



# Antojitos

As I Write This one week before this issue hits your desk, the LAB NEWS staff is scrambling to put out the second 32-page issue in its history (the first was the Nov. 18 issue, known over here as Energy II).

In Energy III this issue, we finish off Sandia's energy programs (speaking figuratively, of course). Writers represented in this issue include Phyllis Wilson (3162), Larry Perrine (3162), Jim Mitchell (3160), Nigel Hey (3161), Bruce Hawkinson (3162), and Rod Geer (3161). Again, Rod was project coordinator and Phyl copy editor. And, again, thanks to all our sources and fact-checkers in the programs described; they're named, more-or-less prominently, in the stories themselves.

Not always named, but always appreciated, are the sources' bosses who had the responsibility for approving the stories -- and, at least in the case of the stories I wrote, faced the same deadline pressures the LAB NEWS staff did. I suspect Virg Dugan (6200) may be just as relieved to get Energy III into print as we are.

\* \* \*

The Good Old (Virus) Days -- The Dec. 3 New Scientist carried an item it lifted from Electronics News: "About a decade ago, apparently, networks in the US were plagued by a virus that earned the name 'Chocolate Chip Cookie.' Perhaps inspired by the ever-hungry Cookie Monster on Sesame Street, the virus would take over a computer's operating system, and print a demand for cookies on all attached terminals. As time passed, the demands became more frequent until the operating system would print only demands for cookies.

"The first demands may have been amusing, but they grew less so as they became more frequent. Programmers tried technical remedies to no avail. Finally, the story goes, someone was inspired to type a reply to the virus: 'Chocolate Chip.' At that point, the virus typed back 'Mmmmmmmmm,' and self-destructed."

\* \* \*

The Bad New (Virus) Days -- A San Jose newspaper is advertising, as this year's version of the pet rock, a Computer-Virus First-Aid Kit. Originated by a Sunnyvale mechanical engineer and a San Jose wine marketer, and priced at \$7.95, the kit contains an ice bag, a scarf, and a suction-cup thermometer for ailing (terminally ill?) computers. Maybe Silly-Con Valley would be more precise.

\* \* \*

## Sandia's Christmas --

No, we don't get turkeys, and we don't get hams,  
We don't get cash, and we don't get yams,  
We don't get a party where we'd stay out late,  
But we get 10 days off to recuperate!

\* \* \*

Lo, How a Rose (and a Ray) E'er Blooming -- Early Christmas gift for Rose (5141) and Ray (3154-3) Chavez: They just learned that number-four child, Andrea, has been admitted to Harvard. She follows in the collegiate footsteps of her three older siblings. Congrats, Chavezes!

\* \* \*

Early Christmas for some no-good grinch(es) -- While Moe Lucero (3426) was enjoying his office Christmas party at the NCO Club, he/she/they stole the 90-lb. hood off his '64 Chevy pickup. I'd call it a clear case of hoodwinking.

\* \* \*

Feliz Navidad a toda, y a todos buenas noches. ●BH



COVER ARTIST FAITH PERRY (3523) works on her latest painting. She specializes in Chinese brush painting and likes to paint waterscapes, nature scenes, and scenes featuring rustic old gates.

## Our Christmas Cover

### Reflects the 'Special Song' In Us

"Moonlight Sonata" is the title of Faith Perry's watercolor on this Christmas issue cover. Faith, of Management and Staff Development Div. 3523, specializes in traditional and contemporary Chinese brush painting. The cover reflects this traditional style.

"This painting, like most that I do, uses a nature scene to symbolize an idea," says Faith. "The singing bird symbolizes my concept that each of us has a special song inside us -- a song that needs to be expressed and listened to, perhaps by others, but certainly by ourselves. I think the Christmas season is an excellent time to get in touch with that song and express it."

Faith, who began showing her paintings professionally in 1984 (LAB NEWS, June 22, 1984), now exhibits regularly in Albuquerque, Santa Fe, and elsewhere in New Mexico (including the Bldg. 802 lobby). Her paintings have been exhibited during four of the past five years at the New Mexico Arts and Crafts Show. She has also shown and sold works at East Coast and Midwest shows.

Faith paints a variety of subjects, but mostly waterscapes and nature scenes that include flowers, birds, and other small animals.

### Fresh, Fluid, and Frustrating

Most of her paintings combine Oriental ink and watercolors. "I prefer watercolor for its freshness, fluidity, and spontaneity, but it's not an easy medium," she says. "You can often cover up mistakes you make with oils, but that's nearly impossible with watercolors."

When Faith isn't busy working or painting, she's still busy. Since September, she has taught nine painting and matting/framing short courses through the Sandia Employee Recreation Program. She has taught art courses at UNM and will teach another this spring. Faith has a BA in fine arts from Indiana University. Her future plans include writing a book or monograph series on Chinese brush painting techniques.

### Congratulations

To Julie and David (8454) Stimmel, a daughter, Andrea Rose, Dec. 3.

To Susan and Ken (8241) Perano, a daughter, Kristin Michelle, Dec. 7.



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## Fun & Games

Square Dancing -- Swing your partner, do-si-do! One way to beat the cold-weather doldrums is to get your feet moving by taking square-dance lessons beginning Jan. 6 at St. Luke's Lutheran Church (9100 Menaul NE). Beginning lessons with instructor Tom Kern are held every Friday at 7 p.m. The first three lessons are free. For more information, contact Tommy Glauner (2345) on 299-0277.

## Happy Holidays

from the

LAB NEWS Staff!

## Blewer Wins Semiconductor Achievement Award

Bob Blewer (DMTS, Radiation Technology and Materials Div. 2147) is the 1988 winner of the Semiconductor International Technology Achievement Award in process engineering. The award — along with three in other categories — is presented each year by *Semiconductor International* magazine to researchers who have made significant contributions to the semiconductor manufacturing industry.

Bob was honored for his work, several years ago, in chemical-vapor-deposited (CVD) tungsten — and for his work since then in stimulating the development and use of tungsten technology in the semiconductor manufacturing community. Glenn Kuswa (then manager of Technology Transfer and Management Dept. 4030) and Bob Gregory (ret.) nominated him.

“Bob’s original research, development, and ongoing technology transfer led to a payoff in industry interest and implementation that has come to fruition in the last 18 months,” says Glenn. “Today, researchers and engineers worldwide are making contributions to tungsten technology, but Bob’s early interest and advocacy of CVD tungsten were pivotal in enhancing the pace and character of its development — and for helping to secure the inherent advantages of the technology for US industry.”

“Bob played a central role in establishing the solid technology base that now exists for CVD tungsten,” says Harry Saxton, Managing Director of Microelectronics 2900. “Tungsten has become the leading candidate for achieving the needed planarization at contact windows and at interlevel vias in submicron IC [integrated circuit] designs. In fact, SEMATECH has chosen it as a baseline technology for its advanced Phase II development.”

### Tungsten Promises Advantages

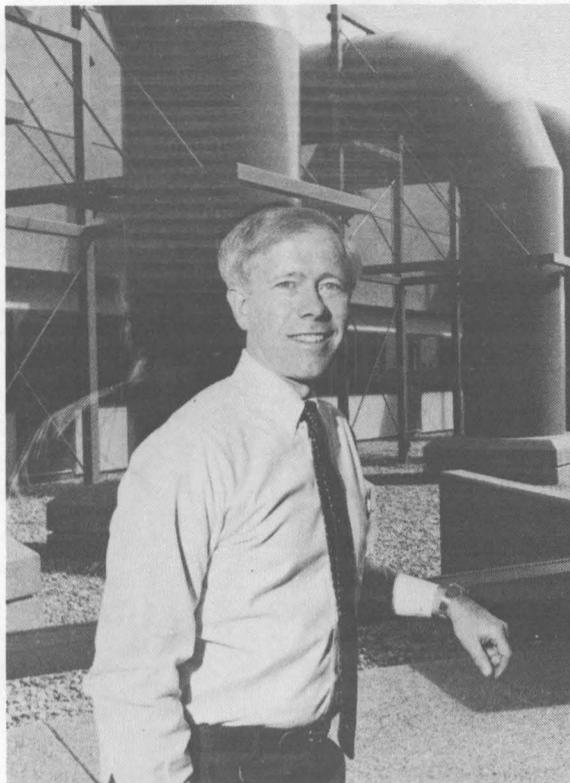
Several years ago, just when most researchers were losing hope that a successful CVD process for tungsten films would emerge, Bob demonstrated the technical feasibility of using the process to deposit tungsten plugs up to one micron thick to fill the holes that interconnect different levels of advanced ICs. He achieved the deposits — three to five times thicker than any previously reported — without losing the self-aligning nature of CVD tungsten (the deposits formed only where they were supposed to, without building up in areas nearby).

“The ability to selectively deposit one-micron-thick tungsten films offers a new method for achieving planar [smooth] chip surfaces,” says Peter Winokur, supervisor of 2147. “This makes it easier to create ICs consisting of several metal interconnect layers stacked on top of each other — and significantly increases the range of possible applications for tungsten in the design and fabrication of advanced VLSI [Very Large Scale Integrated circuit] chips.”

VLSI chips, contrary to the size implied by their name, are very small — smaller than a fingernail — and typically contain from 100,000 to a million interconnected transistors and other components clustered on the small semiconductor surface. “The desire to pack more circuit elements on a chip is pushing feature size to one micron and below, putting ever greater demands on the conventional aluminum metallization,” says Bob. “The use of tungsten could solve several of the resultant problems.”

VLSI circuits commonly use microscopically thin aluminum wires — barely 1/100th the thickness of a human hair — to connect transistors and other components. Even a small current coursing through them may generate a current density high enough to bump aluminum atoms in the direction of the electron flow, eventually thinning the material enough at some points along the interconnect lines to break the circuit. “Tungsten is less susceptible to this kind of behavior,” says Bob. “Its atoms are very resistant to migration under high current loads.”

One of the greatest benefits of selectively depositing thicker tungsten films may be in the design and fabrication of advanced VLSIs that require vertical interconnects. Bob told *Semiconductor International*



BOB BLEWER (DMTS, 2147) has won the 1988 Semiconductor International Technology Achievement Award for his early work in chemical-vapor-deposited (CVD) tungsten and for the central role he played in stimulating the development and use of the technology in the semiconductor manufacturing community. Presented by *Semiconductor International* magazine, the awards honor researchers who have made significant contributions to the semiconductor manufacturing industry. Behind Bob is the new, world-class Microelectronics Development Laboratory (formerly RHIC II).

that “refractory/vertical wiring capability is an enabling technology . . . that could permit the fabrication of active devices stacked on several levels. This would represent true 3-D integration, which would relieve pressure for ever-shrinking design rules, while providing a means to achieve a much greater packing density and device capability.”

Despite such promise, chip manufacturers had not been successful in depositing CVD tungsten films of thicknesses greater than 0.3 micron, without unwanted tungsten deposits forming in nearby areas. They also had difficulties keeping the tungsten films from interacting with the silicon substrates to depths that could interfere with circuit operation.

### CVD Tungsten Technique

In his search for a successful method for depositing thicker tungsten films, Bob separated the two chemical reactions that produce the films and that, in conventional deposition, are allowed to occur simultaneously when tungsten hexafluoride gas is pumped into a low-pressure, heated chamber containing up to 50 wafers. Tungsten in the feed-gas is chemically reduced by exposed silicon on the wafer or by hydrogen pumped into the chamber.

In the first of the two chemical reactions, tungsten atoms in the feed-gas switch places with silicon atoms on the surface of the wafer, depositing a thin layer of tungsten. As the deposition process continues, a second reaction occurs that increases the thickness of the deposited film. In this reaction, as hydrogen molecules contact the newly formed tungsten, they dissociate into hydrogen atoms that chemically reduce the tungsten hexafluoride, depositing more tungsten

on top of the initial tungsten layer.

Bob demonstrated that precleaning the wafers and carefully controlling temperature, pressure, and the feed-gas would ensure that the first reaction, which consumes silicon from the substrate, would be self-limiting when the film had reached a thickness of 0.01 to 0.02 micron — that is, when it had reached one to two percent of eventual thickness.

“Limiting the chemical consumption of silicon in this initial stage of tungsten deposition is crucial,” says Bob. “The desired electrical properties of the chip can be altered or even destroyed if the tungsten digs too deeply into it.”

For the second reaction, Bob established the importance of adding extra hydrogen to the tungsten hexafluoride feed-gas. Extra hydrogen dilutes the hydrogen fluoride reaction by-product, thus limiting or avoiding potential adverse effects on the circuit. Because the dissociation of hydrogen (necessary for tungsten deposition) occurs preferentially on metal conductor surfaces, this reaction remains area-selective — new layers of tungsten form only on the tungsten already laid down by the initial reaction and not on nearby insulating oxide surfaces.

### Tech Transfer

Bob’s successful laboratory demonstration of the selective thick-film process is only part of the story of his award — he was also cited for his efforts to transfer details of the technology to the semiconductor manufacturing community through publications, presentations at national meetings, and on-site seminars.

To stimulate the development of the new tungsten technology, Bob organized and chaired the first workshop on Tungsten and Other Refractory Metals for VLSI Applications (LAB NEWS, Dec. 7, 1984). Since then, the workshop has been held each year — with Bob chairing two of the subsequent four conferences. Each session has attracted scientists and engineers from more than 50 companies in the US and foreign countries (see “Tungsten Workshop Returns to Sandia,” this issue).

Bob also served as editor, or as associate editor, for the publication of proceedings for each of the conferences. Published in a special series of hardbound books by the Materials Research Society, they are among the publisher’s best-selling technical books — the first volume is in its second printing. Together, they contain more than 200 papers and represent more than 70 percent of the work published in the field in the last five years.

The workshops have served as a forum for advancing the state of the art. Interest in tungsten technology is now strong throughout the semiconductor manufacturing industry — most IC companies have formed research teams to study the metal. Almost 80 percent of the papers in the metallization sessions of recent major national conferences have been devoted to the new technology, compared to about ten percent before the first workshop was held.

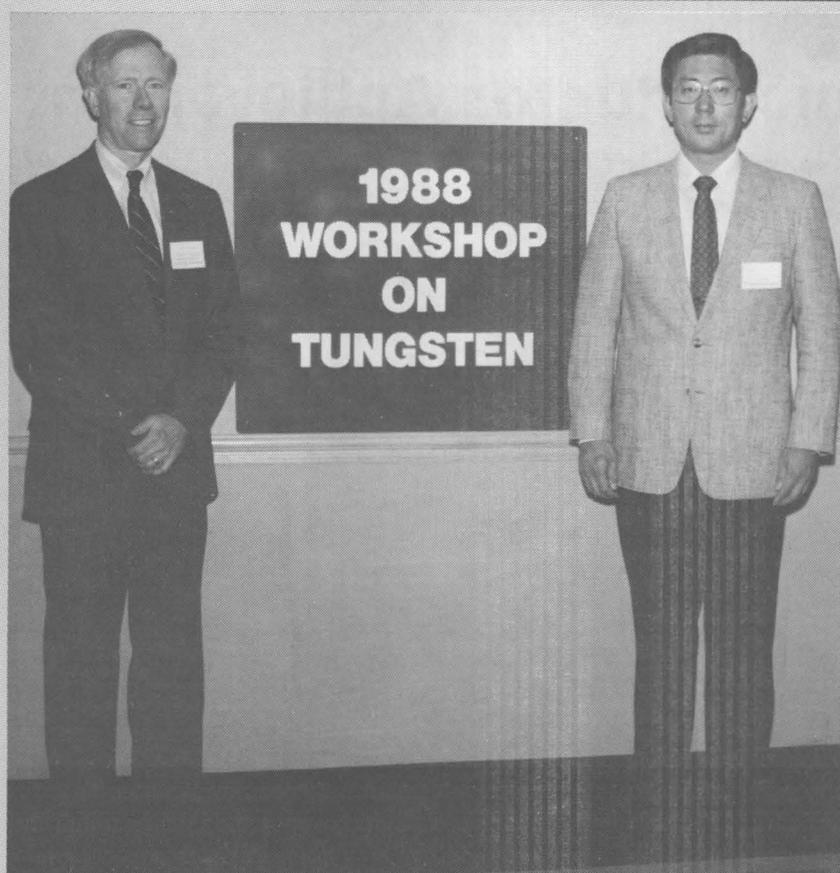
Bob has been active in materials research for more than 19 years, including a one-year temporary assignment at the Max Planck Institute for Plasma Physics in Munich. He has written more than 80 articles and serves on the executive committees of four international conferences: IEEE VLSI Multilevel Interconnection Conference; Workshop on Tungsten and Other Refractory Metals for VLSI Applications; Refractory Metals and Silicides Conference; and the Conference on Metals, Dielectrics, and Interfaces.

•DR



# LAB NEWS

FIFTH TUNGSTEN WORKSHOP — the third sponsored by Sandia — attracted a record number of US and international participants, according to Bob Blewer (DMTS, 2147, left). With Bob is Tadashi Nishimura, director of the three-dimensional integration effort at Mitsubishi Electric in Japan, who delivered the keynote address.



### Again Attracts International Audience

## Tungsten Workshop Returns to Sandia

For the third time in five years, Sandia hosted a Workshop on Tungsten and Other Refractory Metals for VLSI [Very Large Scale Integrated circuit] Applications. The Oct. 2-4 conference was organized jointly with UC Berkeley.

The Workshop has really taken off, according to Bob Blewer (DMTS, 2147), who organized and chaired the first, second, and fifth conferences. "Each year, interest and attendance continues to exceed our expectations."

This year, the conference attracted major representation from 67 US companies and universities, including SEMATECH, AT&T Bell Laboratories, three IBM laboratories, GE Research Labs, Signetics, Harris Semiconductor, Texas Instruments, Intel, Motorola, and Stanford University — as well as from various laboratories in Japan, Sweden, Germany, Holland, France, Italy, Canada, and China.

The keynote address was presented by Tadashi Nishimura, director of the three-dimensional integration effort at Mitsubishi Electric in Japan. The panel discussion — "Enhancing Manufacturability: Opportunities and Concerns" — reflected the overall focus of the workshop.

Increased interest in the conference, Bob says, has been fueled by the growing recognition throughout the semiconductor industry that a new method for depositing metal plugs is necessary to achieve the needed planarization [leveling of surfaces] above contact windows and for selectively filling holes that interconnect the different metallization levels of advanced integrated circuits (ICs) — those consisting of several interconnected layers stacked on top of each other.

Until now, polysilicon or aluminum has been used in the manufacture of ICs to form the fine conductive lines that carry electrical signals from point to point. But with the drive toward greater miniaturization — and with microcircuit dimensions shrinking to the submicron range — tungsten (a conductive, high-melting-point metal) has become one of the leading candidates for meeting the more stringent requirements for interconnects.

### Toward Manufacturability

Hopes that a manufacturable chemical vapor deposition (CVD) method for tungsten could be developed were fired several years ago, when Bob developed a method for selectively depositing one-micron-thick tungsten films (see main story).

Since then, the refinement of the CVD

tungsten process and the use of tungsten for solving persistent structural materials and electrical problems in submicron ICs has been the focus of the workshops.

At this year's conference, seven research groups presented papers on using silane compounds instead of hydrogen to dilute the tungsten fluoride feed gas.

"The flurry of interest in the use of silane was fired by a surprise announcement at last year's workshop," says Bob.

At that workshop, Y. Kusumoto (Ulvac Japan, Ltd.) described a new chemistry for CVD tungsten involving the use of silane. An important feature of the process is that the resulting by-product gas is innocuous, eliminating the undesirable effects on the silicon wafers that are possible when hydrogen is used. It also increases the rate of tungsten deposition — up to 10 times faster (about one micron per minute) even at relatively low deposition temperatures (200°C to 300°C), while maintaining good selectivity.

"This development represents an exciting step forward," says Bob. "It opens the way to much higher wafer throughput, a necessary step to meet the requirements for manufacturability."

Keynote papers in this year's workshop were presented by representatives from Mitsubishi and SEMATECH: Tadashi Nishimura reviewed Mitsubishi's work toward three-dimensional integrated circuits in which tungsten or tungsten silicide plays a crucial role in achieving workable refractory vertical wiring. James Stimmell reported on SEMTECH's decision to use CVD tungsten for contact and via fills and stressed the growing acceptance of "Tungsten-As-Metal-One," or WAMO — the use of tungsten as the first-level wiring material.

Other papers focused on the successful application of tungsten for gate and source metallization in high-frequency power MOSFETs (transistors) and in local interconnect applications.

Proceedings of this year's workshop will be published in February in the fourth of a special series of hardbound books by the Materials Research Society, according to Gordon Pike (1815), who is a past president of MRS and, currently, a councilor for the Society. Ordering information is available from Gail Oare, Director of Publications at Society Headquarters, (412/367-3012) or from Bob Blewer on 4-6125. It's also available by FAX (412/367-4373).

## Take Note

Sylvia Tsao (2147), Harry Weaver (1141), and Dan Fleetwood (2147) have won the Outstanding Paper Award at the 1988 Hardened Electronics and Radiation Technology Conference for their paper, "Sidewall-Hardening Process for Silicon-on-Insulator MOSFETs."

\* \* \*

Readers voted Sylvia Tsao's (2147) paper, "Porous Silicon Techniques for SOI Structures," the outstanding article in the November issue of *IEEE Circuits and Device* magazine.

\* \* \*

Dan Fleetwood, Peter Winokur (both 2147), and Jim Schwank (2144) have won the Outstanding Paper Award at the 1988 IEEE Nuclear and Space Radiation Effects Conference for their paper, "Using Laboratory X-Ray and Co-60 Irradiations to Predict CMOS Device Response in Strategic and Space Environments." This is the third time in the last five years that this award has been claimed by members of Dept. 2140.

\* \* \*

Charles Karnes (400) is on loan to the N.M. Economic Development and Tourism Dept. while he directs the compilation of a computerized inventory of New Mexico's more than 300 high-tech businesses. The list of businesses and consultants — including business names, addresses, telephone numbers, business descriptions, and profiles of employees (and their scientific, engineering, and business backgrounds) — should be available through N.M. Tchnet by spring 1989. The new data base will include information on company facilities, manufacturing and test equipment, lab and clean-room space, computers, and any unique or special-purpose equipment and capabilities.

\* \* \*

Members of Mail Services Section 3154-4 shared their Christmas spirit with 40 elderly clients of Share Your Care Adult Day Care Program on Dec. 7, when they served a chicken dinner and all the fixings.

\* \* \*

"Entrepreneurial Engineering" (ME 456) is again being offered by UNM in the spring semester. Staff members with technical or business backgrounds who have in mind possible business enterprises are especially invited to enroll. Sandians with engineering and science backgrounds have taken the course; some have developed business plans, with class assistance, for companies they have contemplated starting. The class works in teams, starting new businesses each semester. The Labs Technology Transfer and Patent organizations both cooperate with the class. Class meets on Thursdays, beginning Jan. 19, from 6:30 to 9:30 p.m. in Room 218, Mechanical Engineering Building. Enrollment must be completed in the Student Services Building Registration Center (telephone 277-5548) by Jan. 20. For more information, call Prof. Bill Gross on 277-6297.

### Sandia Colloquium

S. H. Mosely (Goddard Space Flight Center) will speak on cryogenic particle detectors at the next Sandia Colloquium on Jan. 13 in the Technology Transfer Center (Bldg. 825) at 9 a.m. Ray Leeper (1234) is the host. Call him on 6-6054 for more information.

A new Kirtland 4-H Club is being formed for children of Air Force, DOE, and Sandia employees. The first meeting will be Jan. 11 at 6 p.m. in the Que Pasa Recreation Center (southwest of the Coronado Club). Sponsored by the Air Force Family Support Center, the club is open to children ages 9 to 19. The club is being organized by the Center's Richard Rocco, who says the first meeting will be an exploratory one at which interested parents and children can get more information about 4-H. Richard is also looking for volunteer 4-H leaders and instructors to teach a variety of subjects. Call him on 6-0741 (or 51) for more information.

# Lots of Coal; Lots of Challenges

“... And, in the Christmas stockings of bad little boys and girls, a lump of coal.”

Such is the reputation of coal, the Rodney Dangerfield of energy sources. And for good reason: As then-Sandia-President George Dacey noted in 1985, “Coal is not an easy substance to use — it’s a solid instead of a liquid, so you can’t pour it into an automobile gas tank. It burns dirty — has sulfur in it — so it creates acid rain [and contributes to the ‘greenhouse effect’]. And it’s hard to get out of the ground.”

Virg Dugan, Director of Advanced Energy Technology 6200, explains why coal presents problems: “It’s a heterogeneous, hydrogen-deficient solid with considerable mineral contamination. On a molecular basis, it’s sort of like dealing with ‘black snowflakes’ — no two are identical.”

But coal has one overriding advantage — it’s abundant. The US has nearly 8 trillion tons of coal that’s minable by current technology. At the current rates of production, that’s enough coal to last four

or five centuries.

So, with the aim of making coal burn more cleanly and more completely, Sandia has worked for 15 years to understand coal combustion better (LAB NEWS, Oct. 21, 1988) and to develop innovative ways to overcome its manifest disadvantages.

Dept. 6210’s ongoing coal liquefaction program, for example, seeks efficient and inexpensive ways to convert a lump of coal into a pint of liquid fuel.

(Continued on Page Nineteen)

## Energy at Sandia

# LAB NEWS

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DECEMBER 23, 1988

### Future Looks Bright, Too

## Petroleum R&D Projects Show Results

Petroleum . . . oil . . . black gold . . . by any name, it’s a main ingredient in the lifeblood of this country’s economy and one of the most versatile commodities known. It’s the source of nearly all transportation fuel and precursor of many medicines, fertilizers, clothing, and plastic goods.

At the beginning of the 80s, some government and industry analysts projected that oil selling at the time for nearly \$40/barrel (which sold for \$2/barrel about 10 to 12 years earlier) would soon bring \$80/barrel or more. That didn’t happen, and some business decisions based on that projection have hurt much of the industry and those who depend on it.

While the confusing oil supply/price situation has prevailed for about the past 15 years, government and industry — separately and together in some cases — have searched for affordable alternative energy sources. They have also sought ways to increase domestic oil production and thereby lessen US dependence on foreign supplies.

According to various studies, today imports account for more than 40 percent — or almost 7 million barrels/day — of US demand.

Similar numbers in the 70s, together with rapidly escalating foreign oil prices, then stimulated various actions to reduce consumption, increase production, and find alternative sources.

The problem today is not entirely an inability to produce enough oil. Domestic oil production is price-dependent, and domestic production would no doubt be greater if prices were higher. Many domestic oil companies claim they simply can’t afford to produce oil or to conduct costly exploration efforts when the product sells for less than \$20 a barrel. It costs more than that, they say, to find and produce a barrel of oil today.

### Sandia Can Help

Regardless of the current situation, however, the US will eventually need to produce all the oil it can, as efficiently as it can. And that’s where Sandia comes in.

Sandia’s oil research effort, geared toward developing better ways to find and recover crude oil, grew rapidly in the mid- and late 70s, peaked in about 81, began a sharp decline in 82 that continued to 85, and has remained relatively steady since.

Some of Sandia’s petroleum research projects have produced useful and regularly used new technology. Some haven’t. That’s the nature of R&D.

Some projects resulted in new technology and hardware that would be viable if oil prices hadn’t fallen so much. That’s good technology, but bad timing.

A prime example is Project Deep Steam, one of Sandia’s biggest enhanced oil recovery (EOR) efforts to date. In the early 80s, Labs researchers and engineers developed a successful field model of a downhole steam generator (DSG) to help recover heavy, molasses-like oil. Several companies quickly developed commercial versions of it. However, even though the DSG is a technical success, low oil prices (and the advent of cogeneration allowing profitable electricity generation from surface steam plants) have so far prevented commercial models from attaining real financial success (see “Making Steam Way Downhole”).

