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DRILLING AND SAMPLING PROCEDURES TO MINIMIZE BOREHOLE CROSS-CONTAMINATION

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ABSTRACT

Drilling and sampling procedures have been developed by scientists from the Idaho National Engineering Laboratory (INEL) to minimize the potential of cross-contamination within the borehole or from airborne contaminants. These procedures employ off-the-shelf wireline drilling equipment, including a Lexan inner core barrel. The procedures have been used in both air and mud rotary operations. Downhole quality assurance steps include the introduction of samarium oxide and/or perfluorocarbon tracers. The procedures were initially developed to support subsurface investigation at a low-level radioactive waste management complex in Idaho and have since been modified and used for Resource Conservation and Recovery Act/Comprehensive Environmental Response, Compensation, and Liability Act (RCRA/CERCLA) investigations in California and Idaho. Most recently, the procedures were employed in a research investigation in South Carolina to collect microorganisms from the deep subsurface. The procedures can be modified to reflect specific drilling objectives. Overall, the procedures have been effective in the minimization or elimination of cross-contamination. This approach to sampling represents the latest technology in hazardous waste subsurface investigations.

INTRODUCTION

Drilling and sampling techniques have been employed in the groundwater and petroleum industries to provide sample material from the subsurface for evaluation of hydrogeologic conditions, for delineation of subsurface structure, and in support of petroleum reservoir exploration and characterization. Coring techniques have focused on the use of conventional rotary core barrels, sidewall coring, and wireline core tools. However, with the advent of RCRA/CERCLA legislation and the need for substantially enhanced quality assurance/control, sampling techniques have been further developed.

Historically, much of the concern expressed by personnel performing subsurface sampling in a hazardous environment has focused on how to deal with a sample that is "contaminated" when it is brought to the surface. Specific concerns have included the potential spread of contamination on the land surface, personnel exposure, and handling procedures for the sample material. Experience at the INEL and in the waste management industry has shown that these concerns can be addressed. A more difficult and significant issue to address, however, is ensuring that samples from the subsurface are representative and not "cross-contaminated" by materials from within the borehole or from surface activities. In essence, a representative sample is one that is isolated from all potential contaminants prior to, during, and after collection. Sample isolation may become even more critical in an environment where a single particle may cause an erroneous assessment of the level of contaminants observed at depth.

The issue of how to obtain representative samples has been at the forefront of subsurface investigations at the INEL for nearly 25 years. The INEL is a U.S. Department of Energy (DOE) research laboratory located in southeast Idaho and occupies approximately 890 square miles. The INEL performs a variety of research and development activities for DOE and other federal agencies. The INEL also has a facility for the disposal/storage of low-level radioactive waste. The facility is called the Radioactive Waste Management Complex (RWMC). The need to characterize the subsurface environment at the RWMC has provided the impetus for scientists and engineers to develop enhanced subsurface sampling techniques.

Levels of contamination on the land surface and in the near-surface materials at the RWMC were expected to be greater than levels at depth. In fact, sampling activities in the 1960s and 70s had varied results; some subsurface sampling indicated the presence of radionuclides while other studies failed to identify any contaminants at depth (DOE, 1983). However, all "positive" findings generally represented concentrations of contaminants that were orders of magnitude lower than those observed on or near the land surface. The immediate concern regarding these results was the possibility of sample contamination, either by particles entering the sample material from the land surface or by contaminated particles driven from near-surface materials to depth by the sampling equipment.

To minimize the possibility of borehole sample cross-contamination, sampling techniques and rigorous sampling procedures have been developed and implemented at the INEL, including quality assurance/control measures to document the integrity of sampling operations. In 1986, following two years of research and evaluation of available options, and two external peer reviews, the INEL finalized a strategy and a methodology that have proven highly successful and are in use today as part of on-going subsurface investigations.

STRATEGY

Cross-contamination will result from the uncontrolled entry of "foreign" material into a sample at depth. Potential sources of such material include windblown deposition from the landsurface, and subsurface materials lying above the sample depth that are either dragged down by sampling equipment or otherwise moved to a greater depth.

