INNOVATIVE TECHNOLOGY
Summary Report

DOE/EM-0498

Dig Face Characterization

Subsurface Contaminants
Focus Area

Prepared for
U.S. Department of Energy
Office of Environmental Management
Office of Science and Technology

September 1999

INNOVATIVE TECHNOLOGY
Summary Report

Dig Face Characterization

OST/TMS ID 12

Subsurface Contaminants
Focus Area

Demonstrated at
Idaho National Engineering and Environmental Laboratory
Idaho Falls, Idaho
MEMP Environmental Management Project
Miamisburg, Ohio

INNOVATIVE TECHNOLOGY
Summary Report

Purpose of this document

Innovative Technology Summary Reports are designed to provide potential users with the information they need to quickly determine whether a technology would apply to a particular environmental management problem. They are also designed for readers who may recommend that a technology be considered by prospective users.

Each report describes a technology, system, or process that has been developed and tested with funding from DOE's Office of Science and Technology (OST). A report presents the full range of problems that a technology, system, or process will address and its advantages to the DOE cleanup in terms of system performance, cost, and cleanup effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. Information about commercial availability and technology readiness for implementation is also included. Innovative Technology Summary Reports are intended to provide summary information. References for more detailed information are provided in an appendix.

Efforts have been made to provide key data describing the performance, cost, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

All published Innovative Technology Summary Reports are available on the OST Web site at http://ost.em.doe.gov under "Publications."

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SUMMARY

Technology Summary

Problem

The Department of Energy (DOE) has numerous sites that contain buried radioactive waste. DOE buried waste sites typically includes transuranic-contaminated (TRU) radioactive waste, low-level radioactive waste (LLW), hazardous waste, mixed TRU waste, and mixed LLW. Waste at these sites was typically disposed of in containers such as steel drums, wooden boxes, and cardboard cartons. The wastes have breached the containers in many instances. Wastes exist in the form of solids, liquids, and sludges.

Remediation of these sites will be accomplished using one of three options or some combination thereof. The three options include waste retrieval and ex-situ treatment, in situ treatment, and containment/stabilization. The retrieval and ex situ treatment system is likely considered to be the baseline. However, many uncertainties exist using this approach. The site must first be characterized to assess the problem and design the excavation operations. Real-time characterization during excavation could significantly reduce costs by minimizing the amount of material to be excavated and could significantly reduce the risks to worker safety. Systems to perform real-time characterization data during excavation are needed.

How It Works

The Dig-Face Characterization System consists of multiple real-time sensors (geophysical, chemical, radiological, and physical) at the dig-face to provide characterization information during excavation (Figure 1).

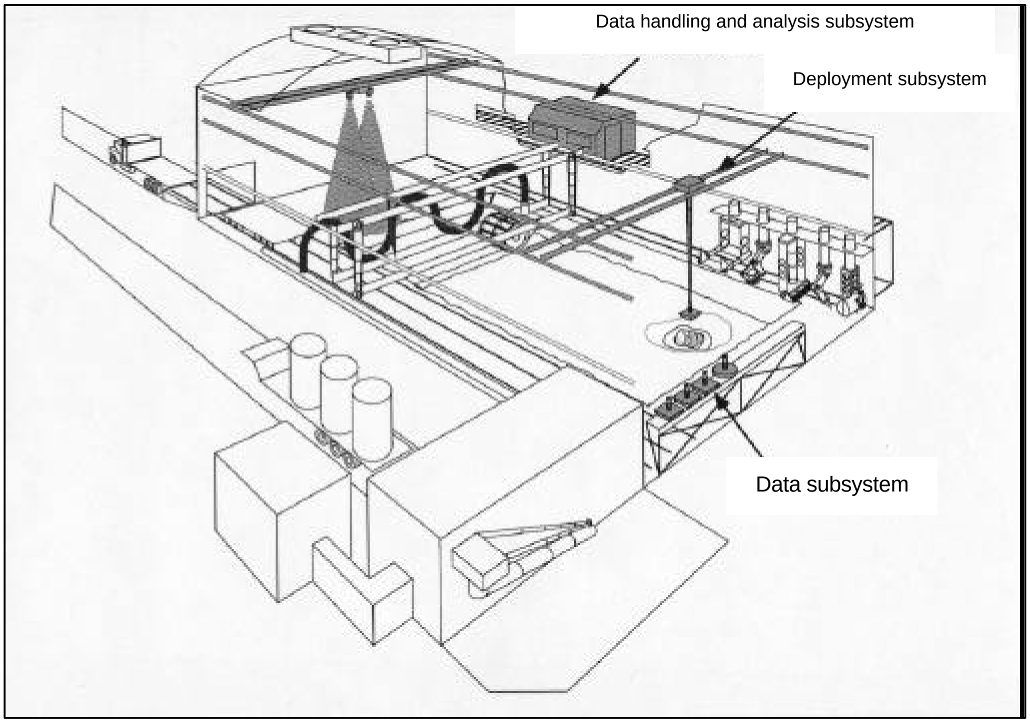

Figure 1. The Dig-Face Characterization System supports radioactive waste landfill excavation projects

This system can be used to provide constant surveillance and screening for all categories of hazards during excavation. Site managers can use this real-time information to recognize and correct potentially dangerous or inefficient operations. Cost savings for this technology are realized by reductions in the quantity of radioactively contaminated solid requiring excavation and disposal.

Potential Markets

The Dig-Face Characterization System has potential applications at all radioactive or other waste landfills at DOE sites where excavation and ex-situ treatment are considered as the remedial option of choice. Landfills within the DOE Complex as of 1990 were estimated to contain 3 million cubic meters of buried waste. All DOE sites have these types of facilities and thus could apply the technology to save costs and improve worker safety. However, the DOE sites containing the largest volumes of this type of waste include Hanford, Savannah River (SRS), Idaho National Engineering and Environmental Laboratory (INEEL), Los Alamos National Laboratory, Oak Ridge Reservation, Nevada Test Site, and Rocky Flats Environmental Technology Site.

Advantages Over Baseline

The baseline technology against which Dig-Face Characterization should be compared is simple excavation and ex situ treatment. The difference between the new technology and the baseline is that the new technology allows for real-time characterization of the buried waste, thus improving worker safety and reducing the quantity of waste material to be removed for treatment and disposal. This can greatly impact costs for remediation of a site.

Demonstration Summary

The Dig-Face Characterization System, has been under development since 1992. The project began under sponsorship by the U. S. Department of Energy (DOE) Office of Technology Development through the Buried Waste Integrated Demonstration and continued under the Landfill Stabilization Focus Area, both managed at INEEL. The system is currently being referred to as the Remedial Action Management System (RAMS).

Based on the original conceptual design, investigators launched several parallel efforts to develop appropriate characterization tools and perform simulated site testing at the INEEL in FY 1993 and FY 1994. Field testing of the prototype system used a test trench at the INEEL Cold Test Pit. Data were obtained from several commercial sensors deployed over simulated targets in multiple passes. As soil layers were progressively removed, the resolution capabilities of the sensors were also evaluated.

In August of FY 1995, the project performed a hot-site demonstration at the Mound Laboratory, now known as the Mound Environmental Management Project (MEMP) in Miamisburg, Ohio. The demonstration involved a track-mounted, trolley-platform, dig-face system, used to monitor a 20 feet by 5 feet (ft) excavation of a radiologically contaminated site, known as Area 7.

Key Results

The spatial information produced by the Dig-Face Characterization System was used to direct the excavation activities into the area containing the contaminants, thereby saving the time and expense of excavating unnecessary soil. Estimated cost savings were approximately $800K (see Section 5 for more detail). The spatial characterization data were also used to develop options for handling the remaining excavation after the Dig-Face Characterization System was removed.

The Dig-Face Characterization System, aka RAMS, was deployed in 1997 at MEMP and at the DOE Savannah River Site in Aiken South Carolina. In 1998 RAMS was successfully deployed at two facilities overseas, in Harwell England and Dounreay Scotland. The data handling subsystem of RAMS has also been deployed as part of the Integrated Suite of Technologies to Delineate Radioactive Contamination in

Soils Project at Fernald Environmental Management Project (FEMP), near Cincinnati Ohio, in 1998 and 1999.

Commercial Availability/Status

The INEEL holds a patent on the excavation mounted deployment sub-system. Currently the system is not commercially available as no licenses have been granted.

Contacts

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Licensing Information

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Other

All published Innovative Technology Summary Reports are available online at HTTP://em-50.em.doe.gov. The Technology Management System, also available through the EM50 web site, provides information about OST programs, technologies, and problems. The OST reference number for Dig-Face Characterization System is 12.

SECTION 2

TECHNOLOGY DESCRIPTION

Overall Process Description

The Dig-Face Characterization System used at the DOE's MEMP site incorporates three technologies:

- A sensor subsystem;
- A deployment subsystem; and
- A data-handling subsystem.

In general, variability in the components of the various subsystems can create a number of different systems, depending on the nature of the application and the site needs. In all cases, however, these subsystems supply the basic capability to perform the following tasks:

- Detect the particular subsurface conditions of interest at the site;
- Collect the characterization data anywhere on the waste-excavation dig-face; and
- Analyze the data in near-real time to provide information feedback for managing the waste-retrieval effort.

Sensor Subsystem

The sensor subsystem consists of an available suite of sensors selected to match the conditions of interest during the retrieval operation. These conditions may be of general interest at many sites (e. g., mapping solid waste boundaries, volatile chemical plumes, and radiation fields), or they may be highly site specific (e. g., tracking a mercury plume or locating a specific object such as a reactor core).

Deployment Subsystem

The deployment subsystem delivers the sensors to points where measurements are desired. Deployment technology may vary substantially, depending on many factors. The most important factors are the scan-mode requirements for each sensor, the overall site dimensions, the expected topography of the excavation face, and the need to avoid impeding excavation equipment functions.

Data Handling Subsystem

The data handling subsystem incorporates technology for transmitting data from sensors to a control station, validating and storing these data, analyzing the data, and communicating result to decision makers.

System Operation

Sensors

The following description of sensors is specific to those used at the MEMP demonstration site. Because at this site, the targets of interest were radioactively contaminated soil zones (specifically thorium [^{232}Th] and actinium [^{227}Ac]) in a suspected septic tank, three sensors were utilized for the demonstration.

- A gamma/neutron mapper (GNM) performed high-sensitivity detection of nonspecific gamma fields at relatively high speed;
- A germanium gamma-ray spectrometer (Ge-spectrometer) provided the capability to identify mixtures or radionuclides point by point; and
- A magnetometer/laser rangefinder (MLR) provided metal-detection capabilities and topographic mapping, the latter enabling adjustment of sensor height for optimal sensitivity.

The low action levels for ^{227}Ac (5 picocuries/gram [pCi/g]) and the high potential for radioactive contamination from other radionuclides were additional considerations in selection of the sensor suite. Other sensors prototyped for the Dig-Face Characterization System include a dielectric permittivity sensor and a focused electromagnetic induction sensor.

Gamma/Neutron Mapper

The Gamma/Neutron Mapper (GNM) was specifically built for high-speed, high-sensitivity detection of low-level gamma fields. Design of GNM was based on the goal of detecting 5pCi/g^{227}Ac at a 1-ft/second scan speed, assuming a 6-inch (in). stand-off distance from the ground. GNM consists of two large, 25.4 x 48.26 x 3.81 centimeter(cm)-thick plastic scintillators in front of two ^{3}He chambers of the same length and width. The four detectors are located inside a protective stainless steel box, as shown in Figure 2. A 1 millimeter-thick titanium window is located directly over the plastic scintillators to reduce the attenuation of low-energy gamma rays (e. g., the 60-keV gamma ray of ^{241}Am).

