Molten Salt Takes the Bang Out of High Explosives

WITH the dismantlement of thousands of nuclear weapons and the demilitarization of millions of conventional munitions, the Departments of Energy and Defense face the problem of disposing of large quantities of energetic materials, including high explosives, propellants, and pyrotechnics. Some energetic materials can be recycled and reused, but others must be destroyed. Open burning, open detonation, and incineration have been the most commonly used destruction methods. Although in some cases the traditional methods are still the best, the trend today is toward alternative destruction processes.

A team at Lawrence Livermore National Laboratory, led by Ravi Upadhye, recently completed development of an environmentally friendly method for destroying these energetic materials from conventional and nuclear weapons. The process involves a crucible of molten salt in which the high explosives and propellants are reduced to carbon dioxide, nitrogen, and water. Depending upon the material being destroyed and the environmental regulations under which the user is operating, the gas by-product, or "off-gas," from the molten salt process may be sent through a cold trap or filter to remove small quantities of salt carried in the off-gas before it is released to the atmosphere. (See the photo next page and the diagram at right.)

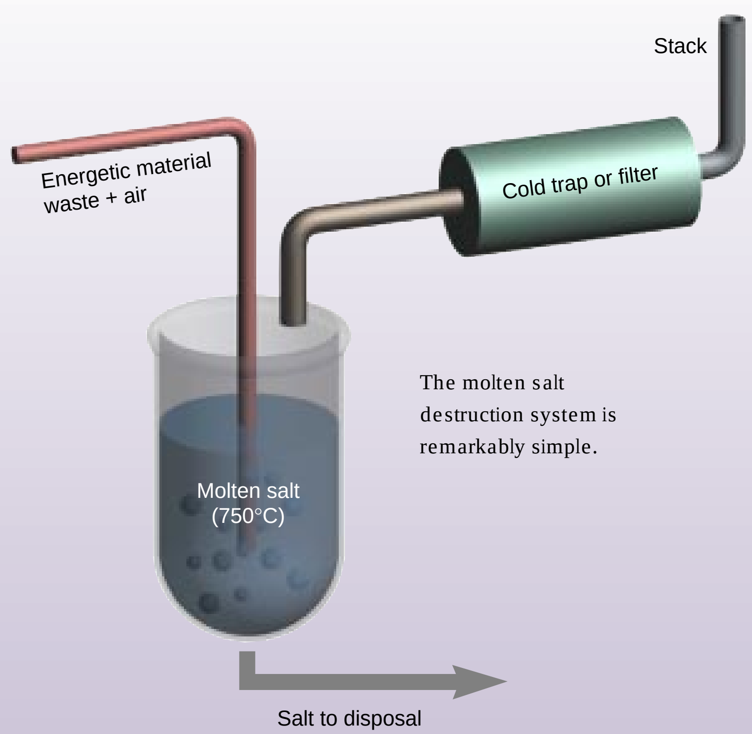
Livermore scientists have received two patents for their process and have two more patent applications pending. In 1995, the Northern California Section of the American Institute of Chemical Engineers named the team's molten salt destruction process their Project of the Year.

The Molten Salt Process

Energetic material waste is mixed with water to form a slurry that is introduced with air into a crucible. Inside the crucible are equal parts of sodium, potassium, and lithium carbonates. The temperature of these salts can be between 400° and 900°C, but 750°C is the temperature of choice for destroying the wastes. The melting point of the salt is about 400°C.

The organic components of the waste react with oxygen in air to produce carbon dioxide, nitrogen, and steam. The inorganic components, in the form of ash, are captured in the molten salt bed as a result of wetting and dissolution. During the pyrolysis and oxidation processes, halogenated hydrocarbons in the waste generate acid gases, which are scrubbed by the alkaline carbonate component of the salt, producing carbon dioxide and the corresponding salt. (For example, hydrogen chloride produces sodium chloride, which is table salt.)

Bottles for sampling off-gas are attached to the crucible's exhaust line. After steady state has been achieved, infrared and mass spectrometers are used for real-time analysis of nitrogen oxides, carbon monoxide, nitrogen, carbon dioxide, argon, and hydrocarbons in the off-gases. As discussed above, the off-gas may be sent through a cold trap if necessary before being released to the atmosphere. Emissions from the process include no acid gases, such as hydrogen chloride or hydrogen fluoride. Furthermore, the quantities of nitrogen oxides are significantly lower than those produced during incineration.