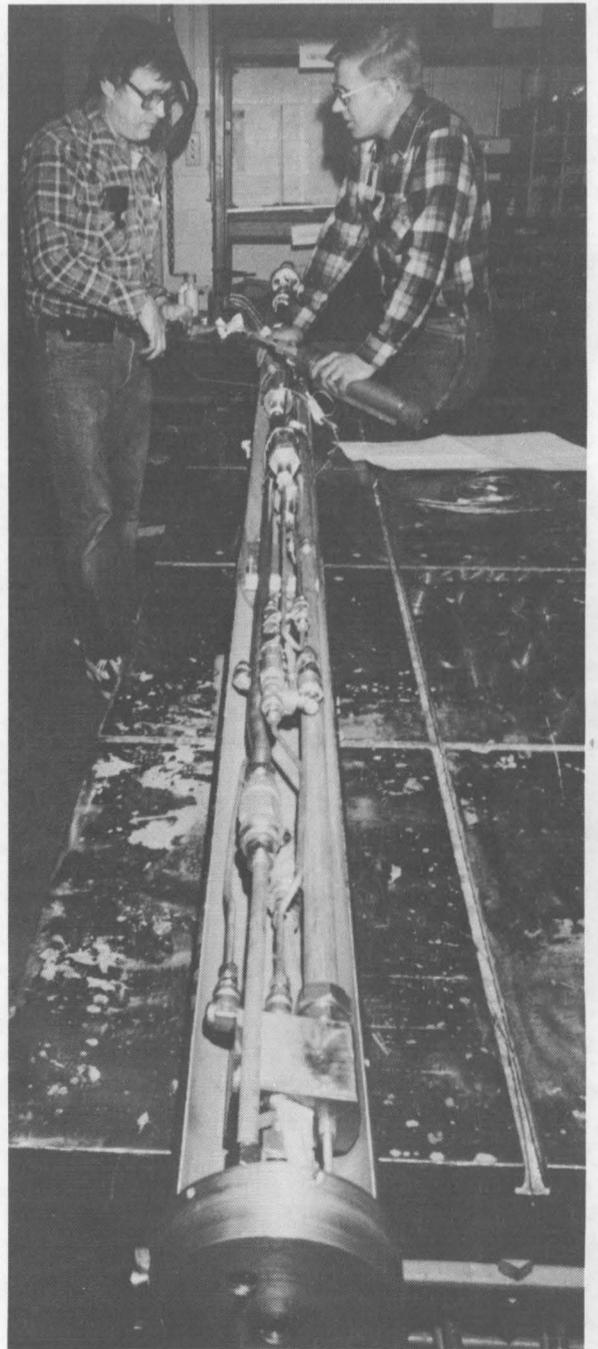
Other Sandia technology developed for Project Deep Steam has made a widely recognized impact. For example, Sandia’s high-temperature materials expertise (centered in 1800) paved the way for improved high-temperature packers that are now widely used in conventional steamflooding projects.

Packers are 3- to 4-ft.-long cylindrical devices placed at the bottom of a wellbore to ensure that EOR-operation steam goes into a formation containing heavy oil instead of escaping back up the well.

“Performance of high-temperature packers had to be improved,” says Bill Marshall (6210). “Ten to 15 years ago, packers couldn’t withstand high pressures and 300°F to 500°F steam for long periods,

meaning that injection wells had to be serviced often. Improved packers make it possible to extend productive periods between servicing, lower servicing costs, and improve overall process efficiency.”

(Continued on Page Two)



DOWNHOLE STEAM GENERATOR SYSTEM instrumentation package — including hoses, one-way valves, filters, temperature sensors, and electronics — is assembled by John James (left) and Dave Paul (now both 2363) before a field test near Long Beach, Calif., in the spring of 1981. Package had to operate continuously in a 500°F environment.

### Energy: Making a Difference

## About This Issue — And Its Predecessors

Today’s issue of LAB NEWS contains the last of the 77 stories describing the work of Sandians on the nation’s energy problems in the past decade and a half. Several of the accomplishments described here and in the Oct. 21 and Nov. 18 issues have already had a substantial impact on the nation’s energy posture — enhanced its supply, improved its conversion, and/or utilized it more efficiently. Other accomplishments will pay off — contribute to solutions of energy problems — in the years ahead.

Advanced Energy Technology 6200 will reprint the stories from all three energy issues as an 8-1/2 x 11-in. booklet. It should be available early in 1989 to those interested in these contributions to the nation’s welfare and security. Precise availability date will be announced in a future LAB NEWS.

*(Continued from Page One)*

## Petroleum R & D

Another tool developed by Sandia — the downhole seismic source — seems to have a promising future. A New Mexico company — Hills Research of Las Cruces — wants to commercialize it.

Sandia developers believe the source, designed as a basic geophysical tool for the Continental Scientific Drilling Program (see "His Thoughts Turn to Alaska"), will be a valuable addition to seismic tools and techniques used to evaluate known oil and gas reservoirs and to explore for new oil, gas, and geothermal sources. Seismic mapping for civil engineering projects is another possibility.

The tool is lowered into drill holes, where it transmits soundwaves into surrounding rock. Underground features — fluid-filled or dry rocks, fractures or structures — alter those waves in known ways so that when they reach receiving antennas in other drill holes, a picture of the ground between the holes results. Field tests in Oklahoma verified that the source's signals can be detected and recorded after traveling at least 1700 feet through the ground. The tool is designed to operate from dry or fluid-filled drill holes, down to two miles below the surface, and at temperatures up to 480°F.

Harry Hardee (6231) says the downhole seismic source avoids several problems associated with surface generators, which have been used for many years. "The new tool delivers seismic energy more effectively because energy is not lost to surface waves and attenuation in surface-weathered layers," he says. "The source generates only the low-frequency waves that are useful for seismic recordings, and less total energy is required because the downhole source is closer to the subsurface region being explored."

Sandia has worked on downhole seismic devices since 1980, when a small tool was designed and built for a magma energy research project in Hawaii (see "Trying to Unravel the Mysteries of Magma"). This work involved technical alliances with industry and cooperative field tests with major companies, including Chevron, Standard Oil, and Amoco.

Besides Harry, others who contributed to the seismic tool development include Gregory Elbring, Gerald Reynolds (both 6231), Terry Steinfort (7116), and Dick Striker (ret.).

### From Field to Lab for Now

Although some Sandia field research will continue (see "Bridging the Gap Between Lab and Field"), Dick Traeger (6250) says oil-related research for the immediate future is primarily in the laboratory, where efforts concentrate on developing a better basic understanding of oil reservoirs and on developing improved tools and techniques for evaluating and producing the reservoirs.

He explains: "Our focus now is on 'bypassed oil.' On the average in the US, we can recover only a third of the oil in place with current technologies and understanding. What remains represents a huge resource. We'll never be able to get it all, but the better we understand reservoirs — microscopic and macroscopic differences, faults, fractures, non-combustible media within reservoirs — the better we will know how to recover as much as possible."

Another part of this new focus can be seen in Paul Hommert's Advanced Technology Div. 6258, where the staff is developing new instrumentation for mapping oil and gas movement and for locating reservoir characteristics that impede recovery processes. The new geoelectric simulation facility (GSF), located in the basement of Bldg. 823, is a sophisticated new tool. It simulates electrical measurements under various reservoir conditions (see "New Facility Filled with Promise"), which permits researchers to extend and expand on earlier work concerning techniques for mapping fossil energy formations.

One of the first such techniques examined by Sandia — long before the GSF went into operation — was the CSAMT (controlled-source audio frequency magnetotelluric) technique, which has been typically used to locate ore deposits. Bob Wayland



**GEOPHYSICAL RESEARCH SPECIALISTS** (from left) Sandy Ballard, Gerald Reynolds, and Greg Elbring (all 6231) prepare to lower the downhole seismic source into a drill hole during field tests at Amoco Production Company's test site near Tulsa, Okla., earlier this year.

(9112), Dave Lee (9243), Tom Cabe (2312), Lew Bartel, and Ron Jacobson (both 6242) have evaluated CSAMT's effectiveness in locating and mapping the progress of a steam front in a Utah tar sand (host for crude oil that has a tar-like consistency) steamflood operation.

### Dipole on the Surface

CSAMT uses a long wire dipole laid out on the surface, a transmitter that excites the dipole to produce an induced electromagnetic (EM) field, and surface receivers and recorders that measure electric and magnetic fields at observation points above the zone

of interest. Key to the technique is the assumption that steamflooding causes significant electrical property changes in the reservoir — something that Chip Mansure (6253) is now studying — and that it is possible to map the front by detecting these changes.

Researchers report that CSAMT applications are promising when used with other oil field information; however, it remains an inexact science. In an article about their field work, Bob, Dave, and Tom concluded that "measurements made from the surface by a nonintrusive technique can indicate changes

*(Continued on Page Three)*

## How Oil, Gas, and Coal Came to Be

Oil, gas, and coal all formed from organic material — ranging from algae to allosaurus — that escaped complete decomposition after burial.

Next to water, oil is probably the most abundant fluid in the earth's crust, yet the processes that formed it and its relatives have been subject to misunderstanding throughout time.

For example, Sinclair Oil Company's still-used symbol of a green brontosaurus was supposed to connect the gas station with the age of reptiles. Scientists used to theorize that reptiles left behind the raw materials that eventually became the oil of today.

Scientists now think very few dinosaurs laid down their lives for the modern motorist. That doesn't mean, however, that it's easy to explain how petroleum, gas, and coal came to be.

### Oil and Gas

Most earth scientists now believe that oil and gas (methane) derive from organic materials that were buried with marine or lake sediments. Favorable environments where organic debris might have escaped oxidation — and thus complete decomposition — include near-shore areas characterized by rapid deposition of silts and sands that quickly buried organic material, or deeper-water areas characterized by a deficiency in oxygen at the bottom, which promoted an anaerobic decomposition.

The major source material for oil and gas is a fine-grained, organic-rich sediment buried to a depth of at least 500 metres (1650 feet) and subjected to increased heat and pressure that compressed the source rock. During the millions of years of burial, chemical reactions slowly transformed a fraction of this material into liquid and gaseous hydrocarbons — compounds whose molecules are chains of carbon atoms with hydrogen atoms attached.

In most cases, this activity produced methane. Oil occurred only when the organic ingredients were heated and pressurized according to nature's strict oil-making recipe. The recipe required, among other things, that the matter be heated cup-of-coffee hot and remain at that temperature for at least one million years.

Once formed, oil and gas tended to be squeezed out of compacting muddy source-rock sediments and into adjacent permeable rocks, such as sandstones or porous limestones. The low density of oil and gas caused them to migrate to the highest place they could reach, where they floated on top of water in the pores of the formations.

These porous, permeable rocks (they look solid to the naked eye) into which oil and gas migrated are *reservoir rocks*. If there were clear paths to the surface, the oil and gas would migrate along those paths. Oil and gas accumulated if, in their upward migration, they were interrupted or stopped due to a relatively impermeable barrier.

### Coal

Coal — consisting of organic materials that have escaped oxidation in the carbon cycle — is essentially the altered residue of plants that flourished in ancient freshwater or brackish-water swamps, typically located in estuaries, coastal lagoons, and low-lying coastal plains or deltas.

Coal-forming processes first required development of a swamp rich in plants that were partially decomposed in an oxygen-deficient environment and that accumulated slowly to form a thick layer of peat — a porous brown mass of organic matter in which twigs, roots, and other plant parts could still be recognized. These swamps and accumulations of peat were then possibly inundated by a prolonged slow rise of sea level and covered by sediments such as sand, silt, clay, and carbonate-rich material.

As more and more sediment was deposited, water and organic gases (volatiles) were squeezed out, and the percentage of carbon increased in the compressed peat. After more burial and chemical transformations of aging organic matter, the peat became lignite, a soft coal-like material. Greater burial depth, longer time, and higher temperatures ultimately caused a metamorphosis of lignite into bituminous (soft) coal, and — in extreme cases — into anthracite, or hard coal.

(For details about oil shale, see "It's Neither Shale Nor Oil.") ●RG

*(Continued from Page Two)*

## Petroleum R & D

that are occurring in the steamed pay zone. Use of this method with other oil field information . . . helped to give a more complete picture of what progressed . . ."

Lew Bartel and Ron Jacobson have used CSAMT during field studies of underground brine reservoirs and high-permeability channels within near-surface aquifers at southeast New Mexico's WIPP site.

### New Sandia/Los Alamos Partnership

The newest component of the Labs' oil program is a recently funded partnership between Sandia and Los Alamos National Laboratory. Funded by DOE, it's designed to further technology transfer from national laboratories to the domestic petroleum industry.

Dave Northrop (6253) is Sandia's lead representative in the partnership, which, he says, is moti-

vated by a similar Los Alamos initiative to enhance transfer of national-labs-developed high-temperature superconductor advances and technologies to industry.

During its first year, this Oil Recovery Technology Partnership will form an industry steering committee and technical review panel, conduct at least one technical forum with industry to define areas and projects for collaboration, and conduct initial projects with industry.

"A priority at all times," Dave adds, "will be to respond to inquiries and requests from industry on specific technologies under development in the national laboratories."

### Gas to Liquid

In addition to Sandia's work aimed directly at crude oil, its program concerned with converting natural gas (methane) to liquid fuels with the help of "designer catalysts" continues to receive widespread recognition and to make steady progress (LAB NEWS, August 28, 1987), reports Barry Granoff (6211).

"We've developed a laboratory procedure to measure how much methane is converted to alcohols, such as methanol," Barry says. "Using this, we can test different catalysts designed by our molecular modeling techniques."

"We have also synthesized new catalytic materials that have deep cavities or pockets. These should enhance reactivity because they will let methane bind more effectively than did previously used catalysts," Barry says.

Barry also points with pride at work in which John Shelnett (6211) uses molecular modeling to design catalysts that are held rigidly — essentially anchored — within a clay support. These materials could be of considerable interest to private industry.

Much of this designer catalyst work also has direct application to the Labs' coal R&D, Barry points out. For example, many of the techniques developed in the methane-to-liquid fuel effort will soon be applied to studies about the molecular structure and reactivity of coal (see "Coal Liquefaction: Looking for the Best Way"). ●LP

### Identifying Steam Refluxing

## Good Science and a Little Luck

Most folks feel fortunate to discover the solution to a problem.

Not Dan Aeschliman, now supervisor of Experimental Aerodynamics Div. 1554. He feels lucky to have discovered a problem. "Sheer serendipity," he says about finding the steam refluxing problem while working in the Geotechnical Engineering Division during the early 80s.

"It was there for 30 years, and no one saw it," Dan says. "Millions of dollars were wasted, but no one knew it."

What Dan refers to is a heat-transfer process that prevents a large amount of energy in steam, flowing down a wellbore and into a heavy oil reservoir in the surrounding strata, from reaching its destination. Generated at the surface, the steam is supposed to flow through insulated pipes and out into strata, heating molasses-like oil so that it flows into other wellbores and is pumped to the surface.

This is a well-established — for 30 years, or so — method of enhanced oil recovery (EOR), primarily used in the Long Beach/Bakersfield, Calif., areas. The technique is known as "steamflooding" or "steam drive."

What Dan and colleague Bob Meldau of Husky Oil learned was that much of the steam never reaches its target. Moisture, always present in a wellbore, contacts the outer surface of uninsulated, very hot couplings (pipe is composed of 40-ft. sections screwed

together through a coupling), and flashes to steam. Vapor clouds rise up the wellbore and condense on the cooler well casing, giving up the stolen heat to rock surrounding the casing.

### 'Raining' Downhole

Condensed water then trickles down the casing or "rains" downward until it again contacts a hot coupling, and again flashes to steam. This is steam refluxing, a self-sustaining, closed-loop process that occurs downhole with little or no sign of the phenomenon at the surface. Depending on the specific case, the percentage of the injected heat energy lost can range from just a few percent to nearly one hundred percent.

The solution to the problem is simple — a doughnut-shaped piece of Teflon insulation placed around the inside of the coupling joining two pieces of insulated pipe. It costs about \$10. But the savings are considerable. "My calculations show that US oil firms could save \$100 million annually — \$1 billion over the next decade — by using insulated couplings," says Dan.

In keeping with the laws of serendipity, Dan and his colleagues — which at Sandia have included Roy Johnston (7173), Jim Moreno (2541), Tom Cabe (2312), Don Hoke (2513), Bill Vigil (dec.), Dale Moritz (ret.), and Ramon Villegas (1273) — didn't set out to discover steam refluxing. They were look-

ing for some answers about efficiency of insulated versus uninsulated tubing (steam-carrying pipe inserted in the larger, seven-inch-diameter pipe that lines — cases — the borehole).

The evaluation began in 1980 as a part of Project Deep Steam. Working with Husky Oil Company, former Sandian Ron Fox and two other former Sandians, Don Johnson and Steve Eisenhower, began instrumenting a 1700-ft. well in western Saskatchewan. Dan assumed responsibility for the project, which involved placing both insulated and uninsulated tubing in the same hole, in March 1981.

"We found, to our surprise, that insulated tubing wasn't much better than uninsulated tubing," says Dan. "We were losing much more heat than our calculations showed we should. The well casing would get to the boiling point of water and stay there regardless of the quality of tubing used."

The experiment was repeated in May 1982 with the same results. Shortly thereafter, Dan and Bob Meldau, Husky's consulting field engineer, began

*(Continued on Page Four)*

## Looking at Insulated Tubing

The serendipitous discovery of the steam refluxing problem tends to divert attention from the original Sandia mission of evaluating insulated tubing, which began in August 1980 and ended in March 1985.

How did that work go?

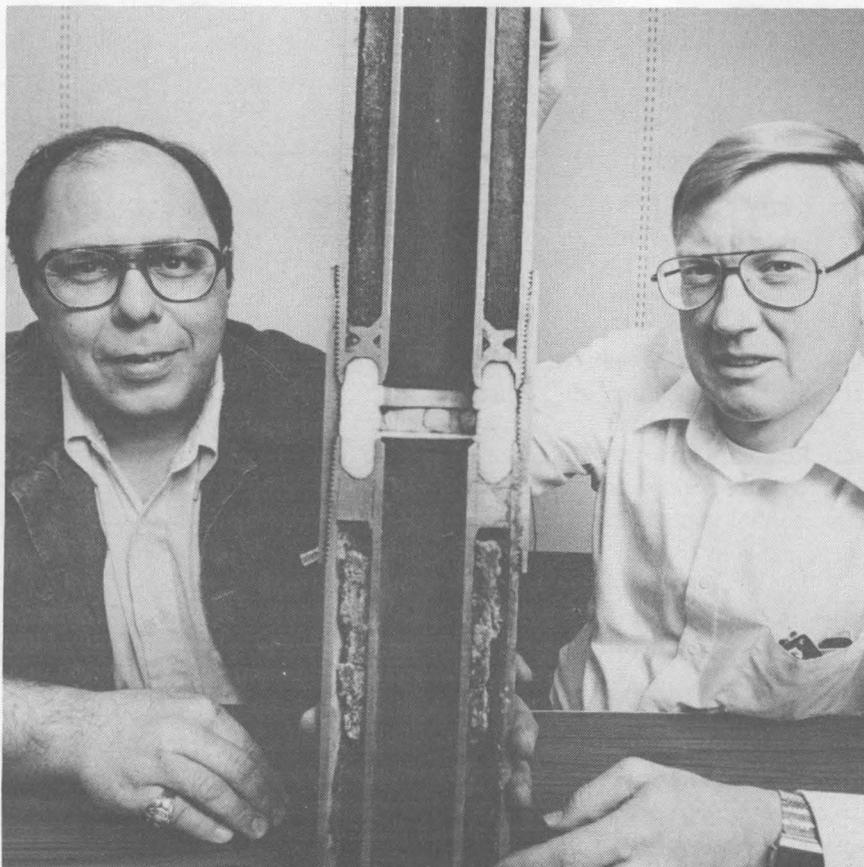
"We met all objectives," says Dan Aeschliman (1554). "We provided an impartial evaluation of insulated tubing, proving that some manufacturing processes were essentially worthless. And we provided empirical data for numerical modelers constructing computer codes to evaluate insulated tubing."

"And, finally, we proved up a method of downhole heat transfer instrumentation and the concept of running long lengths of signal wire downhole. We showed that data could be retrieved for long periods of time in a difficult oil field environment."

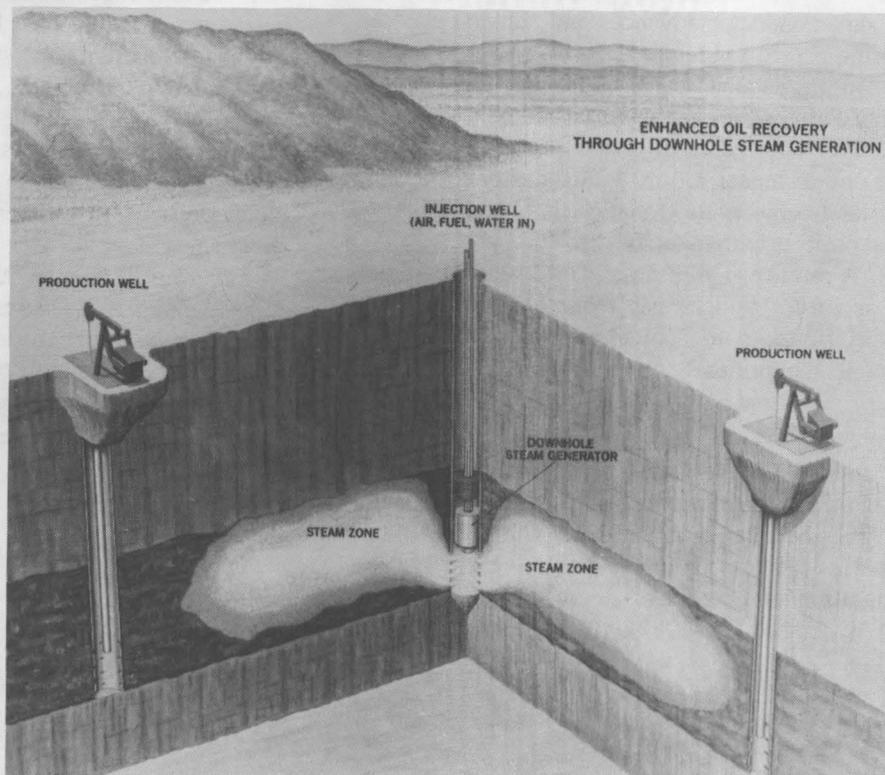
"Another idea we suggested for ending steam refluxing, a casing evacuation system using a steam ejector, is now being marketed by one company."

"The tubing evaluation project was successful in itself," Dan concludes, "and, in the course of it, we detected, explained, and suggested workable remedies for a heat loss process that had gone unnoticed for three decades."

CUTAWAY "DOUGHNUT" (white Teflon in center of tubing section) prevents wellbore refluxing by eliminating loss of steam used to soften reserves of heavy oil. Phenomenon was discovered by Dan Aeschliman (1554, right) and Husky Oil's Bob Meldau, with help from Roy Johnston (7173, left) and others.



# Making Steam Way Downhole



ENHANCED OIL RECOVERY through downhole steam generation the Sandia way.

Supported by DOE's Enhanced Oil Recovery (EOR) Program, Project Deep Steam began in 1977 with the goal of making steamflooding more efficient so that the technology could be used in heavy oil reservoirs below 2500 feet. Dick Traeger (6250) and former Sandian Ron Fox planned the earliest technical experiments.

Common steamflooding uses surface boilers to produce steam that is directed down an injection well and into a formation where oil doesn't flow easily. There, steam heats and thins molasses-like heavy oil, helping to drive it to nearby production wells. Steamflooding is used extensively in southern California near Los Angeles (including offshore) and around Bakersfield in the giant Kern River field, estimated to contain several billion barrels of heavy crude.

Basic steamflooding is not very efficient, particularly if wells are deep and injection tubing is uninsulated (see "Good Science and a Little Luck"). Steam cools considerably as it travels down the wellbore to the target formation. About 80 percent of the cost of a traditional steamflooding project is for steam generation.

## Successful Field Testing

Therefore, an early Project Deep Steam goal was a steam generator to fit inside a 7-in. wellbore so it could be lowered to the bottom. There, it would generate steam and, before it cooled, inject it directly into the formation. Generator combustion products — namely nitrogen and carbon dioxide — would also further improve oil recovery.

A Sandia demonstration model downhole steam generator (DSG) was successfully field-tested in late 81 and early 82. Developed by a division first headed by Ron Fox (before he left Sandia) and then Bill Marshall (now 6210), the field model operated at the bottom of a 2500-ft. California well. The 23-ft.-long, 6-in.-diam. generator produced about 800 cubic feet of 260°C (500°F) steam a minute. The test ended with a 106-day run in which the DSG operated about 80 percent of the time. Downtime stemmed primarily from surface equipment failure, not the DSG.

It used a 44-in.-long combustion/vaporizer section and an 18-ft.-long instrumentation package that measured pressures and temperatures and controlled entry of surface-stored air, diesel fuel, and water into the combustion chamber. The fuel mixture was ignited and then maintained with a diesel engine glow plug.

## Oil Prices Unkind to DSG

Virgil Dugan (6200) says, "After we demonstrated our generator, the well operator secured an industrial firm to place a DSG in the well on a commercial basis. Our main goals were met — demonstrating DSG feasibility and transferring technology to industry."

Several Sandians who worked on DSG development, including Ron Fox, left the Labs to commercialize the technology when oil prices were high in the early 80s. In fact, the company Ron helped found (Enhanced Energy Systems, Albuquerque) has supplied DSGs to a variety of oil companies, including Chevron and Mobil. But the oil price slide has not been kind to commercial DSGs. Many oil companies are reluctant to invest in DSGs or other major devices that increase their up-front costs. "This reluctance, however, has not been as strong with foreign energy companies," Ron says.

Bill Marshall says none of this should lessen the significance of Sandia's technical accomplishments required to make the DSG.

"The conditions under which a downhole steam generator has to operate — including free oxygen, lots of moisture, and high temperatures — offer just about the greatest possibility for maximum corrosion," he says. "To make a device operate in that environment for months at a time was no small accomplishment; it's illustrative of Sandia's system engineering approach to problem solving. In fact, I believe, the synergism that occurred in this interdisciplinary work environment is why we were able to be successful with the DSG, when others were failing."

"Applied research led to a thorough understanding of high-pressure combustion and the complex chemistry that occurs between fuel, oxidant, and water," recalls Bill. "Success also depended upon materials compatibility and development of an automatic control system that eliminated the need for on-site operation. This required expertise in computer hardware and software."

## Bridging the Gap Between Lab and Field

Large petroleum field research projects may be off the front burner just now at Sandia, but DOE is planning one for southeast New Mexico — the New Mexico Improved Oil Recovery Project — in which the Labs will participate.

The project will be conducted by the Petroleum Recovery Research Center at New Mexico Tech, with the cooperation of Sandia and Los Alamos national labs, researchers at several universities, and commercial energy industry.

It will begin with the drilling of a collection of holes — probably between several hundred and 2000 feet deep — into a previously waterflooded sandstone reservoir in southeast New Mexico, east of Artesia. The battery of field tests to follow will include: (1) reservoir characterization involving measurement and interpretation of reservoir properties; (2) reservoir simulation involving improvement of predictive numerical models;

(Continued from Page Three)

## Good Science

to speculate about the possibility of a downhole heat transfer process such as refluxing. Bob broached the subject at a conference in December of 1982, but Dan, with some number-crunching yet to do, wasn't ready until March 1983 to confirm the discovery.

"Even then there was some industry skepticism and criticism," says Dan. "So we decided to study the refluxing process in detail using an experimental well in Area III where we could control temperatures, pressures, and moisture levels closely."

Those tests in a 122-ft.-deep well proved conclusively that refluxing does exist, that it does result in significant loss of thermal energy, and that insulation of couplings can largely eliminate the loss.

"I don't think anyone would have found the effect without doing experiments the way we do — actual data-gathering in the field by experimenters who have a totally independent point of view," says Dan. "It shows the value of someone coming into a technical area who is unprejudiced about the outcome."

How has the industry reacted to the new information?

Slowly. Very slowly.

"Most wells are still not being treated in the most efficient manner," says Dan. "In many cases, it would take more to retrofit older wells than it's worth, especially at today's oil prices. And wells of a 1000-ft. depth or less don't even use insulated tubing — it generally costs more than it's worth."

## Sticking to Estimate

"But wells deeper than 1000 feet should have insulated tubing and couplings — it would pay," adds Dan. "And the more progressive oil companies are now using it."

