “Clean”…
FIDLER Gross Gamma Activity Scans
A Non-Parametric Approach Connects Gross Gamma Activity with the Probability of Requirement Exceedance
Gross Gamma Activity Converted to Probability Map

Probability of Cleanup Guideline Exceedance
Improving Average Activity Concentration Estimation Based on Samples

- The goal of collecting information is often to determine the average activity concentration of radionuclides of concern over an exposure unit.

- For some radionuclides, sampling and laboratory analyses of samples are required to do this.

- The question is how best to design soil sampling programs so that accurate average activity concentration estimates are obtained as cheaply as possible.
Nirvana

- Representative, fast, cheap, high-density method providing definitive data to support an action level or cleanup requirement

- Reality Bites:
  - Expensive, time-consuming analytics
  - Few samples collected
  - Measurement error & interpretation issues
Recall: Heterogeneity Dominates Decision Errors

- When contamination is present, there is typically significant heterogeneity present in soils
- Error in mean estimation is driven primarily by heterogeneity when only a few samples are collected
- Obtaining accurate estimates of average activity concentrations can require a lot of samples per exposure area (e.g., 30 or more)
Incremental Soil Sampling is an Emerging Solution

- Used to cost-effectively suppress heterogeneity to improve mean concentration estimates based on samples
  - Estimates of the mean are less uncertain & closer to true

- Multiple soil increments contribute to a composite that is homogenized and analyzed

- Increments systematically distributed over an area are equivalent to, or less than, decision unit/exposure unit

- Effective when the cost of analysis is significantly greater than cost of sample acquisition
How Does Incremental Soil Sampling Work?

- Physical equivalent of averaging individual sample results
- Tends to “normalize” underlying distribution, making statistics work better
  - Student t-test, UCL calculation
- A set of composite sample results shows less variability than discrete sample counterparts
- Theoretically, the more increments per composite sample, the lower the variability in a set of composite sample results
  - Homogenization is critical!!
How Should Increments Be Distributed?

Six composite samples composed of 10 increments each

- Composite sample increments distributed systematically over entire unit
  - Distribution of each increment set could also be random
  - Data from systematic vs. random sampling will give different kinds of information

- Composite sample increments distributed systematically over adjacent, smaller areas
Both Approaches Have Strengths and Weaknesses

- Each composite representative of the whole unit:
  - Normalizes underlying sample distribution
  - Removes effects of spatial patterning on statistics
  - Provides no insight into spatial patterning
  - Cannot identify elevated areas

- Each composite representative of a sub-unit:
  - Provides insight into spatial patterning
  - Useful for hot spot identification
  - Statistics affected by spatial patterning
Data Management, Visualization, and Communication

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Characterization Activities at Sites Can Generate Enormous Amounts of Data

- Typical gamma walkover surveys, if logged, will produce as many as 400 data points per 100 m² area
- 100s or 1,000s of samples may be collected from a site and analyzed in a laboratory for a range of radionuclides
- Sites may have significant amounts of other data, such as:
  - Aerial photographs
  - On-site photographs
  - Non-intrusive geophysical surveys to look for subsurface anomalies
  - Mapping information (roads, fence lines, hydrology, building footprints, etc.)
These Data, Together, Are Critical to Correct Decision-Making
Coordinates and Mapping Systems are Key to Understanding Results

- Mapping software such as Geographical Information Systems (GIS) are critical to proper understanding of data collection results
- Good coordinate information is needed for all types of data in order for mapping software to be effective
- Obtaining data in a digital format simplifies the work needed to work with, display, and analyze characterization information
Data Management Systems

- Data management systems are important components of site characterization efforts
  - They preserve information over time and organize data in a manner that allows it to be presented, analyzed, and communicated effectively
  - They are typically based on relational databases to facilitate data handling
  - It is important to have well-defined rules and roles to ensure the integrity of data within a data management system is maintained and to prevent intentional or accidental alterations
Generic Relational Database Design
Password-Protected Web Sites are Effective for Project Information Dissemination

Historical Data

Drilling Logs (non-QCed)
- Drilling Logs from PV55001 to PV55229, from Dec. 5, 2006

BEGe Lab Results (non-QCed)
- Final BEGe data as of Dec. 6, 2006 (214 KB)

Downhole Gamma Results (non-QCed)
- Final DHC data (received 12/6/05) (750 KB)

Class 2 Area Static Counts
- Class 2 Area Static Counts (received 12/13/06) (49 KB)

Preliminary Downhole Gamma and BEGe Correlation
- Preliminary Correlation of Downhole Gamma and BEGe (19/12/05) (261 KB)
- Preliminary Correlation of Downhole Gamma and BEGe (3/28/05) (112 KB)

Painesville Remediation — 2010

Formerly Utilized Sites Remedial Action Program

The purpose of this web site is to provide a source of up-to-date information of the ongoing remediation efforts for the Painesville site. The content includes sampling results (maps and data) related to the site's remedial excavation areas and Final Status Survey units.

Use the menu navigation at the top of the page to browse the site.

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