The molten salt destruction system is remarkably simple.

A view of the molten salt crucible and associated piping from above. The slurry of waste and air enters the top of the crucible, and off-gases exit through the larger pipe on the right.

At the end of the processing cycle, the salt can be separated into carbonates, noncarbonates, and ash. The carbonates can be recycled back to the process, and the neutral salts (such as sodium chloride) and ash are disposed of appropriately.

Livermore's latest molten salt unit has a capacity of 5 kilograms per hour (the equivalent of 60,000 pounds per year). It has a chimney-shaped, stainless steel crucible 2.2 meters tall, with a 40-centimeter nominal diameter at the top half and 20-centimeter diameter at the bottom. This design minimizes the amount of liquid salt droplets carried in the escaping off-gas. Waste is injected into the crucible through the top.

The whole assembly is placed inside an explosion-proof cell designed to contain a detonation of up to 10 kilograms of explosive. A remotely operated television monitor allows scientists to check on activity without entering the cell. All the mechanisms controlling the sample and feed sequences are operated remotely, and data are logged continuously by computer.

Upadhye noted, "Nitric oxide emissions from molten salt destruction of XM-46, a U.S. Army liquid gun propellant, were 100 times lower than those from incineration. The molten salt process also has the advantages over incineration of not having an open flame and of operating at lower temperatures. The team also compared it to a new method called supercritical water oxidation, which produced much more waste than the molten salt method. An added plus for the molten salt method is that it can be used to destroy chemical warfare agents."

From R&D to Field Use

The concept of using molten salt to destroy high explosives has been around for more than 20 years, but it took the end of the Cold War to prompt development of a usable system. In 1991, building on decades of experience with high explosives, Lawrence Livermore scientists began to do the chemical engineering necessary to take the molten salt method from theory to reality. They had at their disposal Livermore's state-of-the-art High-Explosives Applications Facility.

Livermore's initial laboratory-scale unit, with a capacity of 1 kilogram per hour (12,000 pounds per year), had a small side feeder and was used at first to destroy pure explosive powders. Then, a larger-diameter top injector was installed for feeding in real-world waste simulants such as machine shavings and sump sludge, including rust, metal parts, string, wood, sand, and floor sweepings. In every case, the waste simulants ran through the peristaltic pumps without clogging, and explosives were completely destroyed.

The 5-kilogram-per-hour unit was built in 1995 and has successfully completed a "shakedown run." In late 1996, it is scheduled to be dismantled and installed at Eglin Air Force Base in Florida for field demonstrations. Once the unit at Eglin is in full operation, it will be the first molten salt destruction system in the world that has proceeded past R&D and into field use.

Upadhye also noted, "Our process is safe, effective, and easy to use. We have built process controls and safety equipment into the system so that the unit can be operated after just minimal training." Ease of use is important because there is a huge job ahead—the Departments of Energy and Defense alone have hundreds of millions of pounds of energetic wastes to recycle or destroy.

Key Words: dismantlement, high explosives, incineration, molten salt destruction, open burning. open detonation.

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Security Clearances Meet the Electronic Age

EMPLOYEES throughout the Department of Energy complex will soon be filling out security clearance and reinvestigation forms on their desktop computers, thanks to a system developed at Lawrence Livermore that applies the latest computer and communication technologies to DOE's personnel security program. The new system, developed by LLNL's Fission Energy and Systems Safety Program (FESSP), promises to transform the traditionally slow—and costly—paper-based data collection systems to the Electronic Age, resulting in significant savings in time and money, as well as increased productivity and improved user satisfaction and attitudes about paperwork.

