Smart Sampling

Preliminary Assessment: Remediation Decision Options 903 Pad Site Rocky Flats, Colorado

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Issues

- Limited sampling leads to uncertainty in spatial distribution of contaminants
- Uncertainty in spatial distribution leads to uncertainty in where to remediate and in total remediation costs
- Where to remediate, uncertainty in that map, and the resultant costs

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Approach

- Consider activity values to be a result of a spatial random function (geostatistical concept)
- Model the spatial correlation with variograms
- Create multiple, Monte Carlo realizations of the activity values
- Map probability of exceeding the cleanup goals
- Derive remediation maps and associated costs as a function of reliability

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Assumptions

- Site boundaries extend 44 feet beyond nearest sample location
- Am-241 to Pu-239/240 regression is correct and $R^2 = 1.0$
- Remediation panel is 25 x 25 feet
- Remediation depth is 6 inches
- Remediation cost is $300/yd^3

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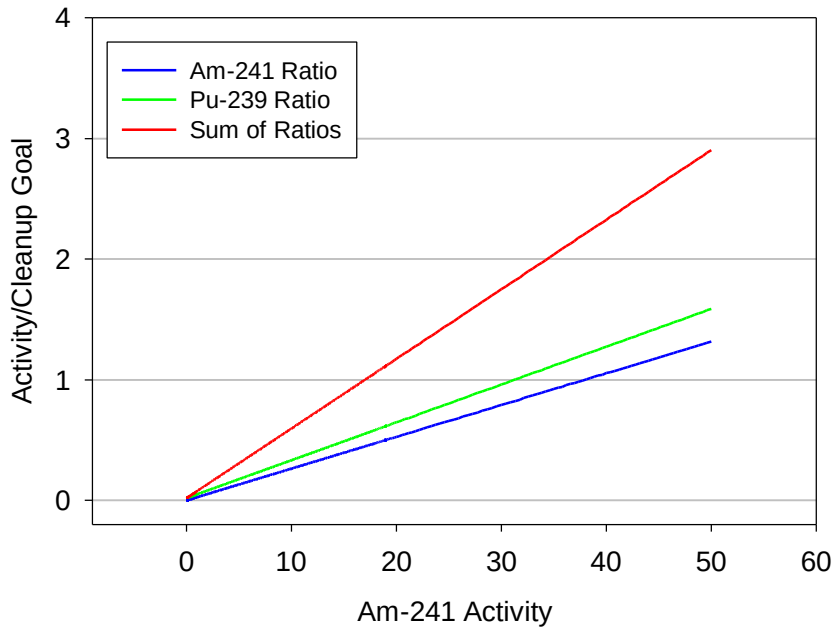
Sum of Ratios



All cleanup goals can be expressed in terms of the single sampled activity (Am-241).

The corresponding cleanup goals in terms of Am-241 are:

- **17 pCi/g (Sum of Ratios)**
- **27 pCi/g (Pu-239)**
- **38 pCi/g (Am-241).**

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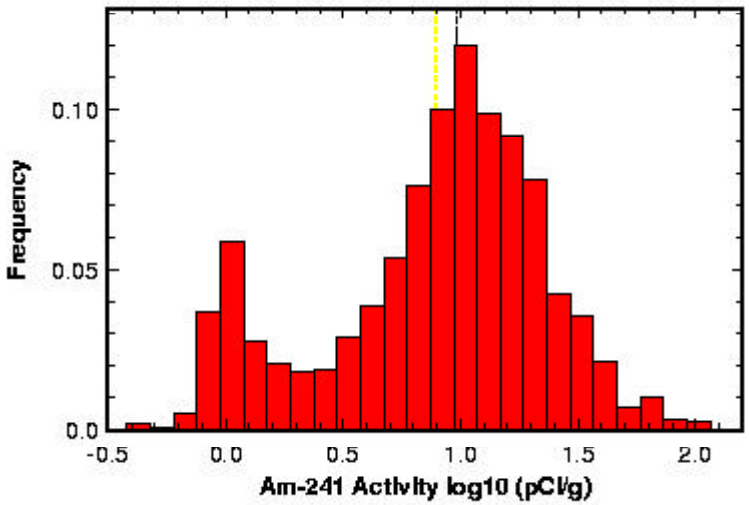
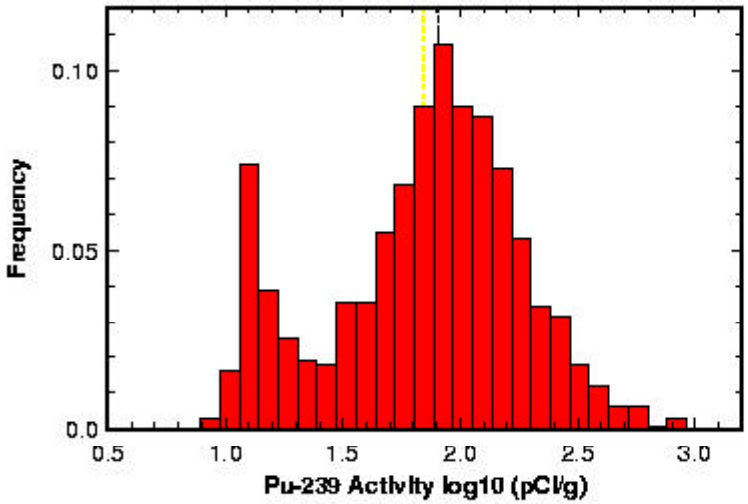
Am-241 and Pu-239 Histograms





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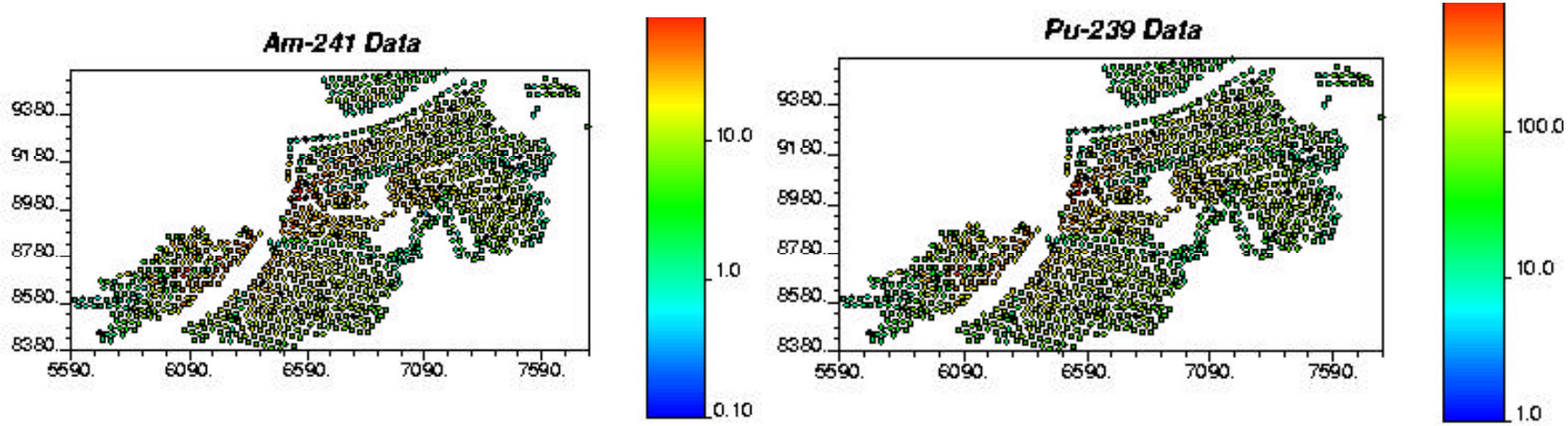
Sample Locations and Contaminant Distribution



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Fraction of Sample Values that Exceed Clean Up Goals

Clean Up Goal	Fraction of Contaminated Samples (percent)
Am-241 (38 pCi/g)	4.3
Pu-239 (252 pCi/g)	7.2
Sum of Ratios	23.2

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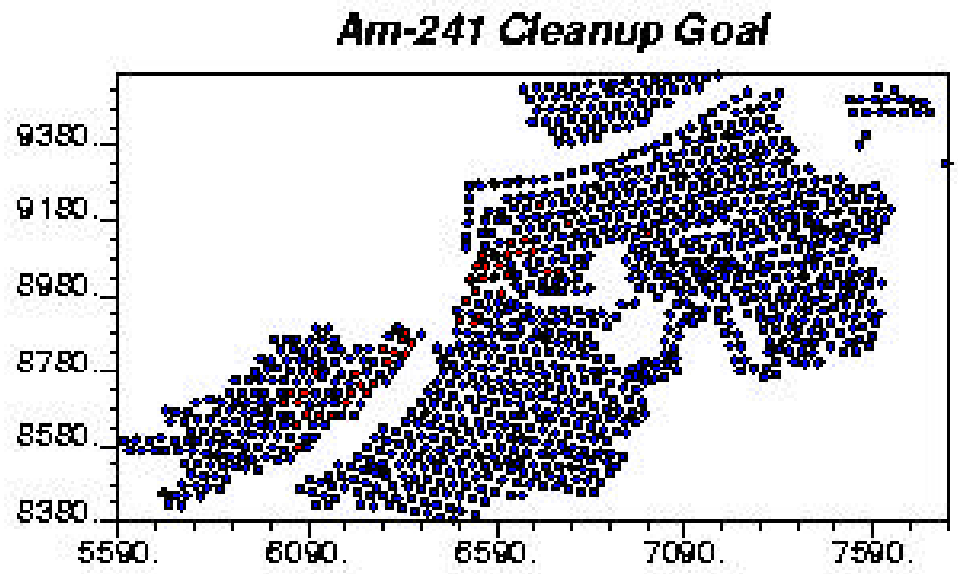
Spatial Distribution of Samples Exceeding AM-241 Goal



