OPN #1

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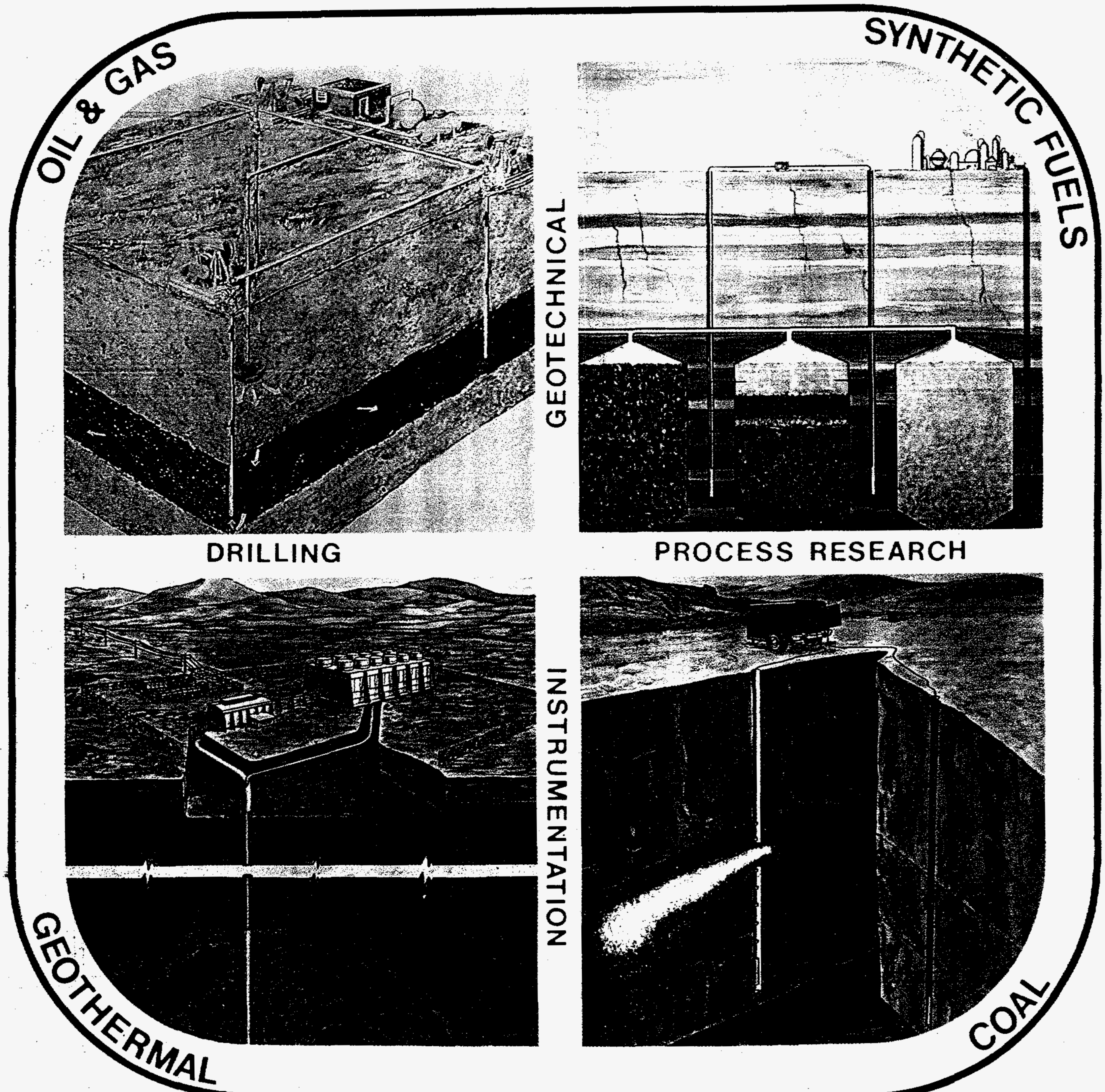
1980 GeoEnergy Technology



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MASTER

Sandia Laboratories

Sandia Laboratories, established in 1945, is a U.S. Department of Energy (DOE) multi-program laboratory employing 7600 persons in Albuquerque, NM, and Livermore, CA. It is primarily an engineering laboratory concerned with development of nuclear weapons. In recent years the Labs has also made significant contributions to the nation's energy research and development effort. The Labs was originally operated by the University of California, but in 1949 a contract with the Atomic Energy Commission assigned management responsibility to the Bell System. This contract continues today with DOE. The Labs also undertakes assignments for other federal agencies on a noninterference basis.

Sandia Laboratories

Albuquerque, New Mexico 87185

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GEO ENERGY TECHNOLOGY

DISCLAIMER

DISCLAIMER

GEO ENERGY TECHNOLOGY — AN OVERVIEW

The goal of the Geo Energy Technology Program is to improve the understanding and efficiency of energy extraction and conversion from geologic resources, hence maintaining domestic production capability of fossil energy resources and expanding the usage of geothermal energy. The Geo Energy Technology Program conducts projects for the Department of Energy in four resource areas — coal, oil and gas, synthetic fuels and geothermal energy. These projects, which are conducted collaboratively with private industry and DOE's Energy Technology Centers, draw heavily on expertise derived from the nuclear weapons engineering capabilities of Sandia. The primary technologies utilized in the program are instrumentation development and application, geotechnical engineering, drilling and well completions, and chemical and physical process research.

COAL

A major effort continues to develop the technology of in situ gasification of coal. Instrumentation and process research studies defined the time-temperature-combustion zones on Laramie Energy Technology Center's Hanna IV field test; diagnostic instrumentation assistance was provided to Lawrence Livermore Laboratory's Hoe Creek III field test. Geological site characterization studies were initiated to support a possible major coal gasification field test in the State of Washington.

New projects were initiated in the geomechanics of coal mine subsidence and in coal mining technology.

OIL AND GAS

Technology development for oil and gas production continues to be the largest activity of the Geo Energy Technology Program. To allow economic recovery of deep deposits of heavy oil through steam drives, Project DEEP STEAM is developing improved thermally-efficient injection strings for use with surface steam generators as well as the new technology of downhole steam generators. Component testing began in a full-scale environmental test facility; agreements were negotiated with Getty and Husky Oil to evaluate thermally-efficient components in field tests. Prototype low- and high-pressure combustors for downhole steam generation were successfully fabricated; a field test of a surface version of a downhole steam generator has been initiated with Chevron in California.

To exploit unconventional deposits of natural gas, diagnostic techniques to characterize stimulation processes have been developed and are being extended to formation evaluation studies. New insights into the physical processes of explosive and hydraulic stimulation have been obtained via the mineback project at the Nevada Test Site. The Labs will conduct a full-scale Multi-Well Research Experiment in a western tight gas sands reservoir.

To define seafloor stability for offshore oil production, the first in a family of seafloor instrumentation systems, the prototype Seafloor Earthquake Measurement System, was successfully emplaced in the Santa Barbara Channel and is recording seismic events. Drilling technology studies have aided the commercialization of drill bits using polycrystalline diamond cutting surfaces through new bit designs and improved bonding procedures.

SYNTHETIC FUELS

Research in synthetic fuels concentrated on oil shale and coal liquefaction. Major accomplishments in oil shale included a quantitative assessment of true in situ retorting and development of improved rock mechanics fragmentation models. Negotiations are underway for Sandia to aid industry's commercialization efforts in modified in situ oil shale processing.

Research in coal liquefaction quantified the influence of pyrite as a catalyst for liquefaction, developed a novel catalyst tagging process to assist in catalyst deactivation studies, and led to development of a proposed new model for coal liquefaction with significant changes in short-residence-time phenomena.

GEOTHERMAL ENERGY

The Drilling and Well Completion Program successfully field tested an improved roller cone bit at the Geysers in California and the chain drill at NTS. Improvements were also made in drilling fluids and bearings and seals for high temperature applications. Logging tools measuring temperature, flow and pressure, developed under the Logging Instrumentation Program, were successfuly tested at several field sites, including one reservoir in excess of 275°C. As part of the Magma Energy Research Program, novel drilling techniques were successfully tested at Kilauea Iki, Hawaii, and the Magma Simulation Facility became operational.

OTHER EVENTS

At the request of DOE, Sandia Labs, through the Geo Energy Technology Program, undertook a special engineering overview study of the Strategic Petroleum Reserve (SPR) Program. At the conclusion of this study, Sandia assumed responsibility for the geotechnical aspects of SPR. This mission is now centered in Sandia's Waste Management and Geotechnical Projects Directorate.

Concurrently, the Geo Energy Technology Program was reorganized into two departments. Department I retains responsibility for all fossil energy projects and newly created Department II, managed by R. K. Traeger, will be responsible for geothermal energy and drilling technology projects.

H. M. Stoller
Geo Energy Program Coordinator
Manager — Geo Energy Technology
Department I

COAL

Coal is the United States' most abundant energy resource; it can meet our needs for hundreds of years provided it can be mined and utilized in an economic and environmentally sound manner. Sandia conducts projects which should (1) permit extraction of energy from unminable coal deposits by underground coal gasification, (2) minimize environmental impact by developing a capability to predict and control coal mine subsidence, and (3) increase productivity by developing improved coal cutting and mining technology. These projects are sponsored by DOE's Division of Fossil Fuel Extraction.

In Situ Coal Gasification

In situ or underground gasification of coal is a method of energy extraction which eliminates the need for mining. Basically, it consists of providing access to the coal seam by drilling wells, establishing permeability in the seam between wells, igniting the seam, sustaining gasification by injection of air or oxygen, and withdrawing the product gas (chiefly hydrogen, carbon monoxide, carbon dioxide, and methane) from neighboring wells. The product gas can be combusted to generate electricity on-site, used as a chemical feedstock, or upgraded to synthetic natural gas.

The process has environmental advantages because the energy is extracted without mining, and most ash and sulfur contaminants remain underground. In addition, the process permits exploitation of deep, thin, or other deposits which cannot be satisfactorily mined with conventional techniques.

There has been worldwide interest in underground coal gasification for more than 100 years. However, inadequate understanding of the process, which occurs hundreds of feet below ground, and lack of satisfactory process controls needed to make combustion proceed efficiently have delayed application of the technique. The Sandia project addresses these problems by applying instrumentation expertise developed in association with the Labs' underground tests of nuclear weapons.

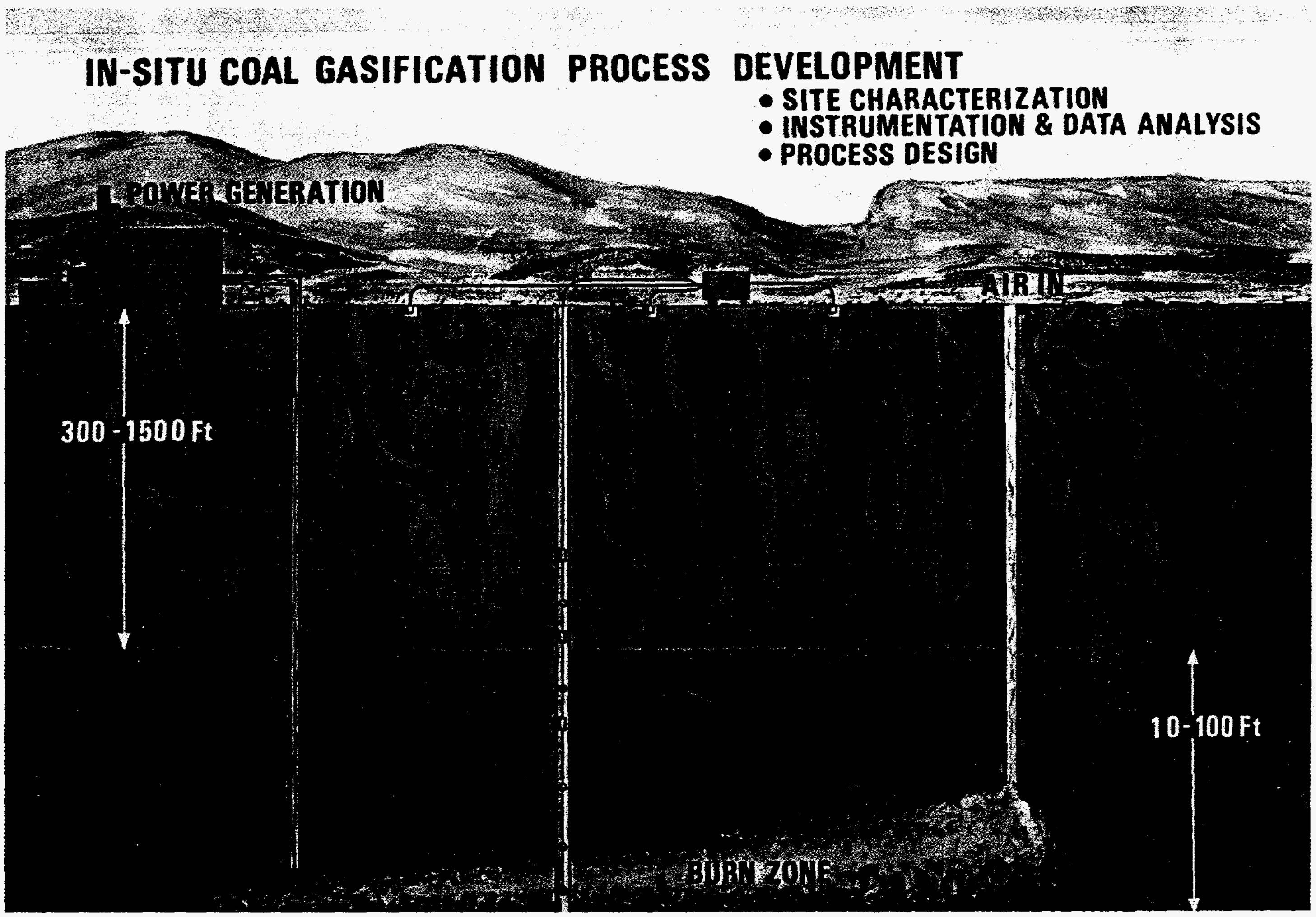
This expertise has been applied to several field experiments which have been conducted during the past five years. Early experiments provided preliminary information on the site geology, gasification concepts, and instrumentation techniques. Sandia studies in more recent experiments by the Laramie Energy Technology Center examined the gasification between pairs of wells and evaluated an areal sweep concept for improved resource recovery. During these experiments more than 15,000 tons of coal were gasified, and gas production rates of 8.5 MMscf/day of 150 to 180 Btu/scf gas were maintained for several weeks. This output is equivalent to power production of more than 6 MWe.

As part of these experiments — the most thoroughly instrumented tests ever conducted — Sandia designed, fielded, and evaluated instrumentation techniques belonging to two general classes: (1) in situ diagnostic techniques (thermal, in-seam gas sampling and pressure, and overburden tilt and displacement) to obtain data for process characterization and (2) remote monitoring techniques (electrical, passive acoustic, and induced seismic) to provide a continuous, real-time map of the in situ process to be used in a process control system. These techniques used a combination of instrumentation wells within the experimental region and instrumentation arrays at or near the surface.