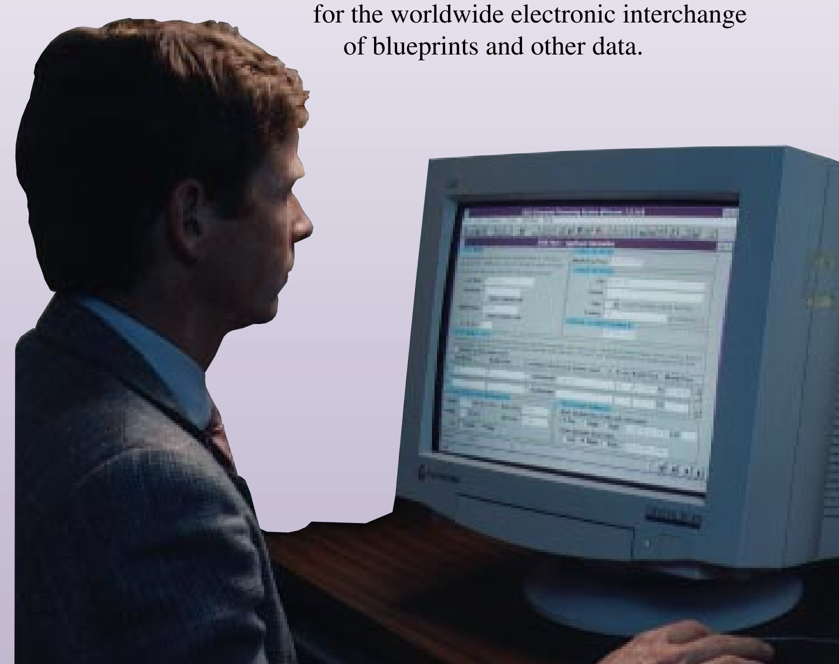
The modernization of the personnel security elements of DOE's Integrated Safeguards and Security System (DISS) is expected to shave at least a month off the average clearance process and save the DOE complex nearly $30 million annually. The project, nearly completed, is essentially reinventing how DOE and the federal Office of Personnel Management (OPM) in Boyers, Pennsylvania, process some 30,000 security clearances and reinvestigations annually and how the agencies maintain and communicate their voluminous personnel data.

The $12-million effort, begun in July 1993, taps the talents of some 25 people drawn from FESSP and the Laboratory's Computation and Engineering directorates who are expert in large computer systems integration and electronic commerce. Project leaders expect to have the new system deployed at 11 DOE operations offices, more than 30 maintenance and operations contractors, DOE Headquarters, and the OPM by the end of Fiscal Year 1996. DOE's Oakland Operations Office, which worked closely with FESSP during a December 1994 pilot evaluation, will be first to go online, followed by LLNL and Sandia National Laboratories, Livermore.

FESSP, along with its nuclear safety work, has long supported the federal government in meeting its security needs for facilities, personnel, and computer data. FESSP experts conducted a security vulnerability assessment of the U.S. Senate computer network and helped to produce an interactive version of the Vice President's "Reinventing Government" report for the Internet.

FESSP also cooperated in the design of Argus, an interconnected, computer-based system for access control, intrusion detection, and command and control that serves LLNL's Livermore and Site 300 facilities. Argus is saving the Laboratory some $20 million annually, and DOE has selected the system as the standard automated electronic security technology for the entire complex. Presently FESSP is overseeing installations of Argus high-security systems at DOE's Pantex Plant in Amarillo, Texas, and at the Idaho National Engineering Laboratory.

The FESSP projects are part of a growing Lawrence Livermore expertise in aiding government and industry to do business more effectively by integrating the latest computer and hardware advances. The Computation Directorate's Technology Information Systems Program, for example, has automated procurement practices for the Air Force's Wright Patterson Air Force Base and the Veterans Administration in Long Beach, California; enabled the Laboratory (and soon other DOE sites) to authorize payment to suppliers using the Internet; and helped establish new standards for the worldwide electronic interchange of blueprints and other data.



Scott Strait uses interactive software developed by the Laboratory's Fission Energy and Systems Safety Program (FESSP) to fill out personnel security forms. This modernization of DOE's Integrated Safeguards and Security System (DISS) will soon be used by DOE complex-wide to save time and money in the security clearance application, investigation, and renewal processes.