Windblown deposition of foreign material can be prevented in a variety of ways. The method chosen will depend upon the type of drilling, either air or mud rotary. The initial sampling strategy developed by the INEL focused on air rotary applications, but the strategy has since been modified for application to mud rotary systems.

Air rotary systems employ air compressors to circulate cuttings and to cool the drill bit. In the case of air rotary drilling, the air intake from windblown particles must be protected and the cuttings routed away from the borehole. Assessments are made of the prevailing wind direction, the susceptibility of the formation to changes in barometric pressure that may result in "blowing" or "sucking" conditions in the subsurface, and overall climatic/atmospheric conditions.

Mud rotary applications require an enclosed mud tank to ensure that muds are not exposed to environmental conditions on the land surface. Mud rotary systems require frequent mud changeouts. When using mud systems, personnel must also address prevailing wind directions, fluid drainage on the land surface, and the impact of climatic/atmospheric conditions on the drilling operation.

Site preparation activities may include, prior to mobilization of the drill rig, the introduction of a drill pad composed of a contaminant-free material.

Cross-contamination within the borehole is considerably more difficult to evaluate than windblown deposition, and its avoidance requires a more sophisticated strategy. To minimize the chances of cross-contamination, it is mandatory to have tooling that can be used downhole without necessitating the "tripping" of the drill string out of the hole for sample recovery. Based on this criterion, the INEL rejected all available coring technologies except wireline systems. Wireline systems also provide a temporary casing as drilling/sampling operations continue. While the lack of tripping will be effective in the prevention of sidewall sloughing within the borehole, it alone will not ensure that contaminants have not been dragged down the hole into a sampling interval.

To further minimize the possibility of contaminants being dragged to depth, a downhole tracer is introduced at the bottom of the corehole prior to each coring run with the wireline system. The intent of the tracer is to determine the extent of any sample material that has been dragged down the hole during sample collection.

The strategy for the introduction of the tracer is based on a decision to subcore all sample material at the land surface in a "controlled" environment. The subcore material is evaluated for the presence of the downhole tracer to determine if the subcore is "clean" of any material that may have been dragged down the hole. Both ends of the core barrel are trimmed prior to the subcoring activities. To facilitate subcoring without exposing the sample material to the open environment at the land surface, the strategy was to use a specialized inner core barrel in place of the conventional steel inner barrel.

Rigorous sample-handling procedures are required for field operations. Procedures ensure that all tooling is clean prior to introduction into the hole. Decontamination procedures include use of a distilled water rinse, high-pressure steam cleaners, or, for flame sterilization, alcohol. Proper handling of the cores at the land surface is a concern, but can be ensured with a variety of techniques. Some circumstances may require the opening of cores in a controlled environment. Others may require that the tooling be opened in the field by personnel with clean gloves and that, prior to collection of the subcore material, the sample material be pared from both ends.

Also vital to the sampling strategy is the documentation of the process employed to collect the samples. The cost of subsurface sampling is simply too great to permit resampling efforts due to inadequate documentation. Daily logs must be kept that are legally defensible.

SAMPLE METHODOLOGY

The mechanics of implementing this strategy depend on the type of geologic formation, drilling technique, and target species for the sampling effort. The following discussion presents, first, the standard techniques employed at the INEL's RWMC and, second, those used on a South Carolina project involving a mud rotary operation.

AIR ROTARY DRILLING AT THE RWMC

The INEL is located in southeast Idaho on the Eastern Snake River Plain (ESRP). The geologic environment of the ESRP consists of volcanic rock interbedded with lacustrine, alluvial, and aeolian sediments. The INEL is underlain by the Snake River Plain aquifer at depths ranging from approximately 250 to 1,000 ft (DOE, 1983).

Beneath the RWMC, the unsaturated zone is composed of a series of basalt flows with two to three relatively thin (less than 15 ft) sedimentary interbeds at depths of about 30, 110, and 240 ft below land surface. The water table is approximately 580 ft below land surface.

The hydrogeologic conditions associated with the unsaturated zone underlying the RWMC have dictated the use of air rotary drilling operations for most subsurface investigations.