Extensive thermocouple arrays, which incorporated special branched circuitry for data validation, provided the most detailed characterization of in situ coal gasification yet obtained. The feasibility of in-seam gas sampling and pressure measurements was demonstrated and compositional changes caused by the advancing reaction front were detailed.

The remote monitoring techniques — electrical, acoustic and seismic — provided promising results. Contour maps of potential data from a surface probe array showed the location and movement of the combustion front at 300 feet below the surface. Mapping the source of process-related acoustic signals was also shown to be feasible. These signals originate in the overburden and are related to areas of gasification and coal removal. Borehole-to-borehole induced seismic techniques also delineated the advance of the gasification process.

Recent in situ coal gasification activity has revealed the importance of initial geological conditions at a site to the ultimate success of the process. Unidentified faults or severe folding, for example, can impede or even halt the burn front. Sandia has been heavily involved in site characterization, using contemporary and innovative techniques to investigate geometric, geomechanical, and hydrogeological conditions. Surface geophysical



surveys include reflection and refraction seismic tests, electrical resistivity and induced polarization measurements, and electromagnetic, magnetic, and gravity surveys. Model calculations aid in the interpretation of the field data. Results are used to delineate site specific geologic features such as areal extension of coal seams, strike and dip of strata, depth of seams, thickness and intervals of seams, and structural characteristics used to determine subsidence.

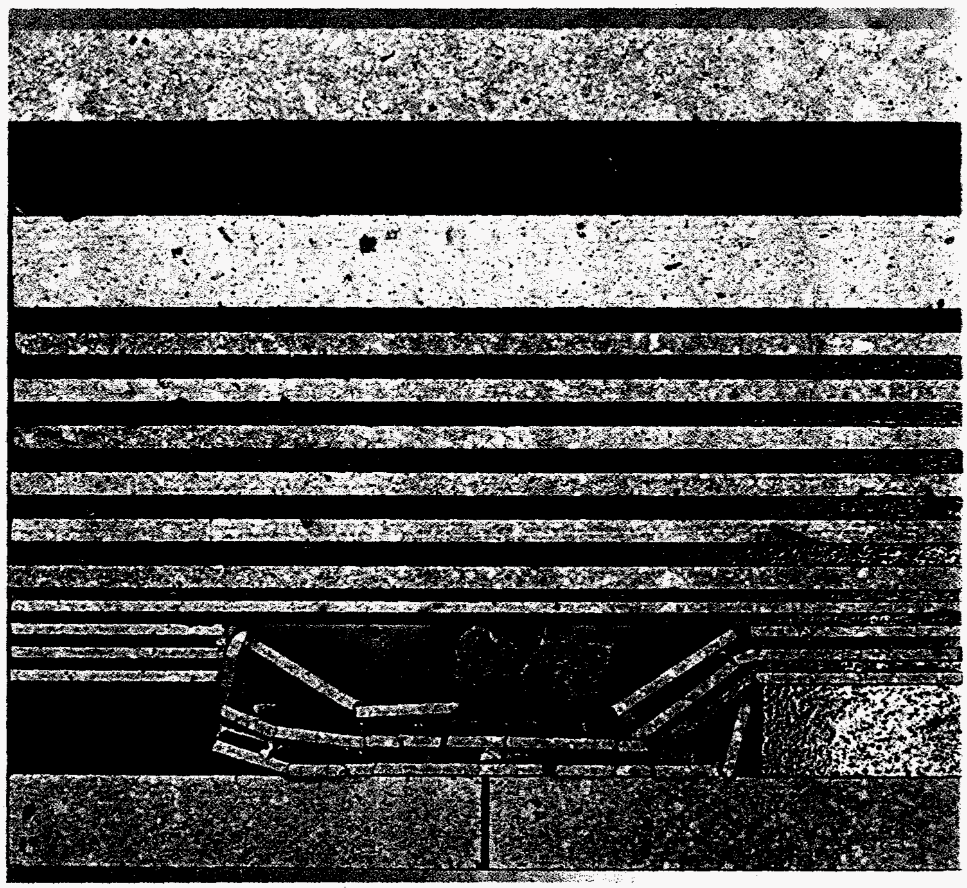
Exploratory boreholes are drilled, cored, and logged to provide reference data for surface surveys and to provide samples for accurate laboratory evaluations. A full suite of geophysical logs — natural gamma, density, sonic, neutron porosity, spontaneous potential, resistivity, and caliper — are used in each borehole. Flow logs are used to determine hole-to-hole permeability in the coal seam, and cross-borehole geophysical measurements are made to determine seam and overburden properties.

The combination of these tests provides information which is comprehensive enough to assess coal quality, geological, and hydrogeological features of candidate sites.

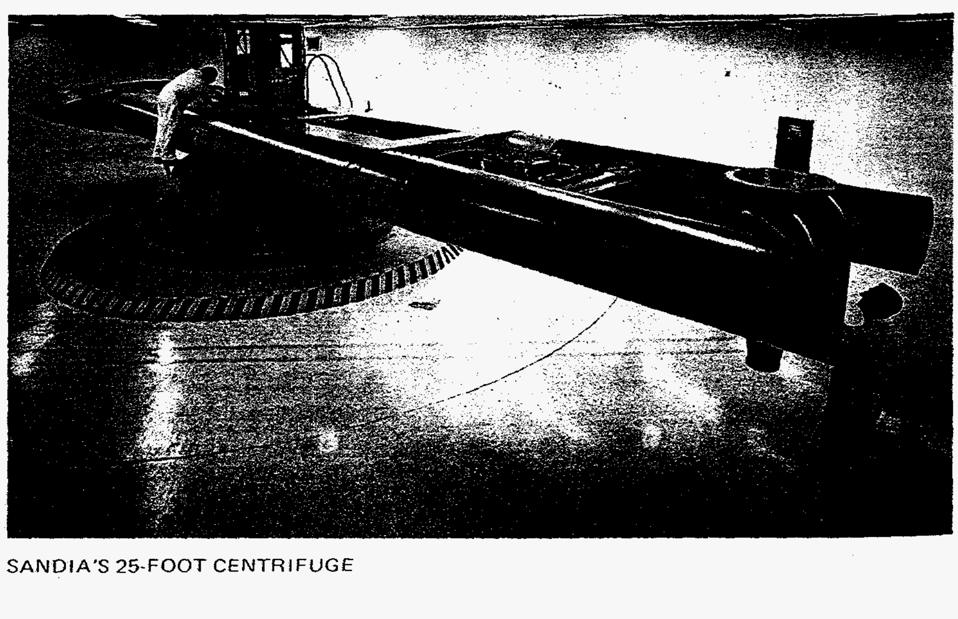
Coal Mine Subsidence

Subsidence-caused by underground mining of coal has impacted more than two million acres in this country, seriously affecting ground water, surface topography, and surface structures, while, at the same time, decreasing mine productivity and increasing costs. To address these problems, DOE has begun a program to improve the ability to predict and control coal mine subsidence and damage. Sandia's contributions are in the areas of predictive computer code development, rock mechanics, and physical simulation. Field instrumentation and field experiment activities are anticipated. Subsidence occurs when overburden collapses into the void created by mining. The geologic material properties and structure of the overburden determine the mechanism of subsidence, the amount of bulking, the time dependence, and eventually, the fraction of the original void which appears at the surface as subsidence. Overburden failure modes and degree of bulking are being determined by centrifuge simulation tests, rock mechanics studies, and field measurements. Models which incorporate relatively simple failure criteria are being used within large deformation, finite element codes to simulate geologic formations and the development of contact stresses as the formations interact. It is clear that discrete geologic features such as faults and joints affect behavior of the rock mass and this behavior is being incorporated into the development of constitutive models. Material property testing is also being done. In the long term, time-dependent constitutive models and behavior will be incorporated.

Sandia's centrifuge testing capability permits the Labs to make unique contributions to the subsidence problem. The stress field produced in the overburden by gravity may be reproduced on a scale model by proportionally increasing the body force on the model with a centrifuge. For example, a one-foot model at 250 gravities (g's) simulates a 250-foot overburden at 1 g. This simulation technique leads to scaling laws which reduce physical dimensions and duplicates the stress field on the model since the stress field cannot be easily produced by direct physical loading. This geotechnical simulation provides precise data under known and controllable conditions and is thus being used to investigate the adequacy of computer codes and constitutive descriptions to predict the response of the overburden at field sites. Sandia's 25-foot centrifuge has maximum rated capabilities of 16,000-pound payload, 240 g acceleration, and 1,600,000 g-pound dynamic load. Fully instrumented models can be tested under computer-controlled operation and data acquisition procedures.



CENTRIFUGE TUFF SUBSIDENCE MODEL SIMULATING MINE DRIFT 8 FEET HIGH AND 46 FEET WIDE AT DEPTH OF 70 FEET.



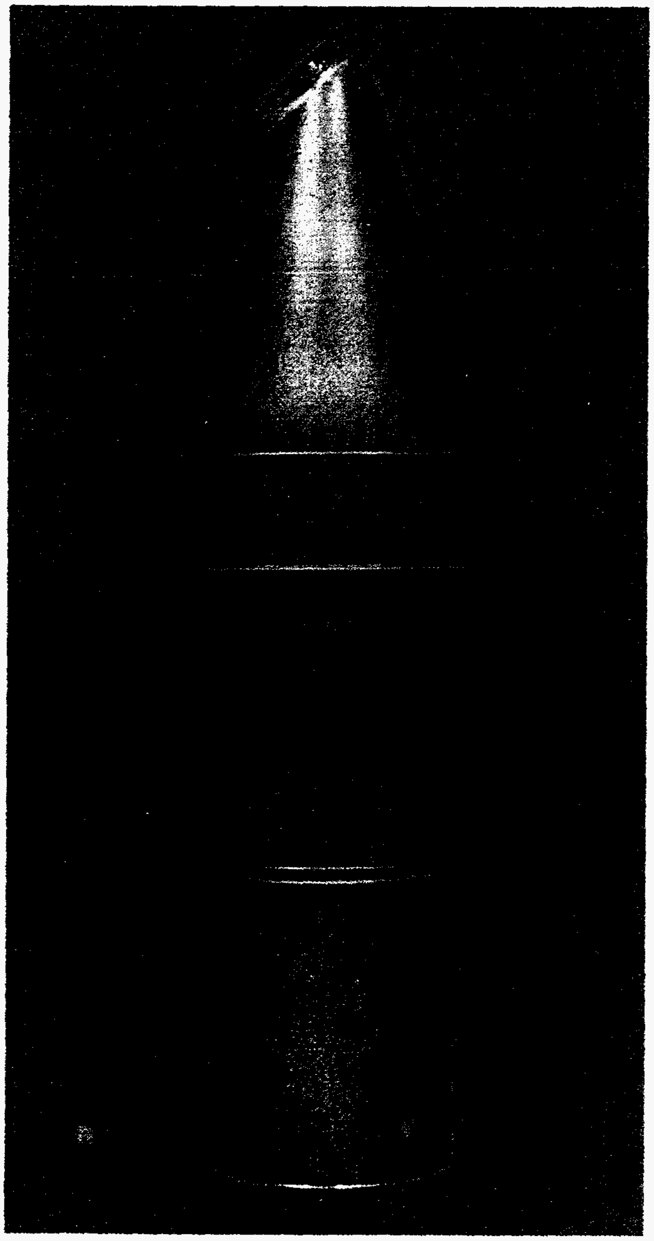
SANDIA'S 25-FOOT CENTRIFUGE

Mining Technology

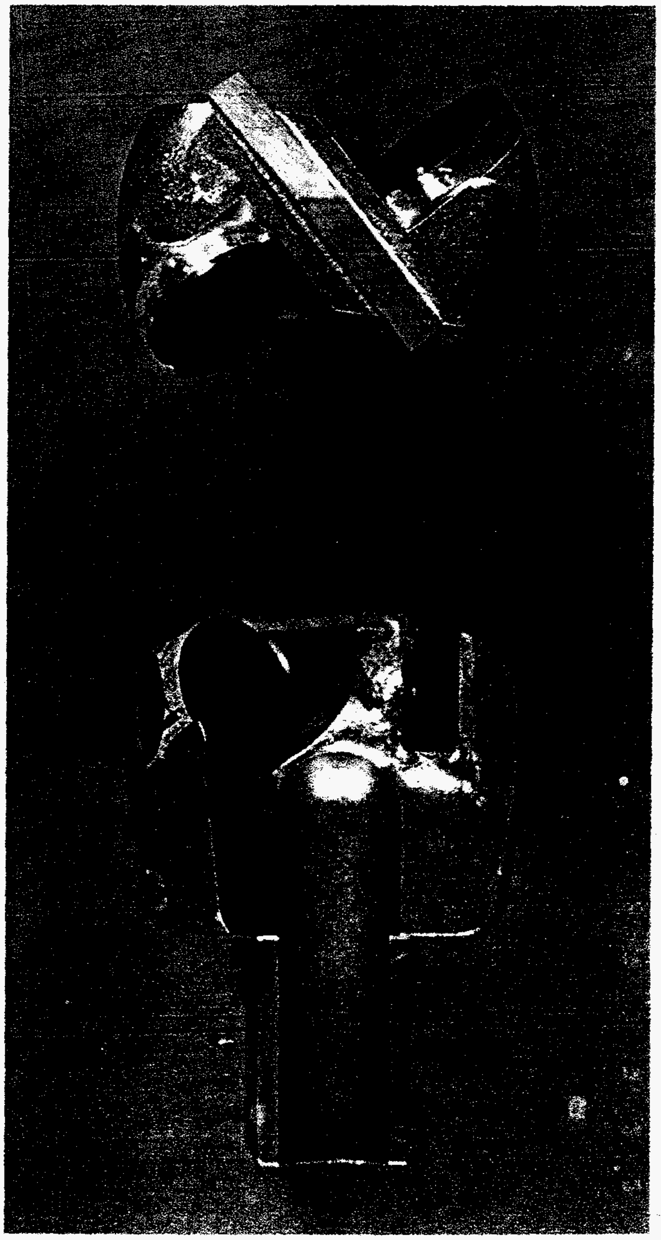
Sandia is conducting a project to improve cutting and drilling operations in coal mines by improving roof bolt drill bits and coal cutting picks. Geologic strata overlying coal seams must be supported so compression bolts are inserted into these formations via the roof bolter to increase roof stability. Coal cutting machines use individual cutting elements, or picks, to mechanically attack the coal face.

Underground coal mining typically involves using a continuous coal cutting machine followed closely by a roof bolt operation to support the mined cavern. The need to frequently replace roof drill bits and cutting pins, a result of the wearing out of the tungsten carbide cutting surfaces, results in significant lost time and expense. Specifically in the area of roof bolt drilling, new drills employing polycrystalline diamond compact bits are being investigated with the goal of improving both the lifetime of the drill and the penetration rate of the drilling operation. This study is an extension of Sandia's fossil energy and geothermal energy drilling research where polycrystalline diamond compact cutting surfaces have demonstrated longer life and more efficient rock removal. Similarly, attempts are being made to design more durable coal picks which would enable continuous mining machines to operate for longer periods of time without shutdown for pick replacements.