Filing Prodigious Amounts of Paper

DISS program leader Scott Strait notes that DOE's personnel clearance activities, like those of most government departments, involve processing and filing prodigious amounts of paper, resulting in slow transmission of information and labor-intensive procedures. All applicant data, for example, are sent from DOE sites to the OPM as paper forms, where they are typed twice into a computer. Several operations offices maintain independent databases of applicant data, and each runs on different software. These systems are not tied electronically to DOE's central mainframe databases, requiring duplicate entry in local and Headquarters' systems.

The job facing FESSP experts was the creation of an integrated electronic system that could be implemented uniformly across the DOE complex with common—and secure—communications, databases, and user interfaces. In short, the Laboratory's team was asked to create a seamless, integrated system among DOE sites, operations offices, Headquarters, and the OPM where an authorized user could gain access to personnel information, no matter where it is stored in the DOE complex.

The overall goals included a reduction in the time to process security clearance requests; improved tracking and monitoring of the clearance process; improved data accessibility, timeliness, and quality; and greater productivity for DOE and contractors. A potential savings from the reduction in clearance time also may be fewer requests for clearances once managers realize how quickly individuals can be cleared.

FESSP people standardized procedures across the DOE complex to eliminate the inefficiencies from maintaining different processes in every operations office. They also standardized the local databases so that the operations offices no longer need to maintain their own software separately. These databases will now store in consistent form all applicant data entry, contractor and DOE additions, notes, current status, scanned documents, fingerprint images, secure e-mail messages, and the database access audit trail. Livermore developers also designed DOE's main personnel security databases to share common data with each other and the operations offices nationwide.

The new system is being linked to DOE's Visitor Access Database to provide the necessary information to interact with automated access control systems at DOE sites and for ensuring DOE badge accountability. This link eliminates the need to re-badge DOE and DOE-contractor visitors from off-site who need entry through automated access control systems and who hold the proper clearance. At LLNL, this change will reduce the number of visitor badges issued annually by about 16,000.

In creating the electronic forms for clearance applicants to enter their data, FESSP people incorporated the latest advances in electronic commerce and interactive technologies and data security features. As an example, they developed a system-wide infrastructure of secure "digital signatures" (a series of numbers unique to an individual) to assure the authenticity of information. They also integrated specialized software that permits the electronic transfer of fingerprints.

The developers had to keep in mind the large amounts of required data, geographically dispersed DOE contractor population, and the wide range of applicant computer skills and hardware. To ensure that an application is complete, for example, they added internal checks to the computer fields, so that warnings pop up if a field is left blank.

Filling Out Forms on a PC

Indeed, the project's biggest impact on most employees will be the opportunity to complete their personnel security forms on their own desktop computers. With interactive software developed by FESSP, applicants will know before they transmit clearance forms to their on-site security office whether their data meet OPM requirements. The data will then be relayed electronically to the DOE Field Office, which in turn will advance it to the OPM.

One of the developers' most important tasks was to assure the privacy of data. FESSP experts developed numerous "firewalls" against intruders and eavesdroppers. In addition, database security features will assure that only those with a "need to know" will have access to personnel data. Finally, all information will be sent over DOEBN, DOE's specialized communication network, and will be automatically encrypted.

Strait says that one of the biggest benefits from the modernization project will be an improvement in a factor hard to quantify—morale. Reduction in clearance processing time, he says, should improve attitudes of DOE and contractor employees awaiting a clearance or a clearance upgrade. And with reduced difficulties in accessing sites throughout the complex, the attitudes of visitors are sure to improve as well.

Key Words: DOE's Integrated Safeguards and Security System (DISS), electronic security clearances.

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Exploring Oil Fields with Crosshole Electromagnetic Induction

WHEN Lawrence Livermore researchers developed a means to detect tunnels in Korea in the early 1970s, they had no idea that American oil and gas companies in the late 1990s might turn to a derivative of that technology to gain a more informative underground picture of their oil fields.