Even given this slow rate of acceptance, Dan is sticking with his original projection that eliminating steam refluxing can save \$100 million a year. "As steamflooding is applied in deeper wells, elimination of refluxing makes a tremendous difference in the feasibility of what can be done," he says. "When the price of oil again begins to rise and enhanced oil recovery goes deeper, my estimate of \$100 million annual savings may even prove conservative."

Another future benefit of more efficient steamflooding is its application in fields of light oil, in addition to heavy oil reservoirs where it is now exclusively applied. "Some 70 percent of the original oil in light-oil reservoirs is still there after conventional recovery stops; when prices rise, some of it may be economically recovered by steamflooding," says Dan. "In general, those reservoirs are much deeper than heavy oil pools now being tapped with steamflooding. Therefore, the problem of heat loss because of wellbore refluxing would be much more critical for them. Stopping the refluxing process may ultimately help make feasible the steamflooding of those deep reservoirs." ●JM

## Looking for Security Through the SPR

Sandia has played a significant — and evolving — role in ensuring that more than \$10 billion worth of oil (figured at \$15/barrel) is stored safely in the nation's Strategic Petroleum Reserve (SPR) and that the oil will be available for use, if needed.

Early work — beginning in 1978 — concentrated on geological site characterization of deeply buried salt domes in southern Texas and Louisiana that the DOE had chosen to host large, man-made, oil-storage caverns. Emphasis then switched to design and testing of caverns, and studies concentrated on better understanding caprock and non-salt sediments located above and around the domes.

Work aimed at learning more about salt creep, cavern integrity and oil losses, and stored-oil chemistry and purity is an important part of the SPR assignment today.

Authorized by Congress in 1975 to ensure a ready emergency oil supply, the SPR is expected to be full before the mid-90s. It then would be ready to buffer an oil supply disruption lasting up to six months, based on today's total daily use of imported oil. Nearly 600 million barrels of crude oil — 80 percent of planned initial capacity — are stored in the reserve now.

A search began earlier this year for new Gulf Coast salt-dome sites that could accommodate another 250 million barrels, the amount needed to maintain a viable buffer if the country's crude-oil imports grow.

### Reasons for Salt Domes

The DOE decided to locate the SPR in Gulf Coast salt domes for a variety of reasons: They are geologically stable; oil does not dissolve or penetrate the salt; underground storage costs are only a fraction of surface-storage costs; and underground storage is more secure than surface storage.

Some SPR oil is stored in a converted salt mine, but most is in huge salt caverns that have been leached out with water. About 70 million barrels of water must be pumped through a dome to dissolve salt and form a cavern. Brine is then pumped from the cavern and piped far out into the Gulf of Mexico. Oil is pumped in while leaching continues.

The top of these SPR caverns typically is located 300 feet deep into the salt formation and is usually at least 2000 feet below the surface. The bottom of the cavern is another 2000 feet farther down. Caverns — each about 230 feet in diameter — are capable of holding about 10 million barrels of oil.

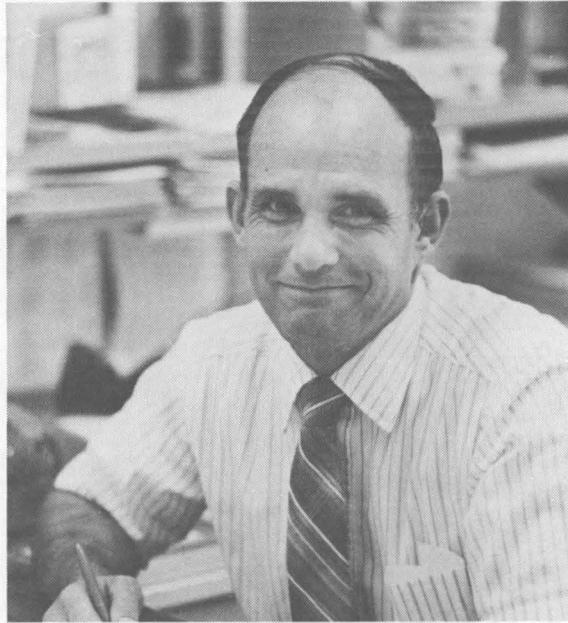
Sandia became involved with the SPR when DOE asked if the Labs would consider conducting, on a very tight deadline, a review of the reserve's technical aspects. Within a few days, some of Large and Small Staff traveled to Washington, D.C., and New Orleans to meet with DOE officials. A deal was struck.

Then, back in Albuquerque, a new SPR Geotechnical Div. was formed and staffed within a few more days. "As I recall, the new division was born the Monday before Thanksgiving [of 1978]," says Jim Ney (now 7230), who had been tapped to supervise the new division. "We had to complete our preliminary SPR technical review before the end of January. That took work and sacrifice — like essentially devoting our evenings, weekends, and much of the Christmas break to the task."

### Sandia's Early SPR Days

Charter members of the SPR division included Jim Linn (who became supervisor of SPR Geotechnical Div. 6257 in 1982), Tom Bickel (6258), Mickey Lyle (now with Mobil), John Mitchiner (1412), R. J. Hart (ret.), and Ken Goin (6257). "But this effort called for support from across the lab — Joe Tillerson [6314], Wolfgang Wawersik [6232], Tony Russo [1511], Marv Becktell [ret.], and Matt Gubels [9141], to name a few — as well as geological consultants," Jim Ney recalls.

Following the technical review, DOE named Sandia to direct continuing geotechnical studies. So Jim Ney converted his division to that task. Sandia continues to provide geotechnical direction today,



JIM LINN (6257)

while working closely with Boeing, which operates, maintains, and manages the site.

"As part of our early work," recalls Jim Linn, "we mapped dome sides, or flanks, tested existing caverns, and developed plans for new caverns."

Another major task has involved developing computer codes to predict how caverns could best be leached to make a stable, reliable storage medium. If a cavern is not leached properly, Labs researchers learned, excessive stresses would cause large slabs of salt on the wall or ceiling to fall. "We also developed techniques to leach caverns while intermittently filling them," Jim says.

The Labs also completed a lot of work on salt creep — understanding its basics and developing ways for predicting its magnitude. "Over time," Jim explains, "an oil-filled salt cavern tends to creep inward because pressures within the earth are higher than those inside a liquid-filled cavern." Creep reduces a cavern's volume.

To accommodate creep, caverns are not filled entirely with oil. Some brine remains at the bottom (the oil floats atop it) and is removed in small amounts as salt creeps slowly inward. This compensates for the reduced volume. Unless a cavern experiences an unusually large amount of creep, it isn't necessary to remove oil.

SPR work has drawn regularly on expertise in other Sandia organizations. Many of the same problems — salt creep is one — have been encountered by other Sandians working on the Waste Isolation Pilot Plant. Both projects have drawn heavily on expertise of rock- and fluid-mechanics specialists in the Engineering Sciences Directorate 1500. Salt creep simulation tests also have been conducted at the Area III centrifuge facility.

As the SPR has progressed, Sandia's role has changed from seeing that oil is stored safely to monitoring the oil to ensure its safety and usability, as well as its retrievability on short notice for refining.

A Sandia-developed technique for testing cavern integrity came in response to concern about well leaks and casing cementing. Key to the technique is a thin nitrogen gas blanket above the oil. By monitoring changes in the blanket/oil interface, it's possible to register losses as small as a few tens of barrels a year. "That's pretty good for a 10-million-barrel cavern, and at least two orders of magnitude better than previously used techniques," Jim says.

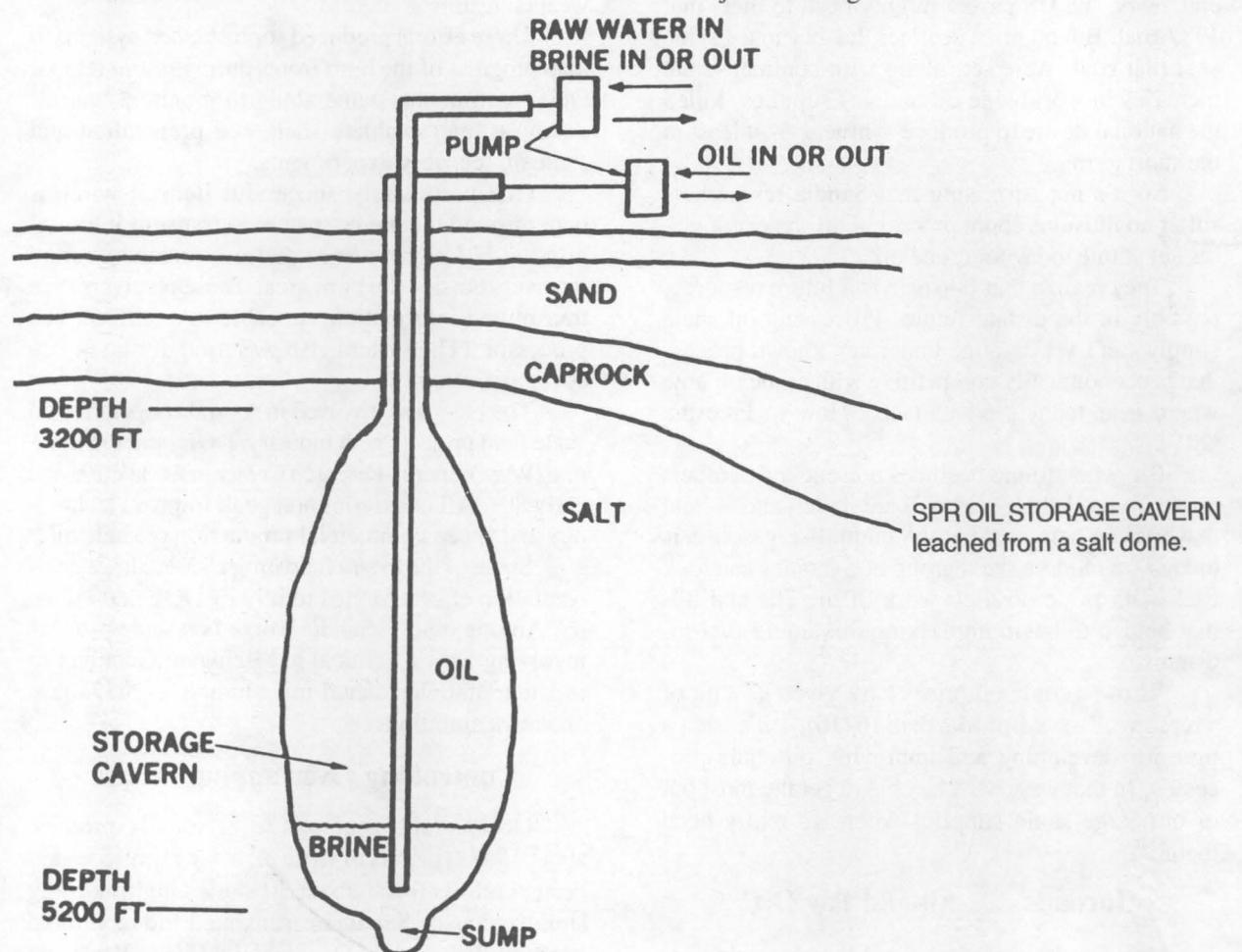
### Ongoing Work Also Varied

Under development are downhole sonars for inspecting cavern walls and shapes, and an autonomous instrumentation system to monitor cavern pressures. To understand oil mixing and trace-element chemistry, natural fluid convection computer modeling also is under way. "That's especially interesting," Jim says, "because the mathematics of iceberg movements forms a close analogy."

Another major current effort is stored-oil chemistry. "We're especially interested in trace metal contaminants that can get into crude oil at many points between initial recovery and refinery," Jim says. "The cost of refining oil goes up significantly if contaminants deactivate catalysts typically used for that procedure."

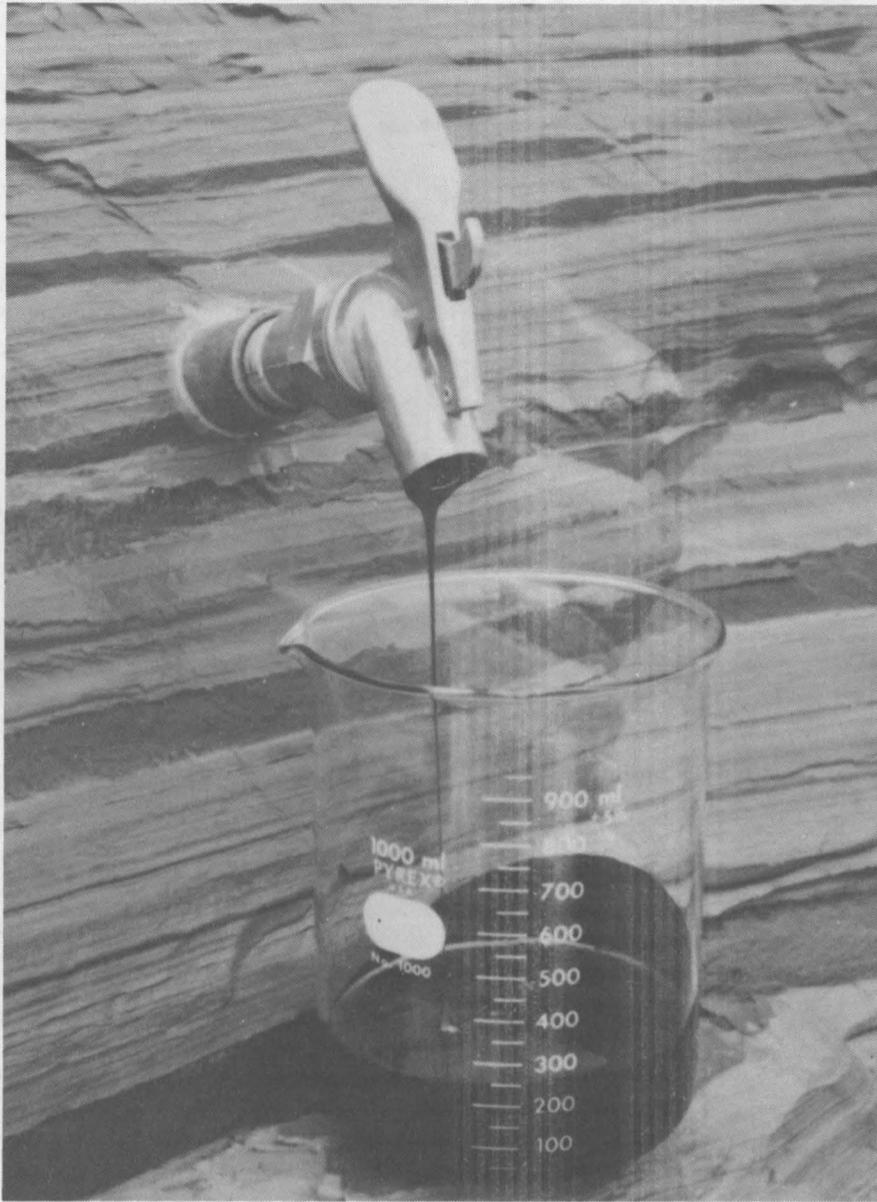
The Labs expects to continue an SPR role for some time to ensure that the oil remains a ready and viable emergency supply.

Where SPR is going, however, is a bit uncertain. "No one knows for sure how long the SPR will be maintained or when the country will need to tap those hundreds of millions of barrels," Jim says. "Meanwhile, the reserve has a stabilizing effect on world oil prices and it makes many Americans feel better just knowing it's there." ●LP



**Oil Shale Retorting****Squeezing Crude From Rock**

IF ONLY OIL SHALE RETORTING could be as easy as installing a faucet and letting the oil flow. Although it's not that straightforward, Sandia scientists are making significant contributions to the synfuel recovery process.



The US was to produce 500,000 barrels of synthetic liquid fuel (synfuel) a day by 1987 and two million barrels a day by 1992. Those US production goals were mandated by Congress in 1980.

The 1987 goal came up short — some 490,000 barrels a day short.

Much of that synfuel was to be produced from oil shale — an energy source with tremendous reserves (see "It's Neither Shale Nor Oil"). For several years, the US gave a mighty push to meet that 1987 goal. But oil price declines that began the same year that goals were set, along with commensurate increases in worldwide oil and gas supplies, killed the national desire to produce synfuels — at least in the short term.

So it's not surprising that Sandia researchers suffer no illusions about processed oil shale as a viable substitute today for crude oil.

They realize that oil shale is a future resource, possibly in the distant future. Processing oil shale simply can't yet be done under any known process that is economically competitive with crude oil anywhere near today's prices (see "How to Free the Oil").

But when future becomes present and synfuels made from oil shale (or coal) are in demand — and maybe even being sold at the pump like gasoline is today — a modest-sized group of Sandians can look back with pride on their work of the 70s and 80s that helped to begin unmasking this liquid-fuel-in-disguise.

"Lower crude oil prices have given us a bit of a reprieve," says Bill Marshall (6210). "It's been a time for developing and improving oil shale processes. In that way, we'll be able to get the most out of our large shale supplies when we really need them."

**'Inroads . . . Should Pay Off'**

"And we're definitely making technological inroads — building our understanding — and that should pay off," he continues. "Right now, we are confident we can do *in situ* oil shale retorting much

more efficiently than anyone could when the big commercial projects were gearing up in the early 80s."

Over the years, as manager of one of DOE's larger programs to improve oil shale synfuel processes, Sandia has conducted many laboratory and field projects aimed at solving oil shale's mysteries and problems. Early instrumentation development drew on the expertise of Sandians who developed and tested similar systems for underground nuclear weapon testing.

These efforts produced sophisticated systems to map progress of the burn fronts during *in situ* retorts. Other instruments came along to monitor, control, diagnose, and evaluate shale bed preparation and shale oil recovery experiments.

One particularly successful item: a wireless underground telemetry system to transmit information via FM signals from thermocouples to buried receivers outside the burn area. Those receivers then transmitted information via cable to a surface data processor. (The system also was used during *in situ* coal gasification.)

The Labs was involved in several cooperative oil shale field projects with industry, DOE, and the Laramie (Wyo.) Energy Research Center in the late 70s and early 80s. All had a common goal: Improve technology and speed commercial production of shale oil.

Some of the *in situ* field projects were large demonstration efforts funded jointly by DOE and industry. Among others, Sandia worked on shale projects involving Dow Chemical in Michigan, Geokinetics in Utah, and Occidental in Colorado — the largest and most ambitious.

**Controlling Overlapping Fronts**

Occidental's goal was to eventually produce about 15,000 barrels of shale oil a day from 15 underground retorts (each about 30 stories high) burning simultaneously. Sandia instrumented and monitored much of this work at Occidental's Logan Wash site near Grand Junction, Colo. (see "Al Stevens' Oxy Experiences"), but those production goals were never approached.

A major problem in field projects always seemed to be that combustion and retort fronts could travel at different speeds and overlap, producing a dramatic, negative impact on process efficiency. This caused portions of the oil to burn up before it had a chance to be recovered. Basically, retorts progressed more rapidly in outer, more highly fractured zones because there was more void space. Sandia work confirmed that retorting-front speed is directly proportional to the amount of air that can flow through a given volume of oil shale to fuel combustion.

About the time big field-demonstration projects halted, Sandia went back to the lab to try to solve that problem and to develop "second-generation" retorting technology.

Higher yields, Labs researchers conclude, ought to result from minimizing the amount of oil that burns up before it can be recovered. This can be done, they believe, by fracturing the shale with tailored explosive charges that produce inner and outer zones of different rubble size, compensating for variation in void space. As a result, the retorting front travels through different zones at the same speed.

Oil shale project leader Tom Bickel (6258) says this work produced a new approach that might yield 30 to 60 percent more oil from an *in situ* retort. Conventional wisdom has been that the maximum possible yield from *in situ* processing is 50 to 60 percent. The new approach might yield in the 80- to 90-percent range. If proven in the field, this could go a long way toward making shale oil more competitive with crude oil — depending on crude prices, of course.

Paul Hommert (6258) groups Sandia's other oil shale contributions into two primary areas: defining (quantifying) *in situ* processes, and understanding and describing shale-fracturing processes.

"In the mid-70s all we knew about a retort was that we could get some oil out," Paul recalls. "We didn't know why we got as much as we did, or why we couldn't get more. Now we can define what to expect from an *in situ* retort. If you tell us the shale type, how you plan to rubble it, and the conditions under which you will process the bed, we can tell you pretty accurately what yield you will get and what your loss mechanisms are."

Now existing are several Sandia computer models that describe how shale reacts to high-energy shock waves produced by different explosive charges. Original work by Dennis Grady (DMTS, 1534) and Marlin Kipp (1533) provided the basis for predicting what will happen by varying detonation spec-

(Continued on Page Seven)

**So What Is It?****It's Neither Shale Nor Oil**

Oil shale is actually a misnamed resource. It's neither oil nor shale, but a marlstone, which is mostly clay, containing a brown to dark gray organic material called kerogen.

When heated to about 900°F, kerogen reacts to form shale oil, plus some gas that can be recycled to heat additional shale. Resulting shale oil is low in sulfur and, although different in some respects from conventional petroleum, can be refined into most petroleum products.

The richest reserves, thick deposits averaging more than 20 gallons of oil per ton of rock and resting anywhere from 100 to 3000 feet beneath the surface, are in the Green River Formation that covers some 16,000 square miles of Colorado, Utah, and Wyoming. Estimates of economically recoverable shale oil range from 80 billion to several hundred billion barrels.

In contrast, more than 100 billion barrels of petroleum have been recovered in the US.

**Highest Highs, Lowest Lows****Al Stevens' Oxy Experiences**

"Some of my highest highs and some of my lowest lows." That's how Al Stevens (6311) describes his three-year hiatus from Sandia in the early 80s when he directed field activities at Occidental Petroleum's (Oxy) oil shale field project in Colorado. Oxy, with Tenneco Oil as a partner, planned then to eventually produce about 95,000 barrels of shale oil a day from rich shale deposits near Grand Junction.

When Al left Sandia in 1981, he was supervising the Labs' oil shale projects and was a strong believer in oil shale's future. So was the main man at Oxy, Armand Hammer, the company patriarch and CEO. So was Exxon, which started another massive oil shale project near Grand Junction. And so were some other big energy companies, the federal government, and a lot of just plain folks.



AL STEVENS (6311)

Oil shale seemed a sure bet to supplement shrinking supplies of crude oil, which had increased sharply in price from about \$2 a barrel in the late 60s to about \$40 a barrel in 1980. Some analysts believed it would be \$100 a barrel before too many more years.

**'Cheaper Than Petroleum'**

Many experts agreed it was time to get serious about developing huge supplies of synfuels from oil shale. Armand Hammer, in an early-81 *National Geographic* special issue, revealed his optimism: "Shale's time has come," he said. And, when asked how much oil-shale synfuel would cost when Oxy's big Colorado retort began producing in 1985, Hammer replied flatly, "Cheaper than petroleum."

The federal government also planned to provide incentives to industry to encourage the production of two million barrels of synfuel a day by 1992.

So, Oxy hired Al in early 81 to manage oil shale research at its labs in California. Later that year, he was asked to help solve some technical problems at Oxy's Colorado field site. Early the next year, he actually transferred to Grand Junction to direct field operations involving two full-scale *in situ* demonstration retorts and about 175 Oxy employees. The demonstration phase was jointly funded by DOE, which contracted Sandia to instrument and analyze the operation.

However, times do change, sometimes in a rush. About the time Oxy got pilot retorts fully cranked up, slowly eroding oil prices slid sharply. OPEC,

**(Continued from Page Six)****Squeezing**

ics such as explosive quantities, types, positioning, and timing.

Follow-up work continues today by Lee Taylor (1523) and Billy Thorne (6258), who are validating computer models that predict shale fragment size as a function of explosive loading.

Today, the work on blasting has expanded beyond oil shale to other mining applications, such as coal (see "Cast-Blasting").

●LP

**It's Called Retorting****How to Free the Oil**

There are two basic methods of oil shale processing — surface or *in situ* (underground) retorting. Both require heat to break down kerogen molecules; this "cracking" process releases a liquid hydrocarbon mixture, combustible gases, water, and solid residue. The liquid hydrocarbon is the "crude" form of shale oil.

Surface technology involves mining oil shale using conventional techniques, crushing it, and heating it in a retort or kiln to extract crude oil, which is then shipped to a refinery.

Air pollution — both dust and gases — created during processing definitely is a surface-retorting negative. So too is the magnitude of the mining operation that would accompany such an endeavor.

Paul Hommert (6258) puts that into perspective: "A single 100,000-barrel-a-day operation would require that about 73 million tons of shale be mined yearly. That's roughly equivalent to one-twelfth of the entire annual US coal mining industry, and one-fifth of the entire underground coal mining production yearly in this country.

"You can see why it's hard to envision a successful oil shale industry that is not characterized by the most efficient and technically advanced mining operation in the world," Paul adds. "Because of that, our program today really is emphasizing the mining operation, instead of processing."

once able to dictate world oil prices, lost its firm grip, and soon the US had all the oil it needed at much lower prices than just several years earlier. Political and public support for synfuel price supports weakened. Exxon abruptly abandoned its big shale project in mid-82.

"By previous standards, Oxy's two demonstration retorts were a roaring technical success when they were finished in late 82, but they caused a big yawn," Al says. "The bottom dropped out of the synfuels business after oil supplies increased and prices dropped. When we were closing those retorts, things were falling apart rapidly. Nobody cared."

Oxy and Tenneco didn't give up right away. Al helped prepare a proposal that went to the Synthetic Fuels Corp. in early 83 that would have provided price supports for Oxy's oil shale work. The objective was to come out of the price support period with a process that could compete with the price of crude oil.

**Goodbye, Synthetic Fuels Corp.**

"By the time we got the proposal turned in [on January 10, 1983], the Synthetic Fuels Corp. was in political trouble," Al says. "We received a non-binding letter that stated the corporation's intent to provide support, but it never really got any further. Congress legislated the corporation out of business soon after that."

Al stayed with Occidental for about another year and returned to Sandia in April 1984. For the past few years, he has worked in Dept. 6310, which is helping DOE determine the feasibility of building and operating a high-level nuclear waste repository at Yucca Mountain on the Nevada Test Site. In 1987, he became supervisor of Div. 6311.

Does Al regret leaving Sandia for something that didn't work out? In a way, yes, but he also believes it was a valuable experience. "Given the facts as I knew them in 80 and 81, I'd do the same thing," he says. "My crystal ball didn't look very deep, and I can't apologize for that.

"The first year or so was a fun and exciting time," Al continues. "That's when the real highs came. The lowest lows came later when I had to lay off most of the people who worked on-site. Everyone knew then we were on our way down, and the business of keeping a technical crew going and maintaining some morale in the face of that was a real challenge."

*In situ* retorting, which Sandia work has always emphasized, means processing shale in its underground bed.

The first major finding of Sandia oil shale field work, however, clearly demonstrated that true *in situ* processing (which, by definition, involves no rock mass removal during bed preparation, except for that produced in drilling wellbores to gain access to the underground formation) just didn't work well. That conclusion was based largely on Labs studies near Rock Springs, Wyo.

"That was a significant finding," says Paul. "DOE was being urged at that time [about 1975] to put a lot of money into that technology, which clearly was flawed. We were able to define those flaws and prevent government and industry from wasting time and money."

Paul says the Labs' negative judgment concerning true *in situ* retorting changed a lot of thinking and helped to popularize modified *in situ* processing.

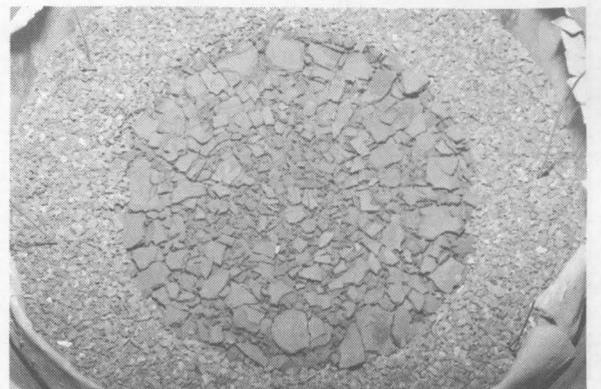
Modified *in situ* retorting requires that about 15 to 30 percent of the shale be mined out to create an underground void into which air can enter and support combustion. Shale that remains underground is broken into rubble by explosives, so it can be more readily heated. The shale is then ignited, and emerging oil and gas are pumped to the surface.