The RWMC has been used for the disposal/storage of waste material since the early 1950s. The waste has been placed in surficial sediments (up to 25 ft deep) on top of the initial basalt sequence. Sampling of the subsurface environment was initiated in the late 1960s in order to determine if radionuclides had migrated from the buried waste. The results of sampling activities in the 1960s and 70s were contradictory, with the exception being, in general, that the concentrations of radionuclides observed at depth were significantly lower than the levels measured on or near the land surface. None of these radionuclide concentrations has constituted a health threat. The inconsistency of these sample results created concerns about the integrity of samples collected at depth.

To address these concerns, the INEL developed an implementation plan, including an extensive set of sampling procedures, as reflected in the strategy presented here. The basic tooling employed during the sampling process, from the time of initial planning of the borehole until final packaging of the sample, included an air rotary drilling rig, a wireline system, downhole tracers, and Lexan liners.

The air rotary system employed at the INEL has been modified in several respects from conventional systems. Surface casing is set to prevent near-surface contaminants from being introduced into the hole. Then the air system is set up. A high-efficiency particulate air (HEPA) filter is placed on the intake to the air compressor system. The HEPA filter is effective in preventing windblown particulates from entering the borehole during drilling and sampling activities. In addition, the orientation of the drill rig, compressor intake, and discharge line are evaluated with respect to the prevailing winds in order to minimize the potential for particulate introduction during the sampling activities. Figure 1 is a schematic diagram showing the site layout for subsurface sampling operations, including support equipment. (If hazardous materials are a target for sampling, an oil-less compressor is employed.)

A wiper gasket is placed over an air diverter for moving the cuttings away through a discharge hose to a cyclone separator and exhaust filter system. The wiper gasket protects the borehole from contaminants. Positive air pressure is maintained in the borehole during drilling in order to reduce the possibility of materials moving into the borehole. Then, when drilling is stopped, the air diverter is sealed with plastic and tape. As Figure 1 indicates, the discharge lines are approximately 100 ft long and go through a series of particle filters designed to minimize the potential for particulate contamination resulting from the drilling operation. These steps are relatively low cost and are easily accomplished by drillers. The most labor-intensive aspect of the operation is the handling of the particle filters at the point of discharge. Whenever the operation is shut down, the HEPA filter, wiper gasket, and discharge filters are wrapped in plastic sheeting to minimize the potential for windblown particles to be introduced into the borehole.

Other considerations affecting sampling activities at the RWMC include the prevailing wind speed and the general atmospheric conditions. For example, whenever wind speeds maintain a velocity greater than 25 mph, field operations are shut down. The specific physical conditions of each site will dictate "action" levels. Precipitation is also a significant consideration, as it increases the potential for moisture to accumulate on the drill string and move down the hole. Significant precipitation compromises efforts to properly decontaminate the drilling equipment.

The primary factor determining the selection of the type of wireline system was the availability of parts and accessibility for service. In 1986 an HXB wireline system was employed at the RWMC for sampling. The tooling worked without incident; however, the small diameter of the