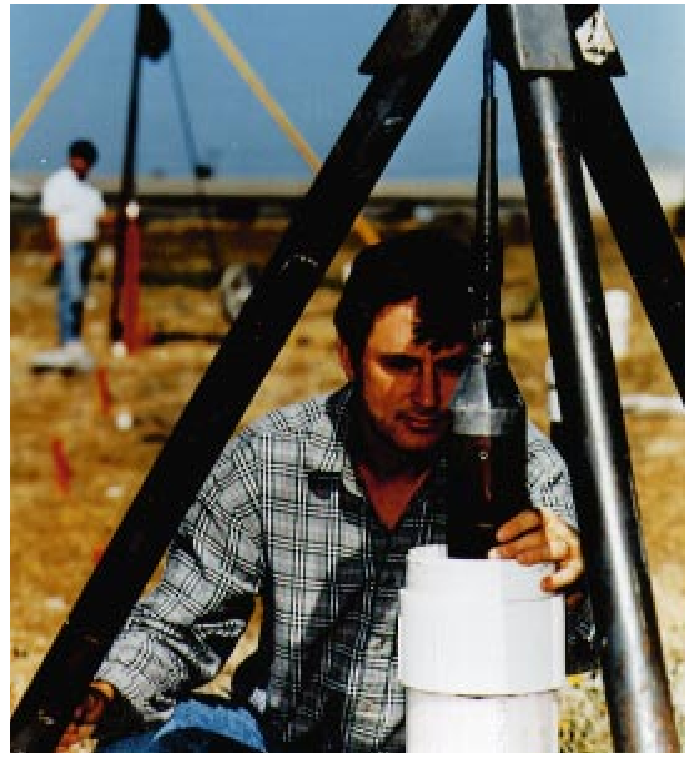
Yet crosshole electromagnetic (EM) induction technology, developed jointly by Lawrence Livermore and Lawrence Berkeley researchers with scientists at Schlumberger (an international provider of oil production services), may hold the key to significant increases in the extraction of oil and gas from existing reservoirs. What's more, the technology also may prove to be a cost-effective means for environmental site characterization and remediation monitoring.

"It is becoming increasingly difficult and expensive to locate new petroleum deposits, particularly in the U.S., so we must devise ways to get more oil out of existing fields," says Michael Wilt, a geophysicist and leader of the Laboratory's crosshole EM induction technology development effort. "Improved reservoir characterization is the key to extracting more oil and gas from oil fields. Producers are missing large pockets of oil because existing exploration methods, such as surface seismic reflection, sample too coarsely, and borehole logging techniques only measure rocks and fluids in the immediate vicinity of wells."

Wilt explains that crosshole EM induction technology is designed to provide high-resolution images of oil, gas, and water-bearing rock layers between existing wells up to 1,000 meters apart. A series of such images over time can also provide insight to changes in the field caused by oil production or by steam or water injection, which is used for enhanced oil recovery.

Determining the Electrical Resistivity

The electrical resistivity (resistance to the flow of electrical current) of rock formations can be determined from EM