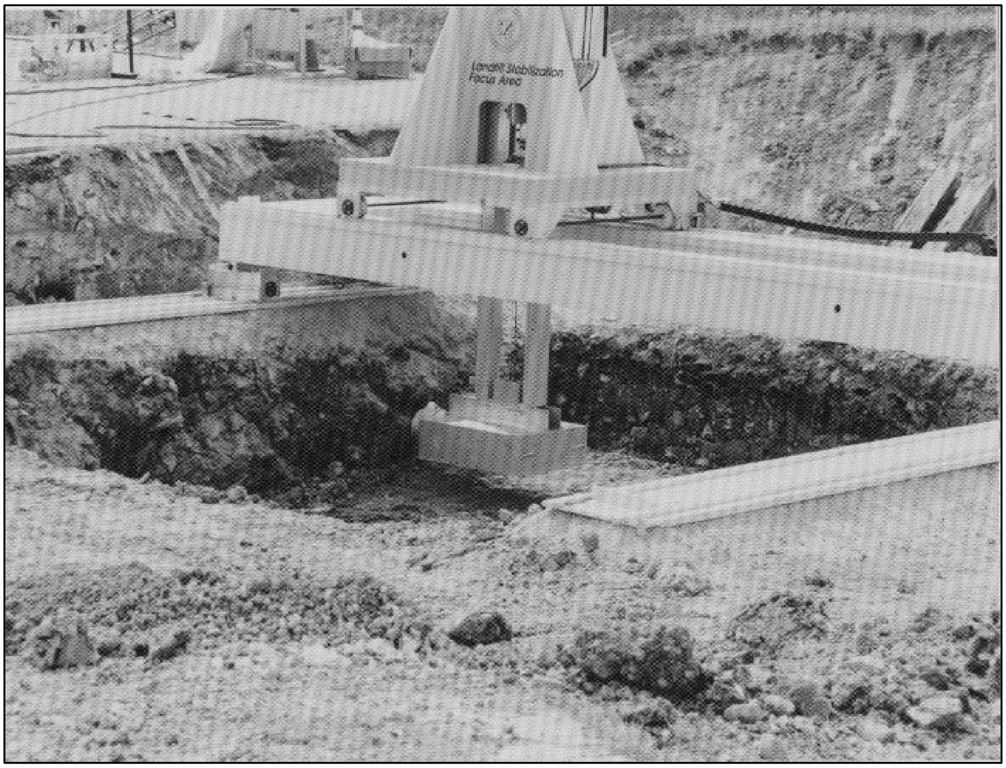


Figure 2. Gamma/neutron mapper mounted on trolley

- Data acquisition electronics, integral to the GNM include analog/digital hardware and radio frequency (RF) ethernet electronics.
- GNM was calibrated with a set of ^{227}Ac sources because ^{227}Ac was understood to be the radionuclide of primary interest. ^{227}Ac was distributed evenly over an area of 9548 cm^{2} and the intrinsic efficiency of the plastic scintillation detectors was measured.

As configured for the MEMP site, the GNM counting range had to be set at a fixed value. The proper range was estimated before each scan, beginning with 5000 counts/second (cps) for the initial scan. When the actual gamma field exceeded the preset range, the electronics became effectively saturated. This situation meant that peak radiation field strength was not captured for some of the observed contamination areas. However, GNM was certainly useful as a screening tool to locate hot spots.

Ge-spectrometer

The Ge-spectrometer measures the energy of each incident gamma ray and keeps count of the number of gamma rays detected at each energy. The resulting gamma-ray spectrum accumulated by the Ge-spectrometer consists of a series of peaks representing the number of gamma rays observed at each energy. Specific gamma emitters are identifiable based on their unique pattern of spectral peaks. At Area 7, where ^{227}Ac, ^{232}Th, and ^{226}Ra were all expected to occur, the Ge-spectrometer provided a means to identify the specific contaminant associated with high gamma fields measured by GNM.

The Ge-spectrometer consists of a 41.5% n-type coaxial germanium detector with an energy resolution of 1.94 full-width at half maximum (FWHM) at 1332 keV (Figure 3). The spectrometer is equipped with a dual-energy pulser developed at INEEL. The pulser provides a means to observe spectral drift and is used as a check on the quality of the spectral data. A bismuth shield covers the detector housing on all but the backside, with removable portions of the shield allowing for different “fields of view.” Currently, the spectral data are accumulated, analyzed, and stored on a dedicated VAX4000 workstation, which functions independently of the Dig-Face Characterization System data acquisition computer.

Figure 3. Ge-spectrometer mounted on the trolley

The Ge-spectrometer was calibrated with 20-gram soil samples containing a homogeneous distribution of mixed radionuclide standards. This calibration configuration was used during the Area 7 excavation to measure contamination in 20-gram grab samples. The Ge-spectometer was also calibrated using an evenly distributed set of point sources of mixed radionuclide standards covering an area of 800 cm^2 at a stand-off distance of 15 cm.

Both the Ge-spectrometer and GNM measure gamma-ray fields in counts per second. To convert count values to estimates of radionuclide activity in picocuries per gram (pCi/g), one must know the detector efficiency and estimate the effective area and depth of soil contributing counts to the acquired data. Because radionuclide activities form the basis for many decisions during a radioactive site cleanup, this conversion is of fundamental importance for a dig-face operation. Appendix B discusses several approaches that were tested using the Area 7 GNM and Ge-spectrometer data sets.

Magnetometer/Laser Rangefinder

The Magnetometer/Laser Rangefinder (MLR) combines two sensors to detect buried metallic debris and to map the topography of the dig face. The magnetic sensor in MLR is a high-speed flux gate magnetic gradiometer mounted in the plastic stinger affixed to the bottom of the sensor housing. Magnetic gradiometers are common metal-detection sensors that measure magnetic disturbances caused by the presence of iron or steel objects.

The MLR topography mapping system operates by measuring the travel time of laser pulses transmitted from the sensor, reflecting off the ground surface, and returning through the sensor lens. Topography measurements are made by scanning the instrument across the ground surface from a fixed height. The sensor is calibrated by setting a zero distance at a fixed calibration point with known elevation.

Deployment System

Figure 4 shows engineering drawings for the trolley-based sensor deployment system that was built for the MEMP demonstration. The design incorporates several features aimed at making the trolley both highly adaptable and inexpensive. The main components of the trolley are:

- the main beam or track (*x*-axis);
- the bridge (*y*-axis);
- the mast (*z*-axis); and
- the motor drive system

Main Beam

The main, or *x*-axis, beam of the trolley has wheeled carriages or trucks that run on a simple track. These assemblies allow the trolley to support excavations of unlimited length by using additional sections of inexpensive track. The carriages are constructed primarily of aluminum with steel axles.

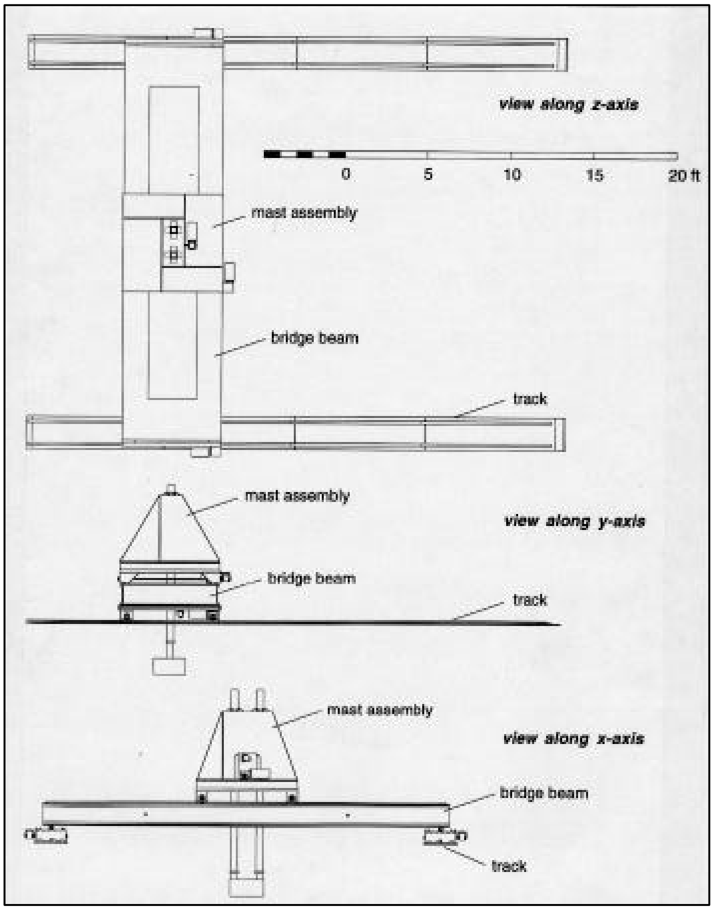


Figure 4. MEMP trolley viewed along each of the three principal axes

For the MEMP demonstration, four 8-ft track sections were used, providing 32 ft of *x*-axis motion and allowing complete access to the 20-ft excavation and a 10-ft parking area. The track rested on gravel foundations to ensure stability and to provide a level track. The trolley was moved to the parking area during digging operations and for changing or servicing sensors.

Bridge Beam

The bridge, or *y*-axis, assembly is constructed primarily of plywood and Truss-Joist I-Beam (TJI) joists formed into box beams. The bridge incorporates a set of rails to guide y-axis motion. The design establishes standard dimensions for bridge components that guarantee compatibility with the main beam and the mast assembly. The bridge length determines a maximum span for the trolley, but the design allows the bridge to be adjusted to lesser spans. Greater spans are possible by constructing longer bridge assemblies, which are relatively simple and inexpensive structures. Coupling between the bridge and the main beam carriages involves fitting a pipe into a box channel, making this operation very easy to accomplish with a small crane.

A 24-ft bridge was built for the MEMP demonstration, providing the required 20-ft of *y*-axis motion to span the pit. The bridge supports loads up to 400 lbs with a deflection less than 1/8 in. The bridge assembly weighs approximately 800 pounds.

Motor Control

A motor controller on the trolley mast assembly that is connected to the operator workstation by an RF link (identical to the sensor communication links) receives operator commands and energizes the motors as needed. The workstation computer monitors and records sensor position at all times. The sequence of motions required to make simple translations along each axis and to perform a complete area scan are preprogrammed and available to the operator through simple menu commands. The operator also sets scan speeds and data spacing.

SECTION 3

PERFORMANCE

Demonstration Plan

Dig-Face Characterization System hardware for the MEMP demonstration was designed based on the project objectives and anticipated conditions at Area 7. The major components of the system were a set of radiation and geophysical sensors, a trolley-type scanning structure, and a computer-based data acquisition and trolley control system. The projected excavation size and ^{227}Ac clean-up levels were critical design drivers.

All aspects of the system were built, assembled, and tested at INEEL before being shipped (Figure 5). The system was shipped to MEMP and staged in the parking lot adjacent to the excavation site. After an overburden layer was removed, gravel foundations were prepared for the trolley *x*-axis track. The trolley bridge-mast assembly was then hoisted onto the track, components were connected, and the system was tested.