As new systems, such as miner/bolters (a combined continuous mining and bolting operation) are developed, the total mining operation will become more continuous. Therefore, more durable and reliable cutting and drilling methods should significantly increase coal production.



IMPROVED COAL PICK



IMPROVED ROOF BOLT DRILL

OIL AND GAS

Petroleum furnishes 50 percent of the country's energy supply and almost half of this oil is imported. Domestic petroleum production peaked in 1972 and since that time oil imports have doubled. Additional production from presently known resources, as well as the development of new offshore resources, could stabilize domestic production.

Natural gas provides 25 percent of our energy supply. While proven reserves have declined significantly, current estimates indicate several generations of supply exist in presently undiscovered reservoirs as well as in unconventional sources, most of which will require improved technology for economic production.

Sandia's oil and gas research and development projects include examination of thermal methods to recover heavy oils, studies to improve natural gas recovery from unconventional resources, development of improved drilling technology, primarily for deep gas wells, and development of instrumentation and geotechnical studies to better define offshore engineering hazards. These projects are conducted for DOE's Division of Fossil Fuel Extraction. The offshore studies also receive funds from the U.S. Geological Survey and private industry.

Enhanced Oil Recovery

In commercial production, oil is initially brought to the surface by natural pressures. Secondary recovery methods, such as injection of natural gas or water, are then used to produce additional oil. After primary and secondary recoveries are no longer effective, some 40 to 70 percent of the original oil still remains in place. A portion of this oil, estimated to be 15 billion barrels in the U.S., could be recovered by application of tertiary or Enhanced Oil Recovery (EOR) techniques.

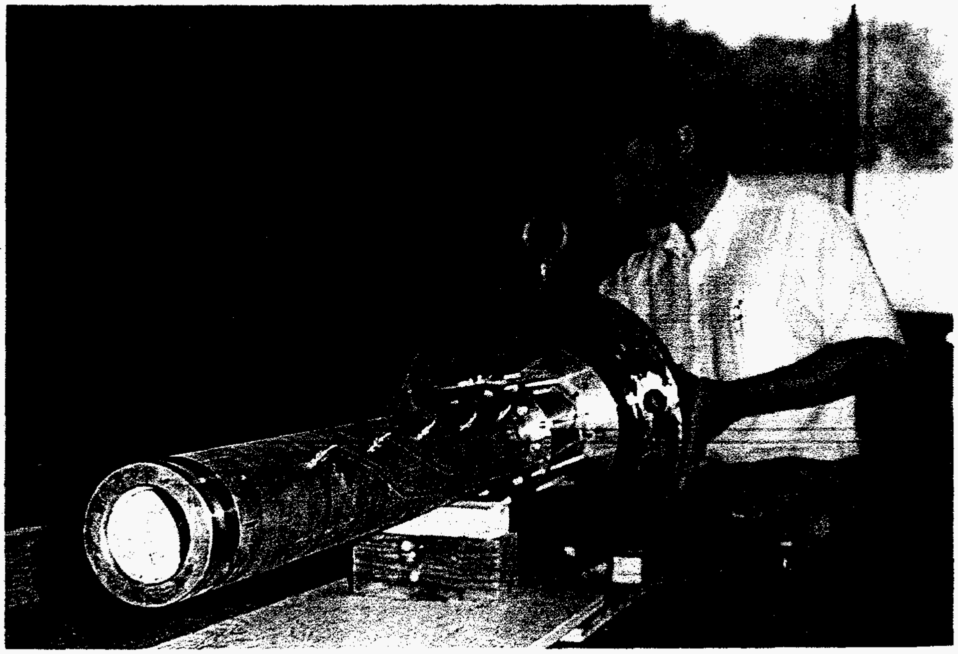
Thermal recovery techniques are the most economic for heavy oil reservoirs. In these processes, steam is injected in the well or in situ combustion is initiated to heat the reservoir, decrease the viscosity of the oil, and force it from the well. A recent survey attributes 373,000 barrels per day of U.S. oil production to EOR techniques, 260,000 of which are due to thermal recovery. As much as 96 percent of this latter amount comes from steam drive and steam soak operations. Sandia is attempting to improve current steaming operations as part of Project DEEP STEAM. The object is to extend the steam drive technique to heavy oil reservoirs located at depths below 2500 feet.

Two approaches are being pursued: thermal efficiency improvement in delivery of surface-generated steam and development of downhole steam generators. Many basic technical problems need to be solved, however. For example, the life of insulation and structural materials is greatly affected by erosion and corrosion caused by air and steam mixtures containing hydrogen sulfide, hydrochloric acid, and sand. To address these problems, studies are underway at Sandia to define downhole chemistry, to develop stability diagrams for different materials in these environments, and to evaluate candidate materials in laboratory and field tests.

Downhole steam generator development requires an understanding of combustion processes at high pressure. Liquid fuels burning at high pressure tend to produce solid particles such as coke. These particles may plug the generator passage or the oil reservoir itself. Methods to achieve efficient vaporization of the fuel and complete mixing with air prior to ignition are being investigated.

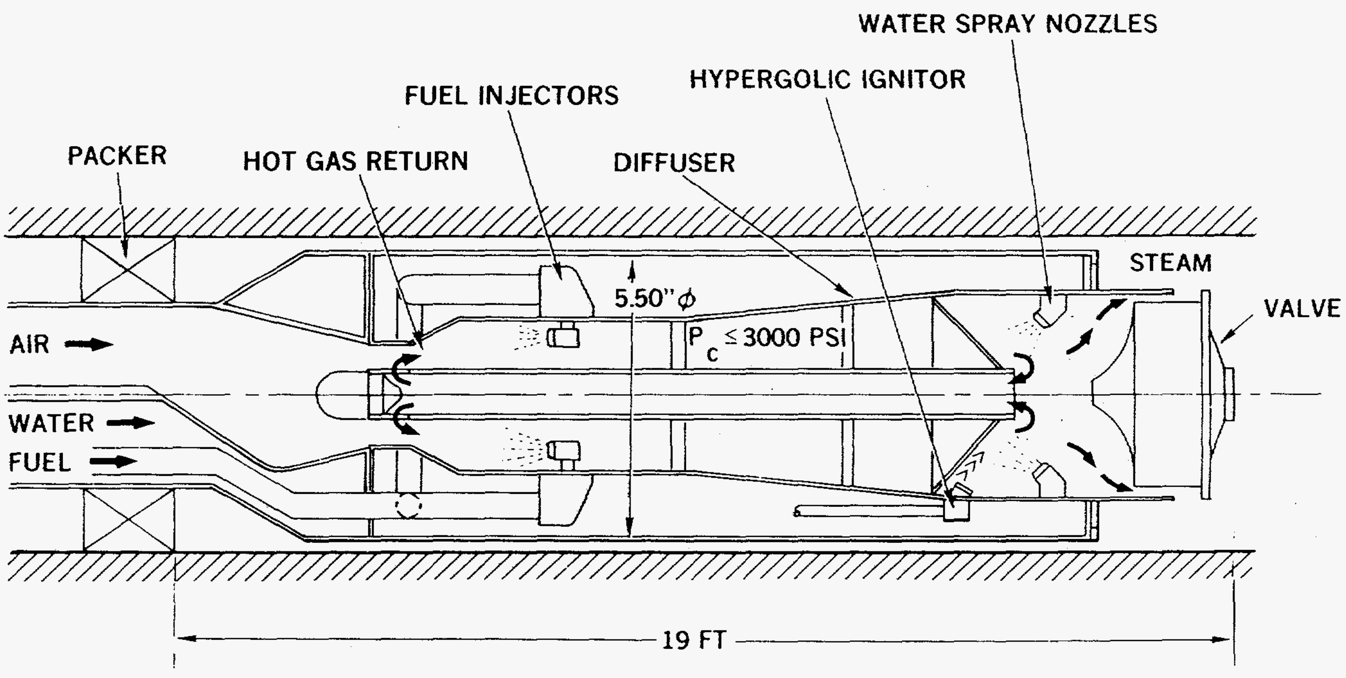
Instrumentation and monitor/control systems are also being studied. Determining and controlling the air/fuel ratio is one function of the monitor and control system of the downhole generator. By maintaining control of the air/fuel ratio, corrosive effects of excess oxygen can be minimized and free carbon production from excess fuel can be avoided.

Field tests of components involved in thermally efficient delivery of surface generated steam are being planned with Getty Oil Co. and Husky Oil Co. Field tests of prototype downhole steam generators will be conducted with Chevron.



PROTOTYPE HIGH PRESSURE COMBUSTOR

SAND/HEAVY CRUDE MIXTURE USED TO STUDY EXTRACTION TECHNIQUES



CONCEPTUAL DRAWING OF HIGH PRESSURE DOWNHOLE STEAM GENERATOR WHICH INJECTS COMBUSTION PRODUCTS AS WELL AS STEAM INTO OIL-BEARING FORMATION.

Enhanced Gas Recovery

A tens-of-years supply of natural gas is thought to be contained in the so-called unconventional gas sources: tight gas sands of the western United States, the eastern Devonian shales, methane in coal seams, and geopressured zones along the Gulf Coast. Recovery of this gas will require improved knowledge of the reservoirs and better recovery methods. Generally, these reservoirs require some form of stimulation to increase formation permeability and gas flow into the wellbore. Sandia is developing diagnostic instrumentation techniques to characterize the formations and stimulation processes and is conducting a stimulation research program centered around in situ experiments at NTS. Cooperative field activities with industry are common and industry has participated in experiment planning and interpretation. This participation promotes transfer of program results into production practice.

Hydraulic fracturing is commonly used to stimulate gas production. Fluid is pumped into the formation at pressures high enough to fracture the rock. Sand is added to the fluid and carried into the fractures to prop them open after pressure release. These propped fractures increase the flow of gas to the well by increasing the drainage area. Massive hydraulic fracturing is often applied to these unconventional reservoirs. In these costly cases, more than 500,000 gallons of fluid and 1,500,000 pounds of specially sized sand have been pumped, creating fractures believed to be more than 5000 feet long. Enhanced gas production success is often uncertain, nevertheless.

Critical to the understanding and optimization of fracturing are characterization of the fracture system and an accurate description of the reservoir. In this regard, four hydraulic fracture diagnostic techniques are under development: (1) surface electrical potential system, (2) surface tiltmeter system (on contract), (3) borehole seismic system, and (4) a stacked hydrophone system. The electrical potential system is a method where the fracturing wellbore acts as a buried electrode which changes geometry as the fracturing fluid is injected. The resulting change in the electric field is measured by surface probes permitting fracture orientation, asymmetry, and growth to be determined. Excellent, consistent agreement between this technique, tiltmeter results, and other evidence has been obtained from commercial well stimulations at depths to 8,000 ft.

Seismic signals are created by hydraulic fracturing and the location of these signals can be used to map the fractures. However, the frequency of the signals and their attenuation by the earth make it imperative that such information be obtained close to the fractures. Thus, downhole instrumentation systems to record seismic signals are under development. The borehole seismic system, placed in the fracturing wellbore consists of three-axis geophones, an orientation package, signal conditioning equipment, and a wall-clamp mechanism. Several classes of signals have been observed and information contained in these is being analyzed. A stacked hydrophone system will provide improved measurement of fracture height during fracturing. Ultimately, the objective is to obtain fracture length, height, azimuth, and symmetry in a single wireline package.

Knowledge of the geometry and properties of the lenticular, low permeability gas reservoirs is important for proper well placement and stimulation design. The state-of-the-art in seismic reflection geophysical data acquisition and analysis is being evaluated as a means of determining the three-dimensional lens geometry and spacing. The technique is first being applied at shallow depths where the geometries of the lenses can be readily inferred from outcrop and drilling data. The technique will then be applied to the greater depths associated with potential production. Improved formation characterization is also the objective of a fundamental study to improve interpretation of well logs by establishing correlations between various electrical properties and the porosity, pore water saturation, salinity, and fluid permeabilities of these reservoirs.

The objective of the stimulation research project is to improve understanding of stimulation processes for unconventional gas recovery. A major activity has been controlled stimulation experimentation under realistic in situ conditions. The experiments are being conducted in a tunnel complex at NTS and include mining back to allow first-hand observation of fracture behavior.

Data from these experiments are used to confirm existing methodology and to develop understanding of factors affecting fracture growth. For example, experiments have demonstrated that: (1) observed fractures usually differ significantly from conventional design predictions, (2) hydraulic fractures are not confined by modulus or other material property changes as originally believed, (3) in situ stress is the dominant factor affecting hydraulic fracture growth, and (4) fracture growth is significantly affected by geologic faults, joint systems and other physical features.

A new stimulation concept is under development; it is based on high energy gas fracturing that avoids the limitations of hydraulic fracturing (a single fracture whose orientation is controlled by the in situ stress) and explosive fracturing (wellbore damage and residual stress) has been investigated. For the first time, multiple, radial fractures from a wellbore produced by a controlled pressure pulse have been observed under realistic in situ conditions.

Supportive rock mechanics, fluid dynamics, petrographic, and geochemical studies are performed to aid in design and interpretation of the field experiments and to extend the knowledge gained. Fracture propagation at well-bonded interfaces where physical properties change over short distances are being investigated. A microcrack model which determines the zone of influence of the crack tip as a function of confining stress has

MINE-BACK OF A SAND-PROPPED FRACTURE

been formulated. Also under development is a comprehensive fluids fracturing model which includes time-dependent terms normally assumed. It will also yield accurate fracture widths. Petrographic and geochemical studies look at such microscopic effects of fracturing as the interaction of the fracturing fluid with the formation and the factors affecting resultant permeability. A major effort is made to translate these results to representative reservoir geologies and to current petroleum and gas engineering technology.

The research and development activity has involved a variety of field experiments — most conducted in cooperation with industry. Several fracture mapping experiments have been conducted with Amoco in the Wattenburg/Denver Basin area, and future field work is planned. Participants in other field tests conducted or planned include: Shell in Texas, Conoco in Wyoming, Gas Producing Enterprises in Utah, Mitchell, Columbia and Weed in the Devonian Shales in Ohio, and Amoco in Texas, Oklahoma, Wyoming and Alberta. Recently, Sandia initiated, as part of the Western Gas Sands Project, a research-oriented, but full-scale Multi-Well Experiment in the Piceance Basin of Colorado. Objectives are to characterize fully a lenticular tight gas reservoir and to evaluate the present and developing technology for its stimulation.

Drilling Technology

Sandia is conducting several drilling projects to help improve oil and gas drilling systems. Oil and gas well drilling is encountering increasingly severe environments as shallow, easy-to-find sources are depleted. Deeper wells, higher temperatures, high formation pressures, and the presence of corrosive gases make it necessary to improve materials, fluids, and techniques so that systems which are reliable and have satisfactory operating costs and penetration rates can be developed.