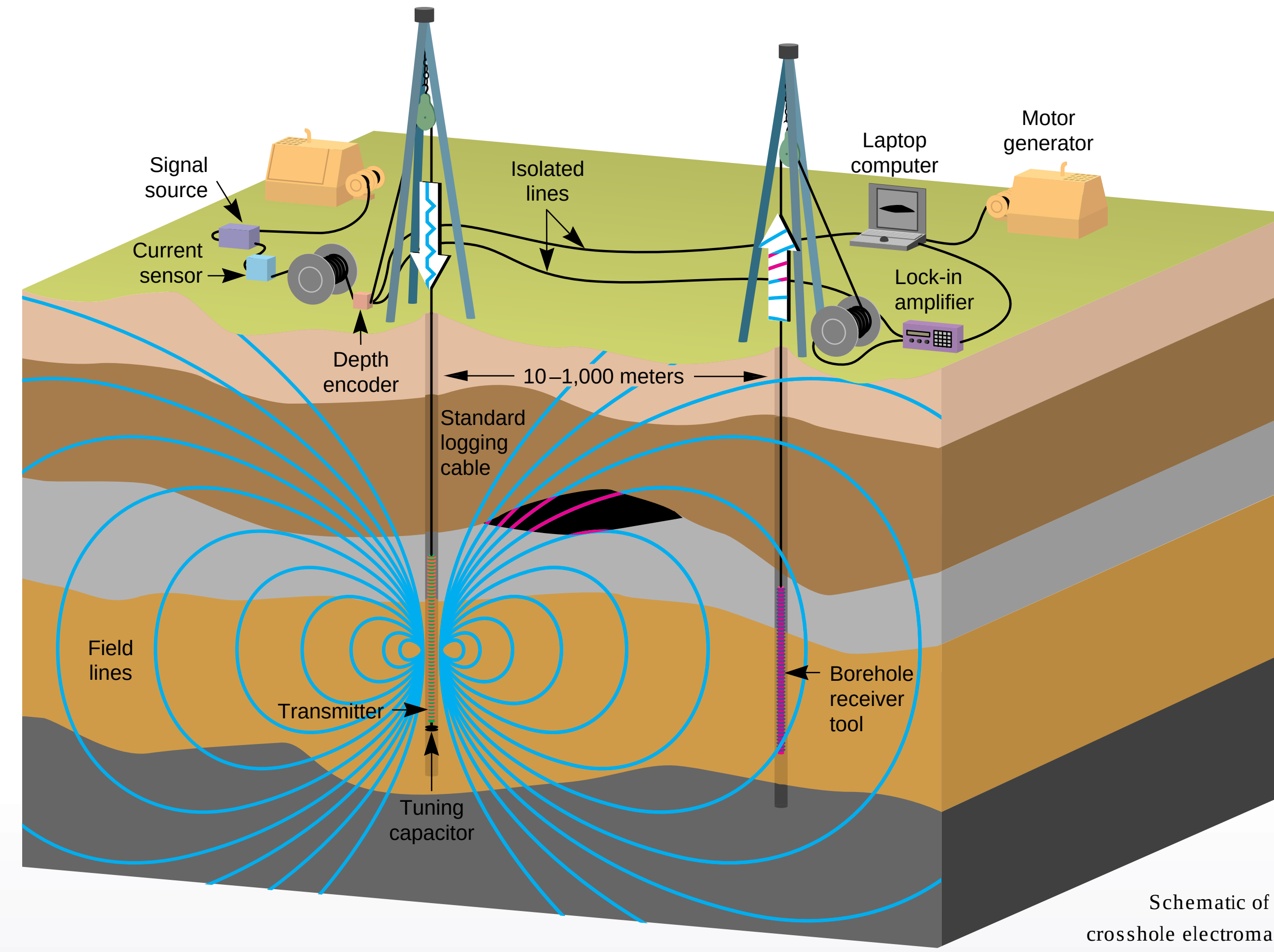


Laboratory scientist Michael Wilt sets up a field trial of crosshole electromagnetic induction technology at the University of California's Richmond Field Station. He is placing the receiver sensor in the borehole; in the background, Hung–Wen Tseng, an associate, is installing the transmitter coil.

induction measurements. Rock formations containing salt water, clay, or metallic minerals conduct current readily and therefore have low resistivity, while rocks containing fluids such as oil or gas have high resistivity. These resistivity differences can be used to distinguish between oil- and water-saturated sands, for example.

Measuring the electrical resistivity near a borehole has long been used to determine production zones in oil and gas fields and to map sand and shale layers. These measurements are usually made with an EM induction logging device that determines the resistivity within a meter or so around the borehole. Crosshole EM induction offers the ability for the first time to map subsurface resistivity between wells, on a reservoir scale (some 100 times greater an area than before), thereby locating bypassed concentrations of oil and gas.

The technology is an outgrowth of radar experiments conducted by Laboratory researchers in the early 1970s. The idea was to transmit high-frequency radio waves (greater than 20 megahertz) through the ground to detect tunnels in Korea. Although the technique proved effective for hard rock, the high-frequency signals could not propagate for more than a few meters in soft rock environments such as oil fields.



Schematic of the crosshole electromagnetic induction system.

However, it was discovered that at frequencies in the kilohertz range, it is possible to propagate signals up to a kilometer through a typical oil field. The penalty is that at low frequencies, the signals are dispersive—i.e., they get smoother as they propagate—making them impossible to image with traditional techniques. Recently, new tools were developed at the University of California at Berkeley and Schlumberger that can determine the resistivity between boreholes from these crosshole EM measurements.

The crosshole system consists of a transmitter tool deployed in one well and a receiver tool deployed in a second well (see above figure). The transmitter uses a vertical-axis coil wrapped with 100 to 300 turns of wire tuned to broadcast a single low-frequency sinusoidal signal that induces currents to flow in surrounding rocks.