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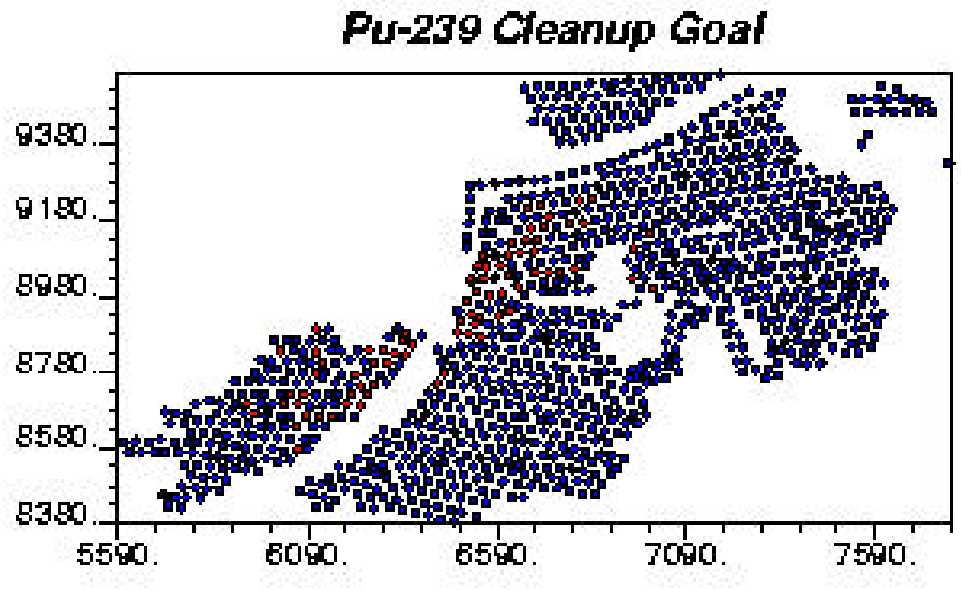
Spatial Distribution of Samples Exceeding PU-239 Goal



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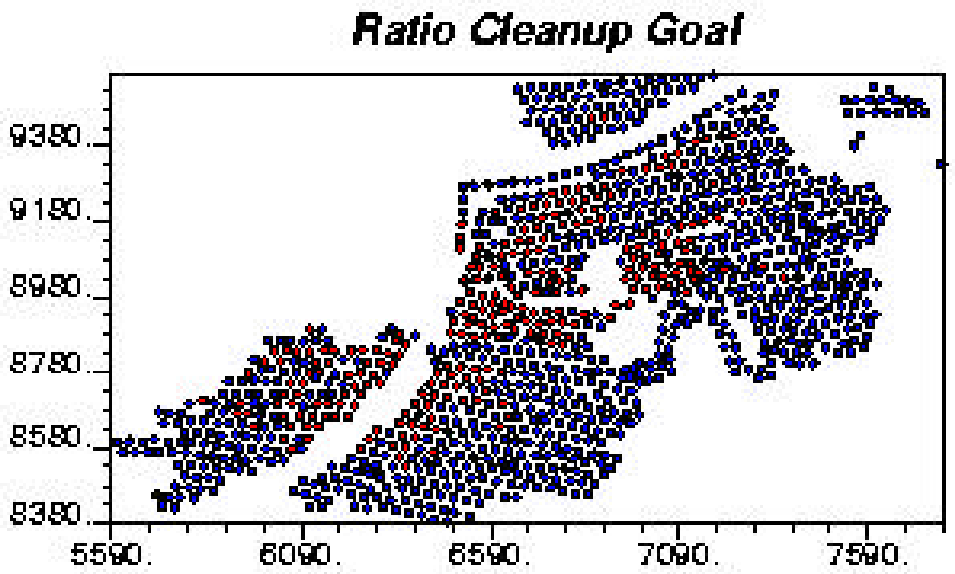
Spatial Distribution of Samples Exceeding Sum of Ratios Goal



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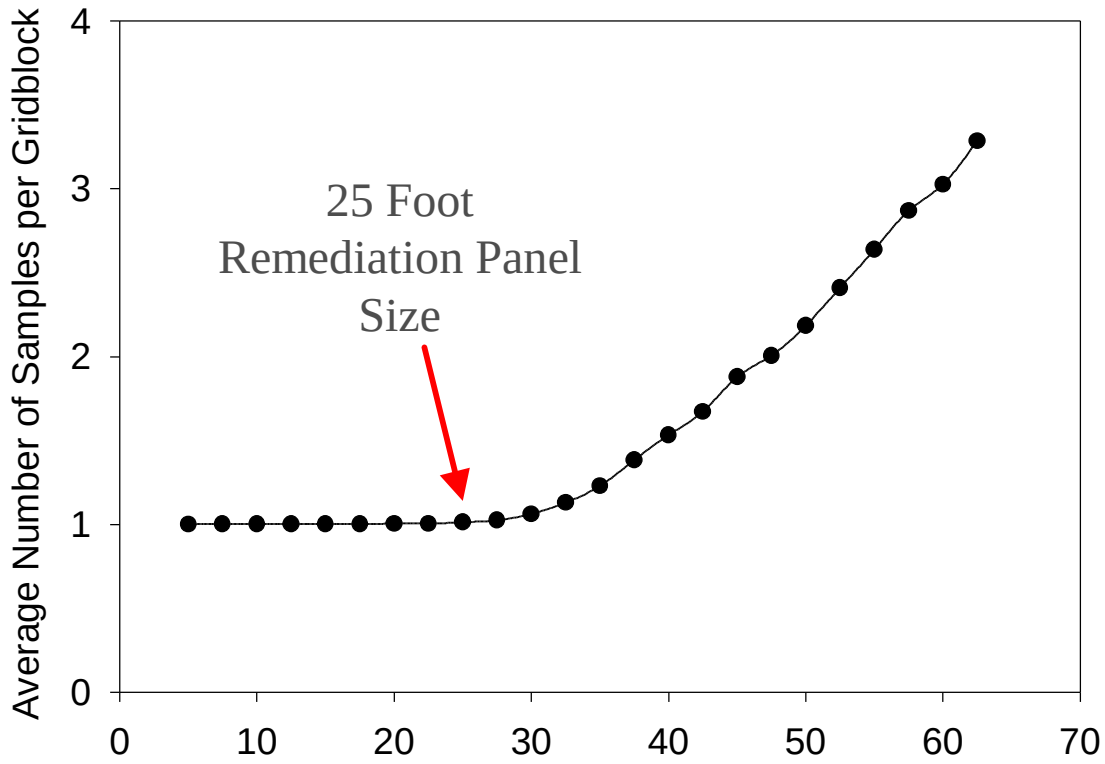
Remediation Panel Sizing Calculation



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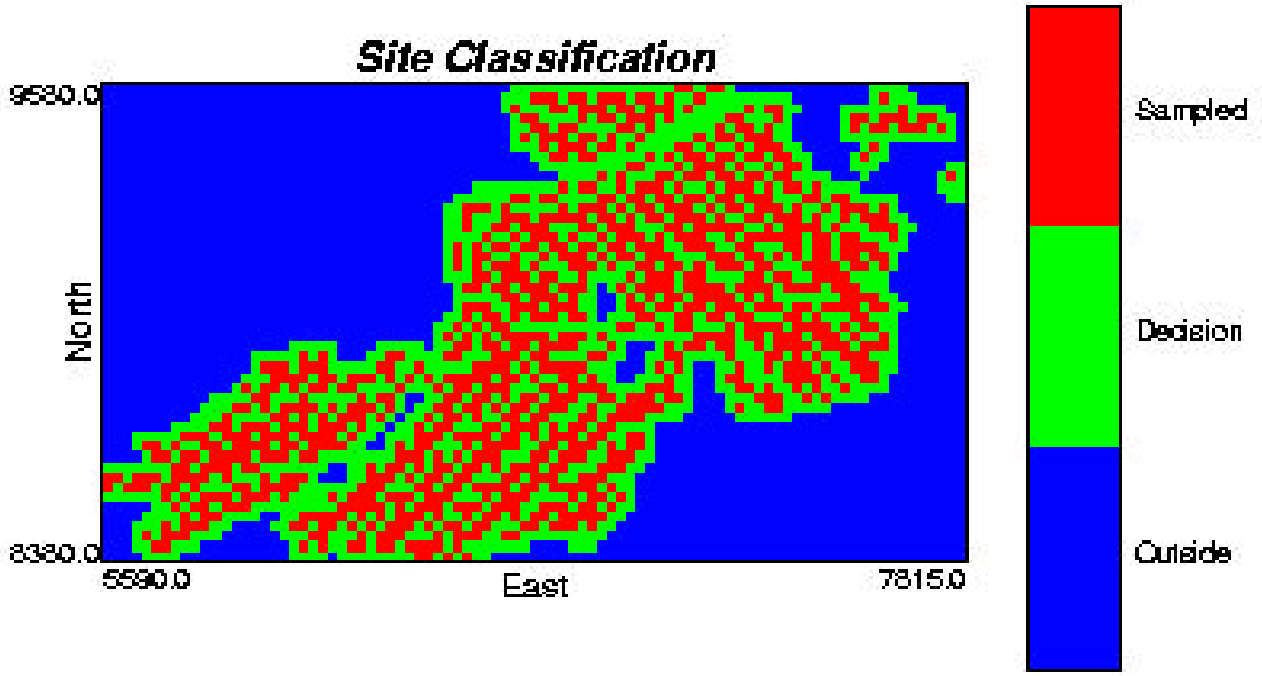
Classification of the 903 Pad Domain