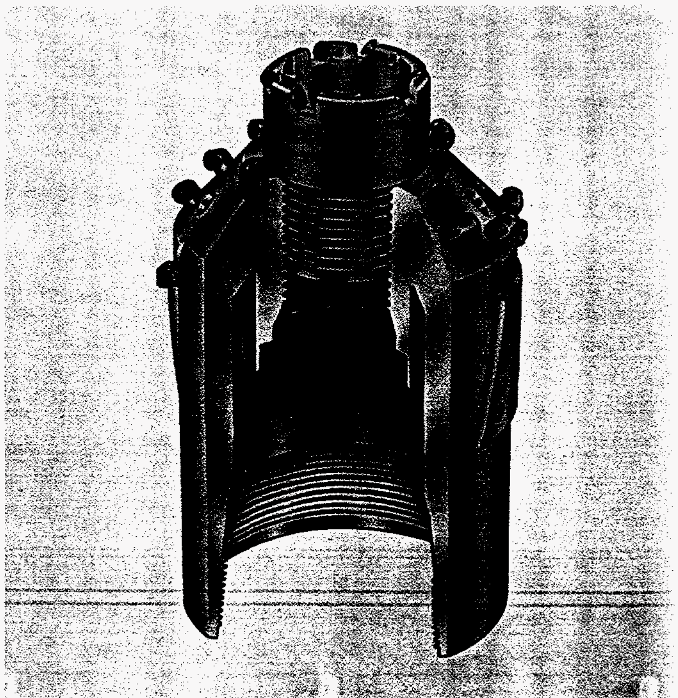
High performance drill bits which use man-made polycrystalline diamond compacts are being developed. A major effort is being made to improve attachment of these compacts to the bit head. A diffusion bonding process has been developed and is approaching commercialization. Field tests of bits using diffusion bonding have been successful and have increased penetration rates by factors of two to three over those obtained with conventional drilling bits. One bit designed and built in collaboration with Smith Tool Company uses both polycrystalline diamond compacts and a conventional roller cone in a hybrid design which has performed very well in granite-type formations.

A project to improve service life of elastomers used in the severe environment found in deep wells is also underway. Coating elastomeric parts with intimately bonded, chemically resistant materials such as Teflon and adding protective fillers to the elastomeric compounds before molding are being tried. Initial laboratory test results show improvements in life and operating capabilities for coated elastomers used in bit seals and O-ring seals.

A project to improve reservoir core recovery under near in situ conditions is being conducted in conjunction with the Bartlesville Energy Technology Center. This project involves design of an improved pressure coring system and testing and selection of non-invading coring fluids. Mechanical design of the core barrel has been made more reliable and a reservoir for the special non-invading coring fluid has been incorporated into the barrel. This special fluid required the design and fabrication of a new coring bit which uses polycrystalline diamond compact cutters and a replaceable pilot portion cooled and cleaned by the coring fluid. Tests of this new system have demonstrated its improved reliability and capability under near in situ conditions.

Recent trends in drilling oil and gas wells, particularly in the offshore environment, require drilling of directional boreholes whose trajectory can be maintained accurately. A project has been initiated to develop an inertial navigation system which fits inside conventional drill pipe and which will improve the accuracy of directional well borehole surveys tenfold. Future systems could have the capability of steering the bit to a pre-programmed location. Error analyses of the system using estimation theory have been performed, and initial laboratory tests are underway to determine the accuracies obtainable in a system packaged in the small diameter cylindrical geometry.

HYBRID BIT



IMPROVED PRESSURE CORING BIT ASSEMBLY

Offshore Technology

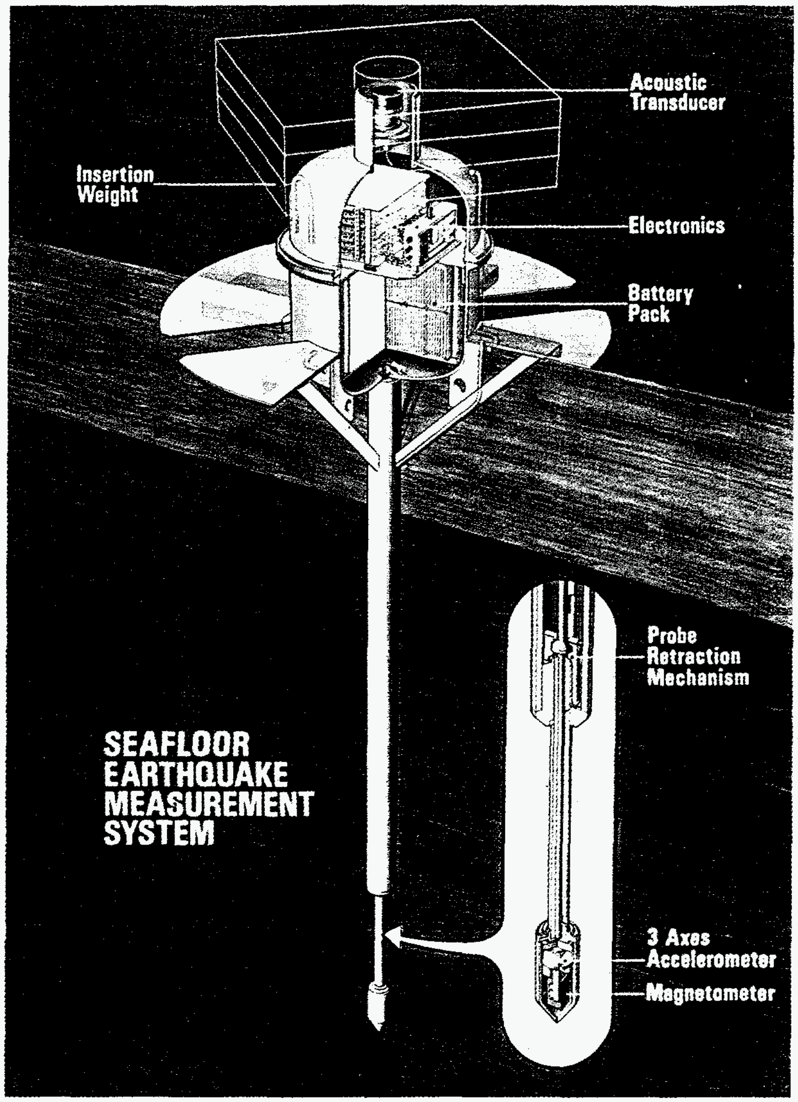
To halt the decline in domestic production of oil and gas, new sources of hydrocarbons must be located. Offshore regions appear to be prime exploration targets. These areas may present the oil industry with such natural environmental constraints as massive storms, extensive seismic activity, large ice movements, and unstable seafloor sediments.

There is a recognized need to monitor these environmental constraints. DOE, with the U.S. Geological Survey, has established an offshore technology program to develop instrumentation systems to characterize the geotechnical environment of offshore areas.

Sandia projects have included:

- the Marine Sediment Penetrometer, a hard-wire system to provide shallow sediment strength profiles
- instrumentation support to Project SEASWAB, a USGS study of the stability characteristics of sediments in the Mississippi River delta area
- a high data rate acoustic telemetry system which can transmit data periodically from long-life seafloor instrumentation systems
- the Seafloor Earthquake Measurement System (SEMS) to measure sediment response to seismic activity
- the Geotechnically Instrumented Seafloor Probe (GISP) to measure in situ properties of submarine sediments
- analytical studies of marine geotechnical phenomena

The Seafloor Earthquake Measurement System measures sediment response to seismic activity through use of force-balance accelerometers with a range of 10^{-4} to 1 g. The accelerometer outputs are digitized at a rate sufficient to reproduce frequencies up to 20Hz. The digital data are stored in solid-state, magnetic bubble memory units with a storage capacity of 10^6 bits. The system is powered by lithium batteries with an operating life of one to two years. The acoustic telemetry is used for data retrieval.



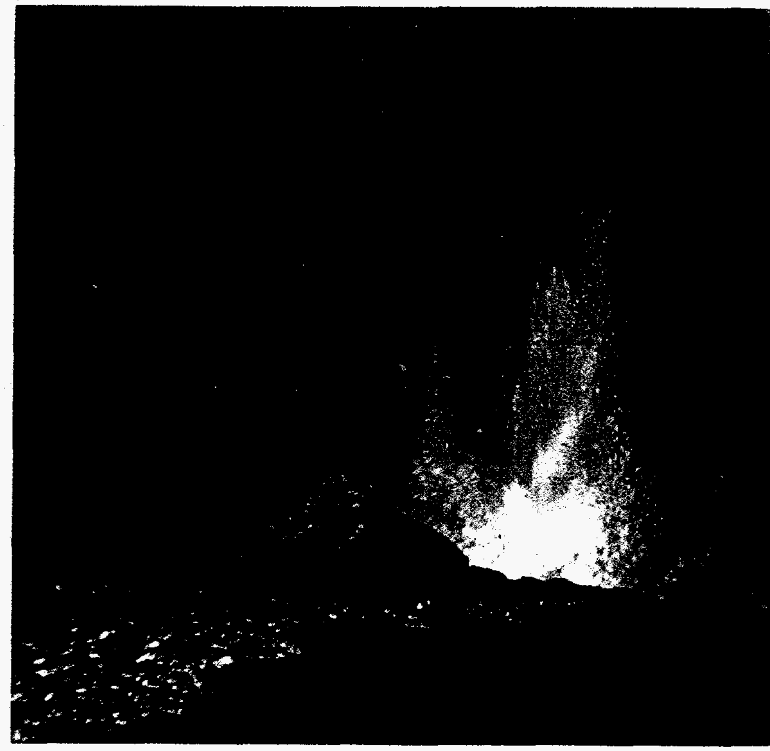
The SEMS prototype consists of a pressure vessel with probe. The power supply, memory, electronics and acoustic telemetry are in the pressure vessel. The accelerometer package is in the forward portion of the probe. The package is emplaced with a ballast weight which forces the probe about 3.5 meters into the sediments. Subsequently, the ballast is disconnected, resulting in a retraction of the probe sting, isolating the accelerometer package from the pressure vessel.

The SEMS prototype has been installed in the Santa Barbara Channel and three additional prototypes will soon be available for deployment. Five oil companies — ARCO, Chevron, Gulf, Mobil, and Shell — are supporting the project.

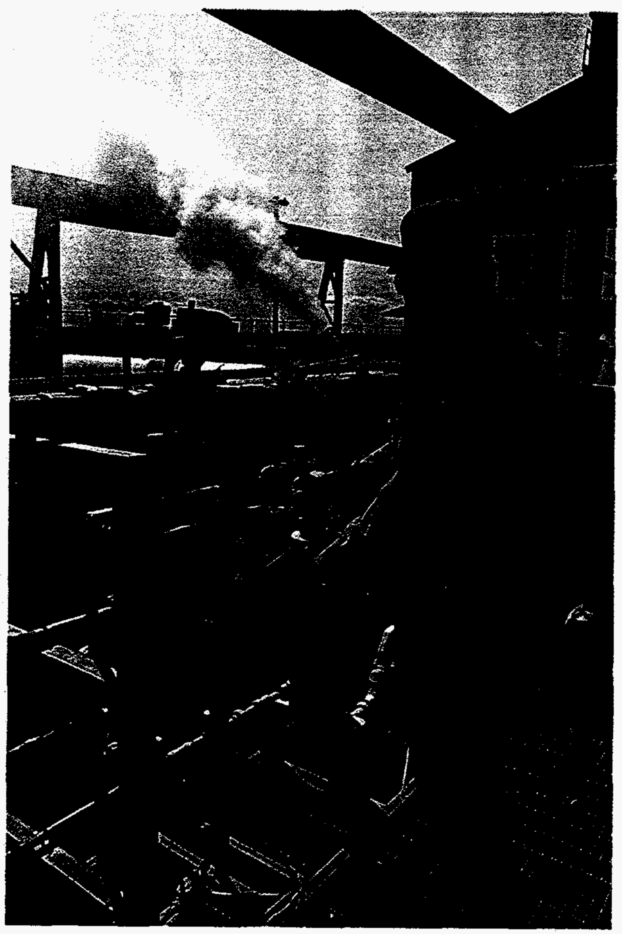
The Geotechnically Instrumented Seafloor Probe (GISP) will measure geotechnical properties of marine sediments in situ. Initial emphasis is on formation pore water pressures of unconsolidated sediments to assess mudslide potential. Pore water pressures are measured at three locations along an inserted 10-meter probe. The GISP incorporates much of the data processing, storage and retrieval techniques developed for SEMS but with a 45-day lifetime. The USGS will select the sites for prototype deployment.

Analytical studies are underway on geotechnical engineering properties of marine sediments — to investigate hazards and interpret data. New instrumentation techniques to measure soil strength characteristics are under study. Extension of these instrumentation techniques to sea ice thickness measurements and to delineate stratigraphic layering is under consideration.