The big synfuel projects (including Oxy's Colorado operation) that were partially government-supported were constantly in the political spotlight. Although his boss handled most of the politics, Al did his share. "It taught me some patience with the political world — not necessarily a love for it — but patience for it," he says.

**Sandia's Instruments Did the Task**

The experience also was an opportunity to view Sandia's technical capabilities from an outsider's perspective, and Al liked what he saw. "The technically complex instrumentation system that Sandia installed and operated proved to be a really good one," he says. "From the harried hours of retort start-up through the year-long operations and into the cool-down phase, the Sandia system provided data on continuous call on all aspects of the process. Occidental recognized and appreciated that."

Does Al still believe in oil shale? Sure! "There's a lot of oil out there in that rock, and the basic task of getting it out is simple," he says. "Mother Nature just didn't have that rock deep enough or long enough in the bowels of the earth to transform the kerogen into crude oil. The challenge is to figure out better, more efficient ways to help her finish the job."



CLEARLY VISIBLE is the contrast in particle size between inner and outer oil shale zones of a lab-scale experiment designed to demonstrate feasibility of Sandia's "second-generation" retorting concept. Experiment used 200 pounds of shale in a 3-ft.-tall test vessel. Although the 8-in.-diam. inner section had a much lower void than the outer region — 25 percent vs. 44 percent — retort and combustion fronts progressed uniformly during the experiment.

**The MWX**

# Putting Gas Into Focus

Like Sandia's work on many defense projects, its MWX research may also improve national security. No, the MWX isn't the latest model of the MX missile and it won't improve military security. But it may enhance the security of the country's energy supply.

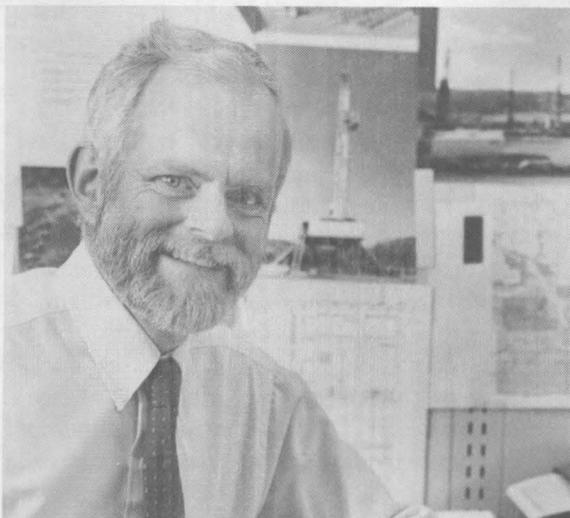
MWX stands for Multiwell Experiment, a long-running, DOE-sponsored field laboratory near Rifle, Colo. Its purpose is to develop better ways to coax natural gas from tremendously gas-rich, tight (low-permeability) sands that underlie much of the western US. The largest of Sandia's enhanced gas recovery efforts since energy R&D began at the Labs, MWX gets its name from three closely spaced wells — 113 to 215 feet apart and arranged in a triangular pattern.

It has permitted much of the Labs' energy-related technology and hardware to be brought together and tested in realistic field conditions.

Selected by DOE in 1981 to be MWX technical coordinator, Sandia has worked closely with CER Corp., prime subcontractor operating the site; provided field engineering; and conducted testing and analysis.

DOE selected Sandia for the MWX job largely because of its expertise and experience gained in fracture mapping, hydraulic fracturing experiments at the Nevada Test Site (see "Early Enhanced Gas Recovery Highlights"), and development and testing of new field instruments for various energy projects. Sandia's weapon program experience in underground testing and instrumentation was recognized as an excellent technical base for the MWX, as well.

After some eight years of research and field testing, MWX project manager Dave Northrop (6253)



DAVE NORTHROP (6253)

firmly believes western tight sands to be an important energy resource, but that it may be some time before they become viable gas sources. "They simply are not paying propositions yet," he says.

### Meeting MWX's Primary Objectives

Dave, Allan Sattler (DMTS), Norm Warpinski, and John Lorenz (all 6253) are now analyzing mounds of data and producing reports based on MWX field work. They believe the first of two primary objectives — to fully characterize the formation and gas reservoirs within it — has largely been met and that significant progress has been made on the second objective — to determine how gas can best be recovered from the reservoir.

MWX's focus has been the Mesaverde Forma-

tion in the Piceance Basin underlying northwest Colorado. Deposited during the late Cretaceous age (65-136 million years ago), the Mesaverde underlies a large region of the western US. Located between 4000 and 8250 feet below the surface at the MWX site, the formation is rich in natural gas. The Piceance is also rich in other energy sources; the Green River Oil Shale Formation (see "Squeezing Crude From Rock") lies atop the Mesaverde.

The National Petroleum Council estimates that about 600 trillion cubic feet of recoverable natural gas are contained in US low-permeability reservoirs like those found at the MWX field laboratory. The Piceance and three other western basins alone — Greater Green River, Wind River, and Uinta — are thought to contain about 136 trillion cubic feet (TCF) of recoverable gas. That's more than an eight-year US supply at the 1987 consumption rate of about 16.7 TCF/year.

### Fully Understanding a Reservoir

Knowing gas is in tight sands and getting it out are different matters. These tight sands are aptly named: Permeability (capability to allow liquids or gases to flow through them) can be near that of dense concrete. Also, most reservoirs are oddly shaped and relatively small, and have indistinct boundaries. That means total gas production from such a reservoir can be disappointing, even though initially promising.

"You can't develop production technology for a reservoir that you don't fully understand," Dave says. "For instance, we've learned during the MWX that the depositional environment under which individual reservoirs were formed controls many reservoir characteristics, including fracturing — and, thus, their ability to produce significant gas."

MWX researchers also were early to confirm something that is taken for granted today: Natural fractures in sandstones play a major role in the rock's ability to release gas. "Fractures, caused by stresses within the earth, are pathways through which gas can flow to a wellbore," Norm says (see "More Oil and Gas the ASR Way"). "An unfractured tight sand reservoir might have a permeability of less than 1 microdarcy [the standard measurement of flow]. One with a good natural fracture system might have a permeability in excess of 20 microdarcies. That is still an awfully tight reservoir, but it could be enough permeability to make a gas well a paying proposition."

The Mesaverde Formation surfaces about 12 miles from the MWX site, along the Grand Hogback. John Lorenz's detailed studies of outcrops near Rifle Gap found natural fractures in the formations to be unidirectional — running nearly parallel with one another. That information could help producers plan reservoir stimulation treatments to exploit fractures. The most common treatment, hydraulic fracturing, involves pumping a sand/fluid mixture under pressure into a reservoir to create and hold open cracks through which gas can flow to the wellbore. Sand in the mixture works as "proppant." After creating a fracture and removing pressure, sand grains "prop" open the fracture.

### Not Getting What You Want

Sometimes such fracturing can produce the opposite of the intended effect (see "New Facility Filled With Promise"). "After about the first year of MWX field testing," Allan Sattler says, "we came to realize the importance of natural fractures and the need not to damage them. Only after some pain did we learn that hydraulic fracture fluid sometimes damages these fractures if pumped in at excessive pressures."

Nature controls stresses, which control the direction of long cracks created by hydraulic fracturing. These tend to run parallel to natural fractures at the MWX site, Dave Northrop explains. "For best results," he says, "man-made hydraulic fractures should run perpendicular to and intersect with multiple natural fractures in order to open paths for more gas."

If that occurs, a 100-ft.-long perpendicular hydraulic fracture that intersects a natural fracture might generate as much gas as a 750-ft.-long hydraulic fracture.

(Continued on Page Nine)

## New Facility Filled With Promise

Tests at Sandia's geoelectric simulation facility (GSF) could break new ground in development of diagnostic techniques that reliably provide real-time maps of underground oil and gas recovery processes like steamflooding and hydraulic fracturing.

In fact, the folks in Advanced Technology Div. 6258 say the new facility should provide the most accurate scale modeling ever achieved of surface electrical potential (SEP) technology.

Although SEP technology has been around for years, and is used commercially to help locate ore bodies, it has not found practical use in the oil and gas industry. "The GSF will help us determine whether SEP and similar techniques can become practical for the energy industry," says Tom Bickel (6258), the facility's primary designer and operator.

For energy applications, the idea is to apply electrical current to a well casing in a borehole. After current travels down the casing and back up through the ground, electrical measurements are taken at numerous points up to hundreds of feet from the well and then recorded. The recorded SEP patterns vary according to formation types, temperatures, and discontinuities (faults and fractures, for example) through which current passes.

After studying changes in the recorded pattern, geophysicists try to infer the location (particularly the lateral geometry) of energy recovery processes under way at the time. The objective is to determine whether the processes are occurring efficiently — for example, whether injected steam is reaching the desired areas. This information could be used to help engineers make adjustments to improve process efficiency.

"The problem," says Paul Hommert (6258), "is that engineers haven't known exactly how to interpret data gathered in field experiments. We have never had validated models to predict the response we should get. So, in the past few years, we have been doing fundamental research to determine if SEP is viable for oil and gas."

The main part of GSF, built by organization 7400, is a hemispherical tank about a metre in diameter. Use of an electrolytic fluid (deionized water and potassium chloride solution) in the tank allows researchers to mimic underground formation resistivities.

Discontinuities in the geology are simulated by placing small, coated metallic strips or tiny balloons filled with an electrolytic fluid of contrasting resistivity into the tank. These discontinuities tend to modify the current paths and, consequently, to change the electrical potential measured on the surface.

"The facility will allow us to do a lot of things that no one has ever been able to do," Tom says. "We can look at ways to optimize electrical techniques — downhole current injection as opposed to surface current injection, for example."

After some detailed GSF studies, Sandia researchers believe they can develop an improved understanding of SEP and other electrical and electromagnetic diagnostic techniques and know whether they are viable for mapping oil and gas recovery processes.



TOM BICKEL (left) and Bruce Engler (both 6258) check settings on the geoelectric simulation facility. Gold-coated copper triangles making up GSF's fluid-filled basin are computer-controlled to vary resistance settings, matching field conditions.

## More Oil and Gas the ASR Way

Early 80s work by Larry Teufel (6232) at Nevada Test Site and the Multiwell Experiment (MWX) site resulted in a new technique for improving placement of oil and gas wells to help drain hard-to-tap reservoirs. Called Anelastic Strain Recovery (ASR), it helps producers position recovery wells to exploit *in situ* stresses.

ASR technology is one of the Labs' technology transfer all-stars. The Federal Laboratory Consortium, an organization that represents about 150 federal laboratories, honored Larry earlier this year with a special award for excellence in technology transfer for developing the technique and for "initiative in arranging cooperative programs for its transfer to industry" (LAB NEWS, May 20, 1988). In 1985, the technique earned the US National Committee for Rock Mechanics Applied Research Award.

The ASR technique basically involves measuring microscopic changes in dimensions of wellbore core samples as they slowly "relax" after being brought to the surface. These changes reveal the direction and magnitude of stresses in rock formations, allowing the direction and distance of man-made fractures from a borehole to be correctly predicted because they are stress-dependent. That permits adjacent wells to be properly positioned for optimum oil and gas recovery. Improper placement of just a single well can cause millions of dollars worth of oil or gas to be left underground.

To implement Larry's technique, Dave Holcomb and Mike MacNamee (both 6232) developed patented equipment sensitive enough to make the proper measurements on these "relaxing" core samples. The equipment consists of a set of metallic support frames, each connected to displacement gauges that detect movements as small as one-millionth of an inch.

The strain measuring technique and accompanying equipment are now used by such oil field service companies as Terra Tek, Rock Mechanics A/S, Halliburton, and Litton Core Lab as part of routine, commercial services in oil and gas exploration and recovery operations.



ANELASTIC STRAIN RECOVERY technique is possible because of this patented tool designed by David Holcomb (right) and Mike McNamee (both 6232). It can detect core movements (strain relaxations) as small as one-millionth of an inch.

ARCO, AMOCO, British Petroleum, Exxon, Mobil, and Shell also use the technique, and Sandia is working with Phillips Petroleum to extend the technique to understanding how oil-bearing rock subsides as oil is extracted.

ASR technology is being adopted around the world, even in places Sandia probably still doesn't know about. In September, on his way back from presenting technical drilling papers in the Soviet Union, Dick Traeger (6250) stopped briefly in the Oberpfalz region of West Germany to visit a deep-drilling project. It is part of the international Continental Scientific Drilling Program that is studying and mapping the earth's crust.

"I was surprised to find the West Germans routinely using ASR technology and equipment at their field lab," Dick says. "I didn't remember any related Sandia contacts with them. They said they had read Larry's technical reports, decided the ASR technique would be useful, and had even built ASR equipment based on the reports."

duced gas flow from 250,000 cubic feet/day to 150,000 cubic feet/day. However, after that zone was shut in for 18 months, and then reopened, gas production averaged about 350,000 cubic feet/day for a 2-1/2-month test period.

MWX also has involved development of seismic tools and techniques to help characterize reservoirs and to measure what happens during the process of massive hydraulic fracturing (MHF) reservoir stimulation — injection of very large amounts of sand and fluid under very high pressure.

Sandia's MHF interest goes back to the mid-70s when Carl Schuster (now 5234) supervised a sensors system division and led efforts to develop fracture-mapping technology using both seismic and electrical resistivity instrumentation. Working with Amoco Production Company in a low-permeability gas formation northeast of Denver, Carl's group found that traditional surface seismic technology wouldn't work. Surface geophones were simply too far above zones being fractured, making it impossible to detect low-noise fracturing. So the Sandia group developed the first workable technology for mapping fractures downhole — from either within the well being fractured or from adjacent boreholes.

### A Borehole Seismic System Map

Their work evolved during the MWX into what became a Sandia-designed borehole seismic system (BSS) that uses quadraxial, directional geophones to detect and record seismic energy released by rock during and after fracturing. Harry Morris (6258) developed the modern BSS, with help from Billy Thorne (6258), Carolyne Hart (9133), and Eric Chael (9111).

The BSS successfully mapped MWX fractures. Researchers placed geophone systems down two holes

to map hydraulic fractures being induced from the third. By examining geophone data and triangulating back to the source of seismic noise, researchers determined where the formation was cracking and, to some extent, how far fractures extended.

Paul Hommert (6258) believes the BSS has added potential when used in conjunction with another Sandia tool — the downhole seismic source (see "Petroleum R&D Projects Show Results"). Paul elaborates: "In cooperation with industry, we plan to use the downhole seismic source with BSS for cross-borehole experiments that characterize geologic environments."

"Existing seismic technology doesn't have sufficient resolution to provide a detailed reservoir picture," he continues. "With these new tools, we hope to turn the sensitivity knob up, so to speak, and get more and better information. The technology should eventually allow us to locate natural fracture systems, permeability barriers, underground faults, and other features that will help industry place wells for maximum production." ●LP

### Predating MWX

## Early Enhanced Gas Recovery Highlights

Sandia's work to understand and improve fracturing technology as a means to enhanced gas recovery predates the Multiwell Experiment (MWX) by several years.

In the late 70s, Dave Northrop and Norm Warpinski (both 6253) led a unique effort to inspect underground formations after they had been fractured.

This "mine-back" project involved drilling boreholes near an existing tunnel 1500 feet below the surface at Nevada Test Site (NTS), fracturing the rock hydraulically, then mining-back from the tunnel to boreholes in order to inspect holes and cracked formations.

This allowed Sandia to study sand proppant distribution along fractures. As a result of findings from this study, naturally occurring underground stresses are now routinely considered by industry when designing hydraulic fracture treatments.

Sandia also was deeply involved in development of high-energy gas fracturing (HEGF) before the MWX. HEGF is intended to increase flow from low-permeability gas formations, particularly in Devonian shales. Developed by Sandia, with funding from DOE and the Gas Research Institute, HEGF uses propellant mixtures in a borehole to create a tailored pressure pulse.

Similar to that used in artillery charges, propellant produces high-pressure combustion gases in several thousandths of a second, compared to millionths of a second for conventional explosives. This relatively slow — but progressively faster — burning rate, produces a pressure build-up that optimizes rock breakage and fracture propagation. Gases generated during the burn enter fractures, making them grow.

Jerry Cuderman (DMTS, 5165) says the technique typically creates four to eight fractures in a star-shaped pattern. This increases the chance that one or more of these fractures will intersect natural fractures and create an improved gas-flow path to recovery wells. Sandia tested HEGF in Devonian-shale gas wells in Ohio. Pre-test production was only about 5000 cubic feet/day; after HEGF, gas flow hit 22,000 cubic feet/day.

Some HEGF technology is used by industry today to optimize explosive fracturing operations. "Our work helped to define pressurization rates for multiple fracturing of low-permeability formations," Jerry says. "This helps producers mix explosives to give the correct pressure pulse for fracturing shales and other tight formations, as well."

(Continued from Page Eight)

## MWX

lic fracture that's parallel to natural cracks, according to the MWX team. Unfortunately, technology isn't yet available to make that happen reliably if existing stresses are from the same direction as they were when natural fractures formed. However, if present-day stresses come from another direction, stimulation may produce fractures that cut across natural fractures. So knowledge of fracturing — past and present — is one of the critical findings in the entire tight sands project.

### Controlling Natural Stresses

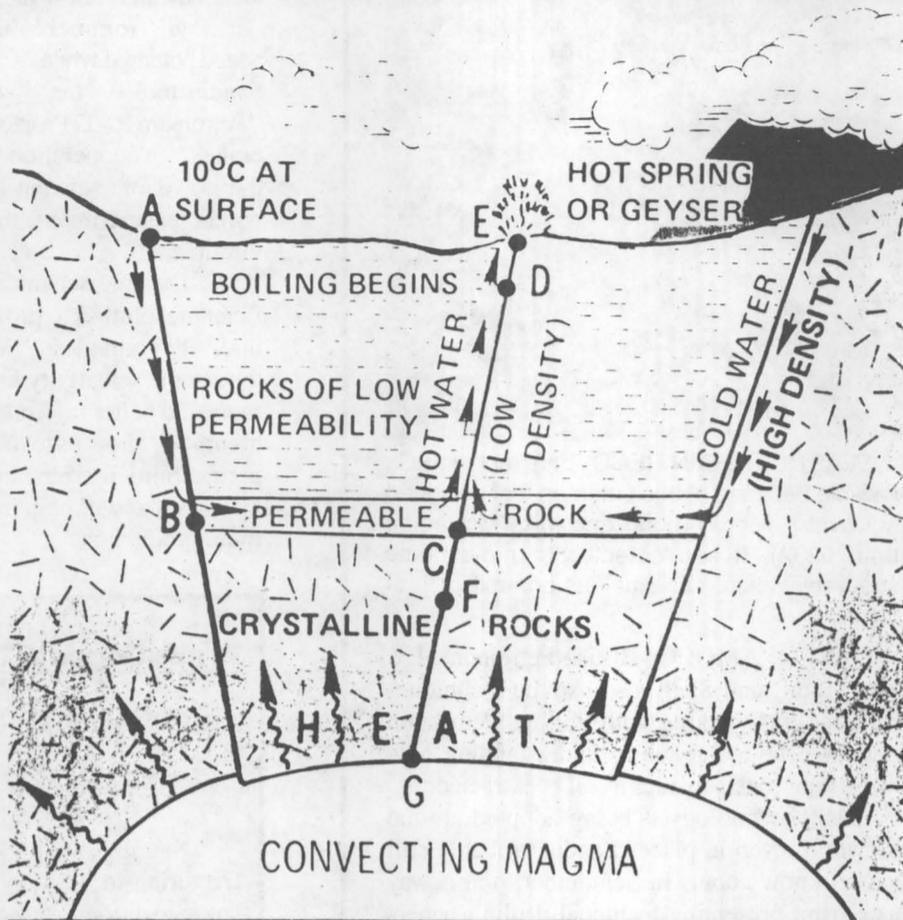
Norm did a recent test that showed potential for altering *in situ* stresses by fracturing one zone to cause stress changes in a nearby zone. "If you then fractured the altered-stress zone," he explains, "it might be possible to make hydraulic fractures go perpendicular to natural fractures."

Anne Rutledge (6334) and former Sandians Dave Heinze and Jim Clark have catalogued and stored more than 4100 feet of cores taken from the three MWX wells. Kept in Bldg. 883, these cores will probably be studied for years to come. Sharon Finley (6253) and John Lorenz are examining the many natural fractures in these cores. "We've looked at more than 1500 fractures so far," Sharon says, "and the closer we look, the more complex the picture becomes."

Sandia researchers have found during the MWX that a combination of well stimulation and patience sometimes pays off. Hydraulic fracturing in the MWX's paludal zone (near-shoreline zone where ancient rivers flowed through swamps) initially re-

# Geothermal Energy: 'Beyond Fantasy and Experimentation'

SCHEMATIC MODEL of a typical geothermal system with underlying magma.



It can't be called a cold, cruel world. But the world that geothermal researchers face *can* be called cruel. Tapping reservoirs of steam and scalding water — as deep as 10,000 feet beneath the earth's surface — to produce power is neither an easy nor an inexpensive task.

Just the same, geothermal energy generates enthusiasm, because it's viewed increasingly by energy experts as an eventual money-saving alternative to other resources — petroleum, natural gas, coal, nuclear — seen in some quarters as having environmental drawbacks.

"Geothermal energy technology has progressed beyond the stage of fantasy and experimentation to where it is now an important part of the US energy spectrum," commented Unocal Geothermal Division President Carel Ottee during testimony before the Senate Finance Committee earlier this year.

And, by most measures, the US now "leads the world in geothermal technology, such as drilling know-how, exploration using electronics, and reservoir engineering," says David Anderson, executive

director of the nonprofit Geothermal Resources Council in Davis, Calif.

Abroad, more than 50 nations rely, in part, on underground steam and hot-water reservoirs for power production. They include Japan, Indonesia, New Zealand, Greece, and Italy; the latter was the first nation to harness the earth's steam power in 1904.

## It's Hot Down There

The thrust of Sandia's geothermal research since its early-70s beginnings (see "Starting From Square Zero") has been to cut costs — especially those associated with drilling and well completions — and to make more geothermal resources available for power production. Labs work has concentrated on hydrothermal heat sources (steam and hot water) — the sources used to produce electricity.

"The geothermal environment is a lot hotter than what you find in oil and gas wells," says Jim Dunn, supervisor of Geothermal Research Div. 6252. "We encounter temperatures between 200° and 350°C [392° and 662°F], in contrast to a maxi-

mum of 150°C for oil and gas.

"The geothermal driller runs into problems that oil and gas people don't have to worry about. For example, we deal with hard rock that's fractured — it's like drilling through a bucket of scrap metal with your hand drill. Drilling muds [see "Mud — Not the Kind Kids Use to Make Pies"] disappear into the formation and don't do their job. Corrosive brines degrade equipment."

"Up to 60 percent of the cost of geothermal power is directly related to the well — that is, drilling, completion, and maintenance," says Dick Traeger, head of Geo Energy Technology Dept. 6250. "That's why Labs research has concentrated, for the most part, on drilling technology — especially drill bits — and high-temperature logging tools that are used to assess an area's geothermal potential."

Dick points out that geothermal well-logging tools are needed because conventional oil- and gas-logging instrumentation is not reliable much above 150°C (see "Hybrid High-Temperature Microcircuits").

## More Than Meets the Eye

Heated by molten matter — called magma (see articles on magma) — oozing up from the earth's core, geothermal reservoirs are a clean source of power. But tapping them doesn't mean just drilling a hole in the ground and watching steam or hot water flow to the surface to power a turbine generator.

First, there's a search for promising reservoirs (using geologic and geophysical data to determine geothermal potential), then reservoir confirmation through exploratory drilling. Next, downhole logging instrumentation and flow tests are used in exploration wells to check pressures, temperatures, and flow rates of the geothermal source. Only after it's determined that the reservoir has electricity-producing potential are production wells drilled.

Production-well completion involves a number of activities: Steel casing must be placed in the borehole to protect surrounding aquifers and to keep rock debris from falling into the hole; next, cement must be pumped between casing and formation to prevent casing expansion during geothermal operations and to ensure that the reservoir's hot water or steam doesn't travel up the outside of the casing.

Once a well is producing in an area of "good" geothermal heat resources, electricity can be generated at 6.5 to 7 cents a kilowatt hour, according to a recent DOE report. Geothermal energy contributes

(Continued on Page Eleven)

## Mud — Not the Kind Kids Use to Make Pies

Sandia began investigating drilling fluids for use in geothermal wells about 1977. The fluids, called "muds," have several functions: to cool and lubricate the drill string and bit, to control formation pressure, and to clear the cuttings from around the bit and lift them to the surface.

Mud, commonly consisting of a clay dispersed in water, behaves differently depending on reservoir conditions. Ideally, as it moves down through the drill string, cooling the bit at the end, it's at low viscosity as it goes through the bit nozzles to clean them. "But when mud exits the bit," explains James Kelsey (5260), "it has to become much more viscous to lift the cuttings out of the hole; otherwise, they'd fall to the bottom."

### High-Temperature Cycling

"The problem in geothermal wells," James continues, "is that muds undergo high-temperature cycling; when they're injected at the top of the well, the temperature is relatively cool. But by the time they reach the bottom, the environment is much hotter. Then it's back up to the cooler temperatures, and down again."

Unfortunately, bentonite muds commonly used in the oil and gas industry undergo chemical changes when they mix with minerals in geothermal debris and tend to "bake" at the bottom of the well — destroying their effectiveness for carrying cuttings out of the borehole. The thrust of Sandia's geothermal mud research has been to develop muds that survive high-temperature cycling.

"Both Sandia's materials sciences organization and private industry contributed to our mud research efforts," James says. "The materials people investigated additives to bentonite to control 'baking', and studied aqueous foams as possible geothermal drilling fluids. Private industry helped out with field experiments, which were necessary because you can't simulate temperature cycling and mineral changes in the laboratory."

Out of a five-year research effort at Texas Tech (under contract to Sandia), a new set of high-temperature muds based on a clay called sepiolite was developed. The muds, now commercially available, do not degrade after cycling, says James, and do a much more effective job in geothermal wells.



FRED HEARD (left, now 9234) and Tom Bauman (now 9127) teamed for development of the geothermal high-temperature, high-pressure acoustic borehole televiewer. Fred holds acoustic sensor assembly — motor, rotating transformer, magnetometer, and transducer. Tom displays a magnetometer pressure housing section.

## Starting From Square Zero

Sandia's efforts to reduce geothermal well costs really began with work on drilling technology back in 1970. "I headed an exploratory development group working on theater nuclear weapons," recalls Max Newsom (now 9120). "Don Shuster [ret., then Max's director], who foresaw the energy crunch long before it happened in 1973, sicced us onto drilling; he considered it a key technology for a number of energy areas.

"There we were — starting from Square Zero in the drilling research business," continues Max. "We had absolutely no background, nor anywhere to turn for help — at least not inside Sandia.

"Of course, drilling was a well-established industry; the Chinese were drilling wells more than 1000 years ago. Those early days more or less constituted a fishing expedition; we needed to find out what we [the Labs] could do that would have the most impact on the drilling industry, and that meant we had to go to people in the industry for input."

### 'I'm From the Govmint'

"I had a couple of major concerns," says Max. "I envisioned our reception from the oil industry as a cool one; it [the industry] was naturally suspicious of anything or anyone related to the federal government — mainly because of regulatory and antitrust actions in the past. Suffice it to say they didn't believe the old saw, 'I'm from the govmint and I'm here to help you.'

"However, Sandia's AT&T connection really helped in that regard; the industry was surprisingly receptive — which was essential, since we knew if we did anything worthwhile related to drilling, it had to be picked up by industry to have any value.

"And that took care of my other big concern — that we would need access to drilling rigs, wells, and other equipment furnished by the oil industry; we couldn't afford to drill our own wells for tests. Fortunately, we had excel-

lent cooperation from industry right from the start. For example, Dresser Industries set up a special three-day colloquium for us in Houston that included its best people in all aspects of well drilling and completion. It really helped us move up the learning curve."