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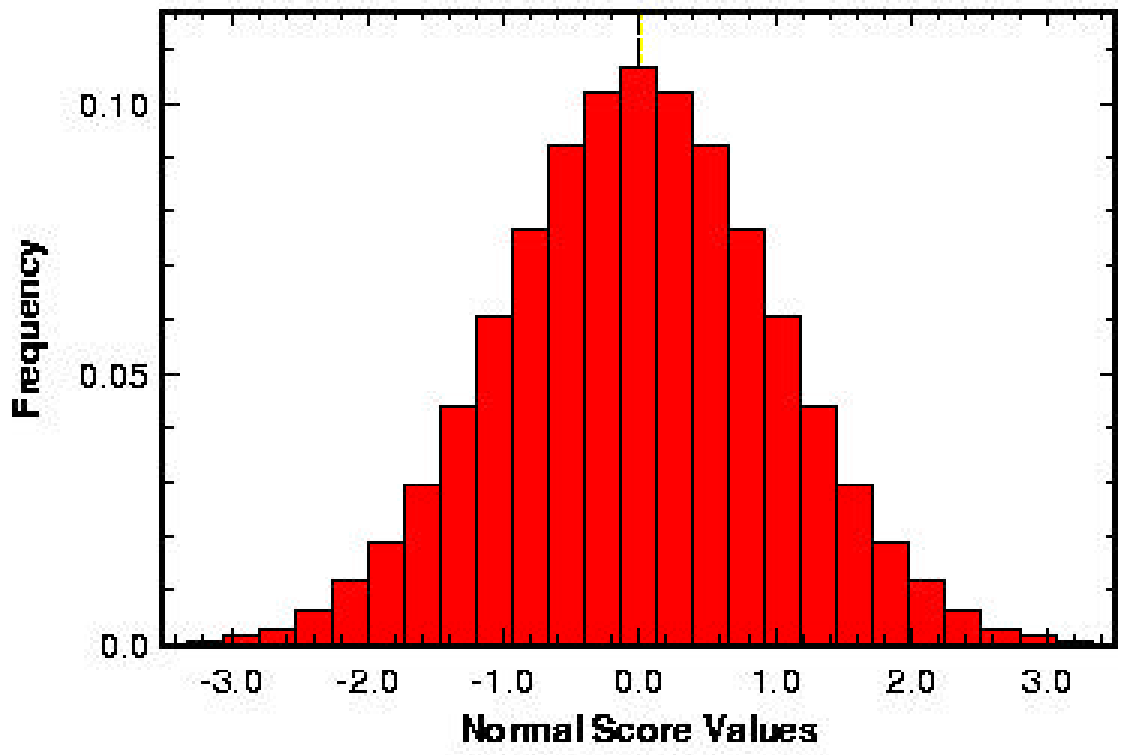
Normal-Score Transform



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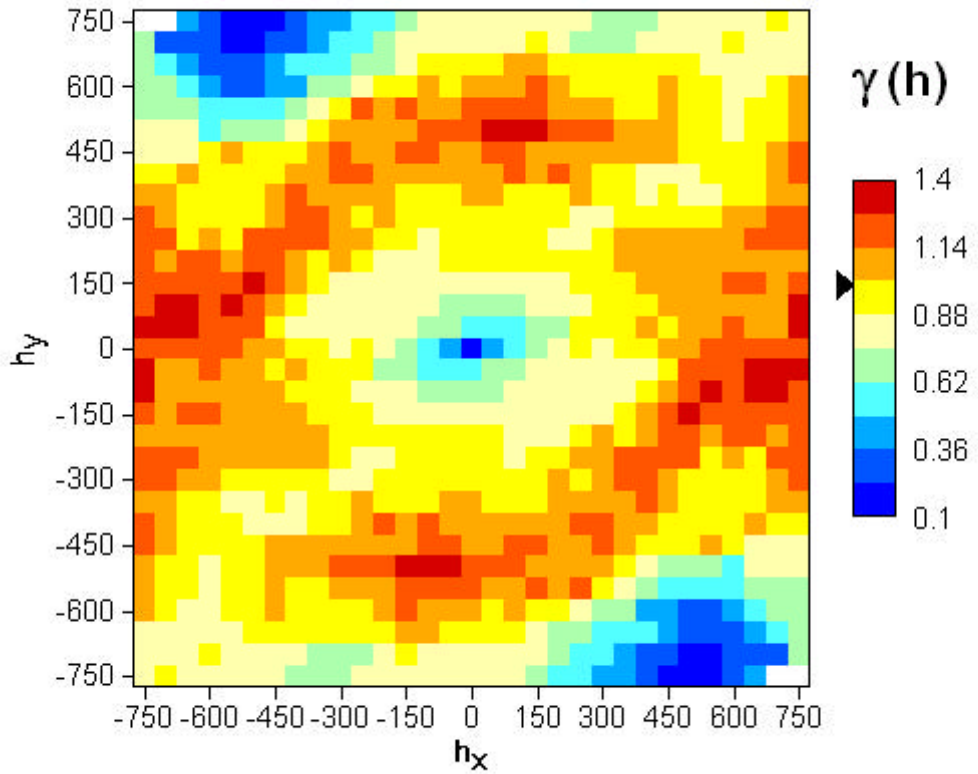
Variogram Map



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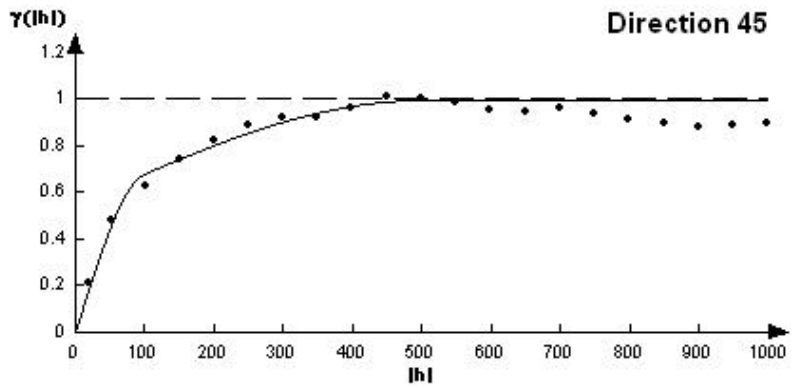
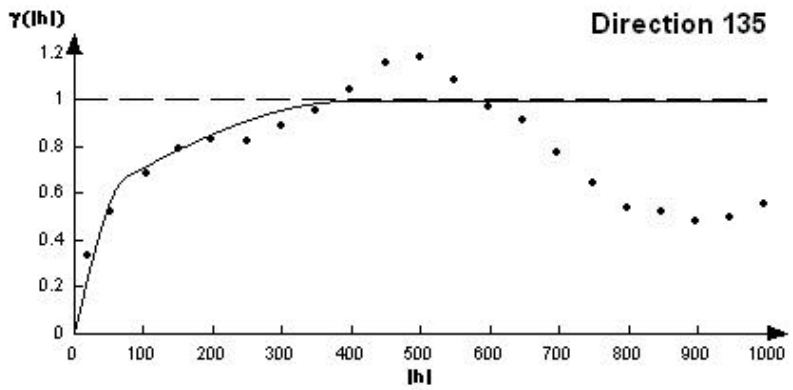
Directional Variograms