MAGMA ENERGY RESEARCH MOLTEN ROCK SIMULATION FACILITY



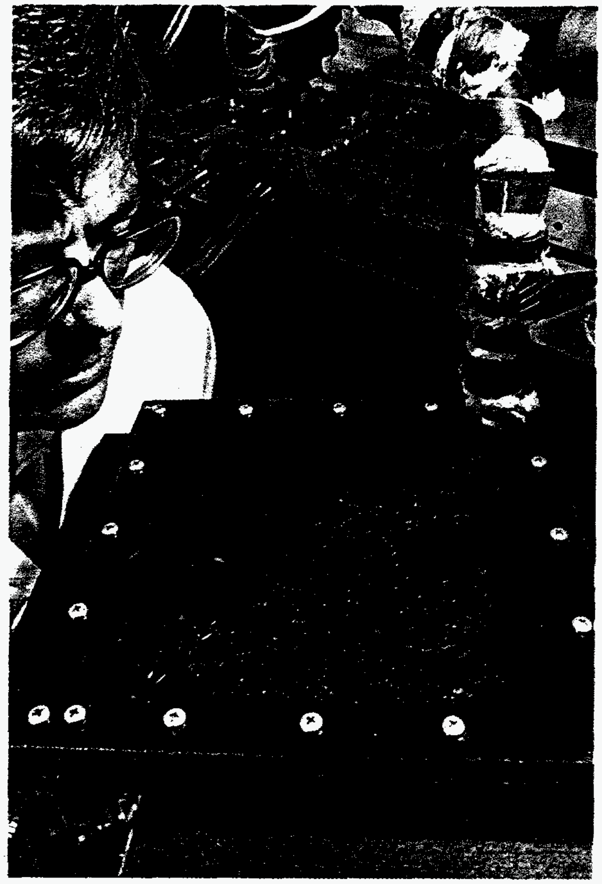
1977 KILAUEA IKI ERUPTION



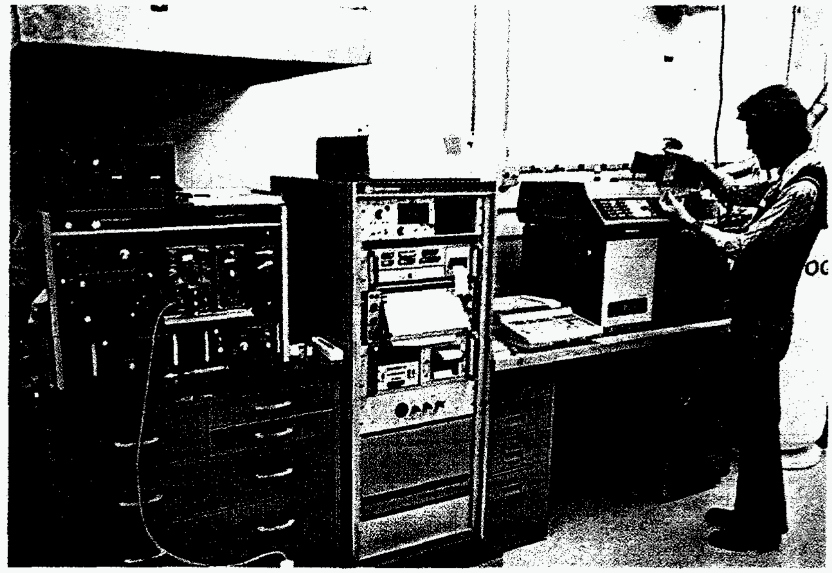
EARLY PROTOTYPE DOWNHOLE STEAM GENERATOR

GASES VENT DURING OIL SHALE RUBBILIZATION TEST

Al Stevens

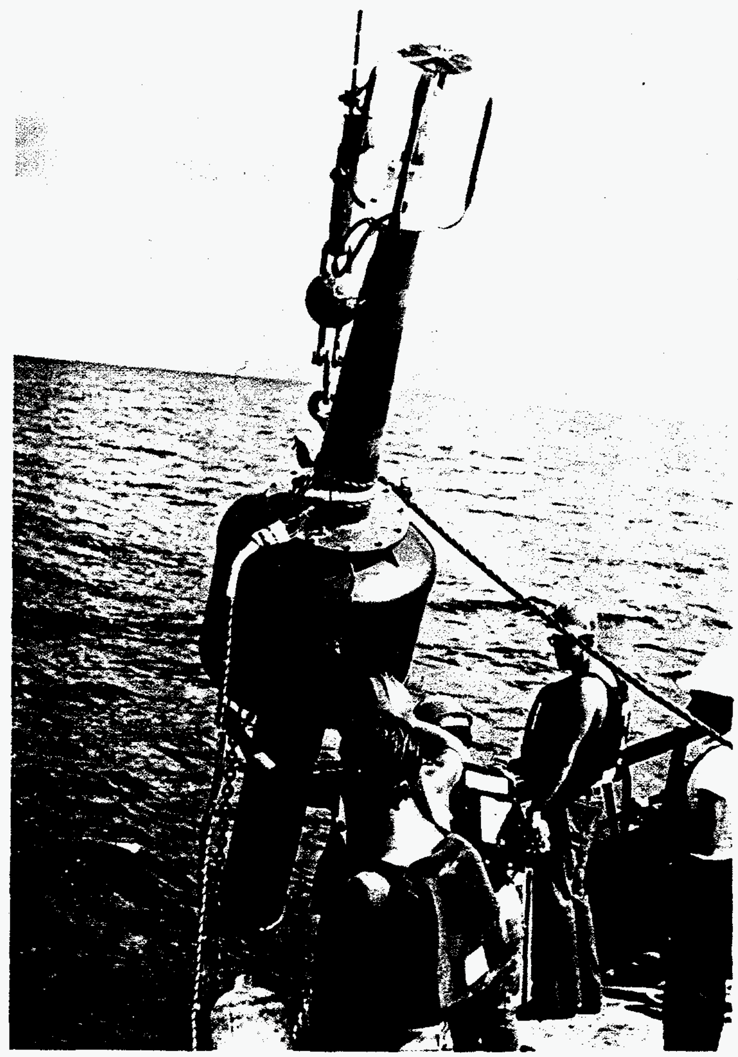


CRUDE OIL FLOW AND PERMEABILITY EXPERIMENT



LIQUID AND GAS CHROMATOGRAPHS TIED TO COMPUTER FOR SYNFUEL CHARACTERIZATION STUDIES

LAB TEST OF CONTINUOUS CHAIN DRILL BIT



ACOUSTIC TM RECEIVER, BUOY AND RF TRANSMITTER USED IN OFFSHORE TECHNOLOGY STUDIES

SYNTHETIC FUELS

Transportation in this country consumes 10 million barrels of oil per day. This represents about 26 percent of all energy used in the U. S. daily and more than half the oil. The private automobile, in turn, consumes more than half of the transport sector's energy. The energy crisis is, in large part, an inability to supply from domestic resources the crude oil necessary to fuel the transport sector.

While it is difficult to conceive of synthetic liquid hydrocarbon fuels produced from oil shale and coal as replacing a major portion of imported crude oil, the successful development of economically viable oil shale retorting and coal liquefaction processes could make a significant contribution to reducing U.S. dependence on foreign crude oil sources.

Private industry will develop these processes. Sandia is conducting supportive research and development projects to assist industry in better understanding critical phenomena and, hence, in improving process efficiency. These projects are sponsored by DOE's Division of Fossil Fuel Extraction and Fossil Fuel Conversion.

Oil Shale

Efforts to recover hydrocarbons from the nation's vast deposits of oil shale have, until recent years, been focused on surface processing methods. Such methods require the shale to be mined, transported to a processing site, crushed and screened, and then heated in a retort vessel to convert the solid organic constituent (kerogen) in the rock to recoverable liquid and gaseous hydrocarbons. While the technology for surface processing is proven, application on a scale broad enough to significantly impact the nation's demands for petroleum products may not occur because of concern about surface damage, water requirements, and spent shale disposal. Additionally, economic constraints will restrict use of these methods only to oil shale seams which satisfy certain richness, thickness, and accessibility criteria. The prognosis for the Green River Oil Shale Formation in Colorado, Utah, and Wyoming is that about two-thirds of the estimated two-trillion barrels of oil in place cannot be recovered by surface processing methods.

To improve the efficiency of resource utilization, as well as to mitigate adverse environmental impacts, efforts are underway by the DOE and private industry to develop methods to process oil shale underground. These in situ methods fall into two general categories — true and modified. In either case, an underground retort bed is formed, typically by explosively fracturing and fragmenting the rock. Subsequent processing occurs, in most instances, by using heat generated by burning a carbon residue left in the shale after the hydrocarbons have been freed. By definition, true in situ methods involve no rock mass removal during bed preparation, except for that produced in drilling wellbores to gain access to the underground formation. With modified in situ concepts, access can be gained through mine shafts or tunnels and rock mass removal is a basic feature. A typical modified in situ bed preparation operation includes creation of a mined cavity into which rock from the surrounding formation is blasted to form a rubble, or retort, bed with a void fraction of 20 to 30 percent. Except in shallow formations, where overburden lift can be achieved with explosives, true in situ retort beds are characterized by much lower void fractions. The void fraction difference implies that fluid-flow properties also differ; the result is that modified in situ processing methods offer a greater chance for near-term success than do true in situ methods. As a result, the bulk of DOE's oil shale research effort is currently directed toward developing viable modified in situ processing methods.

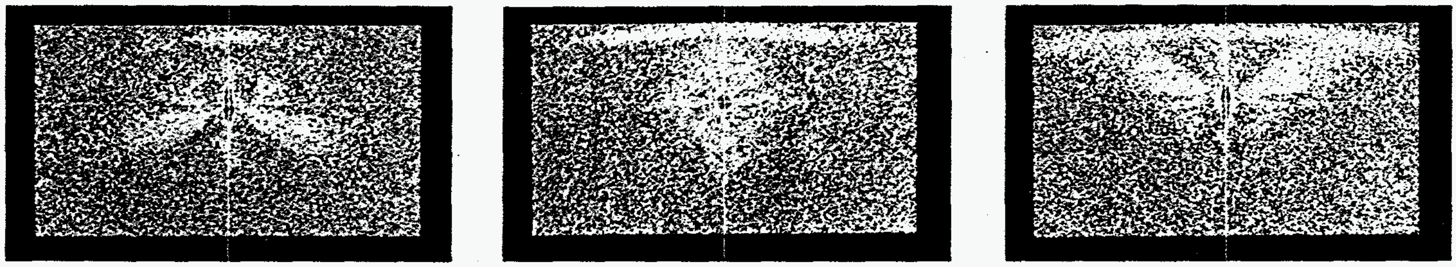
Sandia's oil shale projects are multifaceted, focusing in large part on modified in situ processing, but also bearing on true in situ processing and surface processing. Activities include laboratory and field experimentation and theoretical analyses, on rock fracture and fragmentation, rock mass and rubble pile stability, process chemistry, and instrumentation technology.

Field programs are conducted at various sites throughout the country to monitor and evaluate explosive fracturing and retorting operations. The work is done in conjunction with the Laramie Energy Technology Center. Instrumentation systems are used to monitor the dynamic events that occur during a blasting operation, to evaluate the physical state of the formation both before and after a blast, to monitor and control retorting operations continuously, and to provide information about the stability and integrity of a rubble bed and the surrounding rock mass before, during and after a retort.

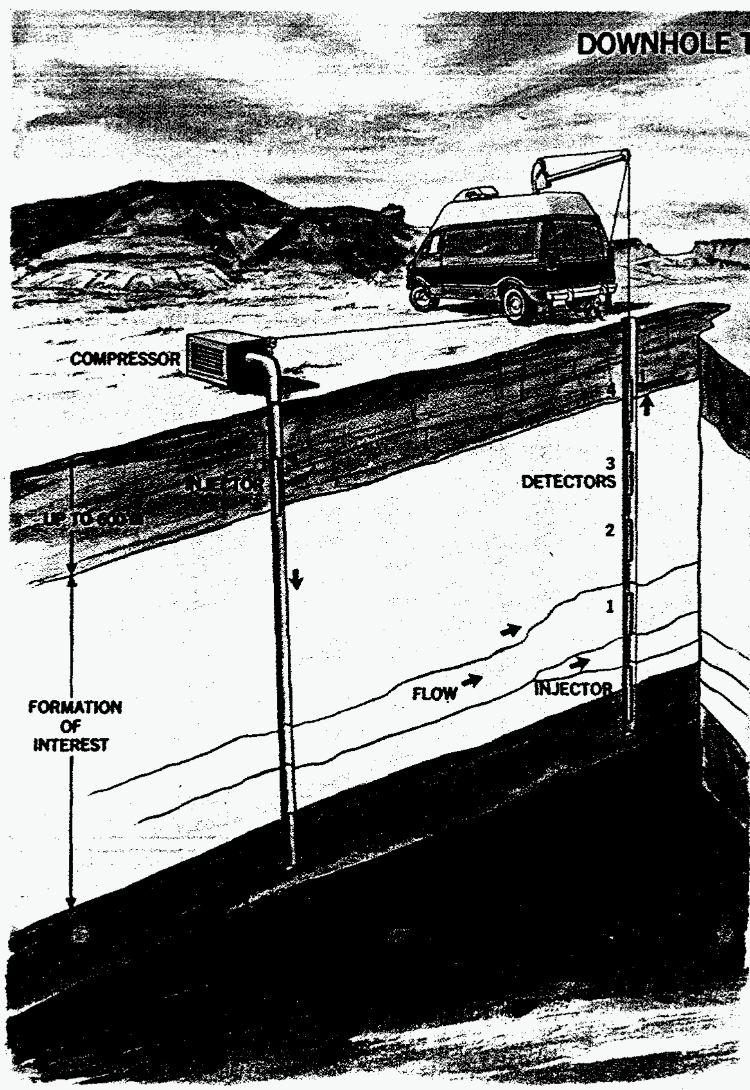
Laboratory studies and theoretical analyses support the field activities in various ways. For example, study of the static and dynamic mechanical properties of oil shale has led to the formulation of computer models to quantitatively describe explosive fracturing events. The immediate payoff of these studies is that instrumentation systems for field experiments can be effectively designed and operated. Ultimately, however, the laboratory, field, and theoretical work will lead to the ability to confidently prepare rubble beds for processing. Work in rock mechanics also is being used to study the strength and creep of materials at ambient and elevated temperatures to provide information on subsidence or collapse of underground rubble beds or surrounding rock masses.

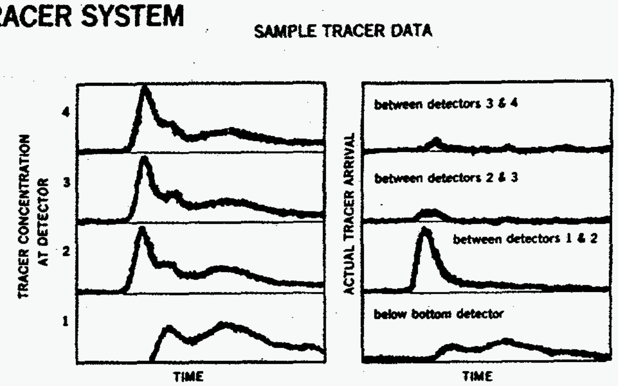
Evaluation of the physical state of a rubble bed (fragment dimensions, void ratio, fluid-flow properties, etc.) is addressed through development of remote sensing devices and instruments used directly in the rubble. Particularly noteworthy is a flow evaluation system which, by means of time-resolved measurements of the transit of tracer elements between pairs of wellbores, is capable of providing spatially resolved information not only about flow, but also about the void volume of the flow path. Methods to enter a rubble bed non-destructively for direct examination (core extraction, TV, etc.) or for instrument emplacement are also under investigation. Remote sensing devices (acoustic, electro-magnetic, resistive, etc.) are being developed for use when intrusion into a rubble bed is not feasible.

Many of the techniques applicable in rubble bed evaluation can be used in monitoring retorting activities. Remote sensing devices or instruments in the bed are needed to provide continuous information about temperature profiles, input and output gas compositions, product status, etc. Computerized methods to handle the data acquisition and analysis aspects of these tasks have been developed in basic form and are being refined and modified for new applications. Theoretical descriptions of process chemistry have also been developed. The non-uniform flow (channel flow) characteristics expected in in situ retorts have been emphasized, as opposed to the uniform or packed-bed flow characteristics that can be achieved in a surface retort.



COMPUTER PORTRAYAL OF DAMAGED OR FRACTURED ROCK (YELLOW) PRODUCED BY DETONATING EXPLOSIVE CHARGES (RED) NEAR FREE FACE IN OIL SHALE





RAW TRACER DATA showing effect of flow in recovery wellbore

REDUCED TRACER DATA (with wellbore effect removed) showing flow entry points

TRACER SYSTEM is used to study flow through coal and oil shale seams in situ. A pulse of Kr^{85} is introduced in the injection well at the top of the seam, and the arrival of that pulse in the recovery well is measured at four or more locations. Data can provide information on the number of flow paths and their location, size, and character (fracture, rubble, etc.) as well as a flow log of the recovery well.