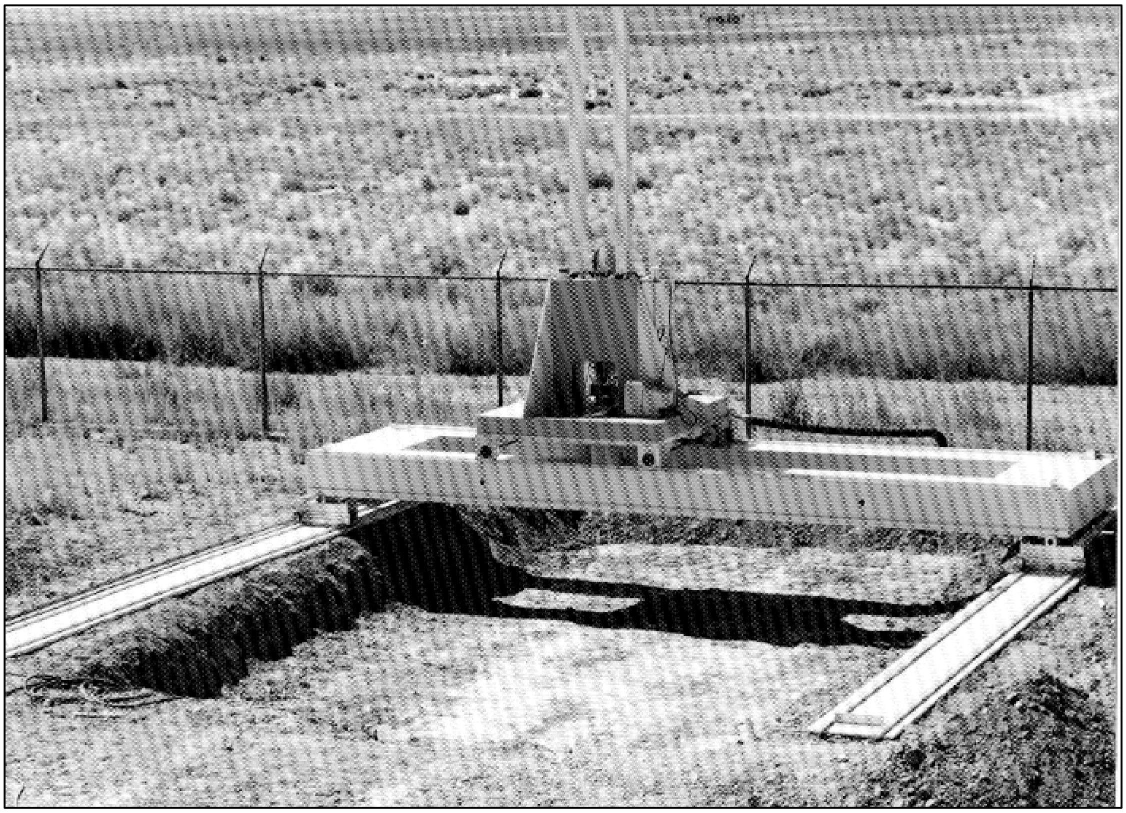


Figure 5. Photograph of trolley during full-function testing at the INEEL Water Reactor Research Test Facility

Dig-Face Characterization activities followed a regular, repetitive sequence (Figure 6). Each cycle began with a topographic scan of the current dig-face. The acquired digital topography data were used to determine the maximum dig-face elevation within the scan area. After setting sensor elevation to maintain an optimal average clearance above terrain (approximately 3 to 9 in.), geophysical and radiation sensor scans were conducted. Following data review, the dig-face system was rolled back off the pit, and excavation resumed, initiating the next cycle.

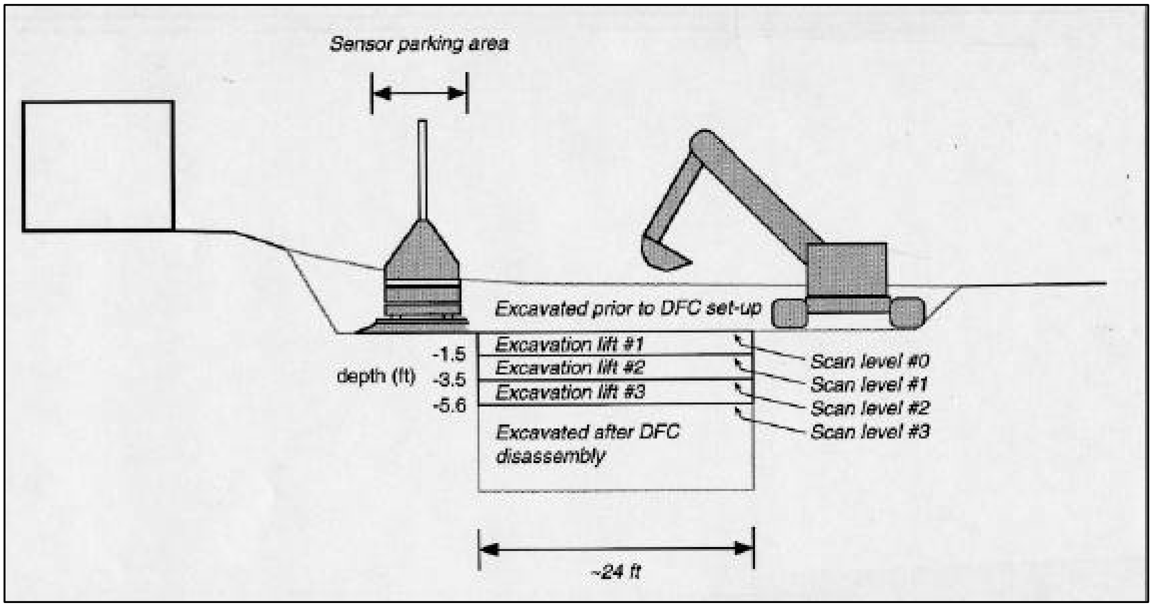


Figure 6. Schematic summary of the excavation sequences at Area 7 during the Dig-Face Characterization support phase

Background and Site Description

Soil borings at Area 7 in the mid-1980s and in 1994 indicated the presence of ^{227}Ac, ^{232}Th, and radium-226 (^{226}Ra) in the subsurface soils. Historical records at the MEMP site linked the contamination to a building demolition in about 1960. Debris was disposed of in a steep ravine alongside (possibly inside) a concrete septic tank. The ravine was later backfilled and turned into a parking lot. Figure 7 shows the layout of Area 7. Regulators approved a time-critical removal action for a portion of Area 7 under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The ^{227}Ac and ^{232}Th clean up levels were set at 5pCi/g and 15 pCi/g, respectively.

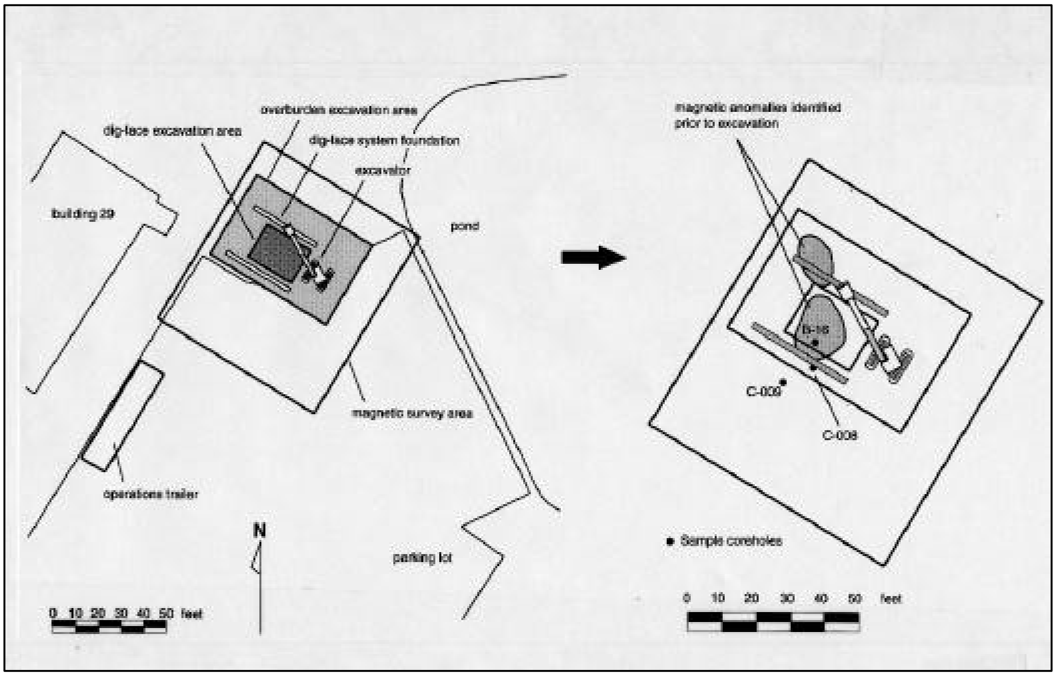


Figure 7. Drawing of the site layout for the Area 7 excavation (left) and detail of the excavation (right)

The original excavation plan targeted a 20 x 20 by 17-ft deep volume centered on the highest detected ^{227}Ac from sample borings. A high-resolution magnetic survey conducted by INEEL in April 1995 detected two possible septic tank locations in the vicinity of the sample borings. The depth of these objects was estimated at 4 to 8 ft, significantly shallower than expected. The magnetic results supplied a basis to modify the original removal action plan for shallower target depths, eliminating the need for shoring and dewatering systems.

^{227}Ac posed a significant radiological health hazard. The inhalation annual limit of intake (ALI) for ^{227}Ac is 20 times more restrictive than for plutonium-238 (^{238}Pu); consequently, the removal action work plan stipulated respiratory protection for excavation workers.

The principal objective for Dig-Face Characterization support during the removal action was to establish a location and in situ geometry of ^{227}Ac as soon as it was encountered, thus protecting human health and reducing potential levels of exposure.

Results

Laser Rangefinder Measurements

The laser rangefinder offered a simple solution to the basic problem of mapping dig-face topography. The dig-face topography is important for the following reasons.

- The changing shape and depth of the dig-face records the progress of the excavation.
- Excavated soil volumes may be calculated accurately, and benchmark depths are documented straightforwardly.
- Objects, debris, or contamination discovered during the course of the dig may be referenced to the dig-face depth at the time of their detection.
- Accurate depth information permits site operators to envision more easily the subsurface in three dimensions and becomes valuable in attempting to predict conditions at greater depth.
- Topography data are used to control the motion sensors.
- Sensor elevation may be set to achieve an optimum offset from the ground surface while avoiding collisions.

Figure 8 shows the excavation sequence at Area 7 as reconstructed from the MLR topography data, acquired at a 0.5 x 1.0-ft data spacing over laser path lengths ranging from 3 to 10 feet. All topographic data were collected relative to the height of a calibration block in the sensor parking area. Laser reflectivity data indicated that the sensor operated very comfortably in this range and that significantly greater depths could be mapped.

Note the irregularities in the pit bottom topography at each stage. These resulted from the dragging action of the backhoe excavator, which caused rocks, concrete, and other debris that was being removed to leave drag marks and voids. These detailed topographic features were reliably captured by the MLR, although some of the smaller features were aliased at the 0.5 x 1.0-ft sampling interval, causing erroneous depths to be reported when reflections were lost at some locations.