### Oversight Committee

Another plus early on, according to Max, was the formation of an industry oversight, or technical review, committee in 1972-73. Representatives from industry and universities would get together with Sandia researchers every six months or so to critique Labs drilling research efforts. "They [the non-Sandians] understood that we weren't asking for a rubber-stamp approval," says Max. "We paid attention to what they said — and, as a result, they became a vital part of our program."

Sandia's early geothermal research had its downs, as well as ups, Max recalls; some ideas generated were technically good, but not economically feasible. "Industry people viewed us as 'far-out,'" says Max, "because our ideas were different — even revolutionary — in their conservative eyes.

"Industry people weren't used to giant leaps, and the high-risk, high-reward kind of approach. For example, the rollercone drill bit, invented in 1908, mirrors that philosophy; it has been continually improved, but it looks pretty much the same today as it did in the original patent papers (LAB NEWS, October 21, 1988).

"One thing became clear early on," Max continues. "Because the geothermal industry is small in comparison to the oil and gas business, all our geothermal advances — especially in drilling mechanics — had to have applications in oil and gas activities; otherwise, private industry wouldn't pay much attention." (Between 50 and 60 geothermal production wells are completed each year in the US. According to *Oil & Gas Journal*, about 37,000 domestic oil and gas wells will be completed during 1988.)

(Continued from Page Ten)

## Geothermal

more than 2000 megawatts (MWs) of electricity — about the same as two nuclear power plants — to the US energy supply at "prices competitive with coal and nuclear power," says the publication, which projects that this country's hydrothermal electric power capacity will reach 4700 MWs of electricity by 1995.

Hydrothermal heat sources hot enough to produce electricity are found only in areas that have experienced volcanic activity, Jim Dunn explains. "The area in our country with greatest geothermal potential is the west coast — our part of the 'Ring of Fire,'" he says. "The Geysers area in northern California is currently the leading producer of geothermal electricity in the US — it contributes some 1500 megawatts, enough to satisfy the electricity needs of a city with more than one million inhabitants." And Geysers power comes in at costs 25 to 35 percent less than fossil-fuel-generated electricity, Pacific Gas & Electric officials say.



JIM DUNN (6252)

"The geothermal industry also is beginning major development of another geothermal reservoir in California's Imperial Valley," Jim adds.

Even geothermal experts have been known to gasp at the estimated size of geothermal's potential. The US Geological Survey (USGS) has concluded that the resource — including its less-developed branches of magma energy and hot-dry rock (being investigated primarily by Los Alamos National Laboratory) — significantly exceeds known US coal, oil, and gas reserves. Moreover, many scientists believe that the heat content of the earth equals five million times the total amount of solar energy the earth receives annually. If geothermal heat could be converted into electrical power, it would satisfy the earth's energy appetite for a million years.

That's a tall order, considering that energy research is not the fair-haired child it once was.

To make up for lack of economic incentive to commercialize technology expressly developed for the geothermal industry, the Geothermal Drilling Organization (GDO), established in 1985, provides a cost-sharing plan between government and its 23 industrial members. DOE and GDO industry partners share the funding burden, on a 50-50 basis, for items chosen by GDO for commercialization.

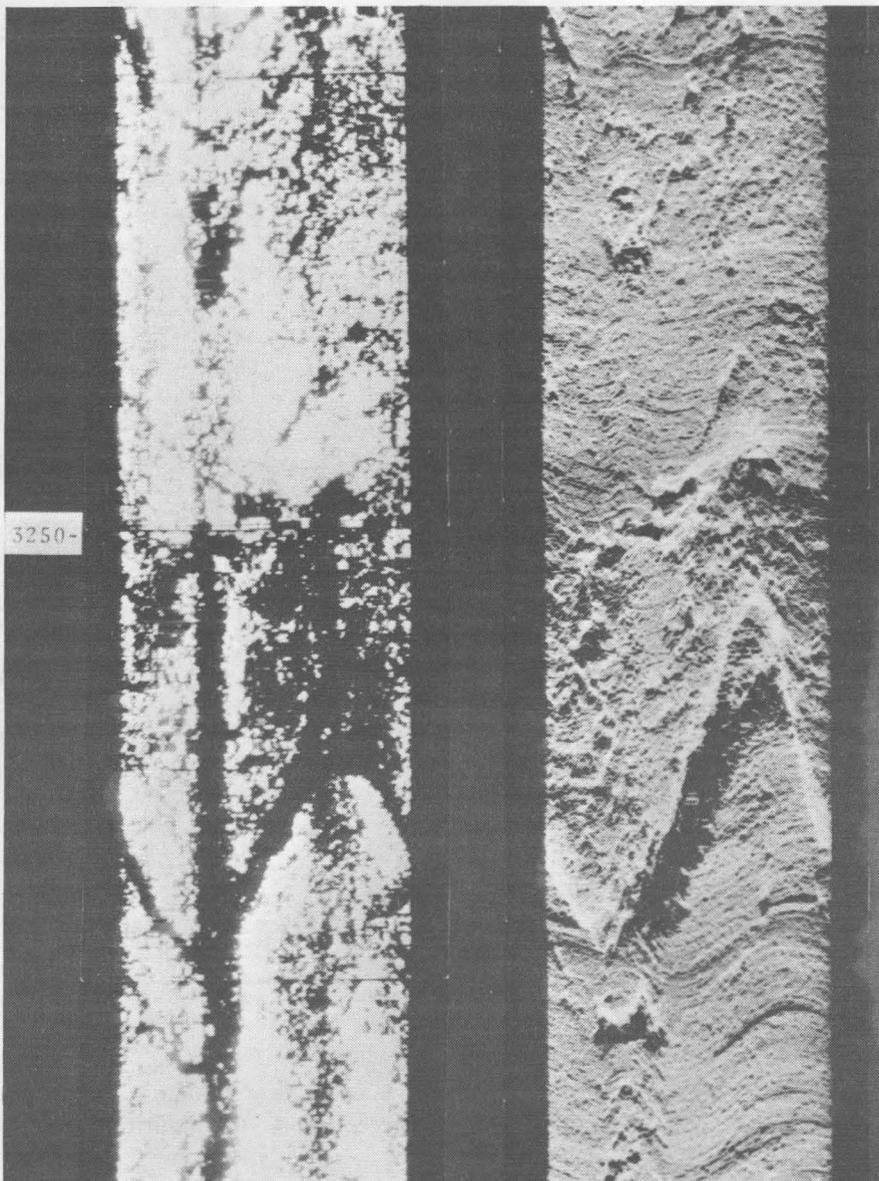
Once a GDO project goes to a company for commercial development, Sandia is responsible for contract management, technical advice to the contractor, and testing assistance. As Jim puts it, "Everybody benefits. GDO partners come out ahead because they receive the primary benefits of new technology commercialization, as well as DOE funding assistance; Sandia benefits from its interaction with industry."

### Inertial Navigation System

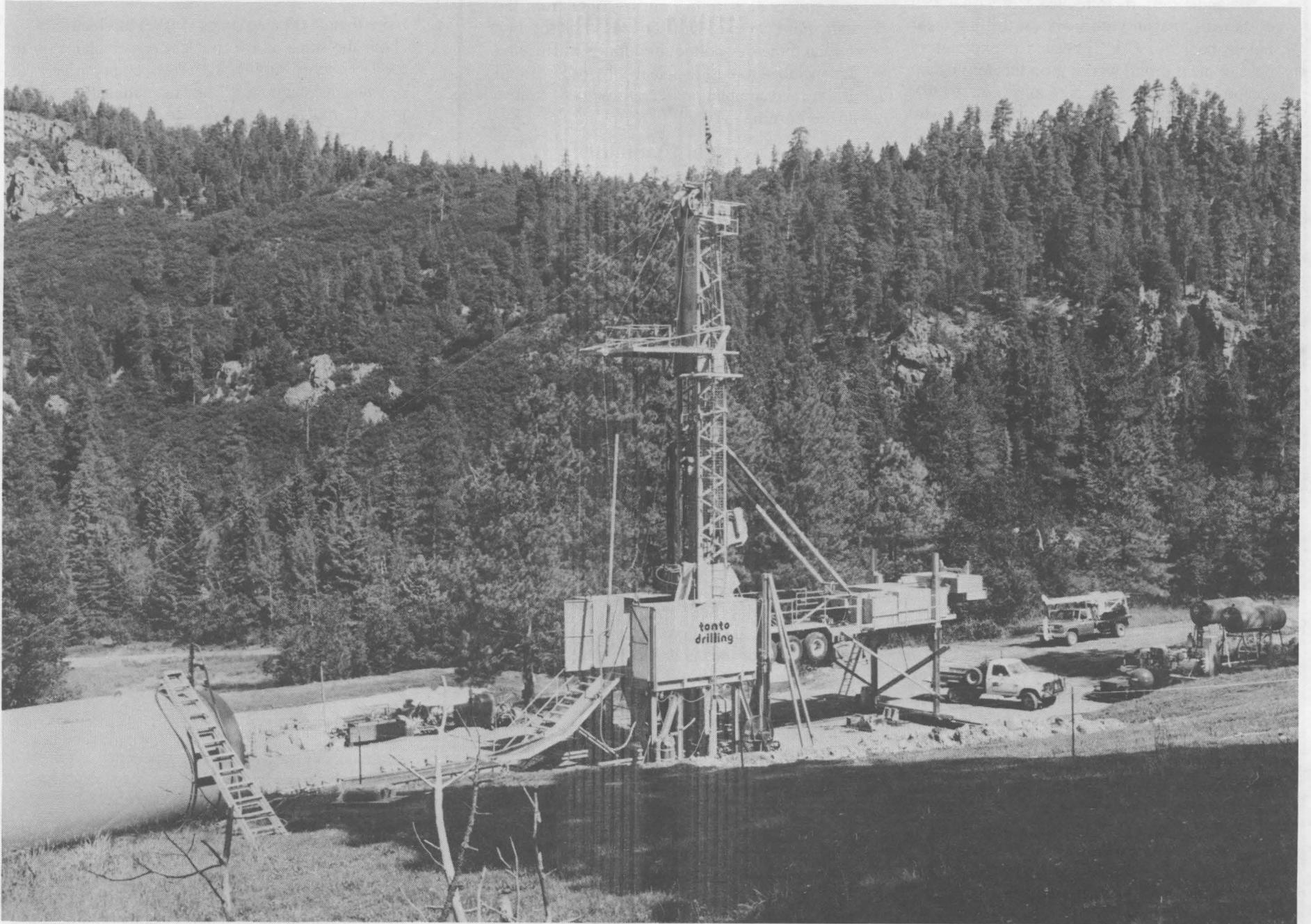
One of the developmental geothermal logging tools successfully designed and tested by Sandia is an experimental wellbore inertial navigation system that logs paths of directional holes much faster and more accurately than conventional surveying systems.

(Continued on Page Fourteen)

FRACTURE that diagonally bisects circumference of a geothermal borehole at a depth of about 3250 feet looks like a dark, sine-wave-shaped line in the center of picture on left. Computer-enhanced version on right shows greater relief. Such views are developed by the acoustic borehole televiewer; they help determine the best lost circulation material to plug borehole fractures and to prevent the loss of drilling mud.



# Valles Caldera Corehole Completed



VALLES CALDERA COREHOLE drilling, completed last month, was both a scientific and an engineering success. The corehole, part of the Continental Scientific

Drilling Program, reached a depth of 5780 feet and a high-temperature (>570°F) geothermal zone. Site is on private land in the Jemez Mountains north of Albuquerque.



AS PETE LYSNE (6252) explains to a site visitor (out of camera range), the 50-ton drill rig sits 12 feet above grade (note rig wheels in large photo). The extra height permitted installation of main BOP (blow-out prevention) stack, a series of valves that can shut off the flow of fluids or gases to the surface whether or not a drill string is in the corehole.

A nearly flawless step toward understanding the geothermal resources nearly under our feet — well, nearly under the feet of our Los Alamos National Lab colleagues — was completed last month.

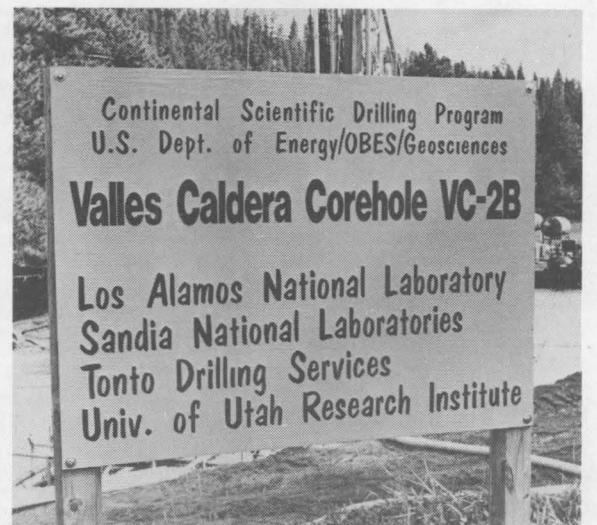
A 5780-ft.-deep corehole was drilled into the Valles Caldera, a 1.1-million-year-old crater in the Jemez Mountains west of Los Alamos; nearly 100 percent of the core was recovered for later analysis.

Peter Lysne (6252) directs the Geoscience Research Drilling Office, a part of the 15-year-old Continental Scientific Drilling Program, which is funded by DOE's Office of Basic Energy Sciences. Purpose of the CSDP is to drill in sites never before explored, especially volcanic areas, fault zones, and mountain ranges (see "His Thoughts Turn to Alaska"), and use the resulting data to create a clearer understanding of underground resources.

As the CSDP representative on this particular project (the third corehole in an isolated but idyllic corner of the Valles Caldera), he was responsible for field-site management and safety, daily operations, etc. — "pulling off the job, in other words," says Pete.

The job — officially called Valles Caldera Corehole VC-2B — came off well. "We'd predicted a 100-day drilling operation, and that's just what it took. We didn't have the typical drilling difficulties, thanks to three years of work by the planning team; a new, heavy-duty drill rig; and an extremely professional drilling crew that took a strong interest in the program and became personally involved in its success.

"The new rig and seasoned drill-rig crew set new standards for ease of drilling, safety, and accuracy — the corehole is plumb to within 1 degree," Pete continues. "It was a spectacular success.



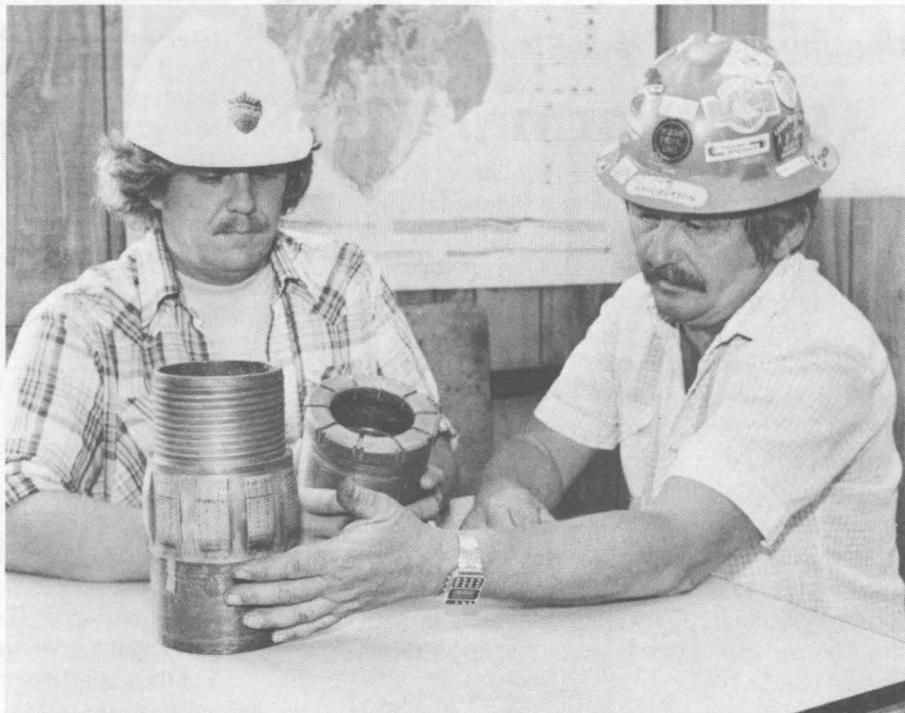
CDSP (Continental Scientific Drilling Program) is funded by DOE's Office of Basic Energy Sciences, the US Geological Survey, and the National Science Foundation. On the VC-2B project, co-principal investigators are from LANL and UURI; Pete Lysne (6252) heads the CSDP's Geoscience Research Drilling Office and headed the engineering and logistical tasks involved in the VC-2B project. (The first CDSP corehole in Valles Caldera area was VC-1, the second — next door to this site — was VC-2A, this one is VC-2B.)

"More important, from the scientific point of view, is that we achieved everything we planned. We drilled completely through an active [570°F] hydrothermal zone, including volcanic and sedimentary rock, and into the granite 'basement' rock.

"Our core-recovery rate was 99 percent; in this business, that means 'highly successful.' And we introduced a new drilling technology, a marriage between traditional rotary coring and 'wireline' coring."



MIKE LaORANGE (right) of Tonto Drilling Services was chief day-shift operator. Here (aided by the depth indicator Pete's pointing at), he's at the control console lowering a coring tube at the end of the wireline. Innovative system permitted core samples to be removed from the corehole without removing the bit or the entire drill string. Unlike most such drill rigs, this one is quiet enough to allow normal conversation at the control console. Depth indicator was one of the devices developed by Ron Jacobson (6252) to provide greater convenience and safety for the drilling operation.



DIAMOND-IMPREGNATED CORING BIT is held by LANL's Jamie Gardner (left), one of the two principal investigators on the Valles Caldera project (the other is Jeff Hulen of the University of Utah Research Institute). At right is Ron Jacobson (6252) with a reamer shell that brings the corehole into final gage.

**(Continued from Preceding Page)**

The Australian-built drill rig, modified with convenience, safety, and BOP (blow-out-prevention) features, is the largest wireline coring rig in the world. The wireline — a cable running down the drill string to the core-collection tube — allows the drilling crew to pull core samples from the bottom of the corehole without pulling the entire drill string (an expensive step in terms of time and, therefore, money).

A drilling crew doing exploration (either geothermal or fossil fuel) could use a faster rotary cutting bit in zones in which coring isn't needed, then switch to wireline with a diamond-impregnated coring bit like the one used at VC-2B in zones where coring is desired.

**Add to the Storehouse**

The coring bit produced 2.5-in.-diam. core samples, which will be analyzed by LANL and the University of Utah Research Institute, the two organizations responsible for the scientific direction of the drilling project. Other members of the science team — some 50 strong — will assist in core analysis with the aim of adding to the nation's storehouse of knowledge about its geothermal resources.

Much of the corehole was cased with a steel liner. Next year, that liner will be perforated at several levels to allow fluid sampling and flow testing in the liquid-containing zone.

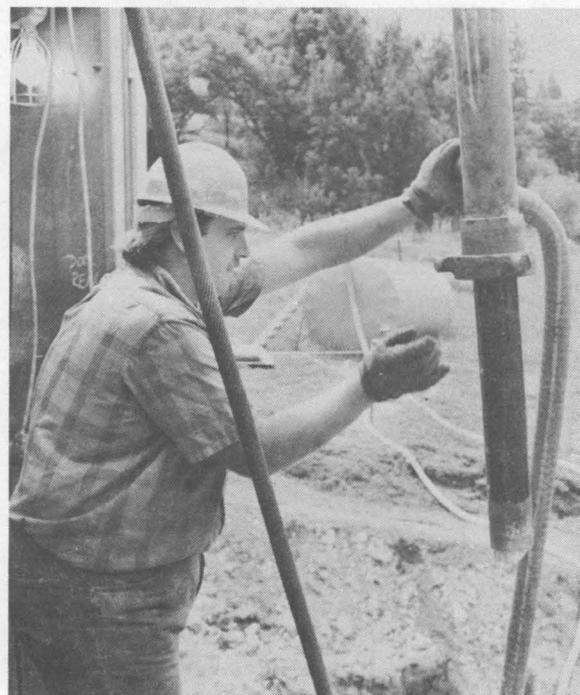
In addition to Sandia's involvement on the sci-



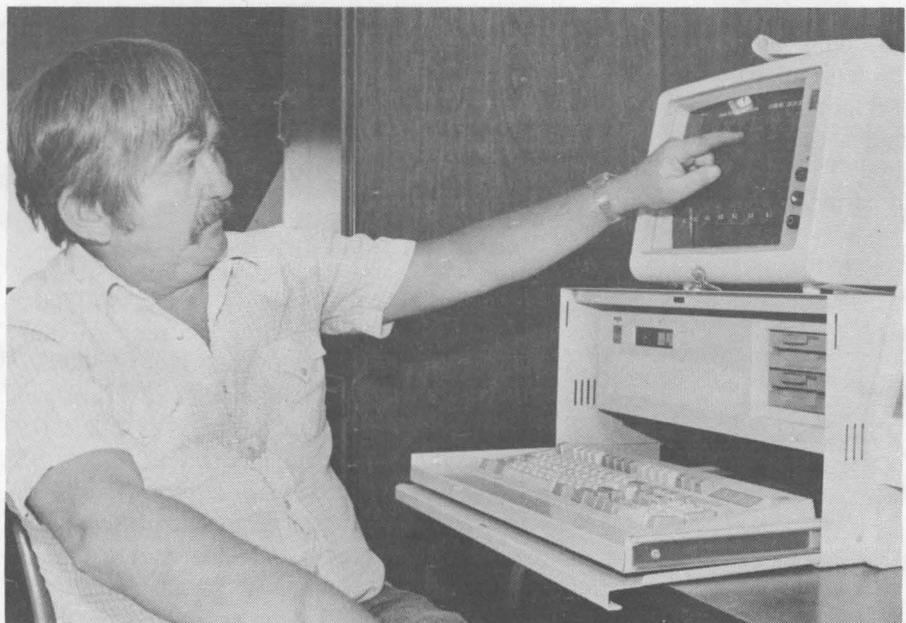
INTERNATIONAL EFFORT — Although the Continental Scientific Drilling Program is a US program, Tonto Drilling Services is based in Canada, and the drill rig was designed and built in Australia. As this license tag shows, it's registered in Queensland.

ence team, the Labs contributed to the drilling project in three areas: lost-circulation materials (notably mica; see "Curing Lost Circulation"); additional instrumentation on the drill rig for safety and convenience; and a strong safety program — emphasizing the dangers of hydrogen sulfide, a potential threat in geothermal formations — for all on-site members of the drilling team.

"Many Sandians — especially those in Medical and environmental health — worked hard on our safety program," says Pete. "We used a systems approach that included safety devices and warning devices, training classes, and linkages with Lifeguard I and local hospitals and paramedics." ●BH



TIP OF CORE SAMPLE is visible at end of core tube. Tonto's Jeff Riley has his left hand on the loading chamber that provides blow-out prevention even when a core tube is being removed from the corehole. Jeff and other members of drill crew received special training in BOP operations.



RON JACOBSON (6252), who served as site manager for the Valles Caldera project, helped develop computer-controlled safety systems for (1) recording flow rates and temperatures of mud pumped into and out of the corehole, and (2) monitoring the levels of hydrogen sulfide gas at the site (seven remote sensors connected to lights and horns to indicate potential or actual danger); he was assisted in this system by Bob Wemple (6252) and Brian Kelly (3314). On the screen is a log of gas sensor data. (Preceding photos by Gerse Martinez, 3162)



SAME TIME, NEXT YEAR Pete Lysne (6252) may be working on another CSDP project in Alaska. Here, he walks along some ground warmed by escaping steam and hot gases in the central portion of the volcano vent formed in 1912 near Katmai National Park. "The Valles Caldera project was only 75 miles from home," says Pete. "Next year it may be 2900 miles — if the project in Alaska works out"; see "His Thoughts Turn to Alaska" story, p. 17.

*(Continued from Page Eleven)*

## Geothermal

"Geothermal wellbores are seldom vertical," says Stewart Kohler (2334), who developed the system in the early 80s with Ralph Wardlaw (9131). "The heat resource may be under a river [or under valuable Imperial Valley farmland in California], for example. Or you may be drilling in mountainous terrain [like the Geysers, north of San Francisco]. In both those cases, you'd have to drill a directional [angled] hole to the reservoir, and you have to know where the drill bit is headed."

A detailed wellbore survey is useful because, typically, several production wells are drilled from a single pad in geothermal fields, Stew explains. Also, several wells may be drilled from one offshore platform. Accurate knowledge of borehole paths allows proper spacing and assures that target formations are reached.

An outgrowth of inertial navigation systems developed at Sandia for reentry vehicles subjected to severe environments, the geothermal logging tool adaptation consists of a surface computer and a downhole probe containing gyroscopes, accelerometers, electronics, and a battery. As the probe descends a well, gyroscope and accelerometer outputs are transmitted via electrical cable to the surface computer, which calculates probe position 16 times a second, producing a log that charts the hole's path in three dimensions: depth, angle, and distance from the drilling rig.

The system achieves surveying accuracy of one foot per thousand feet of well depth and can survey a 10,000-ft.-deep well in about one hour. Key to its superior accuracy and rapid operation is Kalman filtering, a sophisticated error-reduction procedure used extensively in airborne navigation and adapted by Sandia researchers for underground application.

Pieces of the technology are being incorporated in commercial directional logging tools used in offshore petroleum drilling. The complete design is waiting in the wings, perhaps for the time when oil prices go up, and geothermal energy becomes economically competitive.

### Acoustic Borehole Televier

Several years ago, Sandia extensively modified the original design of a borehole televier patented by Mobil for geothermal use. "It's important to get a picture of borehole walls, so you can see where fractures intersect it," says Fred Heard (now 9234), who led the R&D project. "Knowing precisely where fractures are is a key to successful geothermal energy recovery, since productivity is determined primarily by the extent that the wellbore intersects the fracture system.

"Although the original Mobil televier was useful for providing acoustic images of borehole walls in low-temperature oil and gas wells," Fred continues, "it could not function in a hot, corrosive geothermal environment."

Sandia modifications included a redesigned electronics package, the addition of hybrid electronics, and changes in other materials to harden it for

high-temperature use. Design goals — 275°C and 5000-psi (pounds per square inch) pressure — for a new commercial version were met in laboratory and field tests conducted during 1987.

The televier emits bursts of acoustic energy (1500 pulses/sec. at 1.3 megahertz) from a rotating transducer as it's pulled up or lowered into the borehole. The energy travels through an acoustic window made of Teflon, hits the borehole wall, and is reflected back to the transducer.

The amplitude of these reflections and the time it takes them to return to the transducer are recorded and processed on the surface, yielding a picture of the wall. Smooth surfaces reflect a high-amplitude

signal, while rough surfaces or fractures send back a low-amplitude signal.

The televier also provides data on the well's shape by providing an accurate caliper log of its diameter; that's important information, because it can be used to estimate underground stresses. Also, once a well casing is in place, the instrument can be used to inspect the casing for deterioration, holes, corrosion, and physical damage.

Although specifically designed for geothermal drilling, the televier may also be used during oil and gas drilling in deep, hot reservoirs or in hard, fractured formations.

*(Continued on Page Fifteen)*

## Curing Lost Circulation

Lost circulation: For some, it provokes uneasy thoughts about hardening of the arteries and worse.

For the scientist or engineer bent on seeing geothermal energy reach its potential, it certainly can cause heartburn.

Considered by some experts in the field to be the most serious geothermal well development problem, it's a phenomenon that occurs because reservoirs are underpressured — that is, the pressure in a producing geothermal formation is less than that of the drilling fluid pumped down the borehole to clean, cool, and lubricate drill bit and drill string.

Thus, the drilling fluid, or mud (see "Mud — Not the Kind Kids Use to Make Pies") — also used to carry drilling debris to the surface — escapes through cracks or pores in the surrounding rock, clogging it and causing irritating (and often costly) drilling problems. A succinct way of describing the problem, says James Kelsey (now 5260, former Geothermal Research Technology Div. supervisor), is that geothermal wells "tend to suck."

And Dick Traeger (6250) adds, "Losing 20,000 to 30,000 barrels of drilling mud at the bottom of a borehole because of lost circulation gets everybody's attention."