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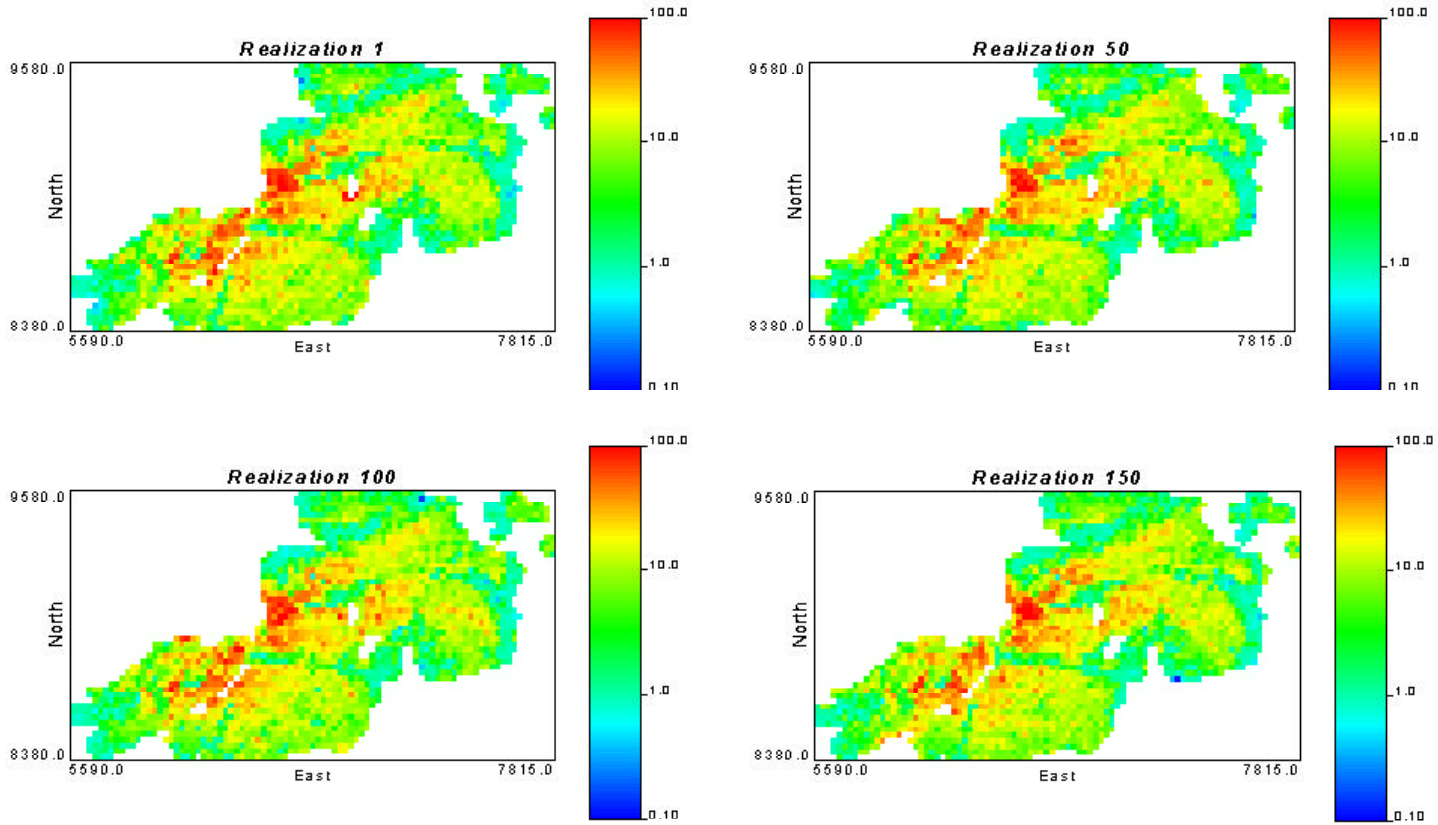
Equiprobable Am-241 Realizations



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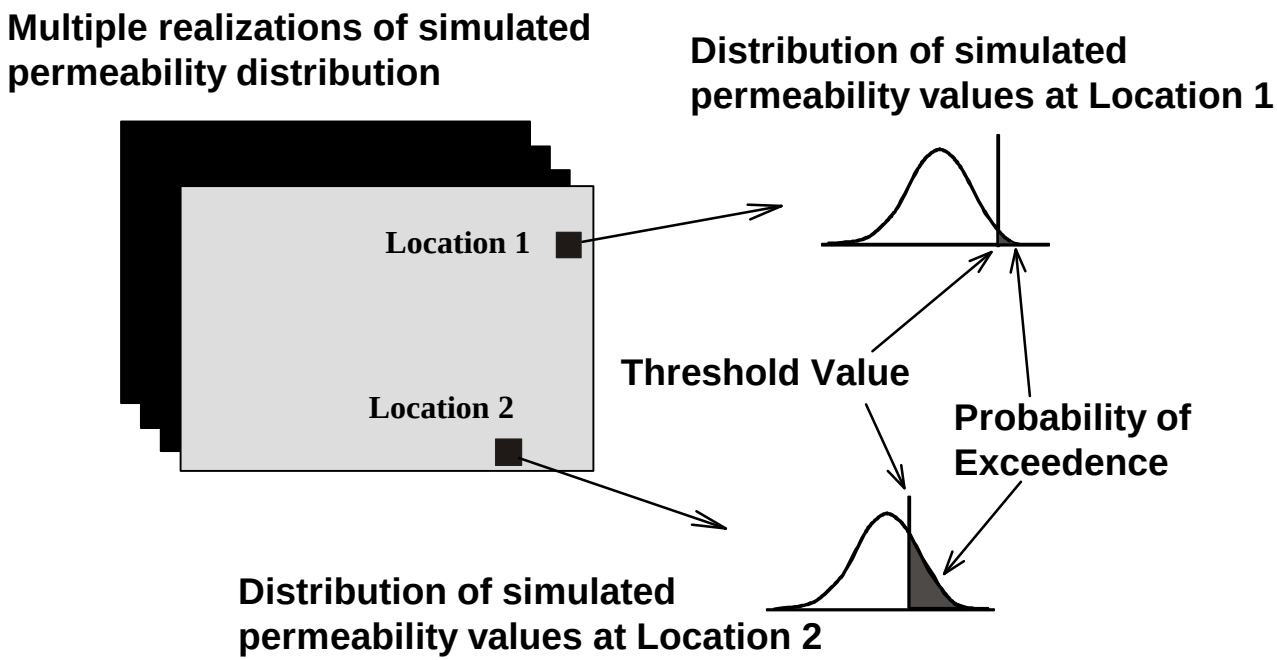
Conceptual Schematic of Probability Mapping



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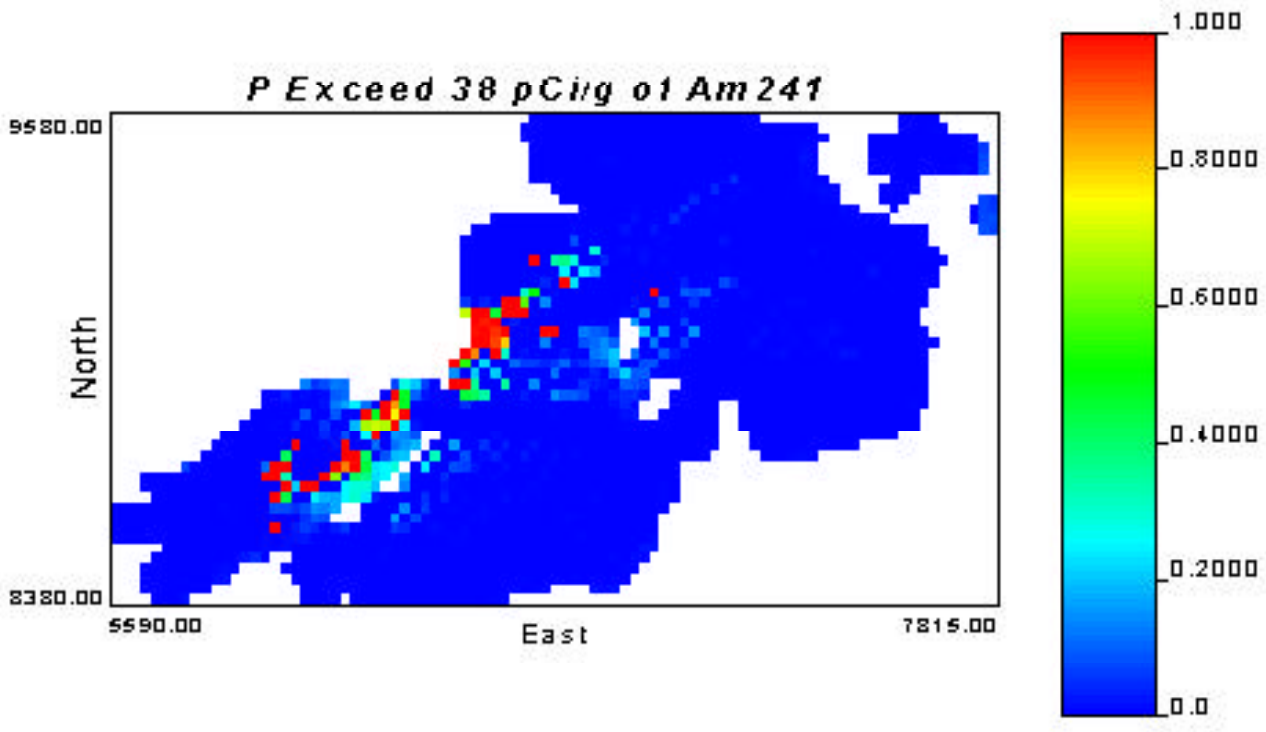
Probability of Exceedance

38 pCi/g of Am-241



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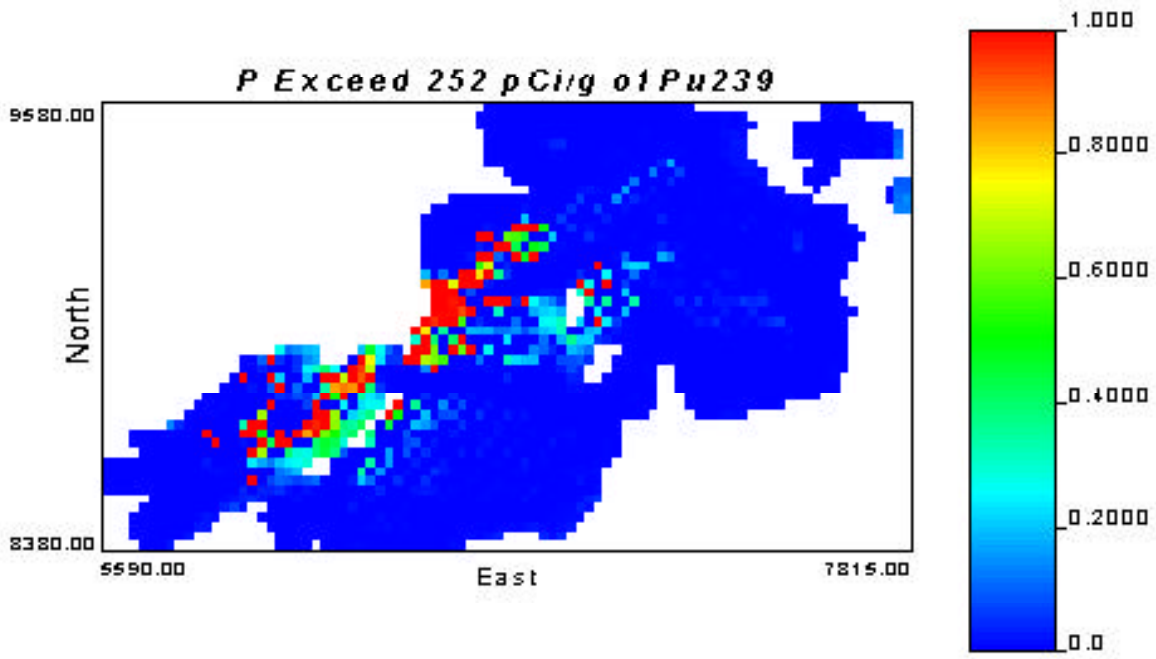
Probability of Exceedance