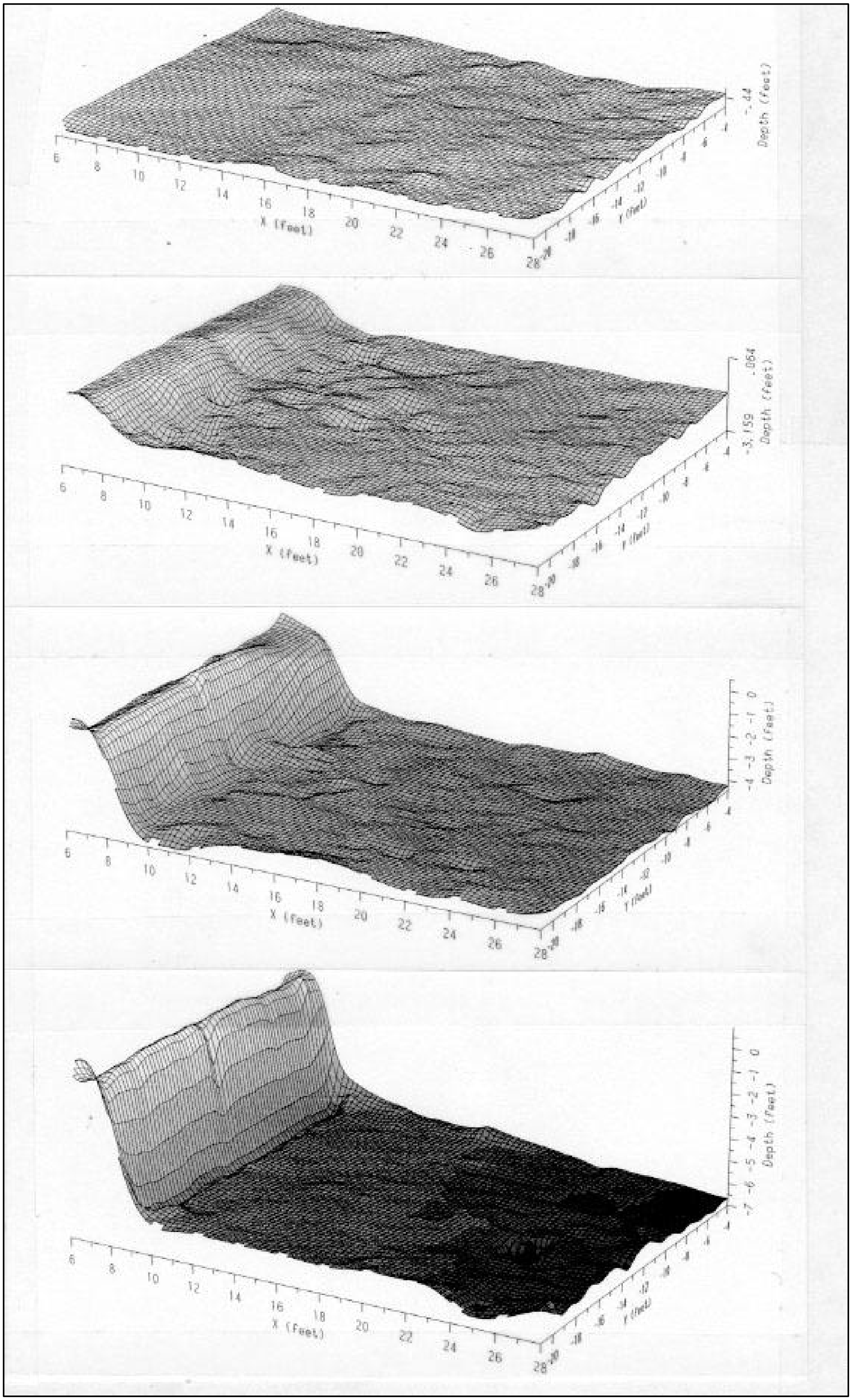


Figure 8. Perspective net drawings of the Area 7 pit topography at each dig-face scan level

Magnetometer Measurements

At Area 7, a high-precision magnetic survey was conducted on the original ground surface several months before excavation began. This preliminary survey and the magnetic scans collected during the actual excavation focused on the problem of detecting and recognizing the concrete septic tank presumed to be buried near the ^{227}Ac plume. In the end, the magnetic data had only minor influence on the outcome of the removal action. However, the general approach to searching for specific objects believed to be markers of contamination is well illustrated by the magnetic data.

Preliminary Magnetic Survey

Figure 9 shows the surface magnetic data collected in April 1995 in an effort to locate the buried septic tank. The magnetic data were interpreted to show two possible locations for the septic tank (D and E), as well as a number of smaller buried metal objects. Small test excavations were conducted to evaluate the magnetic anomalies. These excavations encountered reinforced concrete and construction debris 5 to 7 ft below the ground surface. The debris areas were assumed to be the sources for the magnetic anomalies. Although the concrete septic tank was not positively located, the presence of debris tended supported the conclusion that this area was a former disposal site.

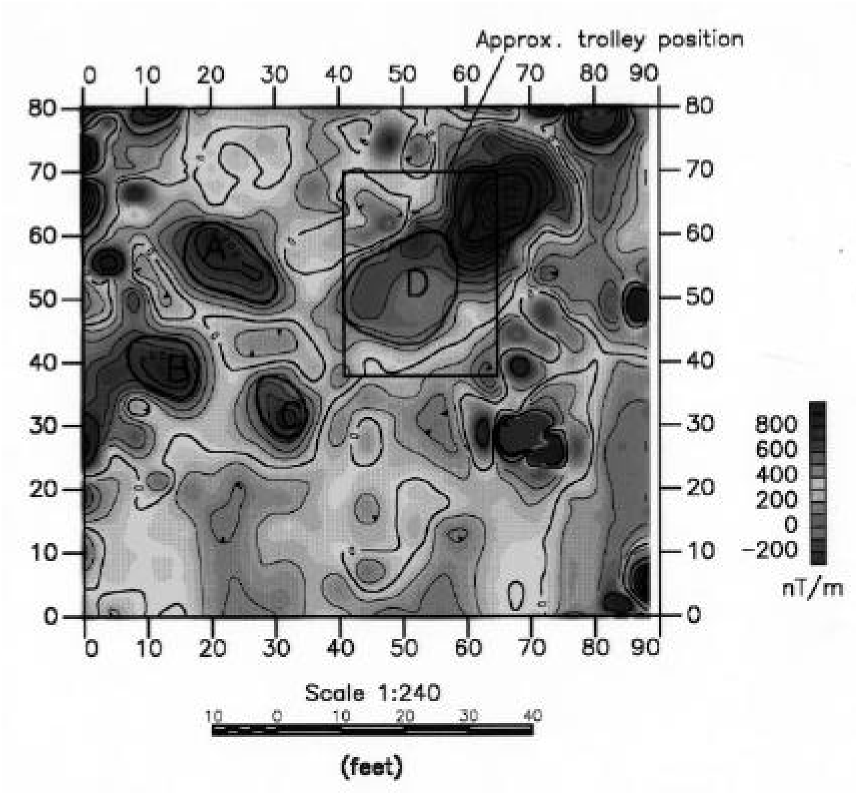


Figure 9. Magnetic map of the Area 7 site before the excavation was begun

Magnetic Data Collected During Excavation

The Level 1 and Level 2 magnetic data are shown in Appendix B, Figures B.1. and B.2. Predicting the detailed characteristics of the magnetic sources encountered during the excavation (i. e., sections of rebar were not distinguishable from a drum lid based on the magnetic patterns) was never possible. However, the general conclusion that none of the magnetic anomalies was caused by large or massive objects, though vague, proved useful. The progressive improvement in anomaly resolution with increasing depth could be important under difference circumstances.

Gamma Neutron Mapper and Germanium Gamma-Ray Spectrometer

The sequence of radiation measurements made during the Area 7 excavation produced the most interesting examples of the capabilities of the Dig-Face Characterization System. At each excavation level, GNM was used to map gross radiation fields. The Ge-spectrometer was then deployed at key points within the measured radiation fields to determine the identity of the gamma emitters. The combination of these tools provided a clear picture of the plan view distribution and insight into the depth distribution of radioactive contamination at Area 7.

Figure 10 summarizes the GNM data for each of the four levels of excavation, shows sample location points for gamma spectroscopic measurements, and magnetic anomalies. More detailed maps of the radiation measurements are shown in Appendix B, Figures B.3. and B.4.

- The level 1 data were collected at the ground surface at the time the trolley was set up (i. e., after the overburden removal stage). At level 1, the only radionuclide detected above background was 232Th.
- After excavating approximately 1.5 ft of soil from the trolley tracks, a new measurement sequence was begun. High-gamma fields were observed along the same trend identified to contain ^{232}Th on Level 1. At Level 2, the high-radiation field had broadened and increased in intensity, giving a clear impression that the excavation has advanced closer to the center of the plume. Again, only ^{232}Th was detected above background levels.
- The site was excavated approximately 2 ft more and the Level 3 radiation measurements were made. The Level 3 GNM data show continued evidence of the ^{232}Th plume with the plume centerline shifted several feet toward the $+x$ end of the pit.
- The site was again excavated approximately 2 ft to Level 4. The Level 4 data show further shifting of the ^{232}Th plume in the $+x$ direction, but no increase in the levels of radiation. In fact, the ^{232}Th plume radiation fields appear to have decreased slightly from Level 3, suggesting that contamination levels are no longer increasing and may be decreasing.

Analysis of the in situ spectral measurements revealed that the gamma radiation field was caused by two separate radionuclides in the subsurface. The main plume contains only ^{232}Th. A significant volume of this plume was already excavated by Level 4. The second plume, with highest concentrations occurring near x=13, y=16 contains ^{227}Ac. Level 1 through Level 3 GNM data show no evidence of this second contamination area, suggesting that the Level 4 dig face occurred close to the top of its distribution. Subsequent excavation recovered ^{227}Ac-contaminated soil throughout the area around and beneath the high-field area mapped by GNM. No other ^{227}Ac-contamination areas were found during the subsequent excavation.