### Forget About Nut Shells

The first line of defense against loss of vital mud when drilling in the oil patch is to add inexpensive lost-circulation material — for instance, ground nut shells, cotton seed hulls, or paper pulp. When pumped downhole with the mud, the material emerges from drill-bit nozzles and flows up the wellbore annulus, which is located outside the drill stem. Along the way, the material plugs fluid escape paths.

But loss of fluid during geothermal drilling can be especially severe because formations tend to have large fractures, fist-size cavities, or even larger caverns. Also, since formation temperatures often reach 400°F or greater, conventional oil and gas lost-circulation materials simply disintegrate.

The standard approach to solving geothermal lost-circulation problems has been to pump cement into the loss zone, and to let it set for about 24 hours before drilling resumes. Sometimes thousands of cubic feet of cement are required. The extra material and required setting time can easily increase well-drilling costs by 50 percent.

Sandia researchers are leading the search for alternative, economic solutions to the problem. "First of all," says Glenn Loeppke (6252), "our studies recognize that loss zones in geothermal drilling come in all types and sizes, and solutions for any given lost-circulation problem must be tailored to the particular type of loss zone encountered."

For loss zones with small fractures — a half inch wide or less — research is aimed at identifying low-cost particulate materials that can survive geothermal conditions.

### How About Battery Casings?

"Recycled plastic scrap may prove to be an ideal material," Glenn says. "Another strong contender is ground automobile battery cases obtained from salvage yards. Both of these materials are abundant, inexpensive, and capable of surviving the severe geothermal drilling environment."

Since "low-cost" in this regard might imply "low-tech," this research may seem at first glance to be an unlikely project for a modern engineering lab like Sandia. "But there's plenty of high tech," says Dave Glowka (6252), "It comes in the form of materials testing in a sophisticated laboratory — the Lost Circulation Test Facility [LCTF]."

Simulating the downhole flow field of a particle-laden fluid in the geothermal drilling environment is no simple task, but the LCTF in Bldg. 851 has such capabilities. Built in 1982 at the suggestion of an industry panel set up to review Sandia's geothermal R&D, it includes two test vessels that operate at temperatures up to 400°F and 1000 psi. One vessel, 10 feet tall and 8 inches in diameter, simulates a length of wellbore and provides a realistic annular flow of mud at velocities up to 200 feet a minute. The other, three feet tall and 20 inches in diameter, holds fractured rock that simulates a lost-circulation zone.

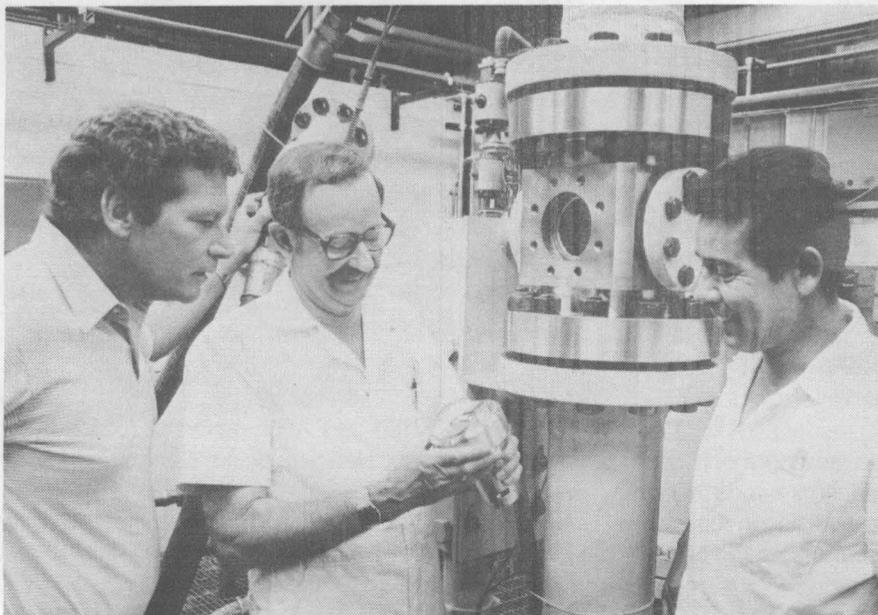
During testing, mud and lost-circulation material flow past slots that simulate different fracture widths or flow into the fractured rock sample. The amount of material mixed with the mud and the material's particle size — ranging from 1/4-in.-diam. to that of fine sand — vary with each test. A computer collects data and controls pressures, temperatures, and flow rates.

### Foams Look Interesting Too

Dave believes that recently developed Sandia computer models are speeding the search for an appropriate lost-circulation material for small fractures. The models accurately predict effects of particle properties, fracture size, and pressure differential on the probability of plugging a fracture.

Loss zones characterized by large fractures, cavities, or caverns cannot be plugged with particle-laden muds. To plug such zones, Sandia researchers are investigating other materials — for instance, high-expansion polyurethane foams, based on those developed at Sandia in the mid-60s as a temperature-tolerant packaging material for weapon electronics.

Sandia and Brookhaven National Laboratory, which has a widely recognized expertise in cement chemistry, are jointly evaluating cementitious muds that rapidly harden as they flow into high-temperature fractures surrounding the wellbore.



HOLDING A "SIMULATED FRACTURE," Glen Loeppke (6252) stands beside the quantitative test vessel of the Lost Circulation Test Facility. Looking on are James Kelsey (now 5260) and John Gabaldon (6252). Glen designed both the vessel and the facility.

(Continued from Page Fourteen)

## Geothermal

Now under development at Sandia is a logging tool that uses radar—and that is designed to precisely locate deeply buried fractures. It's these fractures that are most likely to contain productive geothermal fluids. Previously existing technology couldn't pinpoint the location of potentially productive areas—for oil and gas drilling operations, as well as geothermal—according to project leader Hsi-Tien Chang (6252).

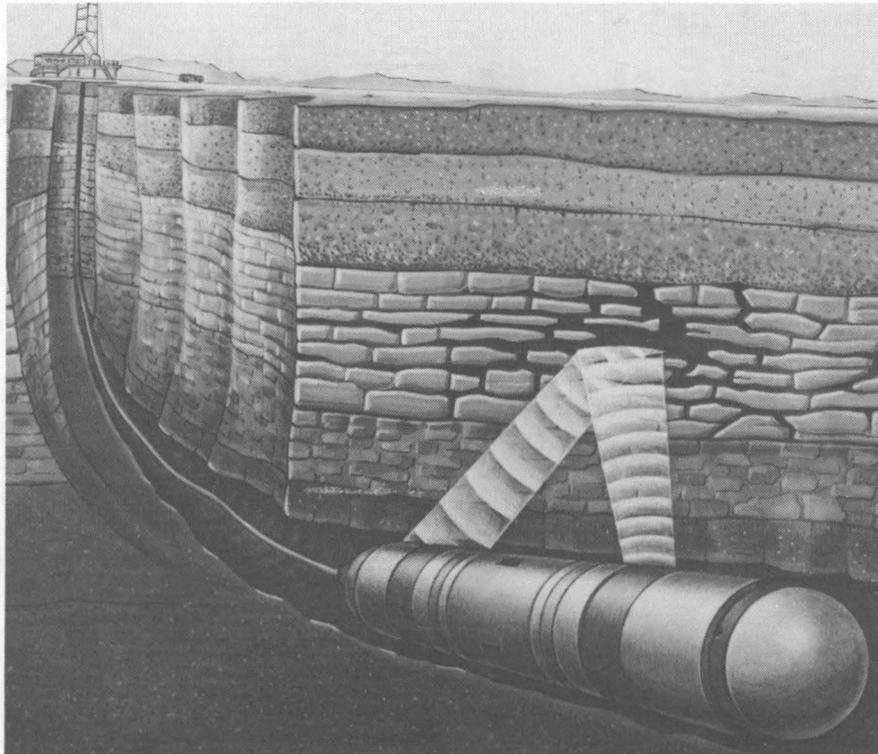
"Between 50 and 90 percent of wildcat wells turn out to be dry wells, because a productive fracture isn't hit on the first try," says Hsi-Tien. "But it's common to find producing wells close to dry wells. So it was important to develop a tool that could be used to find nearby fractures; existing systems couldn't determine the direction of fractures from a borehole."

The challenge, according to Hsi-Tien, was to design a directional antenna that fits inside a typical uncased borehole—about 7-1/2 inches in diameter. Other technical accomplishments included designing the electronics to produce extremely powerful (50-kilowatt)—but short—pulses of electromagnetic energy and developing a technique to transmit the radar's complete return signal through logging cable to data-analysis equipment on the surface.

The mapping tool's transmitter and receiver rotate in place, permitting a 360-degree scan of the hole; fracture direction is determined by transmitting pulses from a known position in the scan. Fluid-filled fractures interrupt and reflect these powerful pulses back to the tool's receiving antenna, signaling location of the fractures. Measurement of the time delay of the return signal gives the distance of the fracture from the borehole.

The first prototype of the tool, built in late 1986 by Southwest Research Institute (San Antonio), has lived up to its billing in tests during the past one-and-a-half years. When the prototype instrument was demonstrated in a lake test at Sandia's Area III and in a hard-rock formation west of Belen, N.M., known metal targets up to 30 feet away were detected, and antenna patterns were measured.

"These tests sufficiently demonstrated the tool's feasibility, so we hope that industry will now pick it



ARTIST'S RENDERING of the Radar Fracture Mapping Tool developed by Hsi-Tien Chang (6252). Besides its original geothermal-reservoir-mapping application, the tool may be useful in nuclear test verification.

up for commercial production," says Hsi-Tien, who has received inquiries almost weekly for the past year from major oil companies, as well as venture capitalists from Japan, France, Sweden, Belgium, and Italy.

Because of its accuracy, Hsi-Tien's development may have another very different application. The tool has been selected for possible use in nuclear test verification. It appears that the device, if placed in a hole some distance from an underground nuclear test site, could be able to reliably survey the surrounding formation, providing an accurate calculation of nuclear yield. In fact, earlier this year, during a Soviet research team's historical visit to Nevada Test Site (in preparation for the US/USSR joint verification experiments), Hsi-Tien briefed the Soviet delegation about the tool.

Sandia's development effort will continue on advanced, even-smaller-diameter models capable of characterizing the fracture target, based on data from the reflected radar signal.

### The Future

Sandia's geothermal effort, funded at \$3.8 million in FY89, will—in the long term—be looking

at huge resource possibilities such as magma, according to Jim Dunn. "Right now, magma exploitation is just in the conceptual stage," he says, "but it's a resource we can't afford to overlook."

"We'll also be taking a continuing look at advanced drilling systems, and working on refinements in high-temperature instrumentation, lost-circulation control methods (see "Curing Lost Circulation"), coring technology, and acoustic data telemetry."

Although geothermal fields are currently producing more electricity than other energy technologies such as solar, wind, or biomass, it's generally agreed that oil prices must rise before geothermal energy can be developed to its full potential.

It's also agreed that the costs of energy are driven mostly by regulations and taxes. Says James Kelsey (now 5260, formerly supervisor of the Geothermal Technology Development Division), "As long as utility companies are controlled by regulatory agencies, the consumer will be protected; alternative—riskier—developing forms of energy will not be used to generate electricity." ●PW



## Hybrid High-Temperature Microcircuits

As it became apparent—as early as 1973—that logging tools developed for the petroleum industry would not stand up in high-temperature environments, part of Sandia's geothermal effort was directed to development of components that would function in environments of 300°C (575°F) or more.

Fortunately, the basic physics of radiation effects on microelectronics is similar to that of thermal effects, so it appeared that Sandia's radiation-hardening work for the weapons program could have direct spin-off.

An industry-university technology panel established to focus on the activity came up with a set of program guidelines. Among them:

- Temperature, pressure, and flow were the highest-priority measurements to obtain from a geothermal well;
- Sandia, in conjunction with industry, would build a prototype temperature and pressure tool to verify operation of components;
- Thick-film, hybrid microcircuitry would constitute the base technology because (1) interconnections and passive components were prepared at 700° to 900°C and so were inherently thermally stable, (2) many companies produced thick-film circuits, (3) the circuits were rugged, (4) many assembly options were available, and (5) technolo-

gies developed could also be used with high-temperature printed wiring boards.

Under contract, several universities worked on different aspects of temperature effects: semiconductor studies at Clemson, thick-film research at Purdue, magnetics at Texas A&M, thin-film studies at Arizona. Sandia's solid-state research organization worked with the University of Wisconsin on new high-temperature semiconductor devices, and the Labs' electronics group collaborated with industry to determine temperature limits of capacitors, resistors, inductors, and other components.

The first logging instrument to result from these studies was a tool to measure borehole temperatures. Sandia developed the high-temperature electronics used in the tool, and Gearhart Industries (now part of Halliburton Services, Ft. Worth) designed and built the mechanical parts.

In early 79, a test in the Jemez Mountains at a Union Oil geothermal well confirmed that the logging tool could, indeed, withstand geothermal temperatures; the tool operated successfully for 1-1/2 hours at 275°C—the highest temperature at which an uncooled and uninsulated instrument equipped with active electronics had ever operated.

### Transfer to Commercial Sector

After the test verified overall system operation, a main goal of the program was realized:

Commercial industry picked up the technology, much of it developed in the weapon program. Sandia contracted with Teledyne-Philbrick to build five different hybrid microcircuits for use at 300°C, and all the major logging companies shifted to hybrid or similar technologies for commercial operation.

Other technology advances developed under the program were commercialized, including high-temperature elastomers and electronic-connection procedures. Several thick-film ink companies developed and marketed new resistor, capacitor, and conductor pastes for high-temperature circuits.

Another program outgrowth was Sandia's building and testing of advanced semiconductor structures that showed stability at extremely high temperatures. In 1983, for example, Labs solid-state science researchers developed a gallium phosphide/aluminum gallium phosphide transistor and thyristor that could function at 550°C—the highest operational temperature ever recorded for such devices.

Although interest continues in high-temperature electronics for use in gas turbine (jet) and piston engines, automobile engine and brake control, nuclear power plant instrumentation, and spacecraft, temperature capabilities of off-the-shelf electronics are not likely to be increased in the near future because of low market demand.

## A Special Brand of Geothermal Energy

# Unraveling the Mysteries of Magma

MANY SCIENTISTS, including Dick Traeger (6250, foreground), took the opportunity to get a good look at the 1979 eruption of Kilauea volcano in Hawaii. Dick's waiting his turn to rush up the bank of a 1095°C lava river so he can hold a calorimeter in the flow for a short time. This was part of early magma energy studies to determine how much thermal energy the hot rock contains.



It's estimated that between 50,000 and 500,000 quads of magma energy — at greater than 600°C (1100°F) or greater — lie at a maximum of six miles (almost 10 kilometres) below the US. A quad is a quadrillion BTUs. Figuring that there are about five million BTUs per barrel of oil, it follows that this amount of magma could contain as much energy as 100 trillion barrels of oil.

But *big* questions remain concerning how to economically tap this special kind of geothermal energy and how to verify those resource estimates.

Known US reserves of economically recoverable oil total about 28 billion barrels. Oil can be recovered, transported, stored, and put to work using known techniques. Not so with magma.

But natural magma-generated steam is used today to generate electricity at a number of locales worldwide. For instance, magma-made steam provides heating for nearly all of Reykjavik, Iceland.

There's a big difference, however, between what's happening at Reykjavik — essentially, magma-produced heat rising to the surface as conventional geothermal energy through the good resources of Mother Nature — and what Sandia calls the tapping of magma. Labs scientists want to go deep into the earth to collect magma's heat. After being brought to the surface with special equipment, that heat could be used to generate electricity.

### Problems: Finding It, Getting It

This is a big order, of course. Magma can be 15 to 25 miles below the earth's surface — too deep to reach easily with present-day technology. Even drilling down to shallow magma — within six miles of the surface and Sandia's real target — remains extremely difficult, although some of the Labs' major

scientific and engineering contributions during its magma R&D have been drilling and well completion successes.

Sandia's initial magma program (see "Sandia's Magma Attachment"), charged with determining scientific feasibility of the magma tap concept, began in FY74 and continued through FY82. Spent in the process was some \$4.9 million, of which more than \$2 million was disbursed to universities and other non-Sandia entities. Harry Hardee (6231), well aware of the difference between theory and practice, took pains to define scientific feasibility. It is, he wrote, "demonstration, by means of theoretical calculations and supporting laboratory and field measurements, that there are no known insurmountable theoretical or physical barriers that invalidate a concept or process."

When work concluded, program participants and the program's advisory panel (consisting of top US scientists in disciplines such as volcanology and heat transfer) agreed that it is "scientifically feasible" to:

- Locate and define magma sources;
- Drill into these magma bodies;
- Determine magma characteristics at given sites;
- Assure compatibility of magma with manufactured materials; and
- Develop useful means of extracting magma's thermal energy.

En route to determining scientific feasibility, Sandia researchers racked up five years' experience of drilling into Kilauea Iki (Hawaii) lava lake (essentially erupted, degassed magma). "We drilled at two different times," recalls John Colp (ret.). "The first was to determine the lava lake's depth. Then we drilled deeper into still-molten rock below the lava lake." To do that, Sandia used core drilling tech-

niques and equipment developed by Jim Dunn (6252) and Dick Striker (ret.), with input from the Eastman-Christensen and Longyear companies.

The bit used was a 59-mm-diam., face-discharge diamond coring bit fitted with nozzles capable of discharging water at speeds up to 90 metres/sec. Water cooled the bit, removed chips, and chilled the molten rock into a drilling consistency. Holes were kept open with a moderate, continuous flow of water.

In the lab, Sandia's magma investigators conducted numerous experiments with a unique Magma Simulation Facility, built a laboratory experiment that proved the feasibility of using a heat exchanger to carry thermal energy from magma to a surface boiler, and performed computer calculations on energy transfer rates, convection dynamics, and other phenomena that are parts of the magma energy extraction challenge.

### Energy Extraction — How to Do It?

In the early 70s, some geoenergy experts proposed liquid metals as a heat transfer medium for tapping magma's thermal energy. Others thought that actually pumping magma to the surface might work. And Sandia even considered, although briefly, reacting water with iron in magma, so that hydrogen is produced for industrial processes. The Labs also addressed pumping biomass — crudely speaking, garbage — into magma, and capturing the resulting mixture of hydrogen, methane, and carbon monoxide for use as fuels and/or chemical feedstocks.

But Sandia's final scientific feasibility research project report emphasized Harry Hardee's 1973 suggestion — pumping water into magma where it is heated. The resulting steam, he proposed, could be brought to the surface and used to drive a turbine/generator to produce electric power. Sandia has addressed two variations. The "closed" system is essentially a conventional closed heat exchanger — typically a water-filled pipe — inserted in a cased hole that penetrates into molten magma. The "open" heat exchanger system involves injecting water directly into molten magma, where it would solidify and fracture the magma, creating an expanded "natural" heat exchange area.

(Continued on Page Seventeen)



JOHN RUNDLE (6231) inspects some white hydrated rocks around a small fumarole — steam vent — on the Resurgent Dome near Mammoth Lakes, Calif.

## Magma: Restless Sculptor

Magma is the stuff of volcanoes — molten or partially molten rock, glass, carbon, sulfur — that lies below the earth's crust and which, when prompted by gargantuan tectonic stresses miles below the surface, can surge upward and outward as lava. Huge magmatic monuments to past volcanic activity are scattered around the face of our planet, from Stromboli to Shiprock to Yellowstone National Park.

Above the surface, pocked with broken gas bubbles and studded with sand and rock, magma becomes the *malpais* near, for example, the New Mexico towns of Grants and Carrizozo. Other magma extrusions form cowpat-shaped, but football-field-sized dollops where Sandians have drilled near Mammoth Lake, Calif. It's also the forerunner of glassy black volcanic obsidian, which is considered a semiprecious stone, contributing "Apache tears" for costume jewelry.

The cataclysms of volcanic action prompted by unruly magma contribute rich pages to human history. Vesuvius fossilized Pompeii and Herculaneum in thick ash; the extinct Thera similarly buried Akrotiri and probably caused the downfall of Minoan civilization; the legendary Krakatoa burst forth from Java a century ago. In modern times, Mount St. Helens erupted with stupendous force, joining the continuing disquiet of the many volcanoes dotted around the Pacific Rim.

Magma is the hot, upwelling fluid contributing to earthquakes, the upthrust of mountain ranges, and the expansion and recession of coastlines. It, along with erosion, is a restless sculptor of earth's ever-changing terrain.

But underground — where it usually stays — magma heats water that feeds hot springs and geysers.

**How It All Began**

## Sandia's Magma Attachment

Sandia's magma energy project — originally called magma tap and first funded in FY74 — was born a couple of years earlier out of the innovative minds of George Barr (now 6312) and Tony Zuppero (now General Dynamics, San Diego).

The first SAND report on the subject, "A Proposal to Investigate a New Energy Source: The Direct Magma Tap," credits George and Tony with the original concept and initial proposal formulation.

As was the case with other oil-embargo-era proposals that grew into Sandia energy programs, the duo was essentially asked to brainstorm possible energy-related projects.

"Back then," Tony recalls, "George and I were considered to be people who thought about the unusual, the strange. We were asked to think about ways to address the energy problem."

Tony and George looked into a number of alternative energy sources, from tidal power to oil shale (see "Squeezing Crude From Rock").

Tony, one of several people at the Labs then doing quality-of-energy calculations on various energy sources, thought magma looked good, and said so.

Shortly after documenting their original magma tap concept (SAND73-0907), Tony and George went on to different projects, while others picked up the magma tap ball and ran with it in all-American style.

Many of those key team members came from the group that pooled its thoughts and expertise to produce that first magma tap SAND report.

Its acknowledgement page: Harry Hardee (6231), heat-transfer calculations; Virgil Dugan (6200), economic analysis; Bill Snyder (6500) magma properties; Dick Heckman (ret.), high-temperature materials study; Dick Lynch (6300) and Mark Davis (1830), materials compatibility; Ed Graeber (5214), magma properties; Glen Brandvold (ret.), program coordinator; John Colp (ret.), magma source survey; and Wayne Young (9122), drilling and *in situ* measurements.

When Sandia's original magma program ended, it had laid the foundation for further studies — determining *engineering* feasibility. By that time, it also had nucleated a special by-product, a strengthened network of people and institutions with magma energy research expertise ranging from tectonophysics to materials corrosion. Prominent among these, predictably, was the USGS. Others included Stanford, Dartmouth, Texas A&M, Brown, Ohio State, the University of Minnesota — all represented on the project's advisory panel along with the USGS — plus Arizona State, MIT, the University of Alaska, and the University of Texas at Austin and Dallas.

### Energy Extraction Experiments

The magma program received a new lease on life in FY84, with the start-up of the Magma Energy Extraction Project by DOE's Geothermal Technology Division. It included follow-on investigations of Sandia's earlier work, with one big addition — studies aimed squarely at energy extraction, and thus a demonstration of engineering feasibility.

With energy extraction on the menu, Sandia's magma experts — Jim Dunn's crew, and others in Dick Traeger's and Bill Luth's departments (6250 and 6230, respectively) — have taken on the dream of drilling into an active magma body (see "Drilling Project Aims for Active System") and then conducting an actual energy extraction experiment. Research is directed at drilling and borehole measurements, energy extraction and conversion, and studies of a 20,000-ft.-deep magma body south of Lake Tahoe in Long Valley, Calif., where there's a caldera, a cauldron-shaped formation that marks the site of an ancient volcanic eruption. "Caldera systems," explains John Rundle (6231), "are probably the foremost source of continental magma because active magma chambers are thought to be under them. At one time, all of these had gigantic eruptions of magma, although this occurred 700,000 years ago at Long Valley."

### Lots of Folks

From the beginning, Sandia's magma program has been a multidisciplinary effort (see "Sandia's *(Continued on Page Eighteen)*")

**(Continued from Page Sixteen)**

## Unraveling

Back in 1979, Harry, Dick Traeger (6250), and Ed Graeber (5214) made the first field measurements of heat extraction rates from freshly erupted molten lava. That was at Kilauea volcano, where they basically walked bravely (but not necessarily intelligently) up to flowing rivers of the 1095°C-lava and inserted highly instrumented calorimeters. Then in 1981, Harry, Jim Dunn, John Colp, and Dick Striker traveled to nearby Kilauea Iki lava lake for field experiments to illustrate — successfully, it turned out — the effectiveness of an open heat exchanger.

The open heat exchanger consisted of a hole extending a little more than 50 feet into the molten zone, with the last 20 feet being uncased. Injection of water into the magma around the uncased por-

tion of the hole solidified and fractured the magma, creating an expanded heat exchange area.

Controlled injection of water into the hot (greater than 700°C), solidified magma (about 200 feet below the surface) produced either a steady flow of steam at the surface or a cyclic, geysering action. Injecting water at 0.04 litres/sec. for 24 hours produced a continuous flow of steam with an energy extraction rate of 93 kW/m<sup>2</sup> (85kW/well). A typical cyclic injection operation involved pumping 19 litres of water into the molten region within a minute. As pressures down-hole quickly increased to 100 psi, a valve opened and steam flowed to the surface.

Harry considers the drilling demonstration, field operation of an open heat exchanger, and demonstration that acoustic waves can be transmitted through molten rock to be the magma program's three most-significant accomplishments to date.

## His Thoughts Turn to Alaska

With summer only a few short months away, John Eichelberger's (6233) thoughts turn fondly to Alaska, specifically to the Valley of Ten Thousand Smokes in Katmai National Park, about 300 miles southwest of Anchorage.

John's Alaskan dream is to sink thin shafts of steel into the volcanic veins of that place where 76 years ago an eruption 100 times larger than that of Mount St. Helens occurred. This largest volcanic eruption of the century spewed an amazing four cubic miles of magma from a 1-1/4-mile-diam. vent in 60 hours. So much magma emerged from the earth that, six miles away, on the crest of the Aleutian Range the 7000-foot-tall Mt. Katmai collapsed to form a crater lake.

John's aim is to find out how magma erupts, how fast it cools, and how metals are transported in magmatic vapor. "All of this will contribute to our knowledge of natural resources and crustal evolution," John says.

Surface investigations designed to map the subsurface shape of the 1912 vent are scheduled to begin next summer. Engineering design of the drilling operation, tentatively scheduled to begin in about two years, is spearheaded by Allan Sattler (DMTS, 6253). John is chief scientist for the overall Katmai project, which is officially titled "Direct Observation of a Young Igneous System."

### Bleak Landscape, Dismal Weather

"The plan to start work in the summer months really doesn't provide that much consolation," John admits. "This field lab is noted for its bleak arctic/volcanic landscape and dis-

mal weather. It can be reached only by foot (which I prefer) or helicopter. It's above the timberline, and winds can reach 100 mph any time of year."

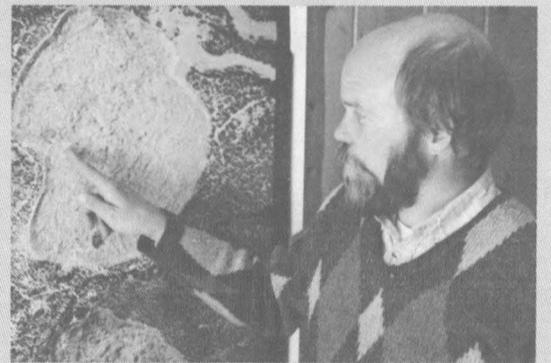
Funds for the project will come from the Continental Scientific Drilling Project (CSDP), joint geophysical progeny of the National Science Foundation (NSF), US Geological Survey (USGS), and the DOE's Office of Basic Energy Sciences (BES).

John says seeds for CSDP were sown some 20 years ago, when a growing number of people were coming to believe that advances in earth sciences would depend very strongly on drilling — in order to take samples and make measurements at depth.

"This philosophy had worked very well in research on ocean basins, and contributed to revolutionary ideas like continental drift," John explains. "So it seemed reasonable that the same approach should be applied to continents. Lots of work has been done for commercial reasons [oil, gas and geothermal exploration, for example], but there are still large parts of continents that have not been explored at depth. This is particularly true for volcanic areas, fault zones, and basic structures of mountain ranges."

With the CSDP, says John, "the idea has been to put holes into places where we'd never done so before and to go deeper and hotter than we'd ever gone before."