252 pCi/g of Pu-239



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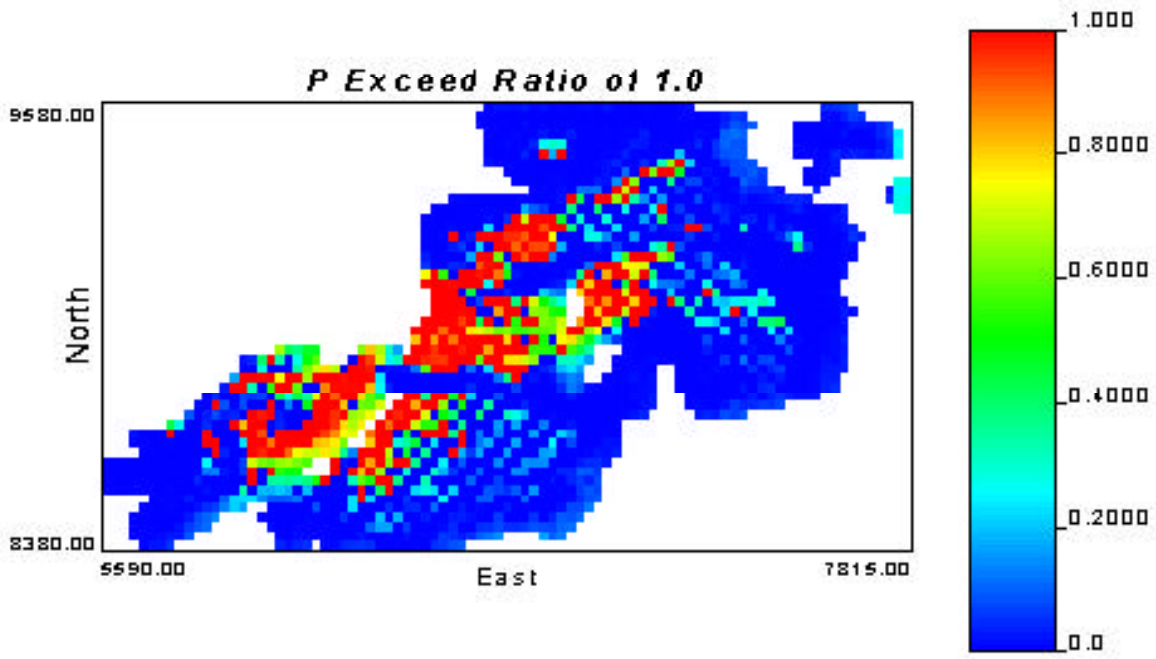
Probability of Exceedance

Ratio of 1.0



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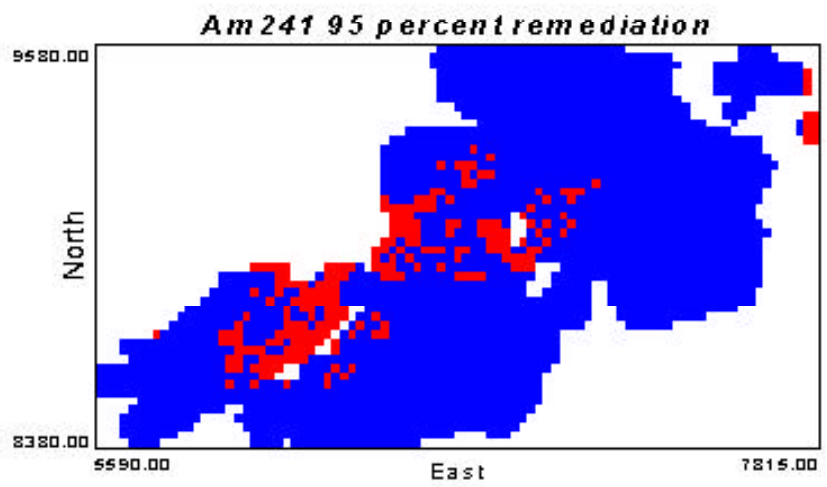
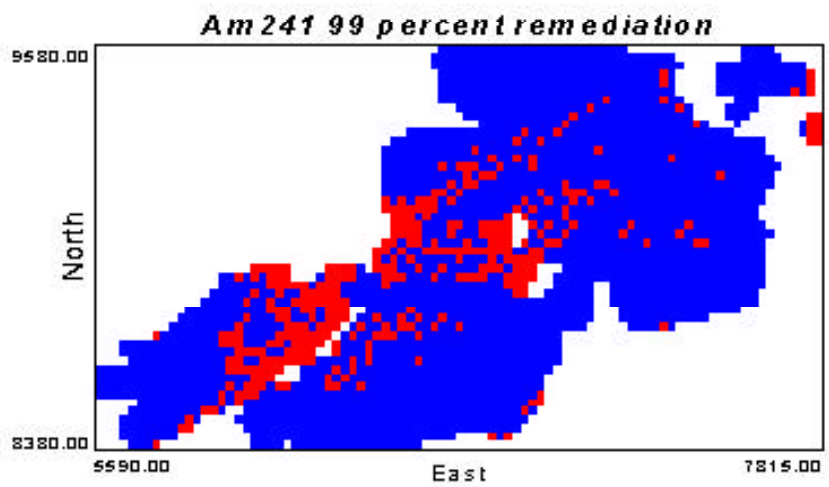
Remediation Maps

Am-241





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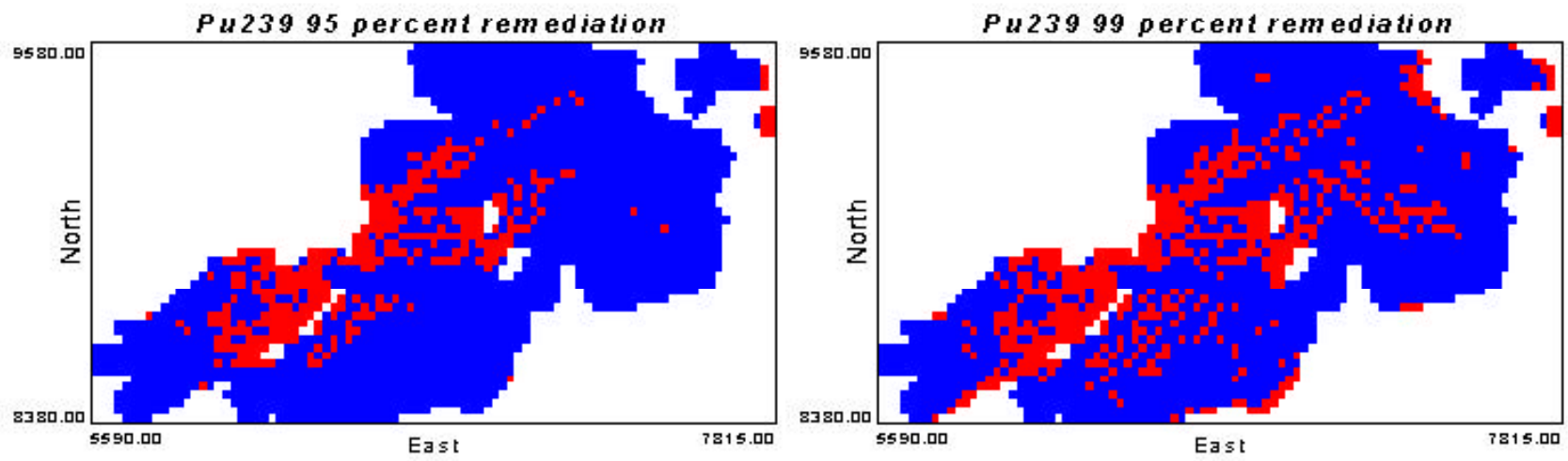
Remediation Maps