Coal Liquefaction Process Research

Conversion of a portion of our large coal resource into liquid fuels will be essential to meet future demands for gasoline, fuel oil and chemicals. Technologies for producing synthetic fuels from coal, by means of both direct and indirect liquefaction, were developed by Germany before World War II. Indirect liquefaction, the steam-gasification of coal to synthesis gas followed by the catalytic conversion of this gas to liquid products, is currently in commercial use in South Africa. Several processes for the direct liquefaction of coal (SRC-I, SRC-II, H-Coal and EDS) are currently in the pilot plant stage of development, and plans for large demonstration units (e.g., 6000 tons/day of coal) have been proposed. Applied research is needed to understand the basic processes and mechanisms of coal liquefaction and to provide a foundation for economic analyses.

Sandia is supporting DOE and industrial programs with process research in three areas: (1) catalyst deactivation; (2) mineral matter effects and disposable catalysts; and (3) short-residence-time reactions.

Catalyst Deactivation

Catalysts such as cobalt-molybdenum or nickel-molybdenum on alumina are used for: (1) hydrodesulfurization, hydrodenitrogenation, cracking and hydrogenation as in the H-Coal process; (2) solvent hydrogenation as in the Exxon Donor Solvent process; and (3) liquid product upgrading as in the Cities Service-Lummus two-stage process. These processes are generally carried out at temperatures high enough (400 to 460°C) to result in dominance of thermal reactions, loss of catalyst selectivity, and generation of large quantities of hydrocarbon gases. Catalysts degrade rapidly because of the formation of carbonaceous deposits and contamination by inorganic species originally present in the coal.

Sandia's effort includes the characterization of used catalysts by scanning electron microscopy, electron microprobe, etc., to identify contaminants and correlate structural changes with the industrial process results. In addition, specificity of new and used catalysts is determined by reactions with model compounds and coal-derived products in small-scale tubing reactors. Analyses have shown that carbon and sulfur are distributed uniformly throughout the catalyst, but that titanium, iron, and boron slowly penetrate the interior of the catalyst.

MoS_2 CRYSTAL GROWTH ON CATALYSTS DURING COAL HYDROLIQUEFACTION (2000X)

Catalysts that have been used at temperatures in excess of 430°C may experience loss of active metals due to vaporization of metal sulfides. Significant crystal growth of molybdenum disulfide, which could substantially decrease the active catalyst surface area, has been observed.

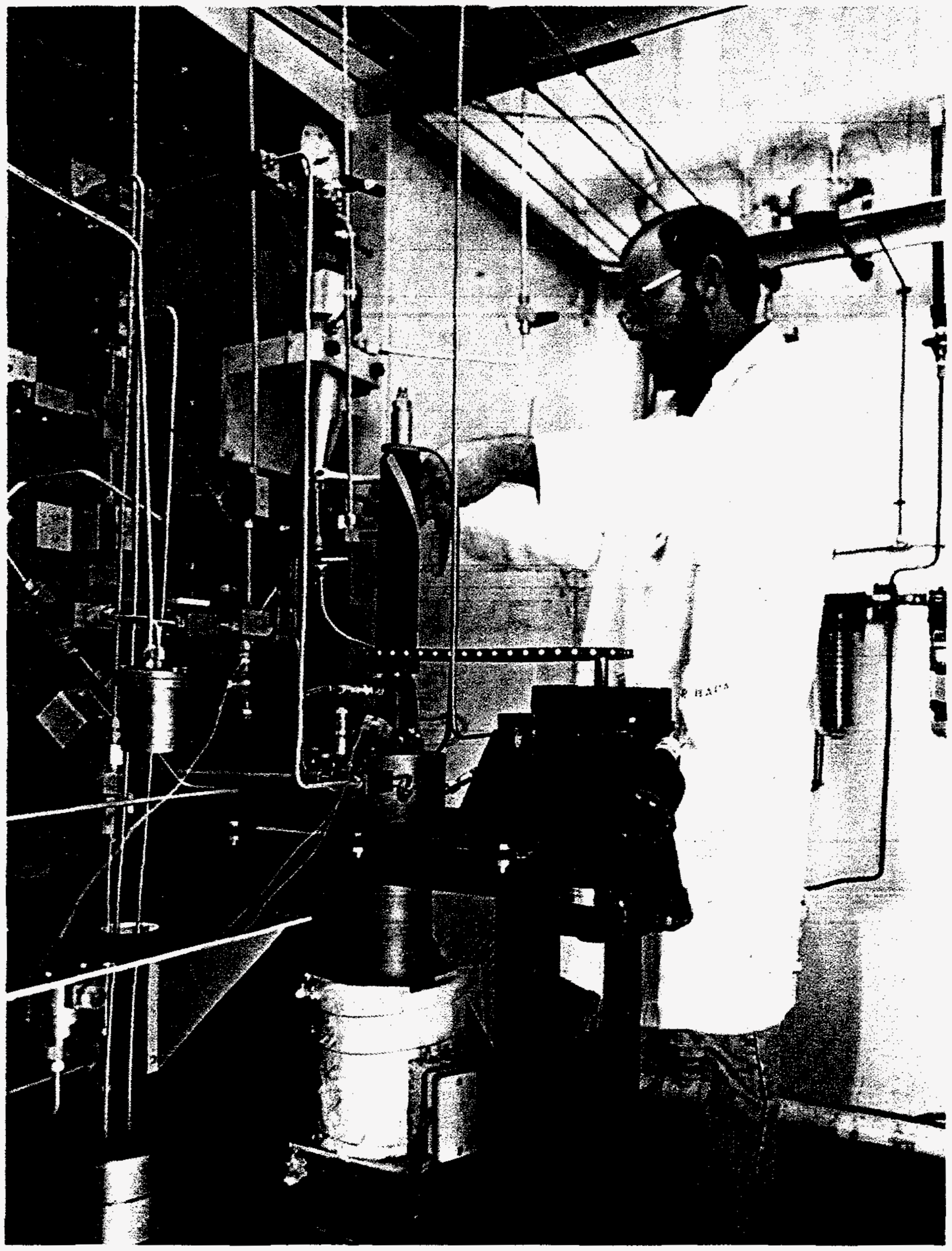
Current studies include efforts to better define the time history of contaminant buildup, and to identify changes in catalyst activity. These results will be used to develop a deactivation model for coal liquefaction catalysts and to provide a fundamental basis for catalyst improvement. Recently, radioactively tagged catalysts were used in the H-Coal continuous reactor in Trenton, NJ. Data from this experiment are to be used to calculate the distribution of catalyst lifetimes and to provide insights into the mixing regime in the reactor.

Mineral Matter Effects and Disposable Catalysts

Naturally occurring minerals in coal have been shown to have a catalytic effect in coal liquefaction. Clays are known cracking catalysts, and iron-containing species may be active in hydrogenation reactions. Conversion to liquid products has been correlated with the total sulfur content of the feed coal, and high-ash coals were shown to be more easily liquefied than coals with low mineral contents. The Solvent Refined Coal process, or SRC-II, makes use of slurry recycle to increase the mineral content in the reactor and results in marked improvements in the yield of distillates. Identification of specific mineral effects is crucial in understanding and, ultimately, controlling the various liquefaction processes.

The objective of the Disposable Catalyst Project, which is coordinated by DOE, is to utilize mineral matter in coal or other readily available minerals as catalysts for coal liquefaction. Current activities include a comprehensive study of the role of pyrite, and the preparation of sub-micron, high-surface-area iron sulfides. It has been shown that the addition of pyrite results in a greater conversion of high molecular weight species to distillates, and enhances the overall yield of liquids.

Under typical liquefaction conditions (425°C, 1800 psig, 30 min), pyrite (FeS_2) is transformed into a non-stoichiometric iron sulfide known as pyrrhotite ($Fe_{1-x}S$). It is currently thought that pyrrhotite may be one of the "active" catalysts for coal liquefaction. Recent Mössbauer studies (a joint program with West Virginia University) have revealed a correlation between coal reactivity and the composition of the pyrrhotite found in the liquefaction residue. This information is being used to improve understanding of the role of pyrite in coal liquefaction and to develop a predictive model for mineral matter effects.



RAPID INJECTION AUTOCLAVE SYSTEM FOR MINERAL EFFECTS STUDIES

Short-Residence-Time Reactions

In most direct liquefaction processes, coal/solvent/hydrogen mixtures are heated to 380-450°C to produce a clean boiler fuel or to provide a product stream for subsequent upgrading. During this heating, the coal initially swells in the solvent and disintegrates, resulting in the formation of a high viscosity gel. Asphaltenes, oils and gases are then formed from the initially solubilized coal.

Design and analysis of preheaters and reactors is difficult because the three-phase flow can alter flow regimes, and the large increases in viscosity, from centipoise to tens of poise, can drastically affect heat transfer coefficients. In addition to these physical changes, there are complex chemical transformations which are not completely understood. Process studies, using a continuous bench-scale reactor, are in progress to provide engineering kinetics data and to characterize the physical and chemical changes that take place in the initial stages of coal liquefaction.

Studies to date have shown that coal and solvent initially interact to form a preasphaltene. During this time, a process would most likely not be in solvent balance. Later on, the preasphaltenes are converted to asphaltenes and oils in a series of parallel reactions. At short residence times, net solvent production is not achieved until the temperature exceeds 425-450°C.

Specific kinetic parameters for the reaction sequence are now being defined for comparison with operating data from larger-scale reactors. Future work will include the development of techniques to define flow regimes, and to measure residence time distributions of solid, liquid and gas phases in pilot and large-scale reactors.

GEOTHERMAL ENERGY

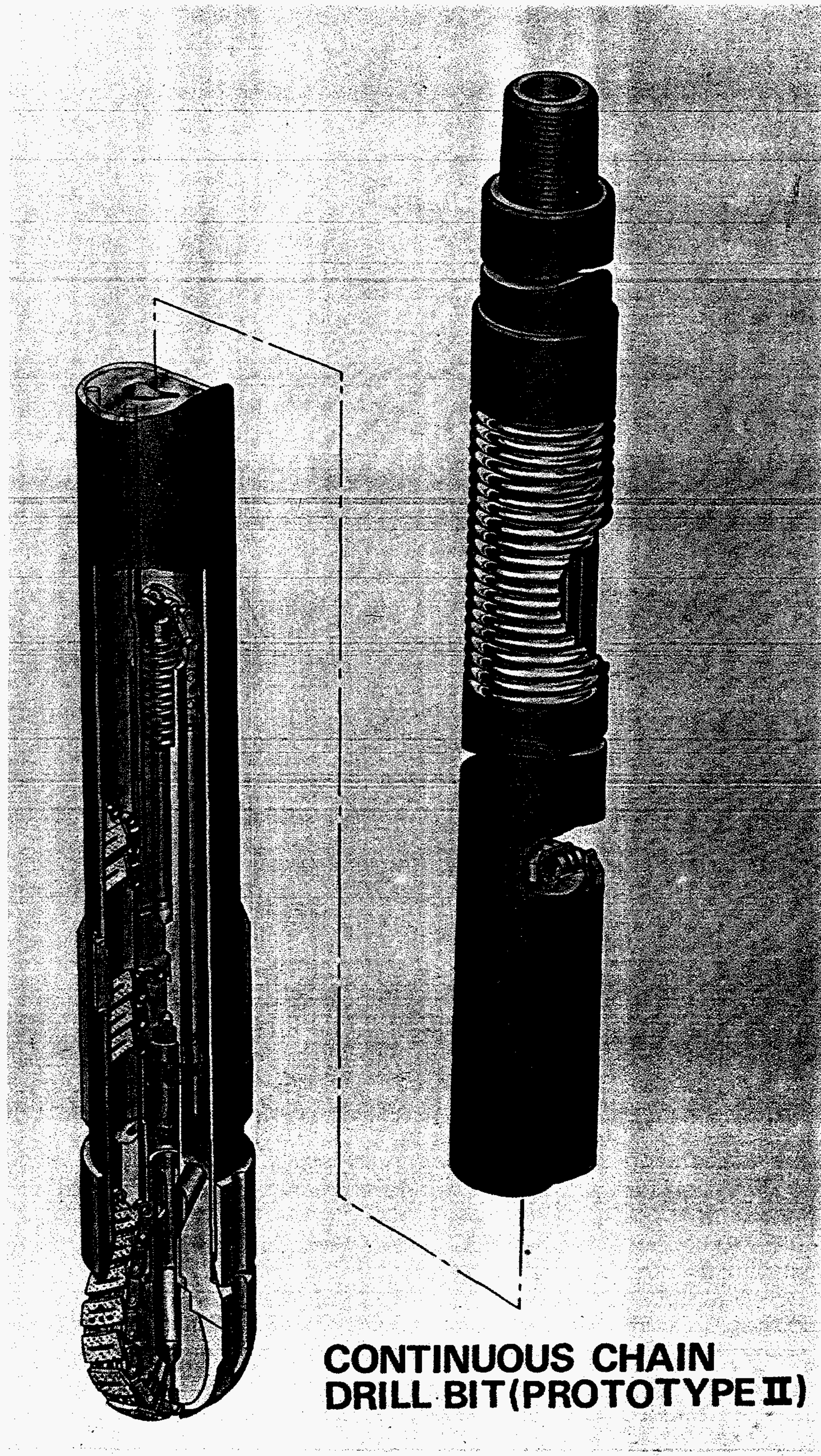
In early 1978, American electric utilities had about 515,000 megawatts of capacity. Slightly more than 500 megawatts of this capacity were produced via geothermal energy. The U.S. Geological Survey in its recent survey of geothermal resources (Circular 790) estimates that the equivalent of 100,000 megawatts of electric power and process heat could be produced from geothermal energy.

State-of-the-art energy production processes from geothermal resources do not appear to make this energy source a dominant contender to enlarge our energy supply — primarily because of the concentration of the resources in the West and because of the relatively low temperatures of most of the resources. Yet, the potential exists for geothermal to make a significant contribution. However, some limiting technological factors — the high cost of drilling and completing geothermal wells and the inability to make reliable measurements in geothermal reservoirs — limit the use of geothermal energy.

