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Smart Sampling™:
Making sensible remediation decisions

Smart Sampling™ is a process that facilitates cleanup decisions by applying techniques, methods, and software that have been developed in other fields. Through the use of Smart Sampling™, site owners, regulators, and other stakeholders can consider the effects of various action levels and risk tolerances on the ultimate cost of a remediation plan.

Sandia National Laboratory developed Smart Sampling™ with support from the U.S. Department of Energy's Office of Science and Technology. The Smart Sampling™ method has been demonstrated on a number of projects since 1992, and it is ready for large-scale deployment. During 1996, Smart Sampling™ was demonstrated at Site 91 at SNL in Albuquerque, New Mexico, where 13 test detonations between 1979 and the late 1980s released 100,000 pounds of lead over the site. Smart Sampling™ was also demonstrated in 1998 at the Mound Plant in Ohio.

Decisions, decisions!

Smart Sampling™ supports cleanup decision makers who must agree on the cleanup goal and the level of risk to accept in deciding on a remediation plan. For example, during negotiations over plans at Site 91, Smart Sampling™ helped decision makers understand the economic consequences of selecting between two cleanup goals—residential or industrial land use. The U.S. Environmental Agency has set lead cleanup for a future residential land use scenario at removal or treatment to the 400 parts-per-million (ppm) action level. The corresponding action level for industrial use is 2,000 ppm.

What are the risks?

The risk of any remediation plan is that it can under- or overestimate the degree of cleanup required to satisfy the action level. Proceeding with a plan that overestimates the amount of soil that must be removed or treated results in unnecessary added expense. Such a plan is based on false positives. Remediation plans that underestimate the amount of soil for removal or treatment are based on false negatives; they fail to achieve regulatory compliance, leading to fines, penalties, and more remedial actions.

Smart Sampling™ is a tool for illustrating the economic consequence of accepting various levels of risk. For example, a remediation plan based on a 5 percent probability that remaining soil will exceed the action level will be less expensive than a remediation plan based on a 1 percent probability of leaving behind soil that exceeds the action level. Smart Sampling™ quantifies the tradeoffs between accepting higher levels of risk and lower remediation costs.

Taking Smart Sampling™ steps

Smart Sampling™ is a generic process that can be applied at any site where negotiating parties must decide to what level to clean a site. Among the steps in the process are

1. **Histogram**—From data obtained on contaminant concentrations at sampled locations, Smart Sampling™ generates a histogram to display the known distribution of contaminant concentrations.
2. **Variogram**—A variogram is generated to quantify the spatial correlation that exists in geostatistics between pairs of samples. In geostatistics, the differences in values between pairs of samples will decrease as their proximity to each other increases. Smart Sampling™ applies spatial correlation algorithms to sampled values to predict values at unsampled locations. A variogram is a graphical display of this correlation.
3. **Geostatistical simulations**—Next, the Smart Sampling™ process uses the histogram, the sample values and locations, and the variogram to perform geostatistical simulations. Many models are generated to show likely concentrations and distributions of the contaminant of interest across a site. Each model accounts for all known information and is equally plausible in predicting concentration and distribution at unsampled locations.

4. **Probability maps**—Smart Sampling™ averages all the modeled values and maps them, showing the likelihood that the true contaminant value at any unsampled location exceeds the selected action level. During its use at SNL, Smart Sampling™ produced four probability maps to help decision makers understand how the lower action level (400 ppm as opposed to 2,000 ppm) and higher tolerance for risk (5 percent as opposed to 1 percent) affected the amount of soil to be removed and, therefore, the cost of remediation. Probability maps provide insight as to the most productive and cost-effective alternatives for remedial design, and they quantify the risks associated with each alternative.
5. **Excavation maps**—Smart Sampling™ generates excavation maps from the probability maps by marking for cleanup those cells with the selected probability of containing soil that exceeds the action level (either 400 ppm or 2,000 ppm in the SNL case at Site 91).
6. **Cost curves**—Seeing how costs were affected by decisions about action level and probability of exceedence helps decision makers clarify their options and understand the economic tradeoffs among various combinations of action levels, more characterization sampling, and negotiated levels of uncertainty. At SNL's Site 91, Smart Sampling™ showed the parties that if they were willing to accept a remediation plan based on a 5 percent probability of leaving soil that exceeded an action level of 2,000 ppm, then they could save $6.6 million over a plan with a 5 percent probability of exceeding the 400-ppm action level. Because all parties were involved in setting cleanup and risk levels, the resulting remediation plan was defensible.