Pu-239



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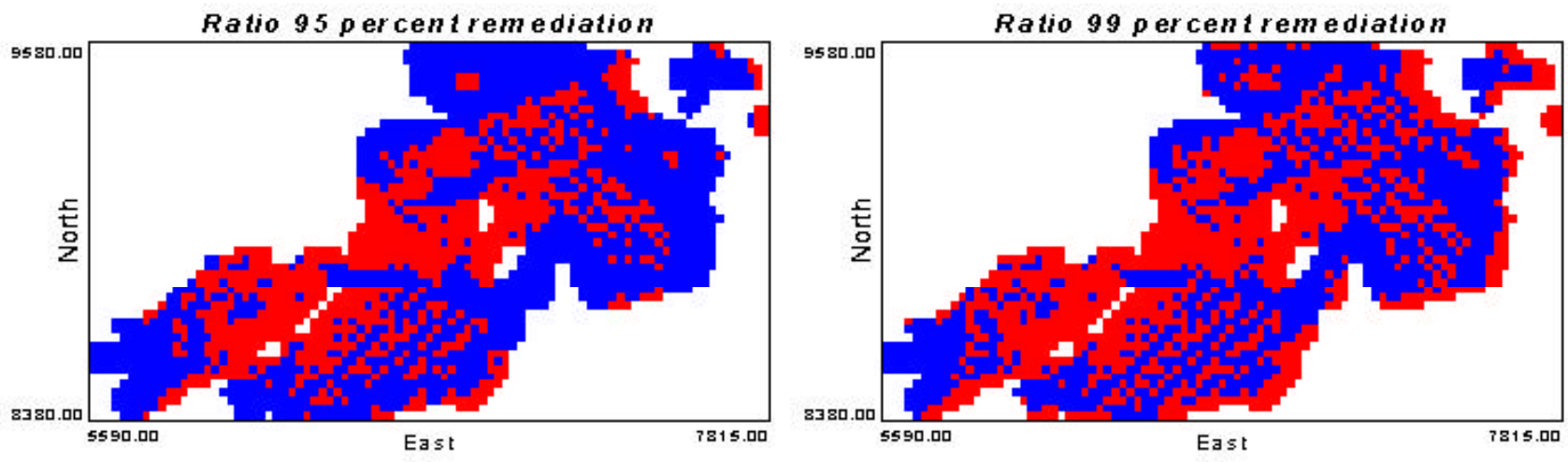
Remediation Maps

Ratio



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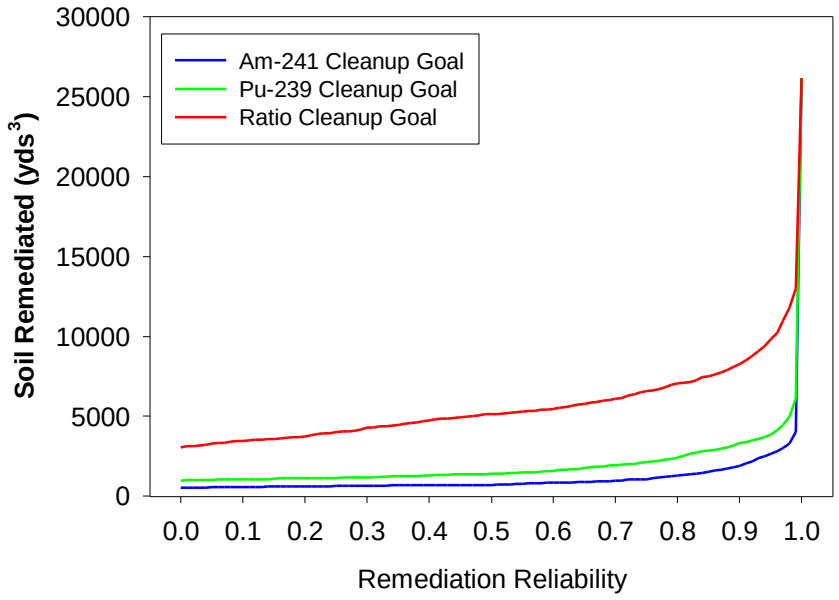
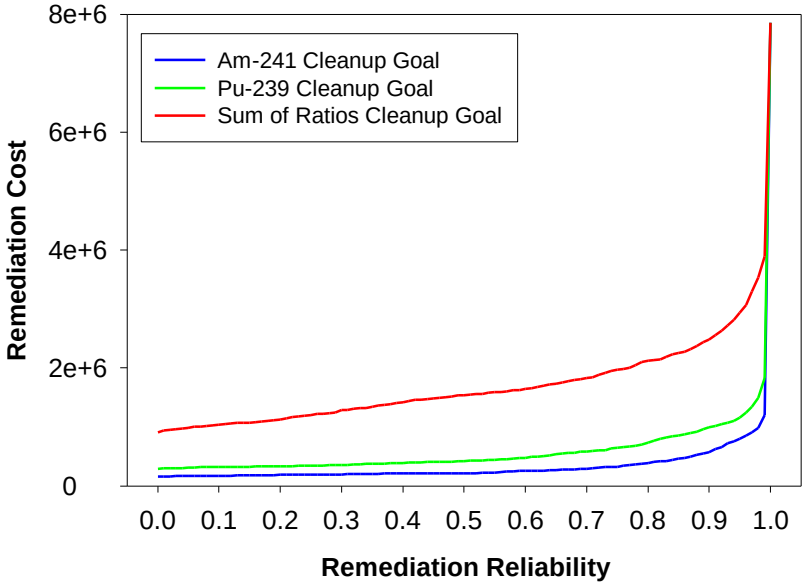
Remediation Volume/Cost as Functions of Reliability





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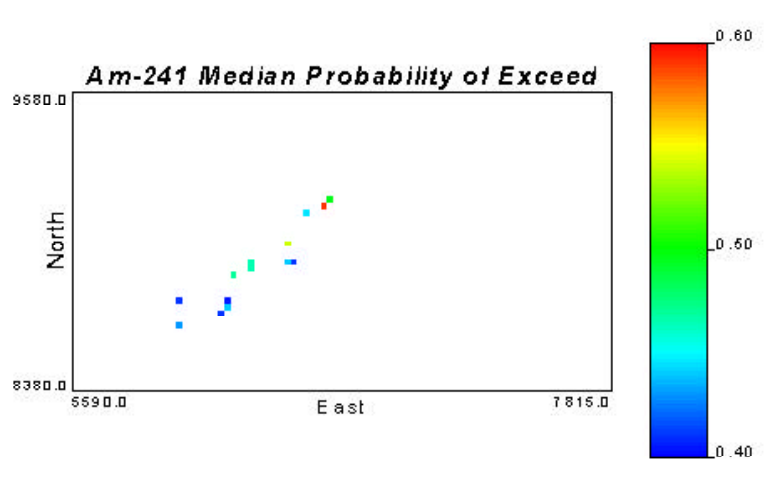
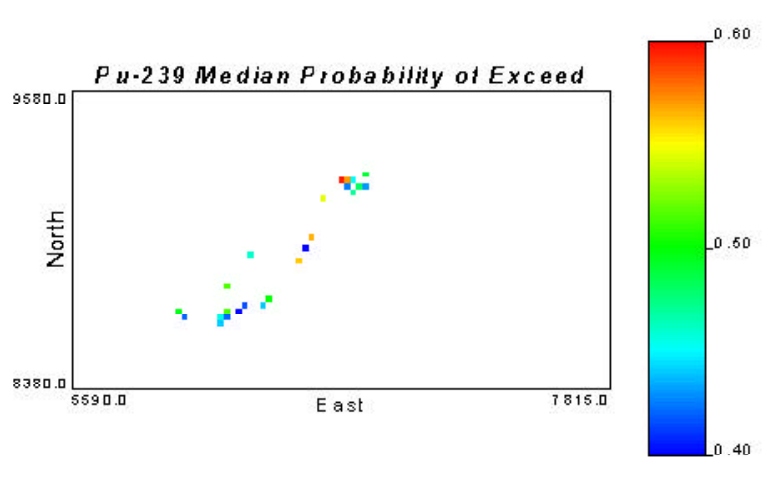
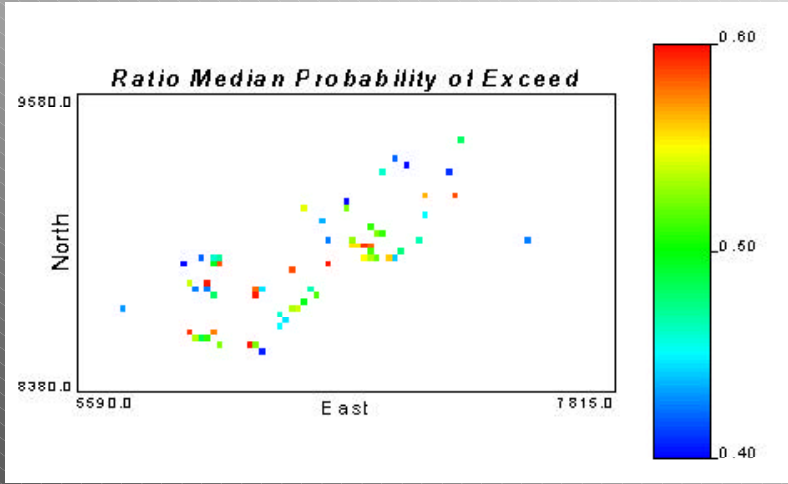
Locating Additional Samples







Optimal location for additional samples in area of median probability of exceedance is a function of the cleanup goal