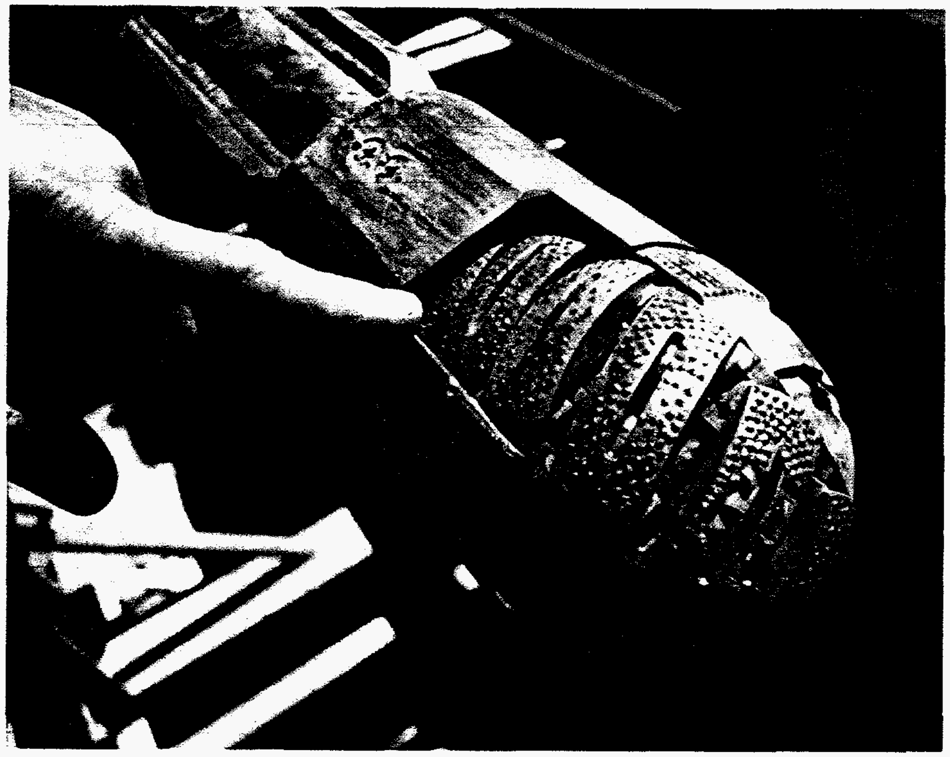
To address these factors, Sandia is directing the Geothermal Drilling and Well Completion Program and the Geothermal Logging Instrumentation Development Program for DOE's Division of Geothermal Energy. Additionally, for DOE's Office of Basic Energy Sciences, Sandia is investigating the scientific feasibility of extracting energy from magma — the ultimate geothermal source.

Drilling and Well Completion

The Drilling and Well Completion Program is a broadly based technology development program to help reduce the high cost of geothermal drilling. Major elements include development of high performance rock bits, downhole motors, high temperature drilling fluids, and systems which permit reliable high-temperature well completions. These activities are conducted inhouse and by the drilling industry under Sandia's technical direction. Development of the chain bit for hard-rock drilling is one in-house technology program. The bit has a diamond studded cutting surface located on a continuous chain which is circulated between the drilling head at the bottom of the bit and a sprocket located several feet distant at the top of the bit. The hole is cut by the portion of the chain wrapped around the drilling head. When the five links which form the cutting structure of the chain become dull,



CONTINUOUS CHAIN DRILL BIT (PROTOTYPE II)



CHAIN DRILL AT FIELD TEST

another segment is cycled into place without removing the bit from the hole. The current design has fifteen complete cutting segments.

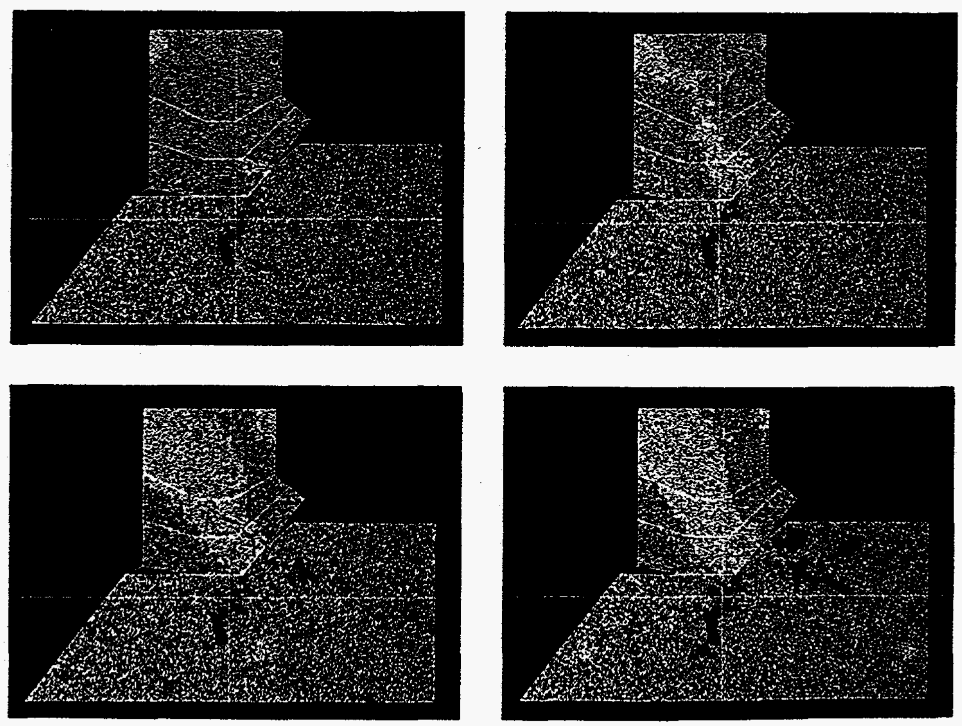
Recent field testing of this bit has demonstrated that the drilling rate of the bit is comparable to the best hard-rock diamond bit. In addition, the ability to cycle new cutters into position without removing the bit from the hole has been successfully demonstrated. Further development of this bit will be done in close collaboration with private industry.

Work is also being done on drag bits utilizing man-made polycrystalline diamond compact cutters. To optimize design of bits using this technology, it is necessary to understand the interaction of the cutter with the rock, the wear rate of the cutter, and the failure modes of the rock. Finite element computer models have been developed for use in calculating the stress induced in both the rock and the cutter under real-time drilling conditions. These calculations can be used to optimize rake angles, weight-on-bit, and cutter placement.

Another project involves the development of a high-temperature, low-density drilling fluid, using surfactants to generate foams. This involves screening existing high-temperature surfactants to determine their rheological properties under simulated drilling conditions. Non-corrosive, stable formulations of high-temperature drilling foams are required to improve penetration rate and to reduce corrosion in the geothermal drilling environment.

An in-house materials study for development of new steel alloys which can be used for fabricating drill pipe used in the harsh geothermal drilling environments is being pursued. Present activities involve formulating new alloys of duplex phase steels in Sandia's melting laboratory and then testing these new alloys in a fatigue tester to determine stress corrosion failure modes. In these experiments samples of the experimental steels are placed inside an environmental chamber containing corrosive gases and subjected to fatigue loading. Crack growth rates are measured and this information is used to rank steels for use in the geothermal environment.

Work on advanced drilling and completion systems is also underway. A workshop attended by participants from industry, government, and universities was held, and recommendations obtained about which advanced drilling systems should be developed. Studies of these advanced systems have been initiated with primary emphasis on cost-effectiveness of the proposed concepts.



COMPUTER SIMULATION SHOWING STRESS DISTRIBUTION DEVELOPED WHEN DRAG TYPE CUTTER (UPPER) FRACTURES ROCK (LOWER). TOP LEFT, 35 μSECS AFTER START OF DRILLING; TOP RIGHT, 45 μSECS; BOTTOM LEFT, 60 μSECS; BOTTOM RIGHT, 70 μSECS.

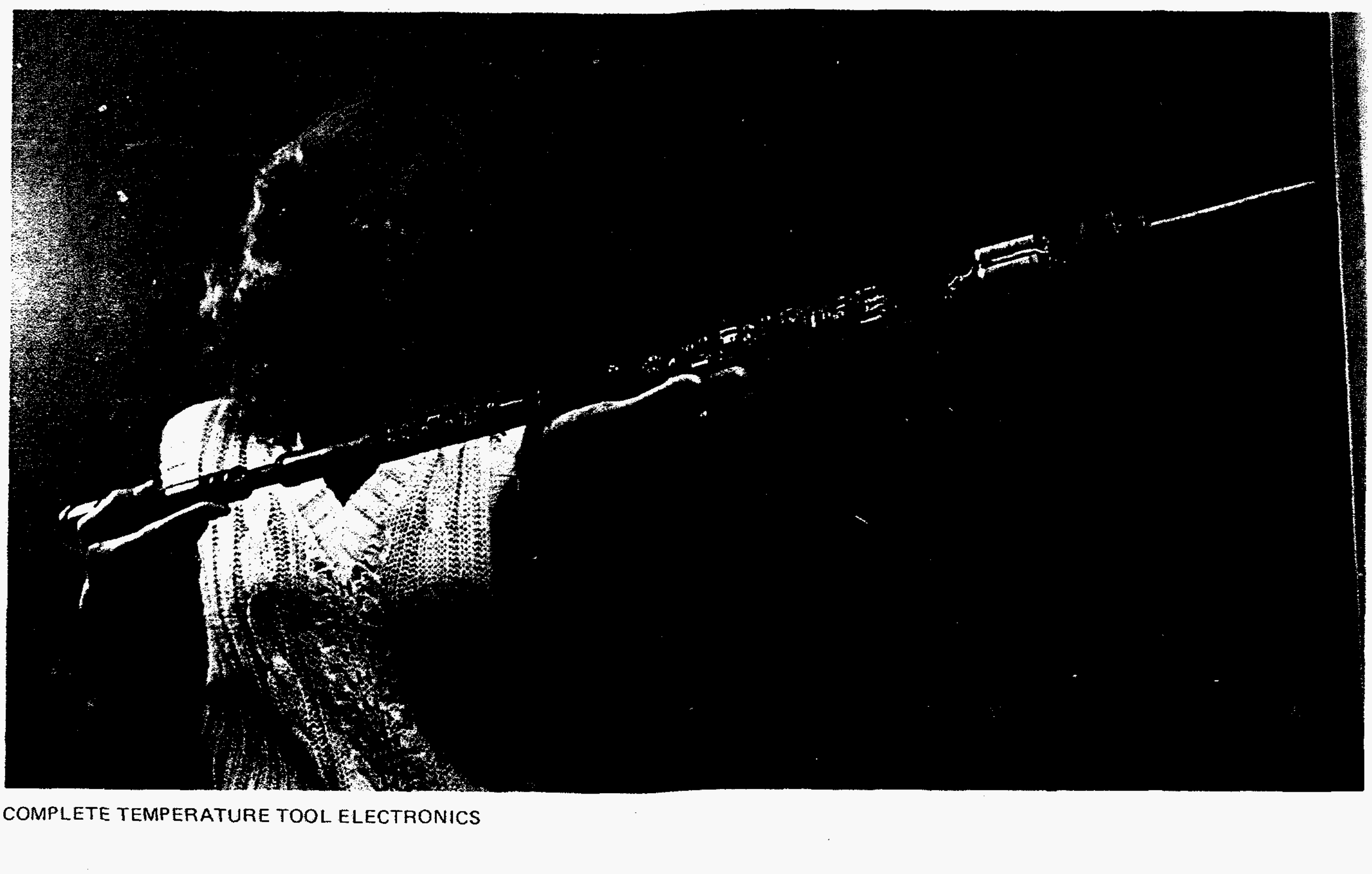
Logging Instrumentation Development

Development of geothermal resources as an alternative source of energy requires measurement of those physical and chemical properties required for reservoir evaluation and production. Well logging is the primary technique for locating production zones, planning the well's completion, and controlling its production. Key logging system components, such as cables, electronics, transducers, and seals, will not function in the hot (over 180°C), corrosive, "hostile" environment of geothermal wells. The Geothermal Logging Instrumentation Development Program is being conducted to correct these technical deficiencies.

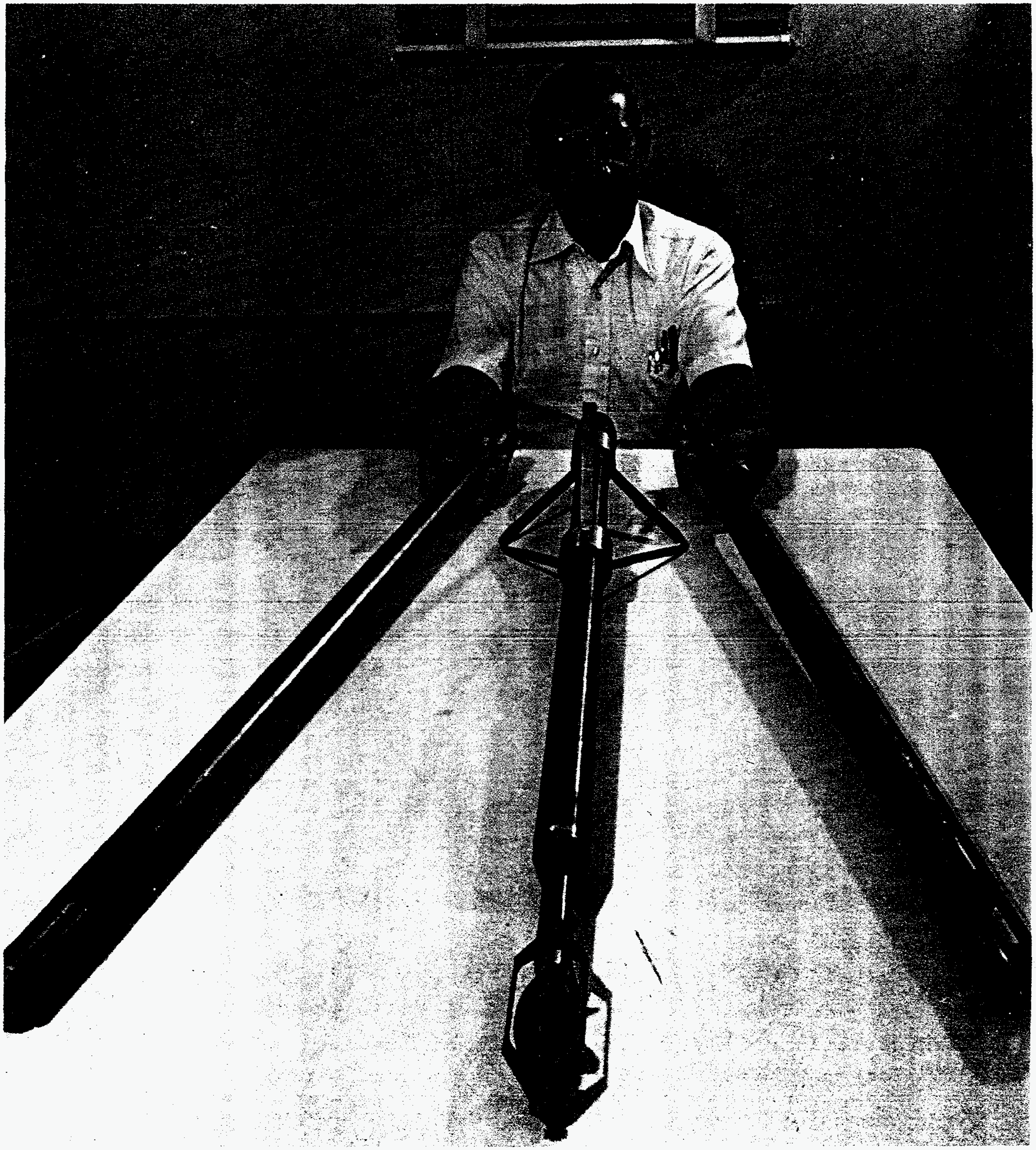
The program combines the advanced, high temperature materials and components capabilities of Sandia with the proven ability of the logging service industry and its suppliers to develop new logging technology. The near-term goal is to develop instrumentation for use at 275°C in pressures up to 48.3 MPa (7,000 psi); subsequent goals are to extend these capabilities to 350°C and 138 MPa (20,000 psi). Tools to be upgraded and/or developed include temperature, flow rate, high resolution downhole pressure, caliper, and fracture mapping sondes.