Engineering and logistical aspects of CSDP are carried out by the DOE-funded Geoscience Research Drilling Office, directed by Peter Lysne (6252).



ALASKA may be a major interest now, but John Eichelberger (6233) has spent lots of time at California's Long Valley Caldera. Here, he points out a 1984 drill site at a geological feature called Obsidian Dome.

CSDP projects typically have been managed either by the NSF or by DOE, with the USGS in close association, along with national laboratories and universities. However, the Katmai work is CSDP's first project for which all three agencies are equal funding partners.

Other CSDP efforts that have provided Sandia scientists the opportunity to explore: drilling — done largely in collaboration with Los Alamos National Laboratory — at the Valles Caldera in New Mexico; hydrothermal studies with Lawrence Livermore National Laboratory at Long Valley Caldera, Calif.; and a project John instigated, which involved drilling into the plumbing of some of the youngest volcanoes in the western US — the Inyo Domes, also at Long Valley.

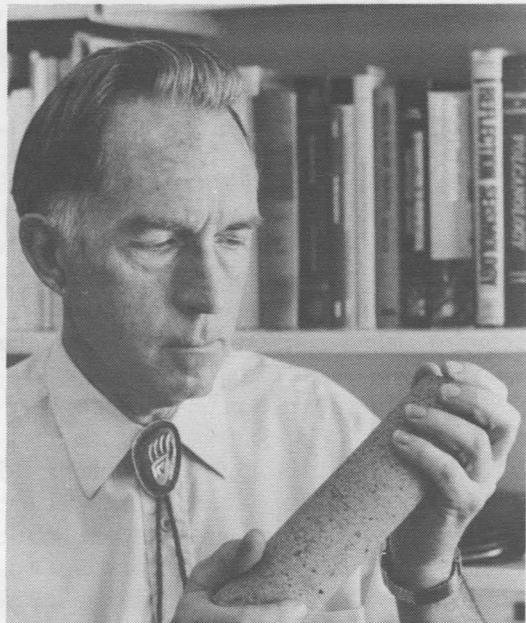
Sandia has also been involved in two CSDP studies at the Salton Sea (Calif.) that feature very hot concentrated brines in a complex geothermal system.

## Improving Magma's Image

Some folk seem to think of Sandia's magma researchers as fellow travelers of Hades, king of the underworld, and his queen Persephone, bringer of destruction.

Absurd? Sure. But read on.

Harry Hardee (6231) remembers the day back in 1980 when retired Labs President Mor-



HARRY HARDEE (6231) displays core sample retrieved in 1981 from Kilauea Iki Lava Lake's crust (above its zone of molten rock).

gan Sparks presented him with a stack of about 30 letters from a class of New Jersey sixth graders. "They seemed concerned," says Harry, "that Sandia's work might end up covering New Jersey with radioactive (yes, radioactive!) magma and hot lava."

Harry composed a soothing reply for presidential signature, marveling at the ingrained human fear of the underworld. "It seems that solar energy is equated with heaven and fusion energy with the stars, while things from deep within the earth are evil," he says. "It's a kind of primeval psychology."

But is there any risk that magma energy exploitation would interfere with natural tectonic processes and increase the likelihood of earthquakes, volcanoes? "When we're talking about such things, the political side is important, not just the scientific aspects," says Harry. "At 6 to 7 kilometres depth [the relatively shallow depth where magma would most likely be initially tapped], you're protected by vast overburden. There's also a critical hole size, based on the magma's heat-transfer and viscosity properties [three-ft.-diam. for basaltic magma] which determines that magma will freeze and self-seal before it reaches the surface."

Magma deserves a better name, Harry believes. "It's without a doubt the most benign source of energy I can think of."

Opinions differ. "It's the chanciest of the chancy," concludes Glen Brandvold (ret.), one of the first to cultivate Sandia's interest in magma and one who prides himself on his skepticism. "It's there, but far away — farther away than we've really drilled into the earth so far. Accessing a magma body as one approaches very high temperatures is just going to be very, very difficult. And we'd have to depend on helping nature to use convection to keep the process working."

Jim Dunn says: "After all, no one has demonstrated that these magma bodies really do exist beneath calderas at the depths predicted or that they represent the resource that has been estimated. Being able to drill a deep exploratory well in Long Valley should resolve some of these uncertainties, I believe."

John Colp — dubbed magma's outstanding "advocator and facilitator" by Bill Luth — is predictably optimistic: "It's a great idea, an idea that ought to have a big chunk of money spent on it. We are not out of the woods energy-wise, and magma certainly has potential. Those forces of nature are tremendous. Here's a great source of energy that can run us until we're successful with fusion energy." ●NH

## A Four-Year Plan

### Drilling Project Aims For Active System

A benchmark event in Sandia's magma energy exploration history — drilling the first phase of an \$8 million deep well in the Long Valley Caldera, near Mammoth Lakes, Calif. — is scheduled to start by July of 1989.

The four-year, Sandia-managed project, expected to sink the deepest well ever drilled in a volcanically active caldera system, is designed to reach 500°C (932°F) temperatures or 20,000 feet, whichever comes first. Rock would still be solid under those conditions, but molten magma probably would be less than 1000 feet away.

Scientists from throughout the US will take advantage of this opportunity to conduct a range of tests to gain insight into crustal magma and evolution of calderas.

John Finger (6252) describes this as the "nation's most ambitious geothermal-technology project yet. It could lead the way to a major new source of low-cost electricity and, with the country again increasingly dependent on imported oil, a boost for our national security."

Jim Dunn (6252 supervisor) calls the project "the world's deepest observation port into an active caldera." In these high-temperature formations, drillers will depend on a rapid mud flow to cool the hole and on insulated drill pipe (being developed by John Finger) to keep the bit and drilling fluid cool enough to be used. A permit has been issued by the US Bureau of Land Management for this operation that will be located on a high forested hill, called the Resurgent Dome, within the caldera.

#### 'Point of Diminishing Return'

A variety of earth-science research projects have been in progress for some years at Long Valley, but "surface geophysical measurements have reached a point of diminishing return," Jim explains. For this reason, new information from deeper sites is needed to more accurately characterize regions beneath the dome. "If high-temperature, near-magmatic conditions are reached," Jim continues, "the well can be used to test newly developed drilling technology, evaluate engineering materials, and confirm heat transfer calculations."

Although completion of a 20,000-ft. well is the project's target, drilling will be staged. "There will be checkpoints, decision times, at various stages for collecting and interpreting downhole data before deciding to proceed," Jim says.

#### Many Scientists Expected at Site

Funding is provided by DOE's Division of Geothermal Technology. But scientists involved in numerous studies sponsored by DOE's Office of Basic Energy Sciences, the US Geological Survey, and the National Science Foundation also are expected to be spending a lot of time at the drilling site.

Formed by volcanic eruptions 700,000 years ago, the Long Valley Caldera was selected from a dozen or more prospective sites where magma chambers are found relatively near the earth's surface. A joint committee with members from the US Geological Survey, the geothermal industry, several universities, and the DOE reviewed the site-selection process. Members were unanimous in their support of the Resurgent Dome as the best site.

"The biggest problem with this large effort," says Dick Traeger (6250), "is that everything we have is circumstantial evidence. Since no one has ever drilled into a magma body, we don't know for sure what's down there. The geophysics information just isn't definitive enough."

On a local note, there's geophysical evidence of several relatively shallow (approximately 23,000 feet) — but small — magma bodies near Socorro, south of Albuquerque. These bodies lie above a very large magma body that scientists believe to be some 62,000 feet below the surface.

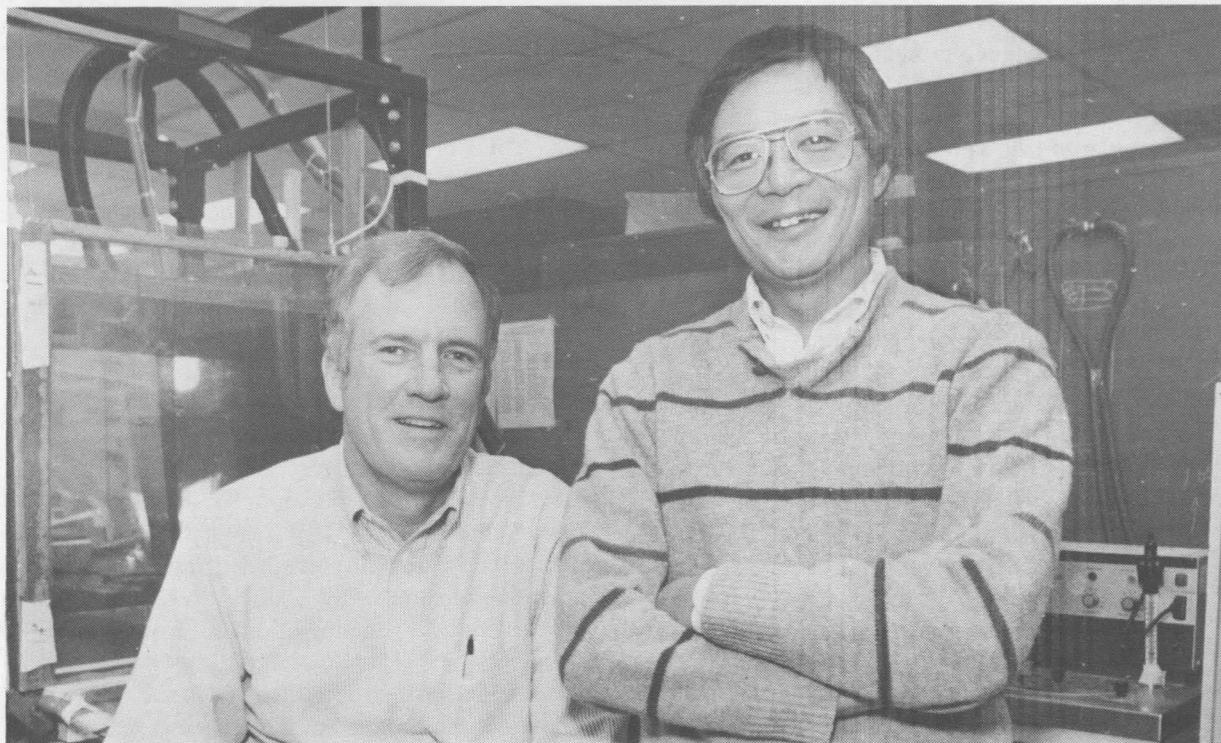
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## Unraveling

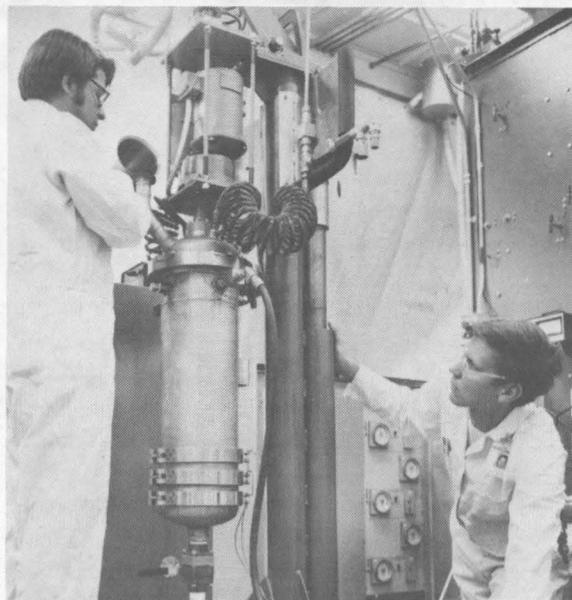
Magma Attachment'). While Terry Gerlach (supervisor of Geochemistry Div. 6233) was sampling gases from an erupting Hawaiian volcano, Al Ortega (now University of Arizona) was poring over computer models for magmatic convection. And while Peter Lysne (6252) and John Eichelberger (6233; see "His Thoughts Turn to Alaska") were probing drilling methods and geochemistry, John Rundle was creating 3-D maps from various components of sound waves bounced off a magma body in Long Valley.

Other more recent experiments continue contributing to the Labs' world-class base of knowledge about magma. In their Albuquerque lab, T. Y. Chu (6252) and Charles Hickox (1513) have used a container of corn syrup to simulate convection within a magma chamber.

But what are the prospects for developing useful new means of tapping magma energy that can be channeled into a commercial power grid?



TEST RIG in background was designed and built by T. Y. Chu (right, 6252) to study convective heat transfer in magma. Colleague Charles Hickox (1513) provides numerical modeling in support of T. Y.'s experiments.



THIS BENCH-SCALE REACTOR, once located in Bldg. 894, was a workhorse for coal-liquefaction lab experiments during the mid- and late 70s. Here, Jim Lyons (now 7471) pours coal slurry into reactor's pre-heater before a test. Dave Hawn (also 7471) looks on. The reactor has since been dismantled and replaced.

**(Continued from Page One)**

## Lots of Coal

The now-defunct coal gasification program sought to burn coal underground to produce a combustible gas that could be used to fuel surface electrical power plants.

Sandia has also worked "the subsidence problem" — how to predict the sinking of the earth's surface above the void created when the coal (or other mineral) has been mined out.

And Sandia is taking a lead role in developing the linkages among the coal industry, university researchers, and DOE's national labs and energy centers that are required to provide solutions to the severe problems coal faces if its "usability" is to match its abundance.

### Tough Challenges

The stories in this section contain more information about each of these programs. The challenges are tough. The amount of foreign matter — dirt, clay, rocks, etc. — varies widely from one coal sample to another. To use the engineer's term, coal is heterogeneous.

Coal varies on the molecular scale too — "an almost infinite number of different kinds and connections of molecules," says Howard Stephens (6212), who's been working with coal since 1980. It's that molecular variation that makes coal liquefaction difficult — what works well in liquefying one batch doesn't necessarily work well with another (see "Sandia-Developed Rheometer").

These and other coal challenges are not new; coal producers have been aware of them for decades, if not centuries. But their knowledge of coal tends toward the empirical ("try it; if it doesn't work, try something else") and the traditional ("we've always done it this way").

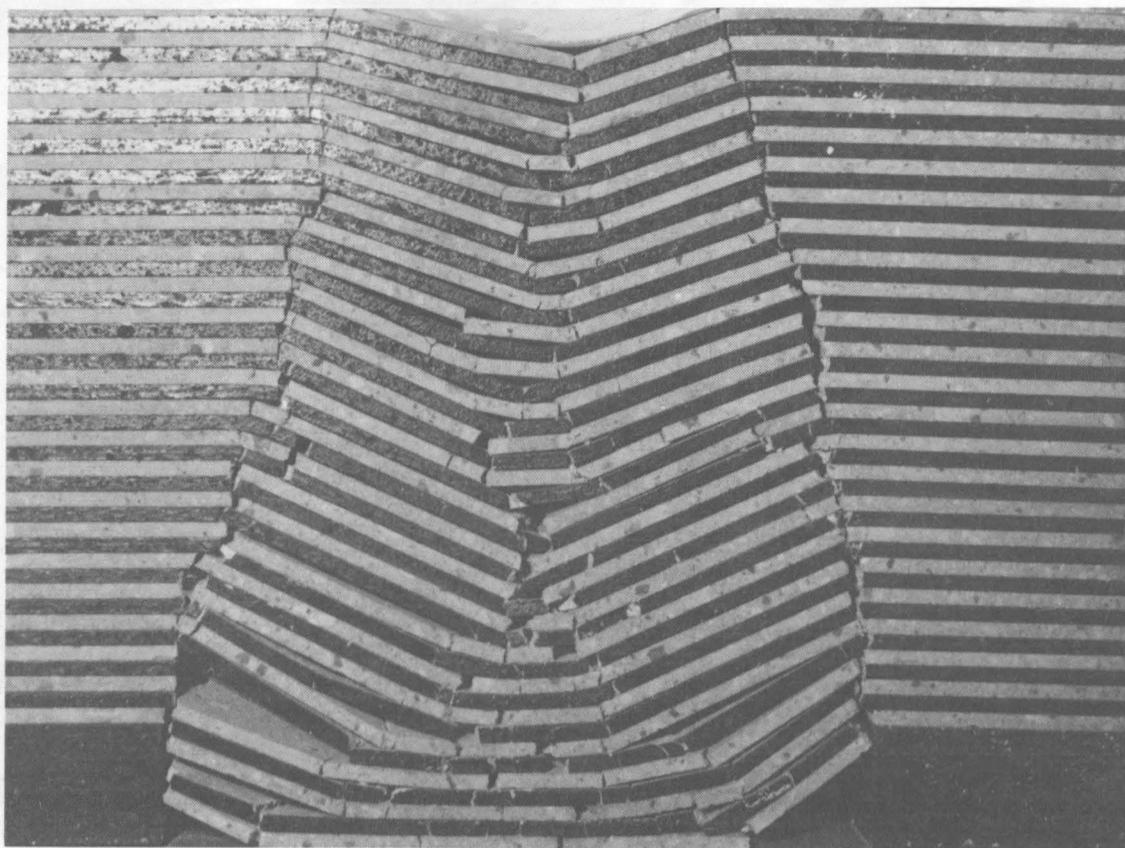
"In fact, the coal industry, in general, has little or no advanced research and development capability," says Bill Marshall, manager of Coal and Process Science Dept. 6210. "The guideline for our work in coal is that we apply our capabilities to advanced ideas and opportunities that are generally beyond current industry emphasis but that are closely coupled to solving real problems."

Sandia's present coal research efforts are, therefore, aimed at gaining a greater understanding of basic coal structure and reactivity (how it reacts with various catalysts in the presence of heat and pressure).

As Barry Granoff (6211) puts it, "If we can understand how coal is put together, then we can more effectively figure out how to take it apart — and put it back together so it's clean, convenient, and cost-effective." ●BH

### Thanks to the Centrifuge

## Mine Subsidence Better Understood



FAILURE PATTERN in generic scale-model coal mine tested on a Sandia centrifuge. Structure substituted Nevada Tuff (alternate layers painted black for optical clarity) for coal and silica flour for overburden. Model featured a simulated 12-1/2-ft.-high, 75-ft.-wide mined drift (bottom middle). During testing, earth collapsed into the drift, causing significant subsidence of the scale model's surface.

It's one of those things that even a technically oriented crystal ball probably wouldn't have foreseen — Sandia's world-class 25-ft.-radius centrifuge becoming an important ingredient in the Labs energy program. But it happened.

That's because the machine — the nation's largest operating centrifuge, typically used to test nuclear weapon components and systems — also is a great place to learn a lot about land subsidence, which can occur over coal mines, underground coal gasification and oil shale operations, and producing oil fields.

Subsidence caused by underground mining of coal has affected more than two million acres in this country. It may not appear for 50 years after mining, but it can decrease mine productivity. It can damage buildings, utility networks, or sewer systems in communities above or near a mine. It also can change water-table levels, causing productive lands to become unproductive.

Sandia's energy-program centrifuge modeling has made several significant contributions during the past decade. In 1983, for instance, a computer model developed from centrifuge scale-model tests correctly predicted that subsidence would not be a problem following a major underground coal gasification operation in Wyoming.

### Subsidence 'Rule of Thumb'

Centrifuge testing — on Sandia's entire suite of rapidly spinning machines — also verified and calibrated a computer model that details land subsidence characteristics for coal mines typical of the eastern US. This included establishment of an eastern-US-mine "rule of thumb" about subsidence: If the mine's width is equal to its depth from the surface, subsidence will affect about twice as much area on the surface as the mine's width.

Physical modeling of a coal tailings dam (an embankment made from coal waste products and located near an operating mine) provided basic stability information that can be applied to any type of earth embankment: Densely packed earth dams are not necessarily more stable than ones with loosely packed earth, and dense packing can restrict fluid flow through the dam, reducing stability.

"So it's easy to see why, over the years, our tests have gone a long way toward convincing many US design engineers that centrifuge modeling is a viable design method," says Herb Sutherland (6225). Herb's been project leader for most of the work sponsored by DOE and the Department of Interior.

The work basically involves subjecting scale models of coal mines or other earth structures to forces far exceeding those of gravity. It's done by loading samples in a compartment at the end of the centrifuge's 30-ton arm and rotating the arm at speeds up to 155 rpm. This subjects the models to many gravities (Gs), the exact load depending upon model size and composition, and centrifuge speed.

### Quick, Accurate Prediction

"Application of scaling laws," Herb says, "has permitted us to predict quickly and accurately how full-sized earth structures will be affected by various loads over a period of time."

For example, loading caused by the overburden on a coal mine 300 feet below the surface can be simulated on the centrifuge by subjecting a 1/100th-scale model (a test section three feet thick) to 100 Gs (100 times the force of gravity) on the centrifuge.

"Also," Herb continues, "by using materials in the scale model that come from the actual site or structure being analyzed, the strains present at the site can be duplicated in the model."

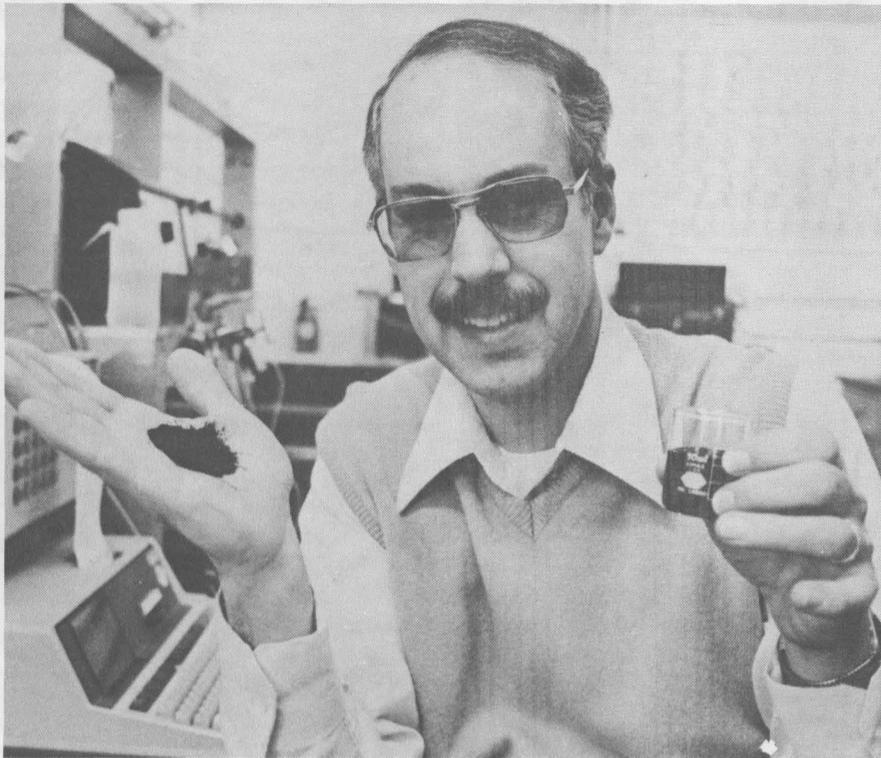
"Moreover, since this physical simulation provides precise data under known and controllable conditions, it's ideal for confirming computer models."

Scaling laws of centrifuge simulation not only compress physical dimension, but also time. "For instance," Herb explains, "30 minutes at 150 Gs scales to 1.3 years when studying diffusion processes such as fluid flow through porous media."

Although most of Sandia's energy-related centrifuge testing has addressed subsidence over coal mines and earth-dam stability, it can benefit a variety of fossil energy programs — for example, better understanding ocean-floor stability where off-shore oil and gas platforms are located. ●RG

**Catalysts Are the Key****Coal Liquefaction: Looking for the Best Way**

HOWARD STEPHENS (6212) displays finely ground coal and beaker of liquid fuel produced during liquefaction experiments. In 1982, Howard received special recognition from the American Chemical Society for development of a method to evaluate liquefaction catalysts.



Ask Virg Dugan, Director of Advanced Energy Technology 6200, which of Sandia's many energy programs have bloomed — achieved beyond expectation, promise to increase the nation's energy supply — in the past five years, and he lists four: "the MWX program in Colorado, including the acoustic strain recovery method [see related stories in this issue]; the progress in achieving high photovoltaic efficiencies [LAB NEWS, Nov. 18, 1988]; RAP-RENOx, the SNLL-developed means for reducing smog-causing nitrogen oxides in diesel engines [LAB NEWS, Oct. 21, 1988] . . .

" . . . And catalysis, as applied to coal liquefaction."

As the term implies, coal liquefaction is the process of converting coal to a liquid fuel, that is, a transportation fuel, one suitable for powering moving vehicles.

At first glance, coal liquefaction shouldn't be difficult. After all, the process has been around for decades — 98 percent of the fuel used by the German Luftwaffe in World War II came from coal. And South Africa currently gets more than half of its liquid fuel from coal.

So why don't we just *do* it? "We can," says Howard Stephens, supervisor of Process Research Div. 6212. "It's just not economically feasible — yet."

There are three ways to liquefy coal:

- *Indirect* — break coal down to its basic elements, carbon monoxide and hydrogen, then build it up again in such a way as to increase the ratio of hydrogen to carbon and thus make it useful as a liquid fuel. This indirect — or "sledgehammer" — approach is the one South Africa uses.
- *Pyrolysis* — that is, heat it. Some useful volatile elements — naphtha, for example — boil off, leaving coal tar. It works, but it's inefficient — it converts only about 20 percent of the coal to liquid fuel; and
- *Direct* — combine coal with hydrogen to produce a synthetic crude oil. This is the process Germany used in WWII, but it demanded 15,000-psi pressures and was, therefore, quite costly.

"We chose to go direct, not because it's the most technically sophisticated approach, which it is, but because we believe it's potentially the most efficient route to liquefaction, and because — in the long run — it has, we believe, the best chance to compete economically with oil," says Barry Granoff, supervisor of Fuel Science Div. 6211.

"South Africa's coal costs less than a third of what ours does in the US, but, thanks to the high cost of indirect liquefaction, gasoline there costs about \$3.50 a gallon.

"In the US," Barry continues, "liquefaction is just not economically attractive as long as oil prices remain depressed and we don't have an import tax."

"What that means," says Bill Marshall, manager of Coal and Process Science Dept. 6210, "is that our researchers have the breathing room to prepare some options for the day when the nation may have to rely more heavily on coal-derived liquid fuels. We'll have the tech base to give industry some new

ways to effectively liquefy coal."

"Sandia is unique here — we're the only national lab doing direct coal liquefaction," adds Howard. "The direct method offers a coal-to-liquid conversion efficiency of 60 to 70 percent. We know we can achieve that efficiency in any of several ways — we just don't know the best way yet. That's what we're working to define now, using a two-pronged attack."