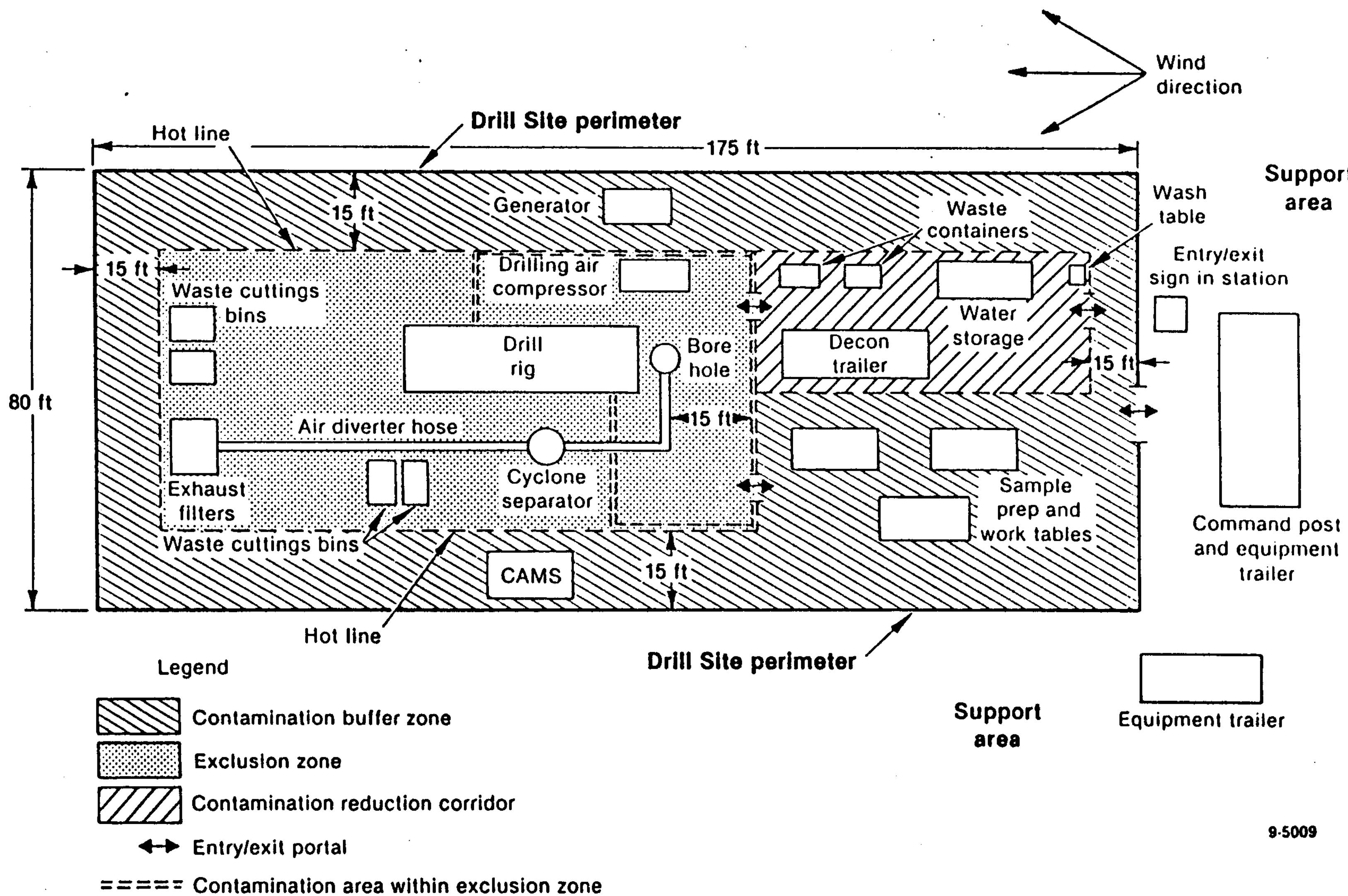


Figure 1. Schematic showing the site layout for subsurface sampling operations.

core recovered (about 2 in.) was later considered inadequate, primarily due to the sub-coring routine required. A CP system, with a core diameter of about 3 in., was procured and has been used since.

The CP system is an off-the-shelf system with the exception of the material composing the inner core barrel, Lexan. In general, core recovery has improved dramatically with time, as the drillers have become more familiar with the geologic formations at the INEL. Core runs of 5 ft are considered routine, although the system allows for runs of varying lengths. A sprung steel core catcher ring is employed and has proven moderately effective in retaining unconsolidated core material. The core barrel will infrequently plug up, necessitating that the coring operation be aborted until the coring system is retrieved and cleared. Each time this occurs, the field personnel must take precautions prior to handling the tooling, in accordance with established decontamination procedures. Once an interval is sampled, protective casing is inserted into the borehole to prevent cross-contamination at the next sampling interval.

The only modification done at the INEL to the CP system involves the inner core barrel; instead of the conventional steel barrel, a Lexan inner core barrel has been introduced. The Lexan barrel has the same diameter as the core shoe and threads directly onto the shoe. The top of the barrel is also threaded and attaches to the overshot assembly.