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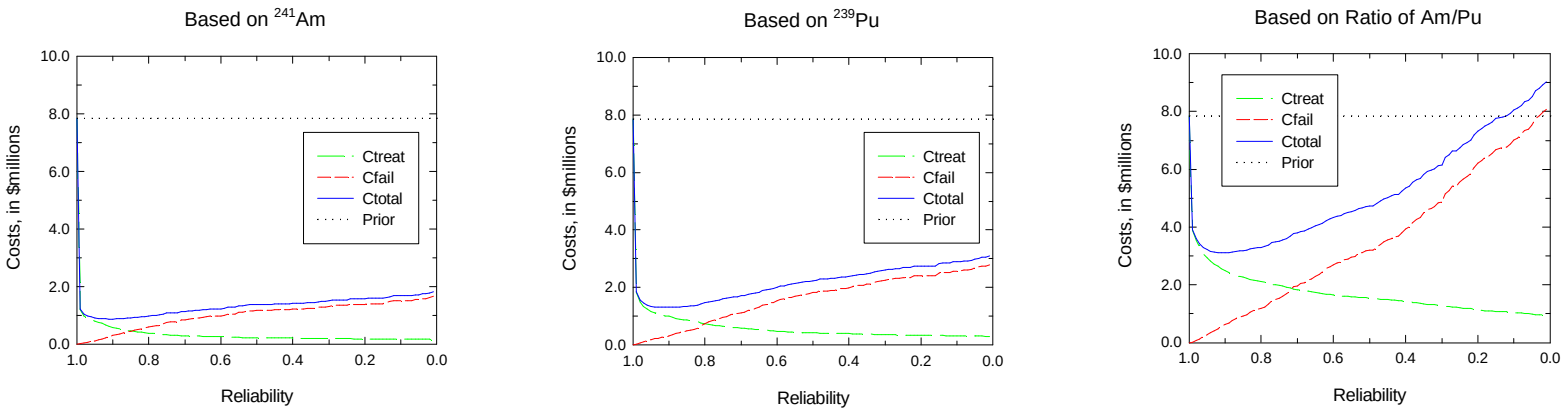
Cost Curves



Assumptions:

Treatment Costs = $300/yd^3 ~$3,500 per panel

Failure Costs = Treatment plus 10x treatment cost ~$35,000 per panel

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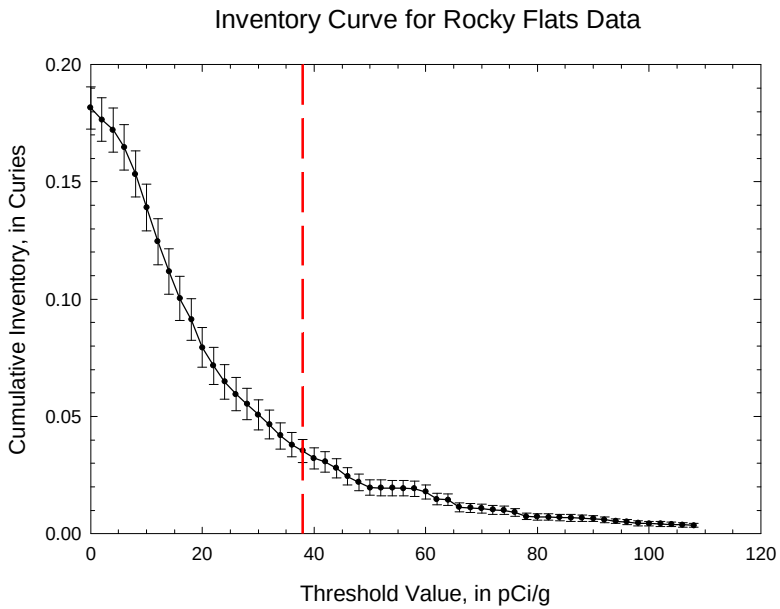
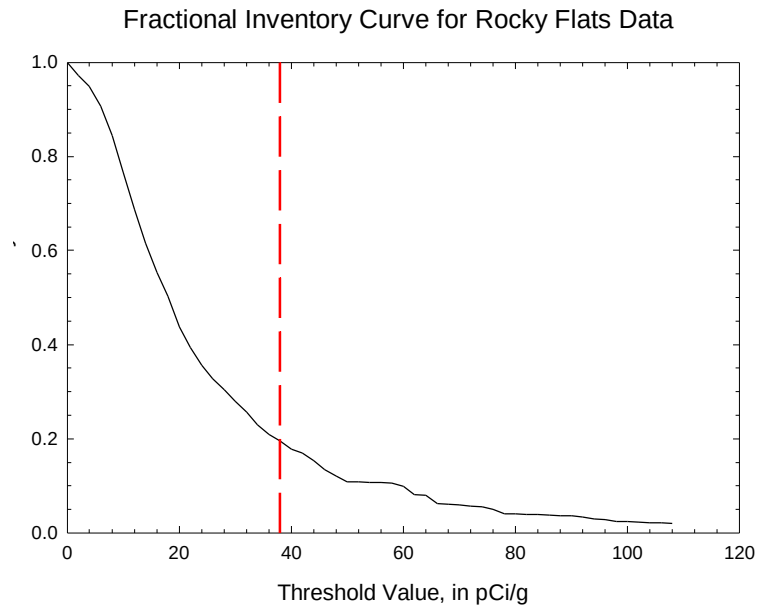
Inventory Curves





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Model Validation

- Randomly Remove 510 samples from the data set
- Complete the geostatistical analysis using only 600 samples
- Compare the remediation decision made at the 510 locations against the actual data
- Is the approach valid? Would 600 samples have been enough?

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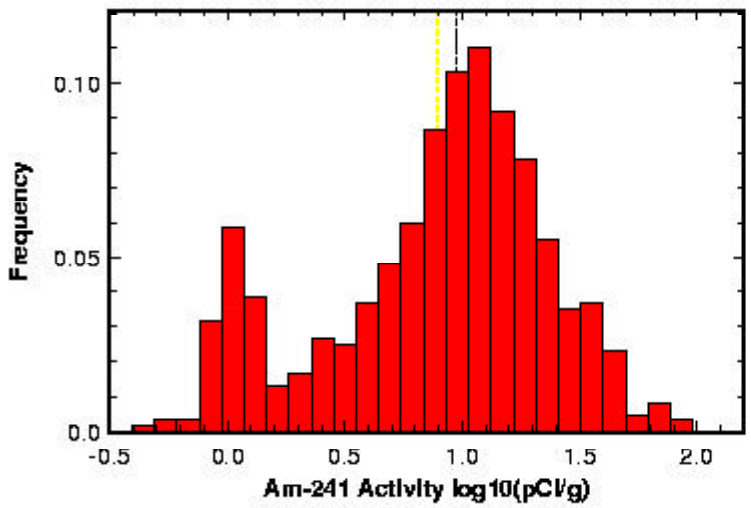
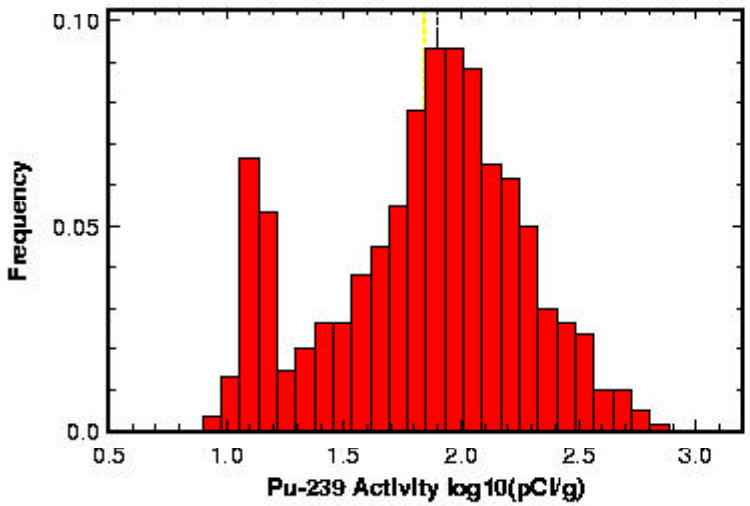
Validation Data Sets





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Validation Data Sets

Table 1: Original Data Set

Clean Up Goal	Fraction of Contaminated Samples (percent)
Am-241 (38 pCi/g)	4.3
Pu-239 (252 pCi/g)	7.2
Sum of Ratios	23.2

Table 2: Validation Data Set

Clean Up Goal	Fraction of Contaminated Samples (percent)
Am-241 (38 pCi/g)	5.0
Pu-239 (252 pCi/g)	8.0
Sum of Ratios	23.7

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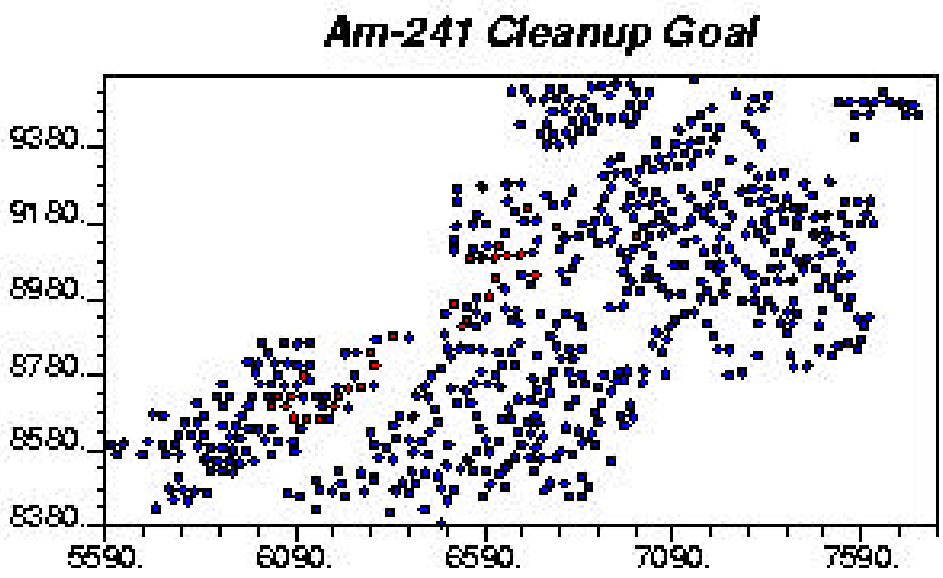
Model Validation: Spatial Distribution of Samples Exceeding AM-241 Goal