The optimum operating frequency depends on borehole separation and background resistivity, but generally the frequency ranges between 40 hertz and 100 kilohertz. A frequency that is too low limits the resolution, while one too high limits the range of the measurement.

At the receiver borehole, a custom-designed coil detects the total magnetic field, consisting of the magnetic field from the induced currents as well as the primary magnetic field generated by the transmitter. The receiver section consists of a magnetic field sensor and a commercial lock-in amplifier located at the surface. The lock-in amplifier operates like a radio by measuring only those signals that are coherent with the transmitted signal while rejecting incoherent background noise.

By positioning both the transmitter and receiver tools at various levels above, below, and within the zone of interest, researchers can create an image of the resistivity distribution between the wells. The EM data are interpreted by computer modeling in which the rock between the wells is divided into thousands of small, two-dimensional, square blocks 1 to 5 meters on a side. Each block is assigned an electrical resistivity value, estimated from the borehole resistivity log (if available). The computer then modifies the resistivity of these blocks until the calculated and measured data agree to within the measurement error. This process usually requires 10 to 12 hours per data set on a 50-megahertz workstation to produce a detailed image of the underground strata.

Application in Oil Fields

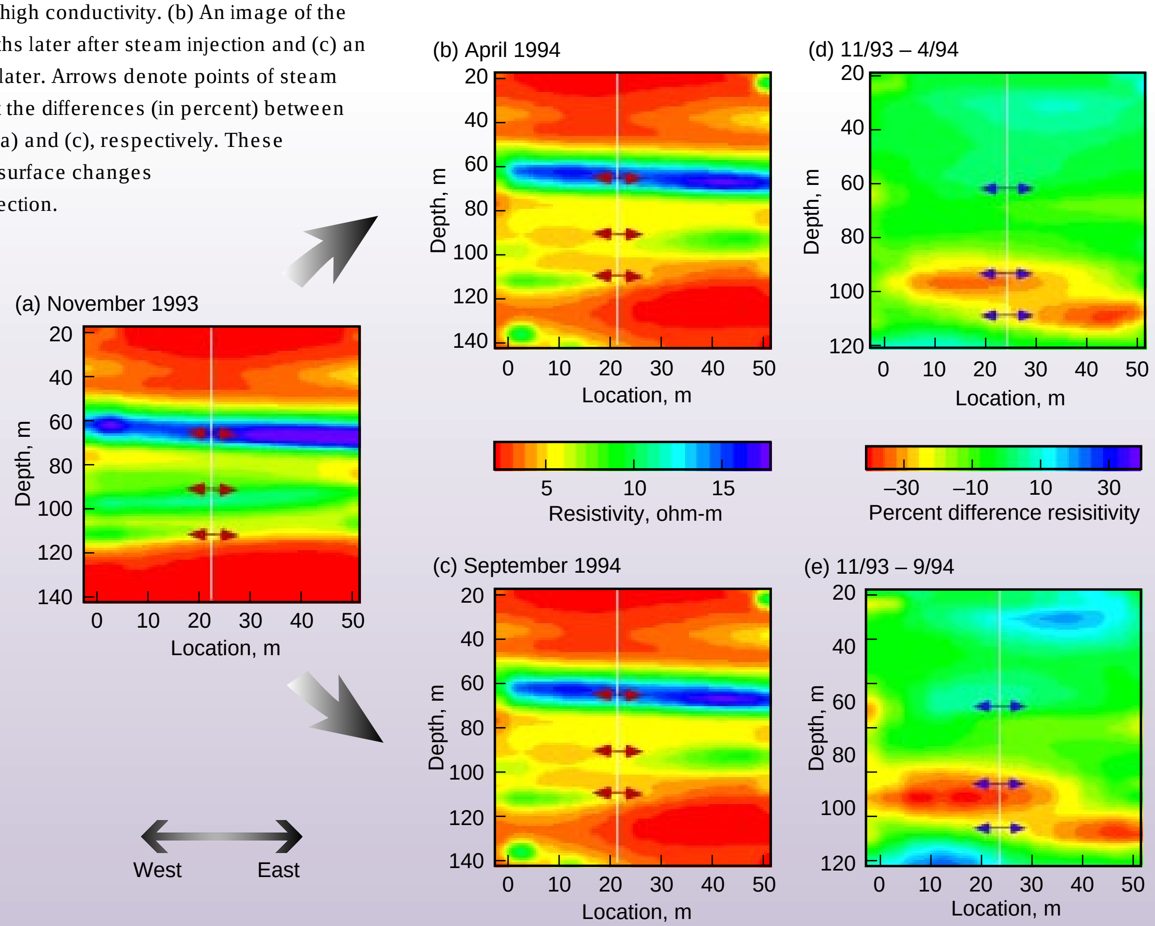
After two years of development, a series of tests was conducted at Mobil Oil leases at Lost Hills in Central California in 1993 and 1994. The experiments were made to demonstrate the technology for characterizing oil reservoirs and monitoring steam floods. Two fiberglass-cased boreholes were drilled about 55 meters apart near a steam injector in shallow, heavy oil sands. Steam was injected at depths of 65, 90, and 120 meters, corresponding to upper, middle, and lower layers of the target Tulare formation.