The Lexan barrel, which was developed specifically for the INEL, has several features that minimize the likelihood that the core material will be exposed to the environment during examination. The greatest asset of the Lexan barrel is that it is transparent. This means that entire cores do not have to be exposed to the environment at the land surface, decisions can be made regarding where to subsample without disturbing the entire core, and core storage is relatively simple in the barrel. Other attributes of the Lexan are that it can be cut, permitting the sampling of specific intervals, and that the cutting can be accomplished with minimal disturbance to the core. A drill "hole saw" can be used, for example, to cut through the Lexan in order to collect a "plug" of material for interrogation with an instrument such as a photoionization detector for the presence of volatile constituents.

Lexan is also suitable for the collection of a subcore. The subcoring technique involves the pressing of a hollow tube into the sample and removal of a core from within the core. In addition, the Lexan core barrel is an ideal container for storing archived core material for extended periods. Figure 2 illustrates the Lexan barrel and subcore.

Two problems do occur with the Lexan barrels that must be addressed. The first is the length of time needed to order the Lexan and have the threads cut; it is not unusual for delivery and threading operations to take eight or more weeks. The other problem is variability in the strength and durability of the Lexan material. The INEL has occasionally received shipments that seem to fracture, twist, or collapse much easier than others. Despite these problems, the advantages of the Lexan barrel have consistently outweighed the disadvantages.