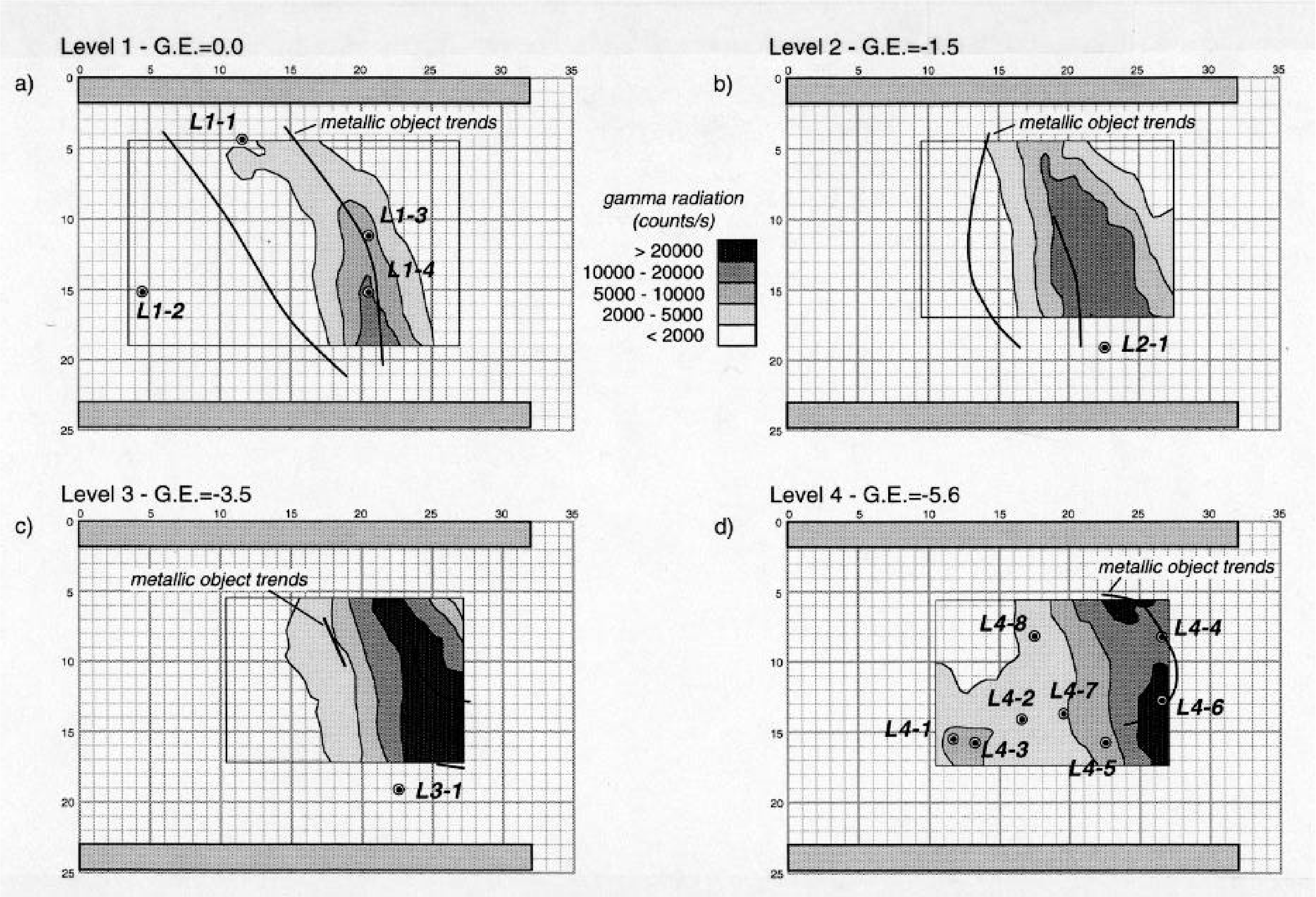


Figure 11. Summary of dig-face characterization data for Level 1 through Level 4 dig-face scans (a-d). (Magnetic object trends are shown by heavy lines. Sample locations and/or Ge-spectrometer measurement point are shown by circles. Gamma radiation fields are shown by contours)

Radiation Measurement Results

Table 1 shows that the activities from the three radioactive measurement techniques (GNM, In situ gamma spectroscopy using Ge detectors, and Ge-spectroscopy of soil samples) agree within about a factor of 4 (with some exceptions).

- Two of the exceptions, L2-1 and L4-6, occur at locations where the GNM was saturated and the calculated GNM activities give only minimum values.
- At two other locations, L1-3 and L4-5, all activities are low; some of the discrepancy between the calculated values may be attributed to the method of calibration (i. e., subtraction of an assumed constant K-40 background).

Despite the scatter, the three methods show general agreement in identifying high-versus low-activity areas and show no tendency to produce highly spurious (i. e., more than an order of magnitude) activity estimates.

Scatter in the Table 1 data may also reflect the more fundamental factor of effective sample size. GNM has a large volume of investigation compared with the Ge-spectrometer. In turn, the Ge-spectrometer has a large volume of investigation compared with the 20-g sample analyses. For each analytical method, the calculations assume that radioactive contaminants are distributed uniformly throughout the volume of investigation. This assumption becomes increasingly precarious as the volume of investigation increases.

GNM gives a bulk-concentration estimate and shows smoothly changing concentrations even if the radionuclide distribution is heterogeneous on a small scale. Although detailed concentration changes are not detected, large-scale changes are mapped accurately. The Ge-spectrometer detects smaller-scale concentration changes than GNM. Because the two instruments are looking at different volumes of soil, some variation in concentration estimates is expected (unless the radionuclides are very evenly distributed). The 20-g sample method detects even smaller-scale changes and creates more variation in determining the fate of large volumes of excavated soil.

Although the quantitative results achieved at the MEMP site are encouraging, further improvements in the instrumentation and in the analysis protocol are necessary before the in situ measurements can be given the same weight as laboratory assays using a good sampling protocol. Methods to define the field of view and the effective depth should be developed when the plume is not well defined. However, the experience gained from this investigation indicates that, with further improvements in the methodology and operational procedures, many operational decisions could be made with the on-site use of GNM, the in situ Ge-spectrometer, and the grab sample Ge-spectrometer.

The relative activities for the 238-, 583-, 911-, and 2614-keV thorium gamma rays as measured with the in situ Ge-spectrometer are also listed in Table 1. These values, within their uncertainties, should be constant and equal to 100. Deviation from 100 is an indication that the activity distribution is not evenly distributed in three dimensions within the detector's field of view.

Table 1. Summary of estimated radionuclide activity concentrations based on dig-face radiation sensor measurements

Sample	Position	GNM[a] (pCi/g)	In situ Ge-spec[b] (pCi/g)	20-g sample (pCi/g)	Activity ratio 238:538:911:2614
L1-1	11.7,—4.2	7.0 Th	6.9 Th	16 Th	125:100:117:59
L1-2	4.7,—15.2	1.5 Th	1.5 Th	3 Th	128:100:-:7
L1-3	20.7,—11.2	22.0 Th	2.4 Th	13.7 Th	52:100:148:383
L1-4	20.7,—15.2	>37.8 Th	32.0 Th	116 Th	53:100:112:154
L2-1	22.6,—19.3	>37.8 Th	412.0 Th	302 Th	102:100:82:52
L3-1	22.6,—19.3	-37.8 Th	—	43 Th	—
			1.9 Th	—	
L4-1	11.7,—15.3	199.0 Ac	189.0 Ac		-:100:125:130
L4-2	16.7,—15.3	14.1 Th?[c]	—	—	—
			4.2 Th	—	
L4-3	13.2,—15.8	199.0 Ac	202.0 Ac		-:100:96:82
L4-4	25.7,—8.3	71.1 Th	21.0 Th	—	72:100:118:139
L4-5	22.7,—15.8	24.0 Th	3.5 Th	—	-:100:186:317
L4-6	26.7,—12.8	>77.3 Th	843.0 Th	—	125:199:71:30
L4-7	19.7,—13.8	16.1 Th	9.0 Th[d]	—	111:100:92:71
L4-8	17.7,—8.3	8.2 Th	1.5 Th	—	82:100:134:215

[a] K_m(Th) = 254.4 (c/s)/pCi/g for ^{232}Th; K_m(Ac) = 28.0 (c/s)/(pCi/g) for ^{227}Ac.

[b] K_g(Th) = 118.667 (pCi)/pCi/g for ^{232}Th; K_g(Ac) = 118.667 (pCi)/pCi/g) for ^{227}Ac.

[C] ^{232}Th is assumed at this position based on GNM map data but was not verified by Ge-spectrometer.

[d] The presence of ^{223}Ra at 270 keV is indicated by the width of the 270-keV peak and its high relative intensity compared with other locations.

Data Interpretation: Mapping the Thorium-232 Contamination

The sequence of radiation field maps in Appendix B gives a clear impression that the radioactive contamination plumes within the Area 7 pit are discrete bodies with relatively narrow distributions and well-defined edges. The exact edges of contamination are not easily derived from the maps because they depend on factors such as the sensor view angle and the thickness of the contaminated zone, which are both still poorly understood. For example, the GNM sensor detects radiation from a contaminated soil zone before it comes into a position directly over the zone, causing the mapped radiation areas to be larger that the actual area of contamination. Even with this smearing effect, the ^{232}Th and ^{227}Ac plumes at Area 7 clearly occupy a relatively small volume of the excavated soil.

Figure 11 shows an attempt to reconstruct the zone of ^{232}Th contamination encountered during the dig-face operations at MEMP. This reconstruction is possible because of the multiple views of the plume that were acquired during the course of the excavation. Figure 11(a) shows centerlines of ^{232}Th radiation areas plotted for each dig-face level. The centerlines migrate farther toward the end of the pit after each increment of excavation because the contamination seam has stratigraphic dip in the +*x* direction. Figure 11(b) shows this configuration in a cross-sectional view. This view was constructed by projecting the 5000-cps and 10,000-cps contours into cross section and connecting them. The actual volume of contamination is somewhere within the projected contours. One explanation for the observed contaminant distribution is that the ^{232}Th soils were originally dumped on a slope.

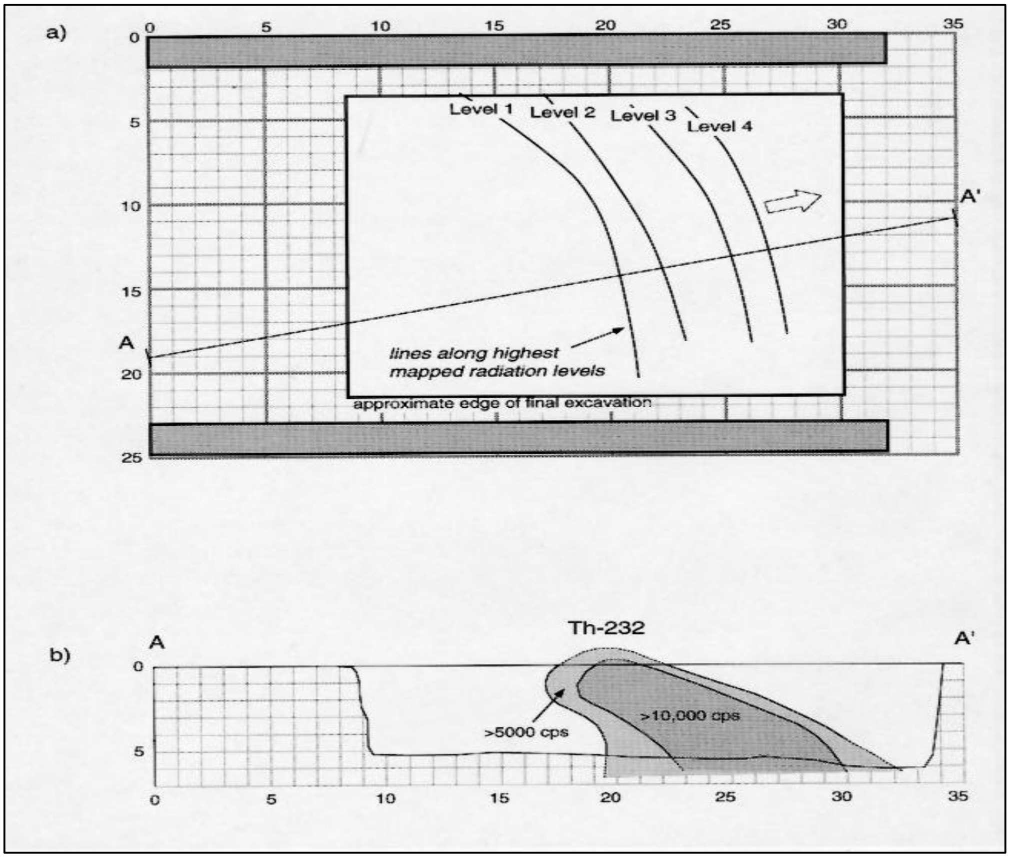


Figure 11. Interpreted geometry of ^{232}Th plume at Area 7. Lines in (a) show the location of peak radiation for each level. The interpreted depth distribution is shown in (b)

SECTION 4

TECHNOLOGY APPLICABILITY & ALTERNATIVES

Competing Technologies

- The current baseline for site characterization involves various intrusive sampling-and-analysis methods. Initial site characterization efforts at many sites within the DOE complex have provided sufficient information to produce estimates of the overall nature and extent of soil contamination but not enough to allow accurate retrieval of wastes from a specific site without some degree of risks. Extensive sampling of a site to reduce risks becomes prohibitive because of budget constraints.
- Additional non-intrusive characterization techniques exist for the identification of radionuclides in subsurface stata, including such techniques as field-portable intrinsic germanium detector/gamma spectroscopy systems; however, these devices typically operate from the surface and can be limited as to the volume of soil they can survey for radioactive materials. Dig-Face Characterization monitors the entire excavated area and can produce maps of radionuclide activities as the excavated area changes.
- Innovative technologies are being developed for monitoring subsurface strata for radioactive components. One technology being developed is the incorporation of an intrinsic germanium detector into a cone penetrometer tip. This technology involves multiple pushes into the examined area and subsequent grouting of the holes upon withdrawal.

