Statistical Methods to Identify Low-level Bias in Radioanalytical Data

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Historical

- Unexpected “false” positive results associated with analysis of environmental media
  - Groundwater, Soil, Concrete
  - Analyses performed to environmental limits (Low MDCs, DCGLs)
- HTD’s
  - LSC (Fe-55, Ni-63, Tc-99, Pu-241)
  - GPC (Sr-90)
  - Alpha spectroscopy (Am-241)
Impact/Needs

• Impact
  – Results not representative of aquifer or sampled media
  – Required additional resources

• Analytical Needs
  – Method to distinguish false positives from real detects
  – Method to identify and quantify analytical bias at low levels (near MDC)
Definitions

• Bias
  – Limiting mean different from the true value
  – Consistent error of same size and magnitude

• Low-level Bias Assessment
  – Limiting mean different from expected zero analyte concentration
  – Limiting mean concentration or bias near MDC
Bias Assessment Methods

• Parametric Statistics
  – Outlier detection
  – Z-score testing
  – Normality testing
  – Student t-testing
General Assumptions

• Data comprised of 2-distributions
  – Underlying background/baseline
    • Attributed to instrument noise
    • Normally distributed around limiting mean
  – Plant related nuclides with unknown spatial distribution (non normal)
H-3 Rank Order for Dec-2004

- Rank Order
- Concentration (pCi/L)
- Baseline (Normal)
- Spatial Dist. Data (Non Normal)
- H-3
- Zero Mean
- -2-Sigma
- +2-Sigma
- Ave. MDC
Bias Assessment Methods

• Segregate data into logical sub-sets
  – Discrete sample events
  – Lab processing batch
• Sort by Rank Order
• Perform Outlier Testing
• Evaluate limiting mean distribution for normality
• Test if limiting mean different from 0
• Limiting mean sign indicates positive, negative bias
Outlier Testing

• Arrange data by rank (ascending) order
• Compute running mean by rank order
• Compute robust sigma statistic ($\sigma_o$)
  – Based on background signal only!
  – Derived from sample MDCs (MDC=2*k*$\sigma_o$)
• Compute modified Z-score $\left(\frac{x_i - X}{\sigma_o}\right)$
• Z-score > critical-T are outliers and not part of underlying background distribution
Normal Distribution Test

• Arrange data by rank order
• Compute mean and std. dev. statistics
• Compute Filliben r-statistic (normal probability plot correlation)
  – Compute sample order median statistics
  – Compute theoretical order median statistics for normal distribution
• Computed r-value near unity is normal
Limiting Mean t-Test

- Compute limiting mean, std. dev. statistics
- Compute t-test statistic where $\mu_0=0$

$$t = \left| \frac{(\overline{X} - \mu_0)}{s / \sqrt{n}} \right|$$

- t-Test statistics > critical t-value statistically different from $\mu_0=0$ assumption
- Sign of limiting mean indicates positive or negative bias
Mn-54 Rank Order for Sep-2004

Rank Order

Concentration (pCi/L)

Mn-54
Lim. Mean
-2-Sig.
+2-Sig.
Ave. MDC

X: 0.3, σ: 1.0

\[ t\text{-stat: } -2.0 < \text{critical-}t: 3.4 \]
Mn-54 Normality Plot for Sep-2004

Filliben statistic: 0.98
Critical Filliben statistic: 0.97
Co-60 Rank Order for Dec-2004

Rank Order

Concentration (pCi/L)

Co-60, Lim. Mean, -2-Sig., +2-Sig., Ave. MDC

X: 0.4, σ: 1.3

T-stat: 2.3 < Critical-t: 3.3
Co-60 Normality Plot for Dec-2004

Filliben statistic: 0.99
Critical Filliben statistic: 0.98
H-3 Rank Order for Dec-2004

![Graph showing rank order and concentration data for H-3.]
H-3 Rank Order for Dec-2004 (Baseline)

Graph showing rank order with concentration (pCi/L) on the y-axis and rank order on the x-axis. The plot includes markers for H-3, Mean Bkg, -2-Sig. Bkg, +2-Sig. Bkg, and Ave. MDC. The data indicates that X: 52, σ: 84, and the t-stat: 3.9 > critical-t: 3.4.
H-3 Normality Plot for Dec-2004 (Baseline)

Filliben statistic: 0.98
Critical Filliben statistic: 0.97
Fe-55 Rank Order for Sep-2002

X: -4.0, σ: 3.4

x-stat: |-4.5| > critical-t: 2.1
Fe-55 Normality Plot for Sep-2002

Filliben statistic: 0.98
Critical Filliben statistic: 0.94
Tc-99 Rank Order for Dec-2002

X: 8.0, σ: 4.7

t-stat: 6.0 > critical-t: 2.2
Tc-99 Rank Order for Dec-2002

Filliben statistic: 0.98
Critical Filliben statistic: 0.93
Sr-90 Rank Order for Jun-2003

X: 0.7, σ: 0.5

\( t \)-stat: 6.6 > critical-\( t \): 2.0
Sr-90 Normality Plot for Jun-2003

Filliben statistic: 0.98
Critical Filliben statistic: 0.96
Conclusions

• Impact of analytical bias on detection decisions

• Include impact of analytical bias
  – Propagate additional uncertainty
  – Add impact to MDC (positive bias)

• Greater impact expected for non-ideal matrices (soil, concrete, bedrock)