Two procedures have been implemented at the INEL to minimize contamination

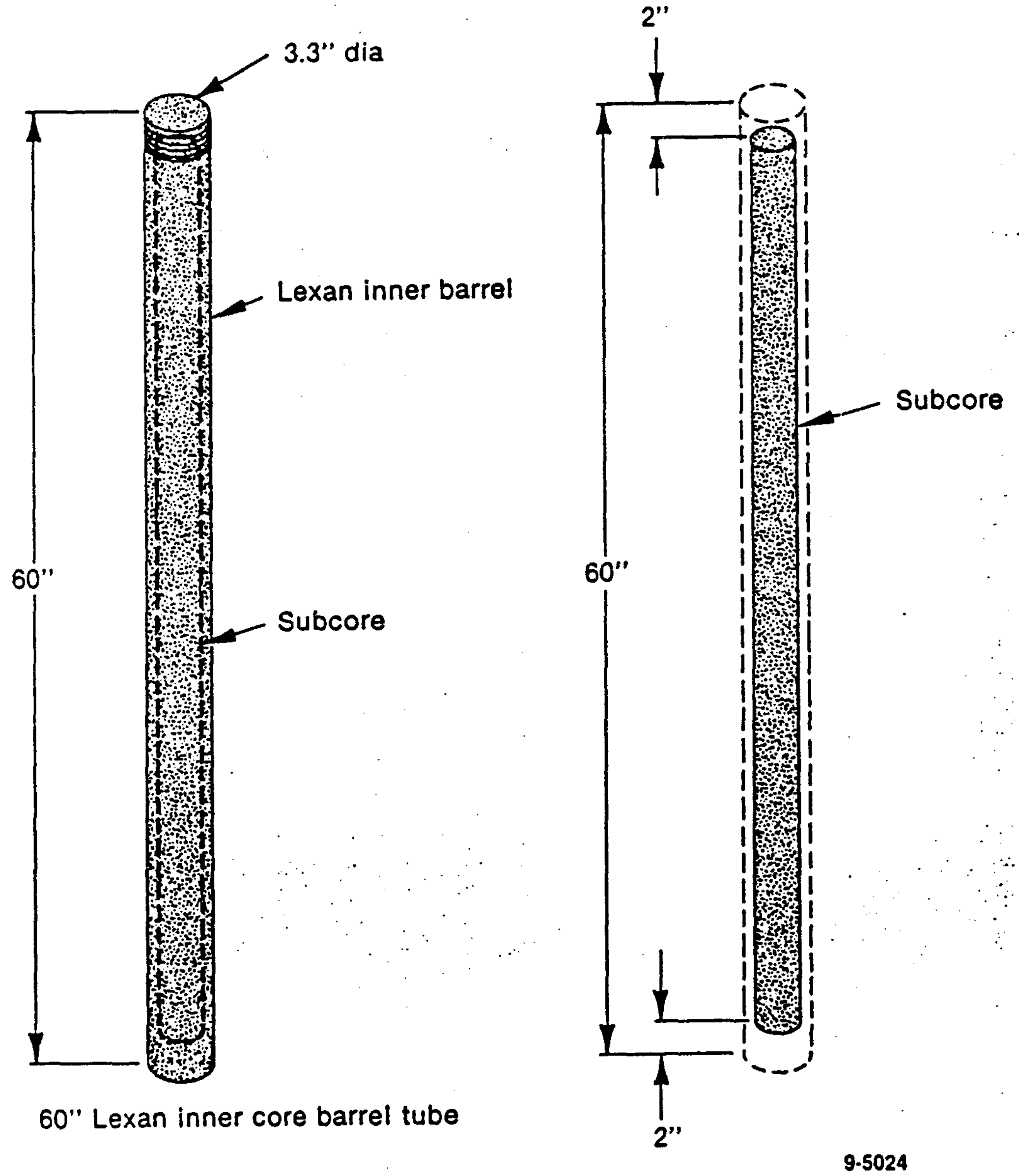


Figure 2. The Lexan barrel and subcore.

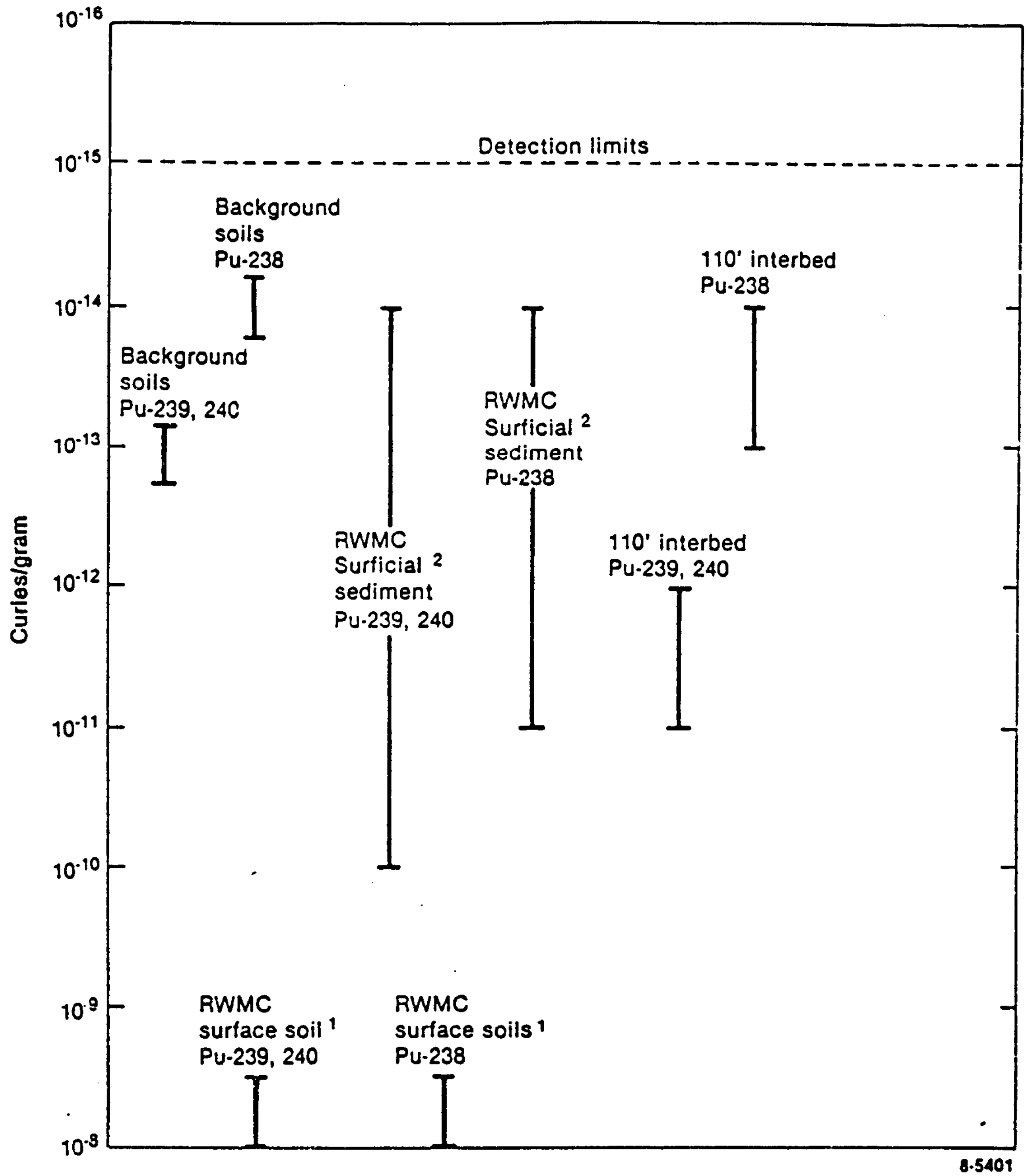
occurring within the borehole. First, once the drill string is introduced into the hole, every attempt is made to avoid having to trip it back out. In cases where tripping out is unavoidable, the string is tripped out as far as possible from the next key target sampling interval. When the string is tripped out, and immediately prior to the collection of the next core, a downhole tracer material is introduced directly onto the material at the bottom of the hole. The tracer employed has been samarium oxide mixed with silica flour. A portion of the subcore material is evaluated by means of neutron activation to determine if the tracer is present. (The tracer is also visible in the field.) If the tracer is present, it is possible that material has sloughed from the sidewall and has been introduced into the sample. If so, then the sample is not defensible. Tracer tests at the INEL, however, have indicated only very limited sloughing problems. A similar downhole tracer procedure is used periodically as a measure of downhole quality assurance.