Technology Applicability

Dig-Face Characterization is targeted for use during excavation of buried waste from landfills. Real-time characterization of the waste during excavation will allow for reduction in the volume of waste to be removed, treated, and disposed.

- Dig-Face Characterization can be used nonintrusively to identify gamma-emitting radionuclides in the subsurface during waste retrieval.
- Dig-Face Characterization can be used to detect buried metallic debris and to map the topography of the dig face.
- Other sensors could be adapted to measure other parameters depending upon site need. The basic system of sensor deployment could thus be utilized for other applications related to retrieval of buried waste.

Patents/Commercialization/Sponsor

- The INEEL holds a patent on the Dig-Face Characterization subsystem for deployment of the sensors. There are currently no licenses associated with this patent. The system is not currently commercially available. The United Kingdom Atomic Energy Agency is considering licensing the system.
- The DOE Office of Science and Technology has sponsored this technology for a number of years, beginning in 1992.

SECTION 5

COST

Methodology

The following compares the costs for the Dig-Face Characterization System and the baseline technology of sampling and analysis for the characterization of the MEMP Area 7 Site. The baseline sampling and analysis scenario consists of acquiring soil cores (down to 17 ft) at 5-ft intervals within the 20 x 20-ft area. The soil cores were partitioned into three segments, from which samples were analyzed in a radioanalytical laboratory.

Cost Analysis

Baseline Sampling and Analysis

The following tables give the cost estimates for the baseline sampling and analyses necessary to characterize the extent of contamination at the MEMP Area 7 site (Table2) and an extensive sampling scenario for the same site (Table 3). This sampling scenario will only define the overall area that is contaminated and is not precise enough to be used to support discretionary removal. A more intensive and costly sampling regime would be required to support discretionary removal.

Table 2. Cost estimate for the baseline sampling and analysis scenario to characterize the extent of the contamination at the MEMP Area 7 site (20 ft x 17 ft)

Item	Basis	Cost ($K)
Sample acquisition	16 cores (5 ft grid) taken via push apparatus (e. g., Geoprobe), 3 people for 1 week	8
Sample preparation	2 people for 2 weeks, core segmentation, etc.	10
Sample analysis	Approximately 50 samples (3 samples from each core) @ $100/sample	5
Total		**23**

Extensive Sampling and Analysis Scenario

Table 3. Cost estimate for an extensive sampling and analysis scenario at the MEMP Area 7 site (20 ft x 17 ft)

Item	Basis	Cost ($K)
Sample acquisition	400 cores (1 ft grid) taken via push apparatus (e. g., Geoprobe), 3 people for 25 weeks	200
Sample preparation	2 people for 50 weeks, core segmentation, etc.	250
Sample analysis	Approximately 6800 samples (17 samples from each core) @ $100/sample	680
Total		**1130**

Dig-Face Characterization System

The total investment for a functional trolley-type Dig-Face Characterization System depends mainly on sensor costs. The system taken to the MEMP site could be duplicated for less than $200K. The equipment can be shipped by flat-bed-truck. Set-up time takes less than a day. Actual operation of the system for routine scanning can be scheduled to create minimal stand-by-time for the excavation operation. Scanning takes about 15 min/sensor and could be performed at night.

During routine use of Dig-Face Characterization, one must consider the cost of the operation. The operation at the MEMP site was conducted comfortably with a three-person crew. It is reasonable to assume that the crew size can be reduced to two when operations are streamlined. The crew could function much like a well-logging crew in the oil-field service industry, with an equipment/software engineer and a professional data analyst. Table 4 gives some very preliminary estimates for the cost of operating a Dig-Face Characterization System.

Table 4. Cost estimate for operation of a Dig-Face Characterization System

Item	Basis	Cost ($K)
System cost	MEMP prototype, including sensors	200
Shipping	Idaho to Ohio (one way)	2
Setup	3-person crew, 1 day, and heavy equipment	2
Daily operation	2-person crew	0.5
Demobilization and decontamination	3-person crew, heavy equipment, and shipping	8
1-month operation	2-person crew, 30 days, and travel, per diem	22
6-month operation	2-person crew, 30 days, and travel, per diem	130
Total		**364.5**[a]

[a] Total based on 6-month operation.

Cost Conclusions

Costs to characterize a site by Dig-Face Characterization are significantly higher than standard site sampling and analysis methods. Extensive characterization of a radioactively contaminated site is prohibitively uneconomical. Cost savings can be incurred by using this technology as a result of significant reductions in the quantity of radioactive waste to be disposed.

In Compartments 1 and 2 of the Area 7 excavation, using the GNM data it is estimated that only about 15% of this volume contained ^{232}Th above clean-up levels. Had it been possible to separate the clean soils and replace them in the ground, only about 29, rather than 191, waste boxes would have required packaging, handling, and shipping to engineered storage facilities. At $5K/box, the cost savings would have approached $800K.

SECTION 6

REGULATORY AND POLICY ISSUES

Regulatory Considerations

- No special permits or Occupational Safety and Health Act (OSHA) requirements will be required for operation of the Dig-face Characterization System. Characterization operations during excavation are conducted under the requirements of CERCLA or the Resource Conservation and Recovery Act (RCRA).
- Regulators will likely continue to require soil sampling and analysis to certify an area clean of contamination. Fernald staff are currently working closely with the Ohio EPA to develop a certification scenario that builds upon real-time field characterization leading to waste minimization during excavation operations.

Safety, Risks, Benefits, and Community Reaction

Worker Safety

Because Dig-Face Characterization seeks to identify and monitor the changing makeup of the dig during waste excavation as a means of avoiding the undesirable consequences of incomplete knowledge, the potential exposure of workers to hazardous materials is reduced substantially.

Community Safety

Because Dig-Face Characterization attempts to identify subsurface structures (e. g., tanks and pipelines) and radioactive hot spots, the potential for unexpected events (i. e., explosions, etc.) is reduced, thereby reducing the potential risk to the surrounding community.

Environmental Impacts

Because Dig-Face Characterization provides non-intrusive data regarding a contaminated site, wastes associated with sampling programs and overall waste volumes are reduced.

Socioeconomic Impacts and Community Perception

- The economy of the region should not be affected by Dig-Face Characterization.
- Dig-Face Characterization has limited exposure within the general public; however, public support is expected because it significantly increases worker safety and reduces the costs associated with waste retrieval, treatment, and disposal.

SECTION 7

LESSONS LEARNED

Implementation Considerations

- Dig-Face Characterization is best applied when scan surfaces are relatively flat, interference from the excavation walls is minimal, the composition and density of the excavated matrix is relatively constant, and contamination plumes are not complex.
- The Ge-spectrometer should be used to compliment the GNM scans to identify specific radionuclides.
- Grab samples of soil should be taken to compliment and verify the in situ Ge-spectrometer measurements.
- Grab samples should be taken directly below each Ge-spectrometer measurement at a depth of approximately 5 cm to approximate most closely the effective volume observed by the Ge-spectrometer.
- The curve relating the effective area (volume) and associated detector efficiency as a function of detector height should be measured for GNM and the Ge-spectrometer to allow for variations in detector height at the excavation.
- The curve relating the effective investigation volume as a function of the energy should be measured for GNM and the Ge-spectrometer.

Technology Limitations and Needs for Future Development

- The shielding surrounding the Ge-spectrometer should be enhanced to better define the field of view of the instrument and to reduce the amount of radiation that penetrates the shield from oblique angles.
- The noise from the trolley, which causes the loss of energy resolution by the Ge-spectrometer, must be identified and eliminated.
- The analog readout of GNM must be changed to prevent count-rate saturation resulting from the limits of the analog-to-digital-conversion circuit.
- The count-rate capability of GNM should be improved so that it will operate at 10% c/s with no more than 10% counting loss.
- The stability of the dual-energy pulsar circuit on the Ge-spectrometer must be improved to ensure proper tracking of the gamma-ray spectrum.
- The cabling associated with the Ge-spectrometer must be simplified with the data transferred to the computer by RF ethernet.

Technology Selection Considerations

Waste retrieval operations involving radioactive components can present worker safety issues as a result of a lack of buried waste historical data and/or insufficient subsurface data. Nonintrusive characterization techniques, such as Dig-Face Characterization, which use a variety of technologies for identifying subsurface objects (tanks, piping, etc.) and radioactive constituents, can provide improved, cost-effective data to conduct more effective waste-retrieval operations.

APPENDIX A

REFERENCES

Akers, D. W., R. J. Gehrke, and D. R. Stapes 1993. *Dig-face Chemical and Radiation Sensor Assay System,* EGG-WM-11034, EG&G Idaho, Inc., Idaho Falls, Idaho.

Beck, H. L., J. DeCampo, and C. Gogolak 1972. *In-Situ Ge(Li) and NaI(TI) Gamma-Ray-Spectrometry. Health and Safety Laboratory,* U. S. Atomic Energy Commission Report HASL-258, TID-4500.

Collins, H. D. 1994. *High-Resolution Imaging of Buried Waste Using Holographic Impulse Radar Array,* RL34002, Pacific Northwest Laboratories, Richland, Washington.

Debertin, K., and R. G. Helmer 1988. *Gamma-and X-ray Spectrometry with Semiconductor Detectors,* Horth-Holland Publishing Co., Amsterdam, Oxford, New York, and Tokyo.

Gehrke, R. J., R. S. Lawrence, and R. J. Pawelko 1995. *Results of Performance Tests on Chemical and Radiation Measurement Systems for Use at the Dig Face,* INEL-95/0036, Lockheed Idaho Technologies Company, Inc., Idaho Falls, Idaho.

Graebner, P. 1993. *Preliminary Data Processing and Data Analysis Concepts, Final Report for Subcontract C93-1204093,* EG&G Idaho, Inc., Idaho Falls, Idaho.

Harthill, N., and A. A. Kaufman 1993. *Conceptual Design of an Optimized Electromagnetic Profiling System for Shallow-Penetration Dig-Face Characterization, Final Report for Subcontract PO36563,* RUST Geotech Inc., Grand Junction, Colorado.