The resulting crosshole EM induction images in the figure below, collected before steaming and 6 months and 11 months after (a, b, and c), clearly show the distribution of the high resistivity oil sands (blue and green) and the intervening shale layers (red). (The arrows indicate points of steam injection.) The image in (a) indicates that the upper oil sand is a thick unit dipping gently eastward. The middle and lower sands are thinner and more discontinuous between the wells. The images shown in (b) and (c) are visibly different only at depths below 70 meters, where the resistivity has decreased significantly due to the steam injection. In all other parts of the image, the before and after resistivity values are unchanged. The resistivity decline is caused by the temperature increase and the replacement of oil by water and steam.

Images (d) and (e) are "difference" images made by subtracting the baseline image (a) from the other two images (b) and (c), respectively to show the percentage of change in resistivity. These images highlight the parts of the section that have changed during the steam flooding. Images (d) and (e) show that the resistivity has decreased dramatically in the middle and lower oil sands, indicating the presence of substantial steam there. The images also indicate that almost no steam has gone into the upper oil sand. The steam also seems to preferentially flow to the west in the middle sand but to the east in the lower unit.

The steam is clearly not as successful in moving the very thick upper layer of oil. The technology showed the steam flood to be much less uniform than the operator anticipated, providing valuable information on the progress of the flood and the parts of the reservoir affected by the steaming.

(a) A baseline resistivity image of an oil field in Central California. Blue indicates high resistivity, low conductivity; red indicates low resistivity, high conductivity. (b) An image of the same area taken 6 months later after steam injection and (c) an image taken 11 months later. Arrows denote points of steam injection. (d) and (e) plot the differences (in percent) between images (a) and (b) and (a) and (c), respectively. These differences indicate subsurface changes caused by the steam injection.



Future Developments

For the past three years, the focus of R&D work centered on a recently concluded Cooperative Research and Development Agreement with Schlumberger. During the developmental work, Schlumberger developed an advanced computer code for imaging the data, and the Laboratory refined the hardware. The end result was a complete prototype system designed for application in deep oil field environments. This system, which is a significant upgrade over existing equipment, will be tested in the fall of 1996.

In addition to the cooperative work with Schlumberger, EM induction research is also proceeding at other national laboratories (Lawrence Berkeley and Sandia) and at other companies (Western Atlas and Oyo Corporation) to improve the quality of field data and to sharpen the image resolution. Among the most pressing problems is the application of the technology through steel well-casing. Although the steel casing dramatically attenuates EM signals, recent field measurements have shown that the subsurface resistivity may still be obtained under the right conditions. Steel-cased wells make up the vast majority of oil field drillholes, so this improvement in the technology could have dramatic effects on its widespread application.

EM induction technology has also been applied to environmental site characterization with good success. It is presently included in the Laboratory's arsenal of geophysical tools for site cleanup and monitoring. Research is also in the early stages for applying the technology to the exploration for mineral deposits.

Key Words: crosshole electromagnetic (EM) induction, electrical resistivity, oil-field imaging.

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