Taking additional samples

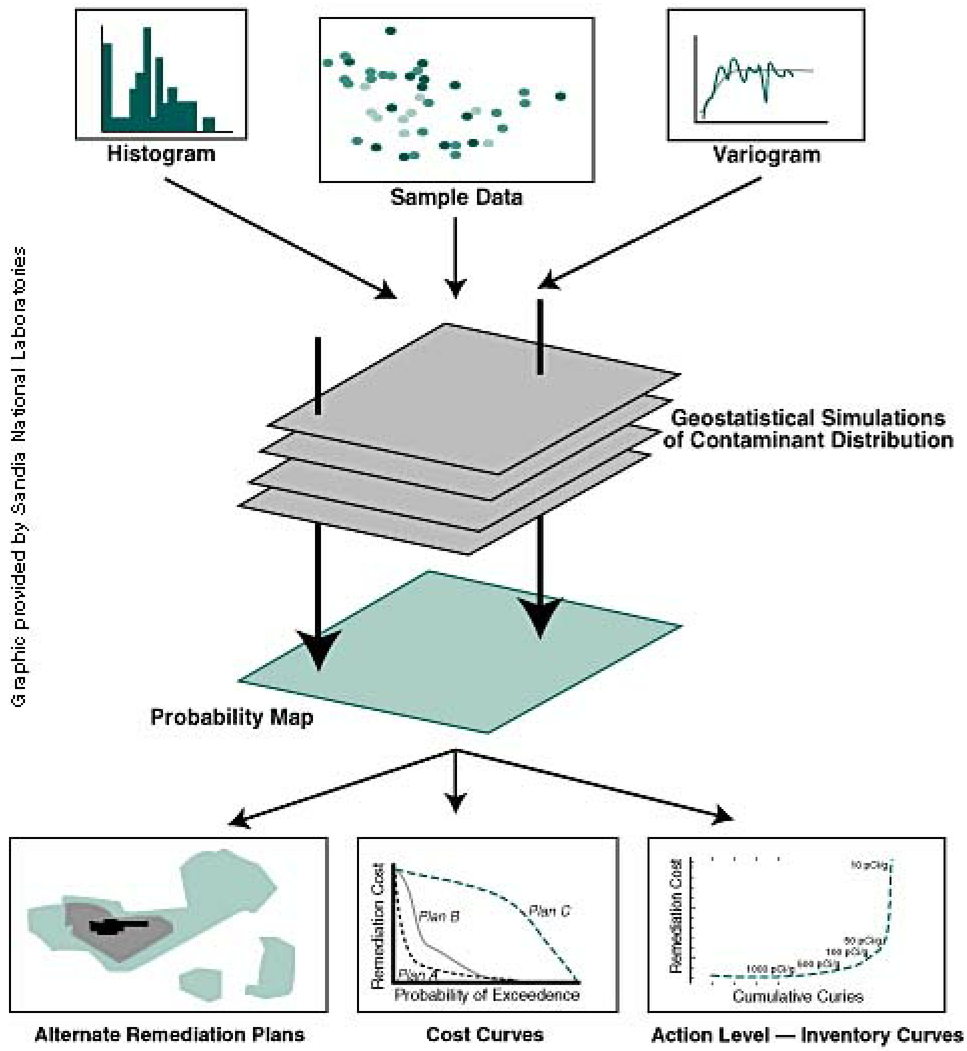
People responsible for cleanups may decide to take additional samples to reduce the risk that undetected contamination will be left in place. Taking additional samples is economical when the data generated by additional samples reduce the cost of remediation beyond the cost of taking the samples. Smart Sampling™ allows for the use of several algorithms to determine sample locations with the greatest potential of reducing uncertainty and contributing to a cost-effective cleanup.

At Site 91, 20 random follow-up samples were taken to validate the geostatistical model. For each additional sample location, the sample value was compared with the distribution of lead concentrations predicted through geostatistical simulation. The variability between measured values and predicted values was dependent on proximity of new sample locations to original sample locations. Comparing data from the new locations with values for these locations generated through geostatistical simulation showed that Smart Sampling™ was effective in preventing false negatives (where contaminated soil is incorrectly classified as uncontaminated and left behind at the site). For example, the accuracy of the remediation decision based on a 2,000-ppm action level at a 0.05 probability of exceedence was found to be 85 percent (17 correct decisions for the 20 extra sampled locations). One false negative and two false positives were identified.

Smart Sampling™ at the Mound Plant

A recent demonstration of Smart Sampling™ at DOE's Mound Plant in Miamisburg, Ohio provides another illustration of how the method can help negotiating parties make cost-effective and defensible remediation decisions. In 1969, a rupture in an underground pipeline released waste from a plutonium processing facility at the Mound Plant. Although a cleanup action was carried out in 1969, samples taken during the next 24 years showed that a 1-mile section of the abandoned Miami-Erie Barge Canal was contaminated.

Since we do not want to give the backhoe operator 100 maps and tell him to figure out where to excavate, we need to summarize the simulation results in a form that is easy to interpret.



This schematic shows components of the Smart Sampling™ process.

Making decisions about the canal's cleanup lies with DOE, the Ohio EPA Office of Federal Facilities Oversight, the U.S. EPA Region V, and local citizens. Recently, DOE and the regulators authorized a demonstration of Smart Sampling™ to learn how the process could help the parties agree on a remediation plan that removes all soil where the probability of exceeding 75 picocurries per gram (pCi/g) of plutonium is greater than or equal to 5 percent. A second goal of cleanup is to remove all soil where the probability of exceeding 150 pCi/g is greater than 1 percent. The parties also want to accomplish cleanup at reasonable cost.

To restrict the scope of the demonstration, only three sections of the canal (of 150 sections) were chosen to exemplify how Smart Sampling™ supports decision making. One hundred fifty-two samples were obtained and analyzed on site.

The Smart Sampling™ process culminated with an excavation plan for removing about 95 percent of the plutonium at a cost of $67,000. The site's original excavation plan would remove about 97 percent of the plutonium at a cost of $108,000. Smart Sampling™ also generated a cost curve that illustrated the diminishing returns from additional excavation. Regulators, site owners, and others saw the cumulative effect on cost of removing more soil and higher percentages of plutonium.

For more information about Smart Sampling™, see its page on Sandia National Laboratories' Web site (http://www.nwer.sandia.gov/sample). Contacts include Paul Kaplan, Sandia Nationa

Laboratories, (505) 284-4786, pgkapla@nwer.sandia.gov, and Anthony Armstrong, Oak Ridge National Laboratory, (423) 576-1555, armstrongaq@ornl.gov. An Innovative Technology Summary Report on Smart Sampling™ is scheduled for release in 1998 by the Office of Science and Technology.

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