International Commission of Radiation Units and Measurements 1994. *Gamma Ray Spectrometry in the Environment,* ICRU Report 53, International Commission on Radiation Units and Measurements.

Josten, N. E., S. T. Marts, and G. S. Carpenter 1991. *Use of Noninvasive Geophysical Techniques for the In Situ Vitrification Programs,* EGG-WTD-9432, Volume 2, EG&G Idaho, Inc., Idaho Falls, Idaho.

Josten, N. E. 1992. *Preliminary Design for a Safe Step Remediation System,* EGG-EELS-002, EG&G Idaho, Inc., Idaho Falls, Idaho.

Josten, N. E., and L. G. Roybal 1993. *Test Plan for Dig-Face Characterization Performance Testing,* EGG-WTD-10766, EG&G Idaho, Inc., Idaho Falls, Idaho.

Josten, N. E. 1995. *Progress on Development of the Dig-Face Characterization Technology,* INEL-95/0093, Lockheed Idaho Technologies Company. Inc., Idaho Falls, Idaho.

Svoboda, J. M., and R. A. Callow 1994. *Dig-Face Characterization Development Plan,* EGG-WTD-11062, EG&G Idaho, Inc., Idaho Falls, Idaho.

APPENDIX B

PERFORMANCE DETAIL

Magnetometer Measurements

Maps of the magnetic field across the area of investigation are shown in this section for each of the four excavation levels. In the left plots, magnetic-field intensity is indicated by colors superimposed on a grid representing the pit topography. Conventional contour plots are presented to the right of the perspective plots. Figures B.1 and B.2 present the data from each of the four excavation levels.

The elliptical pattern of magnetic anomalies observed in the Level 1 data results from the same group of sources that produced Anomaly D in Figure 9 page 13. The discrete sources were unresolvable in the surface data, which were collected from a position 5 to 6 ft above the sensor position of the Level 1 dig-face scan. In the Level 1 data, the existence of discrete, small magnetic sources is clearly evident.

Immediately apparent, based on the Level 1 data, was the fact that a large metal structure such as the reinforced concrete tank would not be encountered in the excavation area. Instead, the subsurface appeared to be littered with small, metal debris. Level 1 through Level 4 data show the progressive excavation and removal of this debris. Some of the excavated material appeared to be remnants of a concrete structure, possibly the suspected tank.

The emergence of a second area of debris is also traceable in the Level 1 through Level 4 datasets. This second area is evident as an anomalous zone near $x = 23$, $y = -10$ in the Level 1 data. This zone becomes more evident at each successive level. The general appearance of this anomaly progression mimics the progression of the first anomaly zone. The debris encountered and removed from this second anomaly zone after the Level 4 scan was similar to the debris seen in the first zone.

Predicting the detailed characteristics of the magnetic sources encountered during the excavation (i. e., sections of rebar were not distinguishable from a drum lid based on the magnetic patterns) was never possible. However, the general conclusion that none of the magnetic anomalies was caused by large or massive objects, though vague, proved useful. The progressive improvement in anomaly resolution with increasing depth could be important under difference circumstances.

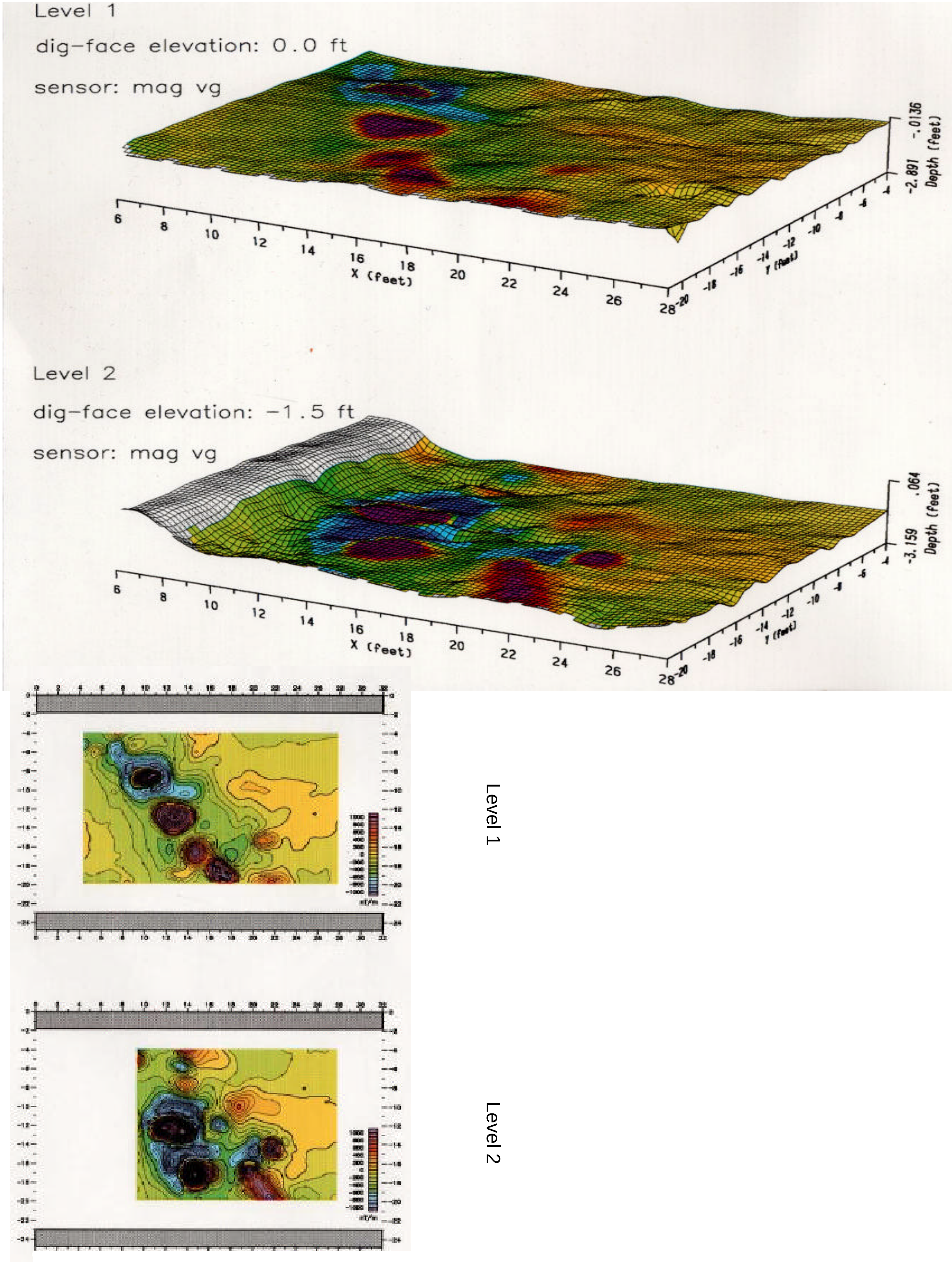
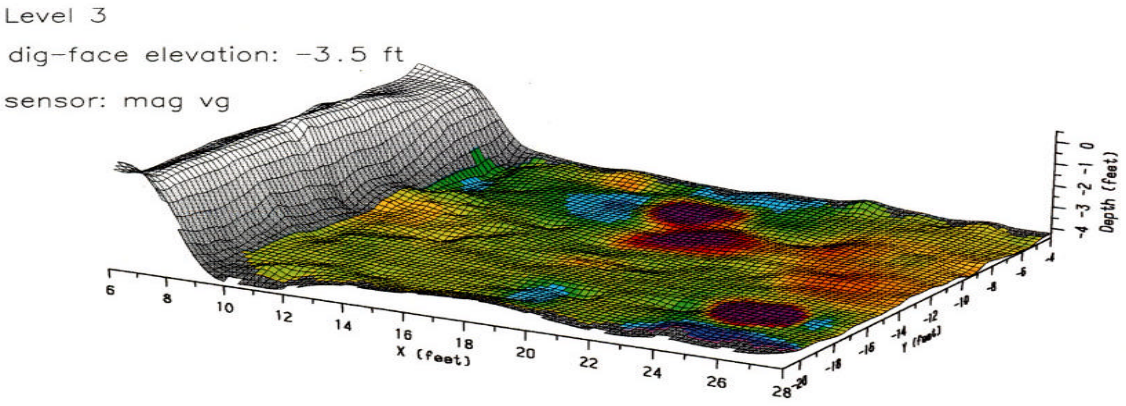
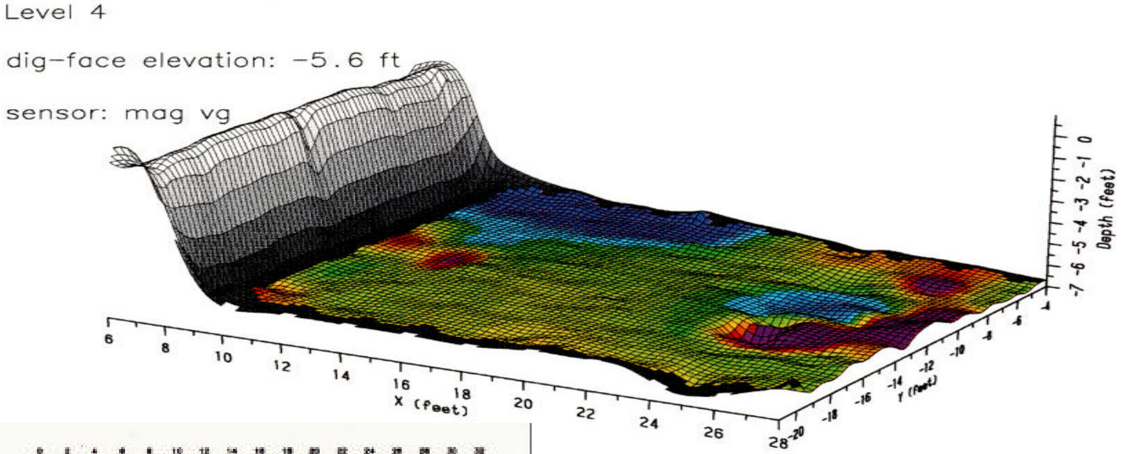
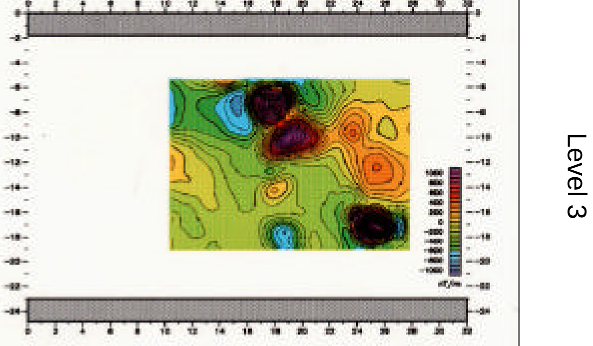


Figure B.1. Magnetic data from Level 1 and Level 2 (*a, b*) dig-face scans







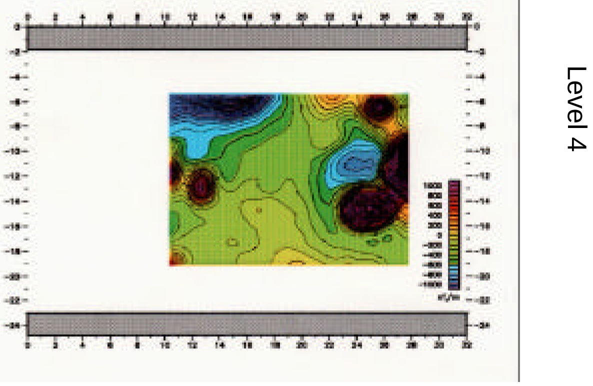


Figure B.2. Magnetic data from Level 3 and Level 4 (c, d) dig-face scans

Gamma Neutron Mapper and Germanium Gamma Spectroscopy

GNM measurements were taken during excavation at four different levels. The following description and visual data presentations represent the results of each of the four measurement activities.