Results of these tracer tests indicate that the tracer moves to the top of the retrieved core barrel with some residual along the sidewall. These findings indicate that subcoring is a necessary step to minimize borehole cross-contamination.

The final major procedure involves sample handling and decontamination by field personnel. Personnel change gloves frequently, particularly when handling tooling that has the potential to introduce contaminants to the hole. During the 1987 INEL field sampling season (June-October) more than 2,000 pairs of cotton gloves were used. Prior to its use, all tooling is decontaminated with a high-pressure steam cleaner, hexane/methanol wash, and distilled/deionized water. A sample of the rinsate is collected periodically as a form of quality assurance. To assess the adequacy of the decontamination process, smears for radiological testing are collected from the drill rig and other equipment several times a day and measured in a field laboratory for near real-time results. All equipment/tooling is wrapped in plastic (sampling tools are triple bagged) for storage prior to use. The plastic is not removed until immediately before it is introduced into the borehole. All sample handling operations are recorded in a logbook, which includes a signature and date for each page and is legally defensible.

This sampling system has been so effective at the INEL over the past three years (Laney, 1988) that it has provided the first set of samples that DOE has considered defensible in more than 25 years. Figure 3 is a summary of the plutonium (Pu) findings at surface and subsurface sample intervals at the INEL and surrounding areas. The level of activity observed at a given sampling interval is generally one to two orders of magnitude lower than that from the next shallowest interval. Radioanalysis of the sample materials indicates that the levels of contaminants are significantly lower at depth than on or near the surface.

The major drawback of this drilling metholodogy has been its cost, due primarily to the slower rates of coring required by the system's rigorous procedures. However, this methodology, because it gets the sample right the first time, is still significantly less costly than one that sometimes involves resampling due to cross-contamination.



1. Surface soil samples represent the top 4-6 in. of soil.

2. Surficial sediment samples represent the zone approximately one ft below the surface to the top of the first basalt flow (2-25 ft).

Figure 3. Summary of plutonium findings at surface and subsurface sample intervals at the INEL and surrounding areas.