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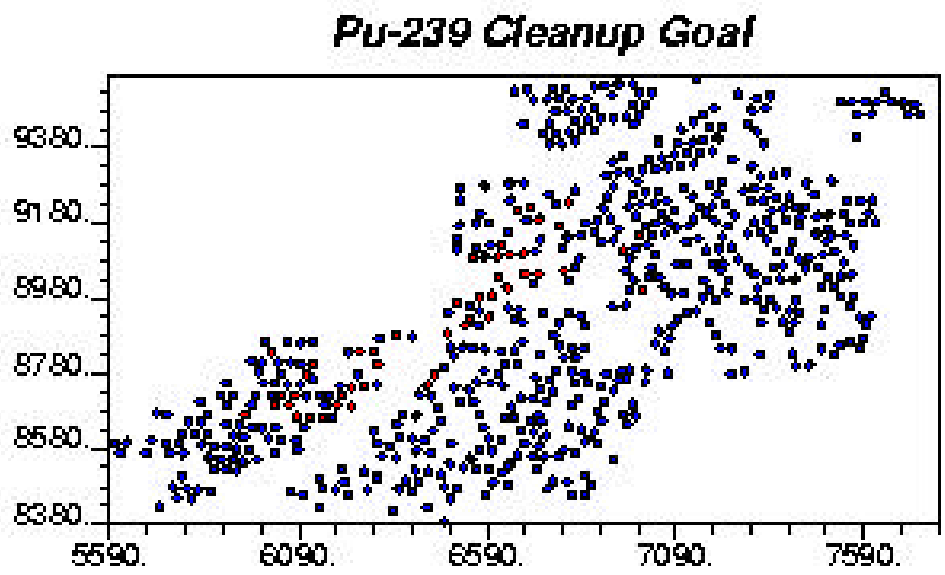
Model Validation: Spatial Distribution of Samples Exceeding Pu-239 Goal



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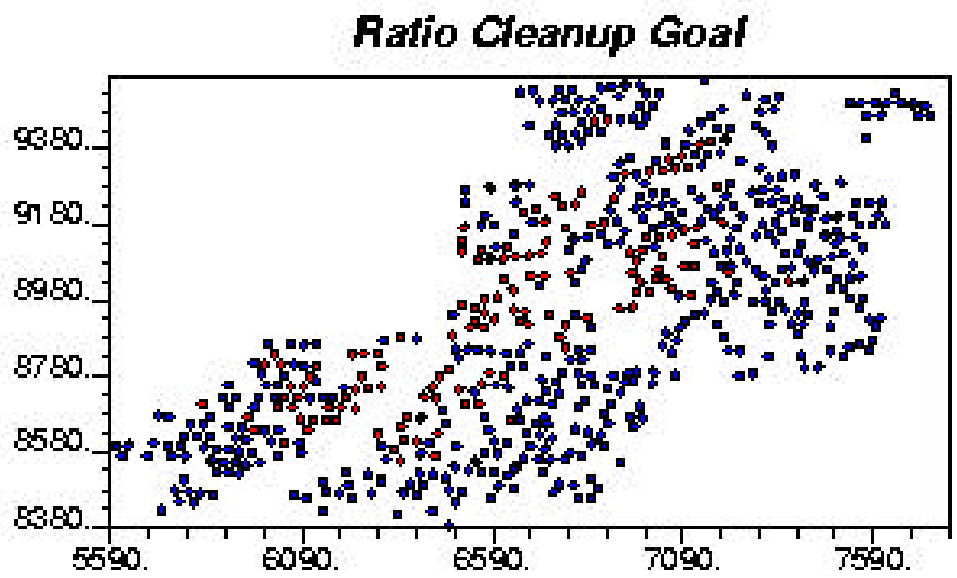
Model Validation: Spatial Distribution of Samples Exceeding Ratio Goal



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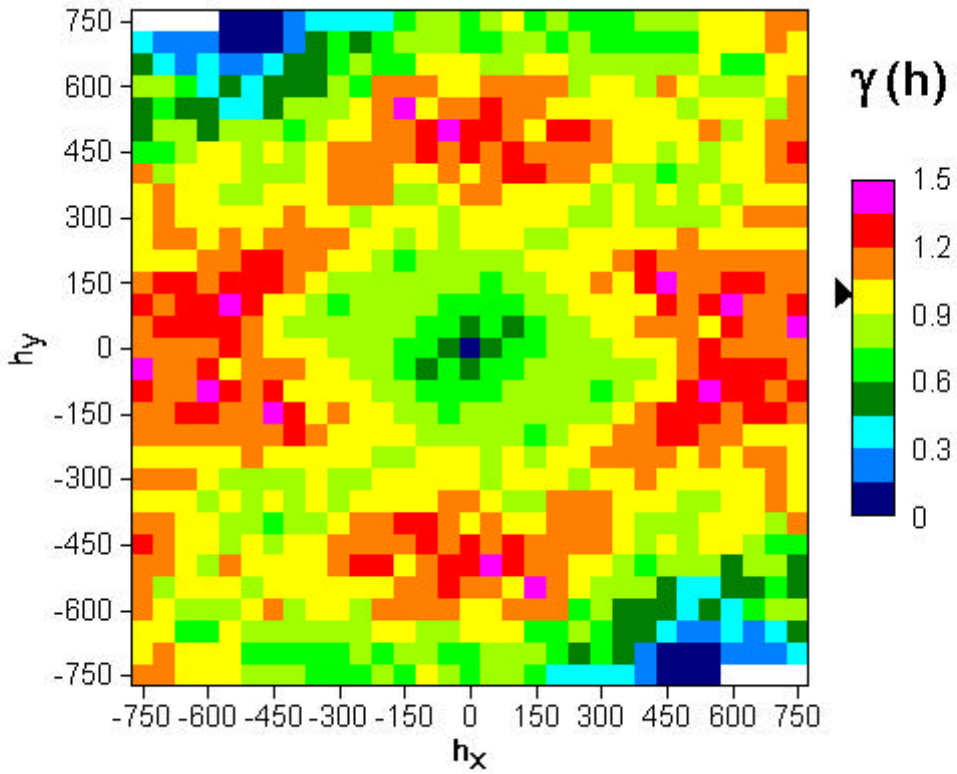
Model Validation: Variogram Map



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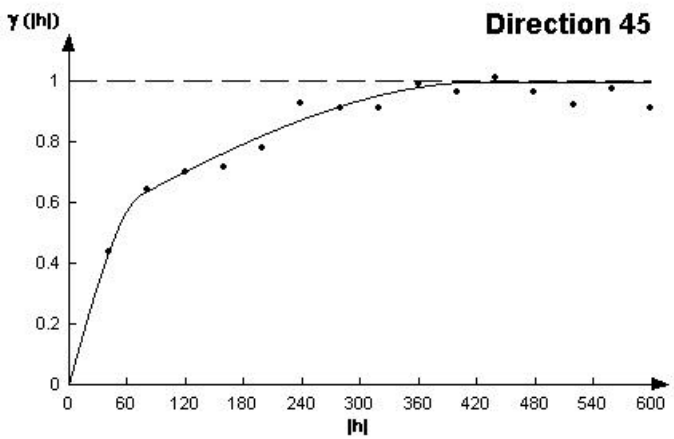
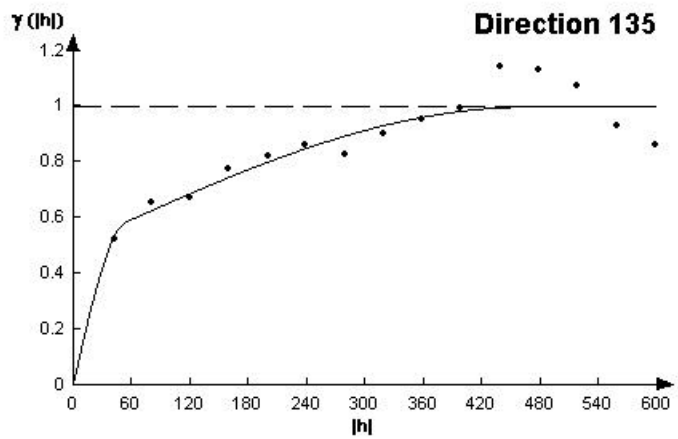
Model Validation: Variograms





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Evaluating Remediation Decisions

Correct decisions: panel remediated and actual value above cleanup goal
or
panel not remediated and actual value below cleanup goal

False Positive: unnecessary remediation (cost = remediation cost)

False Negative: should have remediated panel and did not (cost = regulatory penalties?)

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Validation Results

Cleanup Goal	Specified Reliability	Correct Decisions	False Negatives	False Positives
Am-241	0.99	335	4	171
Am-241	0.95	426	4	80
Pu-239	0.99	273	3	234
Pu-239	0.95	385	6	119
Sum of Ratios	0.99	235	11	264
Sum of Ratios	0.95	293	12	205

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Conclusions

- Limited sampling leads to uncertainty in remediation decisions
- Uncertainty allows remediaiton decisions to be cast in terms of reliability
- Differences in acceptable reliability can lead to large differences in cost
- Validation shows that geostatistical approach works and that 1110 samples were more than necessary

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Conclusions (Continued)

Remediaiton at 100 % reliability for 7.85 million dollars

Remediation at 95 % reliability for 1 to 3 million dollars at different cleanup goals

Inclusion of regulatory penalty shows lowest total cost occurs near 90 % reliability

Different cleanup goals result in double the amount of curies being removed from environment