- Level 1 Radiation Measurements: Ground Elevation = 0.0 ft

  Figure B.3 gives plots of the Level 1 GNM data. Upon completion of the GNM measurements at the first level, in situ gamma-ray spectra were measured using the Ge-spectrometer at four positions. Four 20-g soil samples were taken at the same positions and assayed with the Ge-spectrometer using the calibrated sample-counting geometry.

  Level 2 Radiation Measurements: Ground Elevation = -1.5 ft

  Figure B.3 shows GNM data from the Level 2 scan. High-gamma fields were observed along the same trend identified to contain ^{232}Th based on the Level 1 data. The high-radiation field had broadened and increased in intensity. The Level 2 data give a clear impression that the excavation has advanced closer to the center of the ^{232}Th contamination plume. The GNM sensor saturated at the 10,000 cps level over the central portion of the plume, so the highest radiation fields were not measured. No other high-radiation areas were observed.

  Upon completion of the level 2 GNM measurements, investigators deployed the Ge-spectrometer to make an in situ measurement at one point within the high-field area. A grab sample was also taken at this point [L2-1, Figure 10(b)]. This position is near the projected center of the 10,000-cps saturated portion of the radiation field and is presumed to be near the center of the contamination. Again, only ^{232}Th was detected above background levels.

- Level 3 Radiation Measurements: Ground Elevation = -3.5 ft

  Figure B.4 shows Level 3 GNM data. During this excavation, several large pieces of concrete that appeared to have been part of a concrete structure, possible a tank, were removed. No in situ Ge-spectrometer measurements were made at this level, but one sample was collected [L3-1, Figure 10)]. A sample was also scraped from a piece of concrete debris after it was removed from the pit.

  The Level 3 GNM data show continued evidence of the ^{232}Th plume with the plume centerline shifted several feet toward the $+x$ end of the pit. The GNM range was increased to 20,000 cps before the Level 3 scan, but the measured radiation fields still saturated the sensor along the plume centerline. A separate small anomalous radiation field area (4000 to 5000 cps) is visible near position x=17, y=-9 in Figure B.4. No spectral measurements were made in the vicinity of this feature. Whether the feature represents a satellite distribution of ^{232}Th or is the result of a different radionuclide is unknown.

- Level 4 Radiation Measurements: Ground Elevation = -5.6 ft

  Figure B.4 presents the Level 4 GNM data, which show further shifting of the ^{232}Th plume in the $+x$ direction, but no increase in the levels of radiation. In fact, the ^{232}Th plume radiation fields appear to have decreased slightly from Level 3, suggesting that contamination levels are no longer increasing and may be decreasing. The Figure B.4 maps also show unmistakable evidence of a second contamination area, centered near the lower left corner of the map area and trending at nearly right angles to the ^{232}Th plume. Eight in situ Ge-spectrometer measurements were made at Level 4. Grab samples were no longer easily obtainable because of the inaccessibility of the bottom of the excavation.

  Analysis of the in situ spectral measurements revealed that the gamma radiation field was caused by two separate radionuclides in the subsurface. The main plume contains only ^{232}Th and is continuous with the contamination zone seen in previous levels. A significant volume of this plume was already excavated by Level 4. The second plume, with highest concentrations occurring near x=13, y=16. Contains ^{227}Ac. Level 1 through Level 3 GNM data show no evidence of this second contamination area, suggesting that the Level 4 dig face occurred close to the top of its distribution. Subsequent excavation recovered ^{227}Ac-contaminated soil throughout the area around and beneath the high-field area mapped by GNM. No other ^{227}Ac-contamination areas were found during the subsequent excavation.

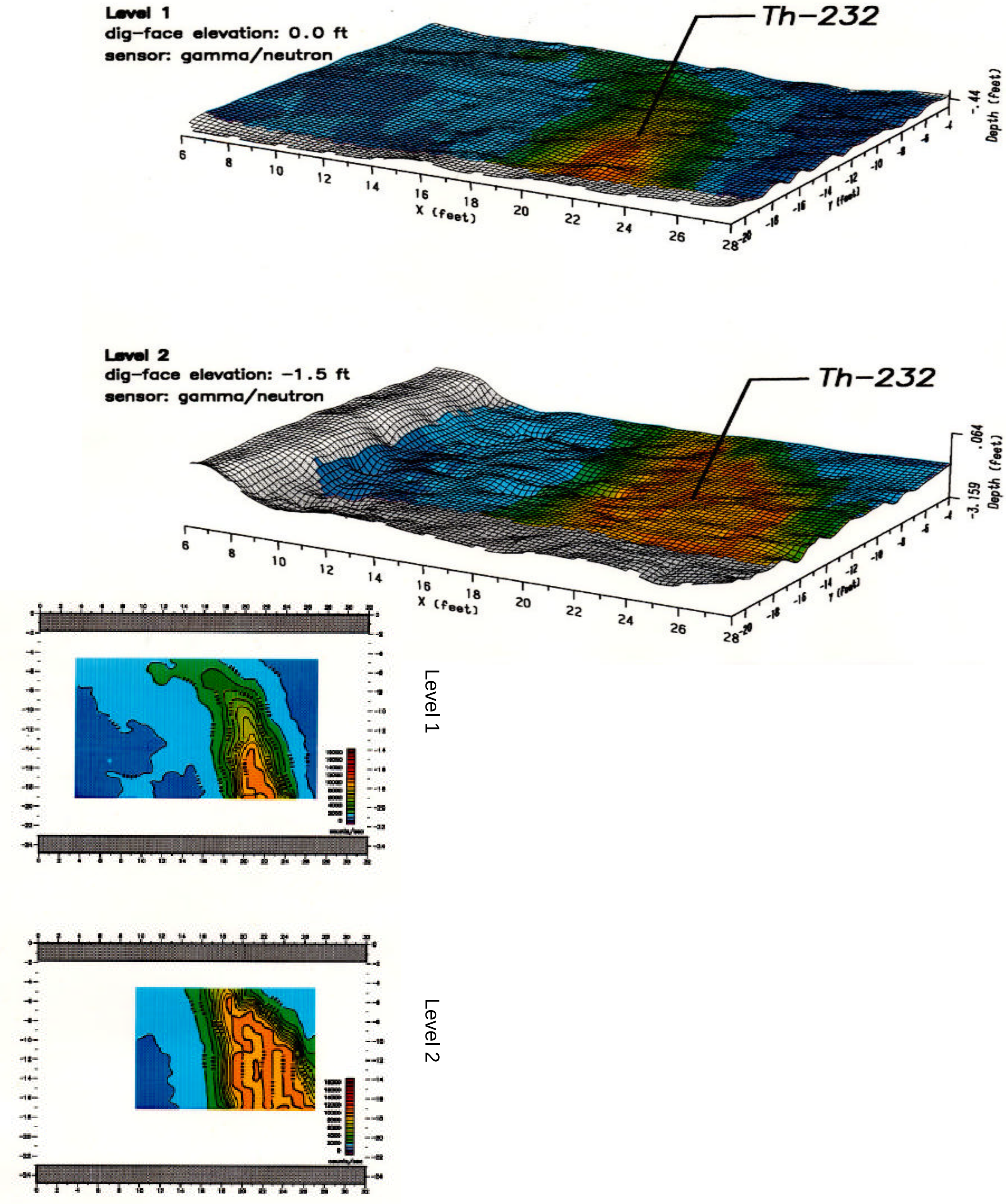
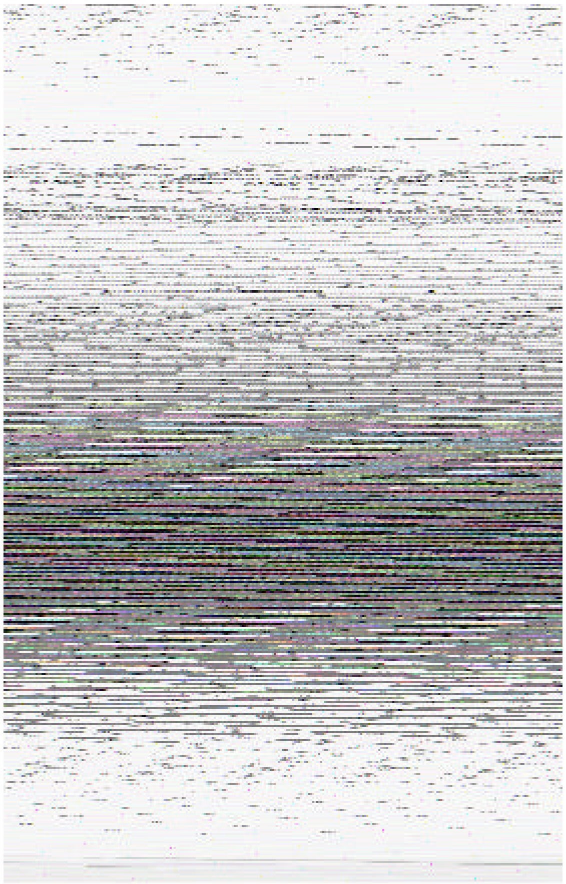


Figure B.3. Gamma radiation data from Level 1 and Level 2 (*a, b*) dig-face scans



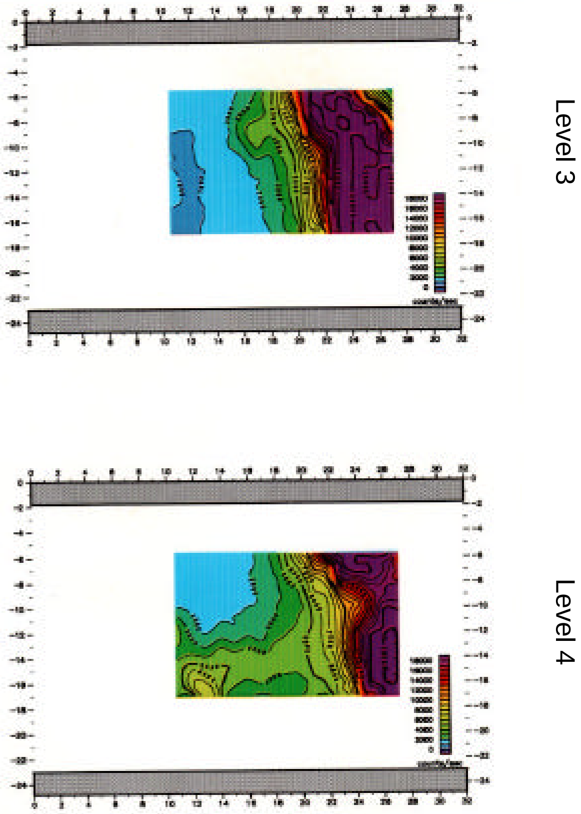


Figure B.4. Gamma radiation data from Level 3 and Level 4 (*c, d*) dig-face scans