MUD DRILLING IN THE COASTAL PLAIN OF SOUTH CAROLINA

A unique opportunity to further develop these cross-contamination control procedures occurred during the summer and fall of 1988. The DOE Office of Health and Environmental Research Office (OHER) in conjunction with the Savannah River Laboratory (SRL) conducted a project intended to sample material from the Southeast Coastal Plain to a depth of nearly 2,000 ft in an effort to collect microorganisms. This work was conducted under the guidance of Dr. Carl Fliermans (SRL) and supported extensively by Dr. Tommy Phelps (University of Tennessee) and the State of South Carolina.

The drilling site was located near Allendale, South Carolina. The upper part of the stratigraphic section was a deeper water marine sequence. The sediments were fine grained with clay and carbonate sequences, with 60 to 80% of the sequence being calcareous. The middle portion of the section was similar to the upper part but had a more open marine sequence with less tidal flat influence. The lower part of the sequence was representative of a lower deltaic environment with tidal flat influences and restricted marine influences.

The project required the collection of pristine microbiological sample material. Therefore, the drilling techniques employed by the INEL were modified for use with a mud rotary system. The following is an overview of the drilling and sampling techniques employed in the project. Further details will be available soon in a paper in preparation (Russell, Griffin, Phelps, and Sargent).

The mud rotary system required the circulation of drilling fluids through the hole in order to maintain an adequate wall cake, thus preventing caving, and to cool and lubricate the drill bit. The target depth for the subject hole was approximately 2,000 ft with nearly 25 different coring intervals identified. The research team selected a CP wireline system for the coring operations. The mud tanks were enclosed to prevent the introduction of surface windblown materials (microorganisms) into the hole, and tracers were introduced into the mud circulation system. A Lexan liner, within the inner barrel, was used to contain the core material. Rigorous procedures for drilling and sampling were prepared and the site was set up to minimize the introduction of surface contaminants by site drainage, equipment exhausts downwind, etc.

Three separate tracers were used in the drilling muds: rhodamine WT, potassium bromide, and perfluorocarbon tracers (PFTs). These tracers were introduced to the muds periodically, and immediately after each changeout of the mud circulation system. All sample material extracted from the Lexan liner was evaluated for rhodamine WT in a field laboratory to provide an indication of sample integrity. Sample material was also sent to individual laboratories for evaluation of potassium bromide and PFT content. The results are pending at the time of preparation of this paper.

A modification was made to the sampling system for the mud rotary application: the shoe extending beyond the coring drill bit was lengthened. The researchers had expressed significant concern that the muds would penetrate the more permeable zones of the sample material due to the mud pump pressures and hydrostatic head in the borehole column. As a result, special shoes were manufactured that were longer than the conventional 2-in. shoe used at INEL. Shoes of 4, 6, 8, 10, and 12 in. were manufactured and tested. The longer shoes were tested in the more permeable zones, and the shorter shoes in the tighter, clay formations. In general, the longer shoes created difficulty for the driller as the shoe tended to plug easily, necessitating the tripping out of the core assembly. The shorter shoes were effective in the recovery of the clay zones but did not always protect the core material from mud invasion. The 6-in. shoe appears to have been the most effective.

Other modifications and tools were developed by personnel in the field. Since some of these tools are under consideration for patent, no further discussion will be presented in this paper.

In general, the sampling procedures were effective for sampling with the mud rotary system. The tracers in the mud circulation system replaced the downhole tracers employed in the air system. The drilling equipment was virtually the same, with the exception of the mud pumps. The operation was more difficult to keep "clean," and the mud changeouts that were required frequently to minimize borehole cross-contamination were time consuming and dirty.

RESULTS

The sampling procedures presented in this paper have proven valuable to sampling with both air and mud rotary systems. These procedures have been successfully applied to hazardous waste site investigations in Idaho and California (EPA Regions IX and X). The procedures employ off-the-shelf materials and can be implemented in a variety of geologic environments. The Lexan barrels are particularly valuable because they permit the examination of geologic material without requiring exposure of the entire core to the environment. Samples collected in the Lexan may be retained there for extended periods or for permanent storage. Although the procedures require additional time, they facilitate the collection of samples at depth that are considered representative. Detailed written procedures employed at the INEL are available by written request to the authors at the INEL.

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