High temperature electronic circuits are needed for gathering, processing, and transmitting the required information. Component development has emphasized hybrid thick film microcircuitry. The passive devices, such as resistors and capacitors, use special inks that are deposited and baked onto the circuit at high temperature. The active devices, such as amplifiers, consist of silicon field effect transistors specially screened and selected for operation up to 300°C. Several generic circuits have been fabricated and tested in prototype temperature, pressure, and flow tools in geothermal wells up to 275°C — the highest operational temperature ever achieved for an uncooled, nonthermally insulated instrument equipped with active electronics. Efforts are now underway to commercialize these prototype tools and the technology they represent. Electronic manufacturers are fabricating the new generic circuits under contract to Sandia, and several private firms are investigating the new technology for use in high temperature logging tools.

Exploratory development efforts are continuing. An experimental high-resolution quartz resonator pressure transducer has been successfully tested to 275°C and 1,000 psi, a gallium phosphide diode has been designed and operated successfully up to 400°C, a new metal sheath logging cable configuration is being investigated, and both silicon and compound semiconductor designs and fabrication techniques are being developed for reliable long-term (1,000 hours) operation at high temperature (up to 300°).



COMPLETE TEMPERATURE TOOL ELECTRONICS



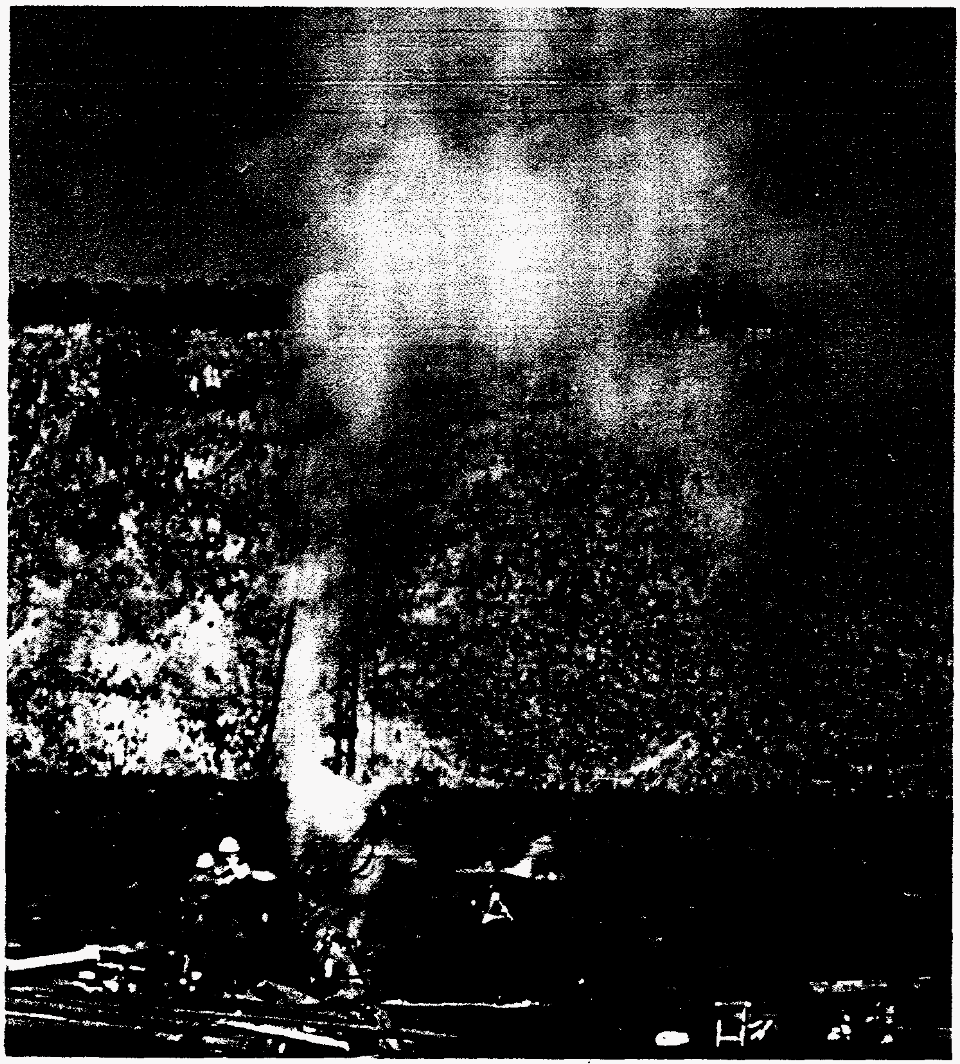
PRESSURE, FLOW, AND TEMPERATURE TOOLS

Magma Energy Research

Magma, the source of all geothermal energy, provides an enticing resource for high quality thermal energy. The USGS estimates (Circular 790) that the energy content of molten rock deposits within 10 km of the earth's surface in the continental United States is 500 times greater than the total annual U.S. energy consumption in 1979. The Magma Energy Research Program is investigating the scientific feasibility of extracting energy directly from buried, magma sources.

The project has five major elements: (1) locating and defining buried magma bodies, (2) tapping and maintaining access to the source, (3) estimating the chemical and physical properties of the high pressure-high temperature magma bodies, (4) determining if materials can survive in a magmatic environment, and (5) evaluating concepts to extract energy.

To better understand application of geophysical measuring techniques to buried liquid rock bodies, seismic and electromagnetic experiments were carried out over Kilauea Iki lava lake on the island of Hawaii by the USGS, MIT, University of Texas and Sandia. Although the initial measurements provided a good description of the hydrothermal and hot, dry region of the crust, the thickness and state of the molten lens were less clearly defined. Recent drilling penetrated the molten region where the temperature exceeds 1000°C. These tests indicated that portions of the upper crust contained veins of molten material and that the liquid lens consisted of a high viscosity mixture of 40 to 60 percent crystals in melt. The drilling data are being used to re-evaluate the previous geophysical data and to define future experiments using this field laboratory.



GEOSCIENCE FIELD STUDIES IN 1000°C MOLTON ROCK

In addition to the limited drilling studies used to characterize the lava lake, a study is underway at the Center for Tectonophysics at Texas A&M University to evaluate the mechanical stability of boreholes drilled through the deep, hot rock regions. Strengths of representative rocks measured to 1100°C under 0 and 50 MPa confining pressures suggest boreholes will be stable to depths of 10 km under certain formation stress conditions.

In situ magmatic compositions are being estimated by thermodynamically folding volcanic eruption gas compositions back to magmatic environments and tying these to known lava analyses. These compositions are being duplicated in an 80cc, 4 kbar, 1600°C test vessel for measurement of chemical and physical properties.

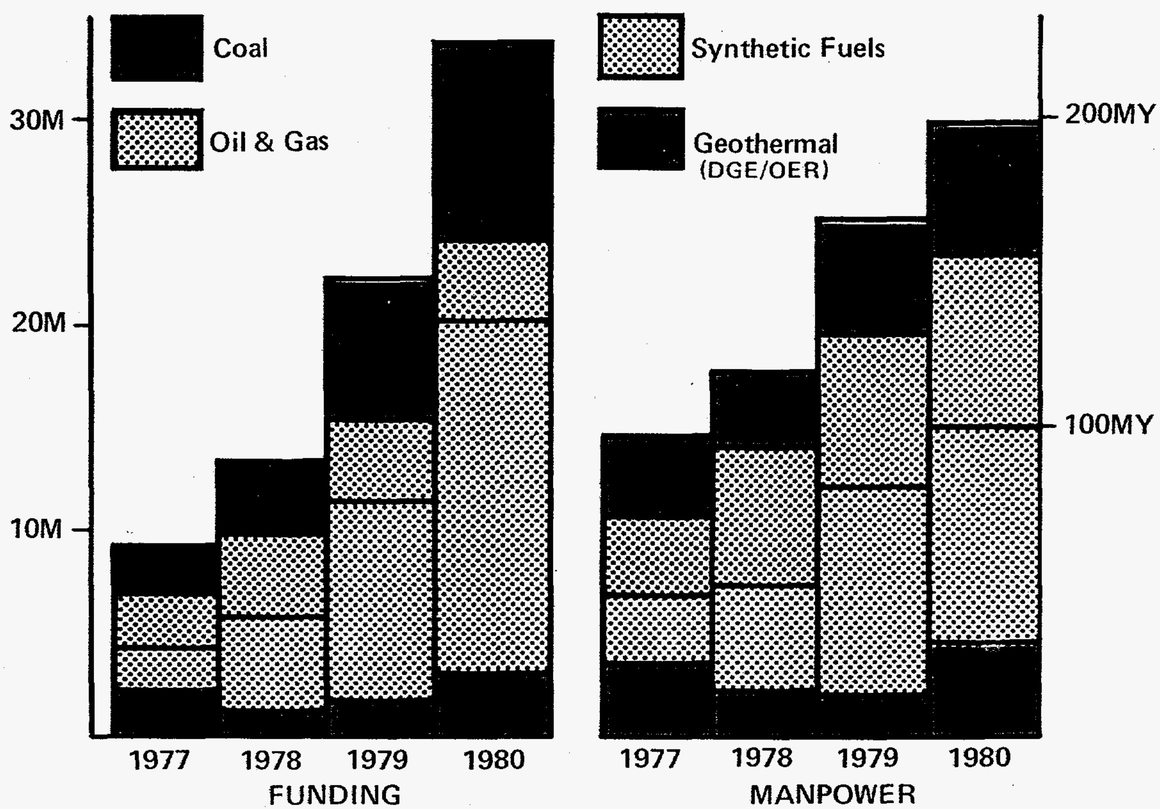
The simulated compositions are also used to evaluate material compatibilities and to identify engineering materials for possible drilling and energy extraction equipment. Some super-alloys and high chromium steels have been shown to be compatible with simulated magmas for 100 hours at 1150°C.

Energy extraction investigations have included laboratory and calculational studies of hydrogen and synthesis gas production by reaction of simulated magma and biomass. In addition, investigations into methods for the continuous extraction of heat have included a steam boiler inserted into a vat of molten rock, insertion of a heat transfer probe in the flowing lava river during the 1977 Kilauea eruption, and limited heat transfer studies in the lava lake.

The Magma Energy Research Program is a scientific feasibility study pushing the state-of-the-art in such diverse areas as volcanology, geochemistry, geophysics, materials, heat and mass transport and rock mechanics. Magma energy utilization, if proven scientifically feasible and subsequently developed, could provide a significant and environmentally acceptable portion of the nation's future energy needs.

GEO ENERGY TECHNOLOGY PROGRAM

Division	Programs
DEPARTMENT I **H. M. Stoller**	
Process Research Division B. Granoff	Coal Liquefaction Oil Shale Retorting EOR Chemistry
Geotechnology Research Division D.A. Northrop	Enhanced Gas Recovery Mining Subsidence
Instrumentation Development Division C. L. Schuster	Enhanced Gas Recovery Diagnostics Offshore Technology Program Instrumentation Development
Oil Shale Projects Division A. L. Stevens	Oil Shale
Thermal Processes Division B. E. Bader	In Situ Coal Gasification Fossil Energy Program Development
Enhanced Oil Recovery Division R. L. Fox	Project DEEP STEAM Tar Sands
DEPARTMENT II **R. K. Treager**	
Drilling Technology Division S. G. Varnado	Fossil Energy Drilling Mining Technology Geothermal Drilling Well Completions
Geothermal Technology Division A. F. Veneruso	Logging Instrumentation
Geothermal Research Division H. C. Hardee	Magma Energy Research
Systems Analysis Division H. M. Dodd	Fossil Energy Systems Analysis Geothermal Systems Analysis



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P. J. Hommert, "Analysis of Conduction Responses During an Underground Coal Gasification Experiment," Proceedings of the 6th International Heat Transfer Conference, Toronto, 1978.

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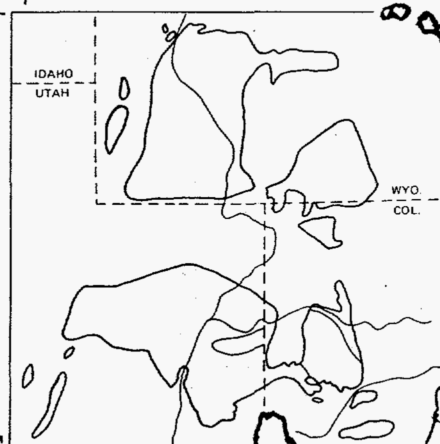
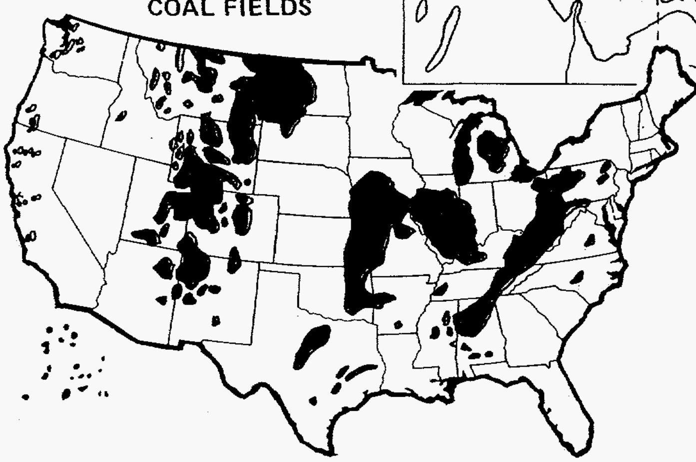
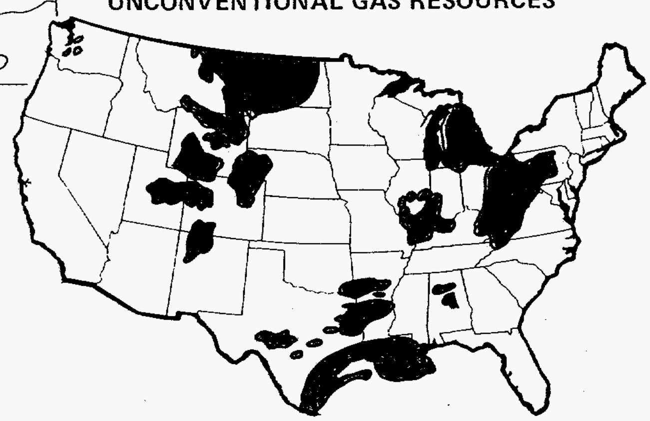


COAL FIELDS



UNCONVENTIONAL GAS RESOURCES



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