**Catalysis Analysis**

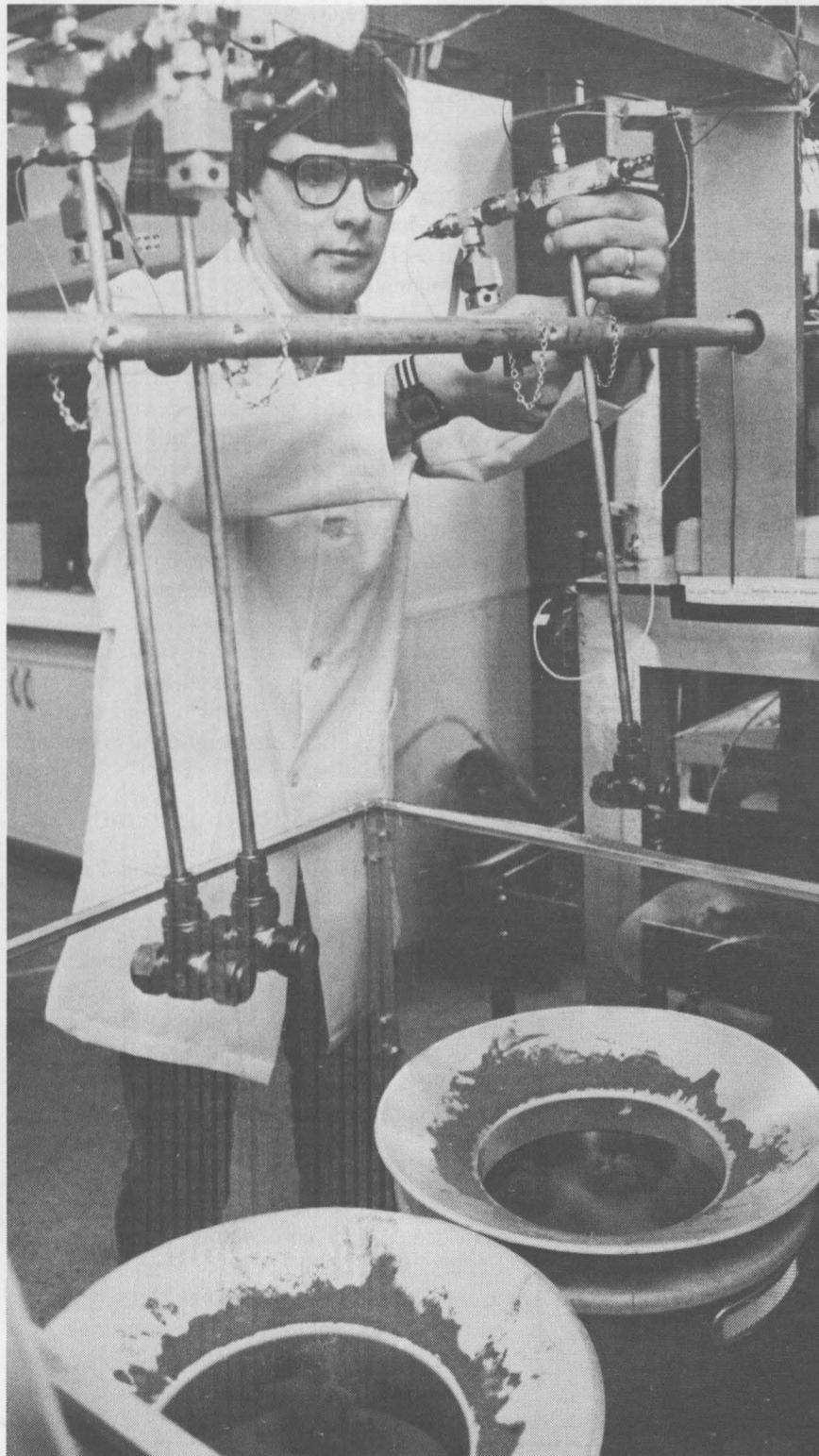
Direct coal liquefaction means breaking coal's large chemical structure down into molecules — into, for example, benzene and xylene (both are components of gasoline). The process involves pulverizing the coal into "coal dust," mixing it with a coal-derived liquid solvent to form a slurry, and heating it (typically at 800° to 850°F under 2500-psi pressures) in combination with a catalyst and hydrogen (to increase the hydrogen-to-carbon ratio). It reacts chemically to become pre-asphaltene, then asphaltene, then "oil."

The result can be blended into traditional crude oils, refined into gasoline or diesel or jet fuel, or used as a chemical feedstock (the raw material of, for example, plastics).

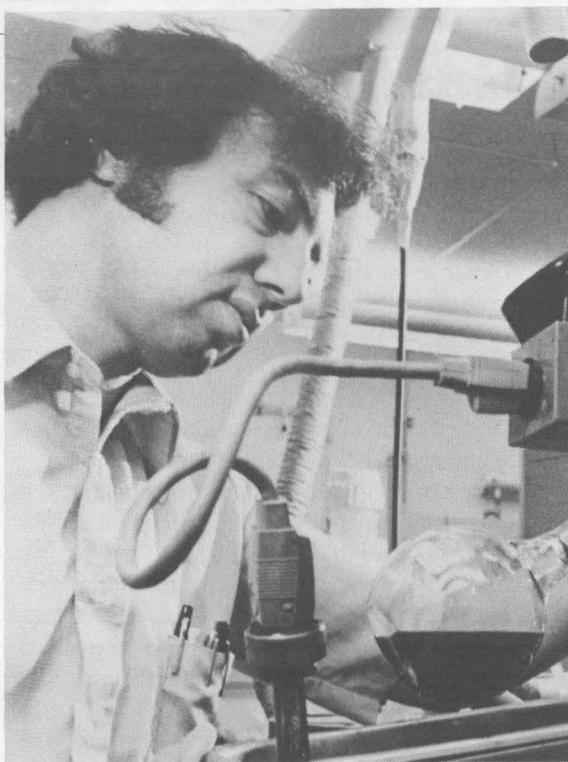
The kicker is the catalyst, the substance added to an industrial process to make it work or to make it work better. That is, the catalyst decreases the minimum energy needed for the reaction to occur.

In the coal-liquefaction process, traditional catalysts (molybdenum and nickel treated with sulfur, for example) are both expensive and short-lived —

*(Continued on Page Twenty-One)*



RICH KOTTENSTETTE (6212) prepares reactor chambers (35cc volume) containing coal, coal solvent, a catalyst, and high-pressure hydrogen for insertion into hot (400°C) sand in coal-liquefaction experiment.



DURING EARLY DAYS of Sandia's coal liquefaction investigations, Barry Granoff (6211) spent many hours in his lab studying such things as catalytic abilities of pyrite — "fool's gold" — during liquefaction.

**(Continued from Page Twenty)**

## Liquefaction

they deactivate in a couple of days to 20 percent of their original strength.

"To improve our ability to convert coal into a liquid," says Bill Marshall, "we have to investigate catalysts that show promise of achieving a higher product yield at less severe, and therefore less expensive, conditions of heat and pressure."

"So we're now trying to understand what goes on chemically [in catalysis] so we can identify better ways to do it," Howard adds. "That understanding involves both the kinetics and the thermodynamics of the chemistry involved. It's a complex, interrelated reaction — but we wouldn't be in business if it were simple."

The liquefaction effort, which began with Sandia support of ERDA's "Synthoil" project in FY75, has two major parts: (1) catalyst R&D, and (2) novel process studies relating to hydrogen transfer.

"In our catalyst research, we've identified a promising class of hydrous metal-oxide materials, which Bob Dosch [DMTS, 6211] developed in the early 70s for removing parts-per-million quantities of radionuclides from liquid streams," says Barry.

"We're now working to define the basic structure and properties of these materials, to evaluate their response in liquefaction-like environments, and to compare their conversion characteristics with those of commercial catalysts," adds Howard.

### Investigating New Catalysts

An extension of this catalyst R&D program, the one that Virg Dugan mentioned in his list of four "blooming" projects (above), is the use of computer-aided molecular design and interactive graphics to guide in synthesizing novel catalytic substances for the conversion process.

"By using molecular graphics techniques borrowed from the biological and pharmaceutical sciences, we can investigate 'on the screen' thousands of potential new catalysts, then create and test only those that appear most promising," says Virg. "Without the computer, the search could take lifetimes."

"Essentially, what we've done so far is to demonstrate the feasibility of using computer-aided molecular design to 'tailor-make' novel catalysts for specific applications — such as a catalyst that will allow us to convert methane directly to methanol," adds Barry (see "Petroleum R&D Projects Show Results").

"But we now have a new program, Chemistry of Large Molecules, that will enable us to focus on the molecular structure of coal. We will apply state-of-the-art computer-aided molecular design techniques

*(Continued on Page Twenty-Two)*

### The Turn of the Screw

## Sandia-Developed Rheometer Solves Some Liquefaction Problems

Some four or five years ago, Sandia coal-liquefaction researchers recognized the need for a better way to predict the flow behavior of in-process coal slurry in a liquefaction plant. The helical screw rheometer (HSR) is one solution to this problem.

Given the heterogeneous nature of coal (samples — even from the same mine — may vary considerably), it's no wonder that slurries react in different ways when subjected to the high temperatures and pressures required for direct coal liquefaction.

Gelling is of particular concern. It sometimes occurs, explains Art Lynch (6212), as a result of chemical reactions during the dissolution process — reactions, for example, that might cause the particles of suspended coal in a coal-derived solvent to expand. "The material thickens, perhaps by as much as a thousand times," he says. "And that means big problems — the worst of which is pipe clogging — in a liquefaction plant.

"Before the HSR, there was no way of accurately measuring a wide range of slurry viscosities under very high temperatures (as high as 400°C) and pressures. We needed to know, for example, why and when a given slurry sample was likely to gel — and how we could prevent it."

### The Paint Connection

"Shear rate — the force applied to the slurry — also has an effect on viscosity," Art continues. "I like to use the analogy of paint: A can of paint sitting on a store shelf is subjected only to the force of gravity — a low shear rate; particles in paint then settle to the bottom and, to assure the right consistency, you have to stir it up before you use it. If you apply that paint with a roller, you move up on the shear-rate scale; you're applying more force — and viscosity requirements are different. And if you decide to spray it, you're subjecting it to even more shear rate — and a new set of requirements; it needs to be thinner as it goes through the sprayer.

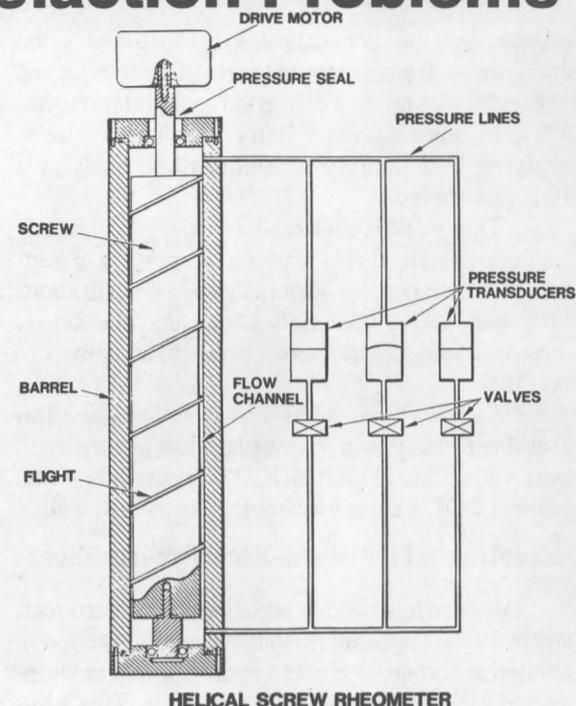
"In comparison, high and low shear rates on coal slurry will make it react in different ways. The ability to predict its behavior under different circumstances is vital to the coal-liquefaction process."

The HSR cleared the way for viscometric measurements of complex fluids such as slurry. It was developed, built, and tested in the 1983-84 time frame by a trio of Sandians: Andy Kraynick (now 1511, formerly 1813), Jim Aubert (1813), and Rick Chapman (formerly 6254, now 6223). The device has since been used for coal-liquefaction research and for a more recent project of Art's on using coal/water slurries as a direct substitute for commercial fuel oil.

### How HSR Works

The HSR consists of a motor-driven screw (the prototype design size was two inches in diameter) that rotates at constant speed inside a close-fitting sealed cylindrical cavity that's gas-pressurized at the top. (Rotation rpm — revolutions per minute — can be varied from 25 to 400.) Band heaters around the outside of the cylinder generate the high temperatures required.

The fluid sample, fed in at the top, is forced downward by the rotating screw threads through the narrow channel between the screw and cylinder wall. In the process, pressure differences build up in the fluid along the axis of the screw. "The HSR is essentially an extrusion pump," says Art. "As the screw rotates, it pushes the slurry down, so that pressure on fluid at the bottom of the cylinder is much greater than pres-



sure on fluid at the top."

Pressure transducers (three or more) located outside the cylinder measure the pressure differences on the sample fluid from the top of the screw to the bottom. "The HSR allows us to monitor dynamic pressure differentials from as little as 1 psi [pound per square inch] to as much as 2400 psi, so we can measure viscosity over a wide range of shear rates," says Art.

"And once you see what happens to slurry in the HSR, you can fine-tune it for better performance in the future. For example, maybe you add more solvent and less coal to make it flow through pumps and pipes as it should. And you have a better handle on the force rate needed to move it through the system in a liquid state." The HSR would thus be a part of the process control system in a liquefaction plant.

Not only can the HSR test fluids at higher temperatures and pressures than previously possible, it also has a mixing capability that other viscometers do not. That's an advantage, says Art, because — if desired — researchers can measure behavior of a single fluid over a long period of time.

When viscosity is not being measured, the HSR's "mixing mode" moves the fluid out of the bottom of the cylinder through a circulation loop and carries it back to the top, where it starts through the system again. Material in the flow loop can't "settle out," and can be tested at different rotation rates.

There's no "standard-size" HSR. Screw diameter varies, based on how much shear rate is required (a larger diameter produces a higher shear rate). Likewise, if a wider range of differential pressure readings is required — on, say, a relatively thin fluid — longer screw length will help achieve that goal.

It's speculated that HSR viscosity analysis might also be useful for characterization of other complex materials such as drilling muds, heavy oils, magma, and polymers.

During the recently completed coal/water slurries project, the HSR was used to characterize the viscosity behavior of water with a high coal-powder content. "Our objective," says Art, "was to put as much finely ground coal as we could — something on the order of 70 percent by weight — into a given amount of water, but still maintain a fluid.

"To predict its behavior as it atomizes into a fine spray — a process required for combustion — we needed to observe it under a high shear rate. We were able to do that by using an HSR with a short, six-in.-diam. screw rotating at 400 rpm."

●PW

*(Continued from Page Twenty-One)*

## Liquefaction

to understand the chemical paths by which coal is first disrupted — from its tangled network of interlocked molecules — and then converted to liquid products.

“In other words,” Barry concludes, “we’re applying 20th-century techniques and tools to a 19th-century fuel.”

“This work is an excellent example of cross-cutting research. It cuts across a fair portion of Sandia’s tech base people, notably those in Organizations 1100 and 1800 — materials scientists, ceramicists, surface-science researchers, chemists, and others,” says Bill.

“And, with our multi-year development effort to evaluate catalysts in a pilot-plant-like facility, we’ll work with industry — AMOCO, for example — and some of DOE’s energy technology centers as well.”

### Creating a Hydrogen-Rich Environment

All three liquefaction processes (direct, indirect, and pyrolysis) must increase the level of hydrogen in relation to carbon — create a hydrogen-rich environment during conversion, in other words. That’s important because coal contains less hydrogen than carbon (about 0.8:1). To be useful as a liquid fuel, that hydrogen-carbon ratio needs to be about 2:1. So the underlying principle in the second part of the liquefaction effort, novel process studies, has been “how to better manage and utilize hydrogen,” says Bill.

“A key to our technique,” explains Howard, “is a realization of how hydrogen is transferred to coal. Efficient liquefaction can take either of two distinct hydrogen transfer paths — thermal or catalytic. The two should be separated as much as possible because they have very different optimum conditions.”

The thermal, or high-temperature, path involves transfer of hydrogen contained in the solvent to coal molecule fragments. But its prerequisite, the catalytic transfer of hydrogen to the solvent in the first place, works best at low temperatures. By catalytically reacting a mixture of steam, hydrogen, carbon monoxide, and high-boiling-point aromatic hydrocarbons found in coal liquids — phenanthrene and pyrene, for example — Howard has produced a liquefaction solvent rich in hydrogen donors.

“The primary advantage of this process is that it works at comparatively low temperatures and pressures — about 300°C and 800 psi,” says Howard. Lower temperatures and pressures would mean considerably lower costs for building a commercial liquefaction plant. (A patent application covering the concept has been filed in Howard’s name.)

Another advantage is that “purified, therefore expensive, hydrogen gas is not needed to make either the thermal or catalytic paths to liquefaction successful,” Howard notes. “The hydrogen-rich solvent efficiently transfers its hydrogen to coal without the need for additional gas-phase hydrogen.”

(Another promising concept deals with pyrolysis rather than direct liquefaction. A recently completed collaborative effort with British Coal has shown that hydrous metal-oxide catalysts — the same ones useful in the direct approach — convert nearly all the coal tar vapors derived from pyrolysis into high-quality liquids. “When we placed these catalysts directly in the coal, we increased the conversion efficiency of the liquefaction process,” says Bill.)

### In the 90s

“We’ve certainly made progress already,” says Virg Dugan. “For example, we’ve reduced the temperatures and pressures required to liquefy coal.

“But, as we look into the 90s, we see greater potential. If we can combine our knowledge of how to build a tailor-made catalyst with our new understanding of how a coal molecule is assembled, we should be able to create, on a deterministic rather than an empirical basis, a catalyst that can selectively rearrange a coal molecule to optimize the opportunity for upgrading coal to a transportable and environmentally acceptable fuel form. That’s the key to future improvement.”

●BH

## Underground Coal Gasification: Reducing the Uncertainties

It’s not often that a Sandia program assignment begins, “First, try to duplicate what the Soviets are doing.”

But that’s essentially what happened in the mid-70s when Sandia was first asked to play a site-characterization role in ERDA’s (Energy Research and Development Administration, DOE’s predecessor) underground coal gasification (UCG) program. Under the slogan, “Free the workers from the mines,” the technology was pioneered by the Soviets in the 20s and 30s. Their program ran through the 50s, when gas reserves were discovered in Siberia.

“Only one of their coal-gasification plants kept operating, primarily to sell the technology,” says Paul Hommert, supervisor of Advanced Technology Div. 6258; he was involved with Sandia’s UCG program from 1976 until the program was phased out in 1986.

Sandia’s UCG program began in early 1975 and, with its oil shale program soon thereafter, served as the Labs’ entree into fossil energy work.

“ERDA’s first UCG field site, near Hanna, Wyoming, had been operating since about 1973,” says Paul. The work was headed by ERDA’s Laramie Energy Research Center, “but LERC was having trouble in delineating the burn from one day to another.

“That’s why, in early 1975, ERDA asked Sandia to help out by doing the instrumentation needed on ERDA’s attempt to duplicate the Soviets’ UCG work,” says Dave Northrop (6253), who headed the Labs’ UCG effort from 1974 until 1978. “There were lots of uncertainties about what was going on underground at Hanna — why some things were working and some weren’t.

“In essence, ERDA told us, ‘You people know how to make measurements underground, and we need your help.’”

Sandia had, of course, years of experience in getting data from underground locations characterized

by harsh environments — nuclear weapon effects tests at Nevada Test Site, for example. And “we’d already gained some experience in UCG, by a quick look at Hanna in the winter of 1974,” says Dave. “So when ERDA asked us to assist up there, we had some foundations to build on.”

“A burn is a dynamic process, and, of course, it’s vital to the UCG process to be able to define burn characteristics,” says Paul. Three basic types of instrumentation — seismic, electromagnetic, and thermometric — have proved valuable in characterizing the geometries of a UCG burn.

“But, given our experience with site characterization work at UCG field sites near Hoe Creek [Wyo.] and Centralia [Wash.], we also recognized the importance of using our instrumentation capabilities to determine beforehand the geometry of a UCG site — its geology, its natural fractures, the structure of the coal seam and its overburden. That kind of knowledge is also an important result of Sandia’s instrumentation program.”

Sandia’s UCG program developed both passive and active seismic instruments. Essentially, passive means putting geophones above the burn — and then listening. “That scheme didn’t work well with 1976 technology,” says Paul. “Tom Schultheis [6333] did the best he could with what was available, but we didn’t have enough computer capability, and we lacked the software needed to make our detection algorithm work. All we really proved was that it *should* work.” (It does; it’s now used in the hydraulic fracturing of gas-containing formations.)

“We now consider that early work as merely a foundation,” Paul continues. “Since then, we’ve acquired greater computer capabilities and developed a better sensor and array design. That gives us the really high sensitivities we need for UCG. So we’re ready if there’s a next time.”

*(Continued on Page Twenty-Three)*

### UCG’s a Useful Option

## Simple in Theory, Difficult in Practice

In theory, underground coal gasification (UCG) is simple — drill two (or more) wells, perhaps 100 to 200 feet apart, into a coal deposit that’s 10 to 30 feet thick (and may stretch for miles horizontally). Ignite the coal at the bottom of one well, and force the air needed for combustion into the second well.

In a process called reverse combustion, the burn progresses along an air path toward the second (injection) well. It’s like blowing into a lit cigarette — the burn will travel toward the injected air.

Once that path is established, the direction of the burn is reversed: Air is fed down the first well, and, if all goes as planned, a combustible gas can be recovered at the top of the second well.

(This reverse combustion technique, pioneered by the Soviets, works efficiently only in suitable underground geology. Lawrence Livermore National Lab has successfully linked two wells by using directional drilling.)

The gas recovered results from this series of reactions: Oxygen is added to coal, which is rich in carbon; burning it creates carbon dioxide and carbon monoxide in an exothermic (heat-creating) reaction; given the water that’s naturally present in a coal seam, carbon plus water result. When that’s heated — or gasified (an endothermic reaction) — the result is hydrogen plus carbon monoxide. These latter two generate a gas that can be used as a chemical feedstock or refined to become a liquid fuel.

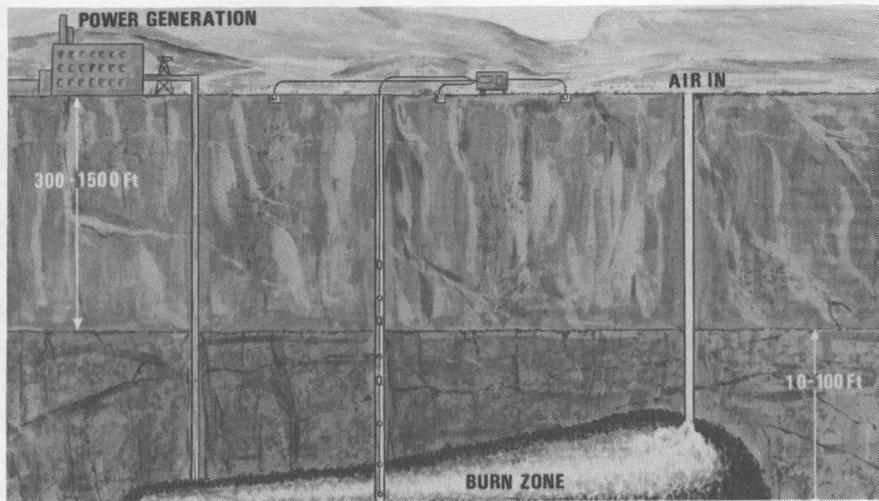
“So we have combustion and gasification going on simultaneously,” says Paul Hommert (6258), “with the combustion providing the energy for the gasification.”

In practice, UCG’s not so simple. Often it’s difficult to create a path from one well bottom to the other. Sometimes the burn can’t be sustained. Almost always it’s very difficult to determine from the surface whether the burn front is progressing properly, and whether all the coal between the wells is being burned. And UCG could pollute a nearby aquifer system or cause surface subsidence.

But new instrumentation devices, many of them developed by Sandia (see main story), can now provide most of the answers needed to understand the operation of a UCG facility. “There are still some unanswered questions about UCG,” says Paul, “but we’ve come a long way — it’s now better understood and accepted.”

Today, UCG remains an option that could be useful in tapping deep coal reserves, those that are too expensive to exploit with current coal mining technologies.

“It’s a promising technology,” Paul concludes. “But it has some drawbacks. One is economic — traditional means of mining coal are currently cheaper than UCG. Another is environmental — water table pollution and surface subsidence are possibilities. And still another is attitudinal — gas and coal company managers are uneasy about reactions they can’t see.”

*(Continued from Page Twenty-Two)*

**TYPICAL IN SITU COAL GASIFICATION SITE** — On the surface, product gas can be burned to generate electricity on-site, used as a chemical feedstock, or upgraded to synthetic natural gas.

## Biography of Basic Burn

There is no such thing as a typical UCG experiment. But, if there were, it might look like this:

First, a 4-in.-diam. horizontal hole is drilled along the bottom of a 30-ft.-thick coal deposit buried several hundred feet beneath the surface. (Today's drilling technology allows a drill string to make a sharp turn to the horizontal hundreds of feet down.)

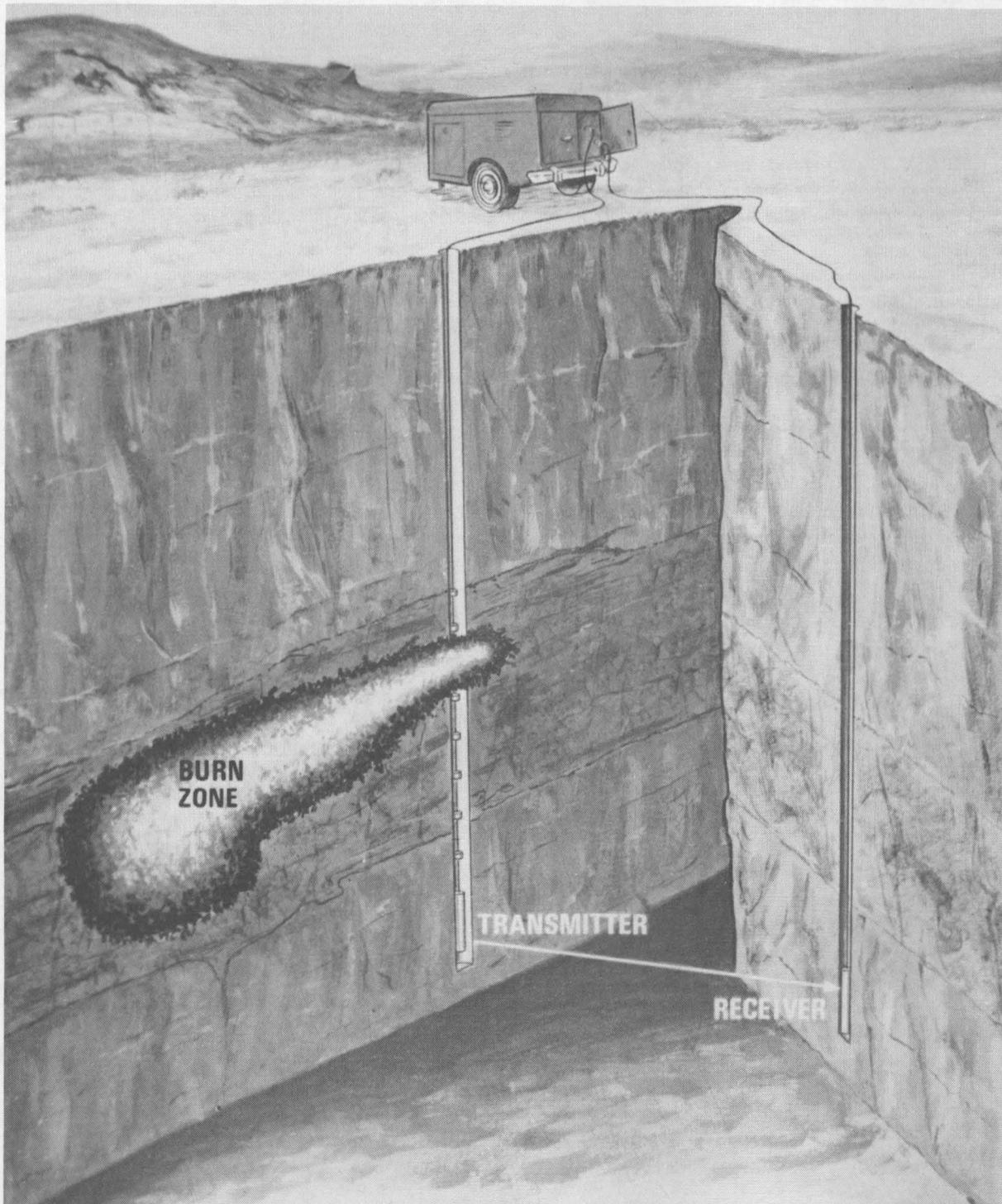
Separate 8- to 12-in.-diam. injection and recovery wells, 100 to 150 feet apart, are then drilled into the horizontal hole, and the coal at the base of the injection well is ignited. The burn is fed by oxygen-steam or air forced into the well at the rate of 3000 to 4000 cubic feet per min-

ute, and the coal both burns and gasifies (see main story).

The burn slowly expands, at perhaps 3 to 4 feet per day, along the horizontal hole, creating an ellipse that typically becomes some 30 feet across and eventually reaches from the injection well to the recovery well.

The void created by the burn will contain ash and, if the overburden collapses, some rock or other material as well. Depending on the overburden strength and the presence of aquifers, the void may eventually fill with water.

This basic module, replicated several times over, could serve as the basis for a commercial-sized UCG operation.



**WIRELESS UNDERGROUND TELEMETRY SYSTEM**, developed in late 70s, transmitted information from thermocouple strings in coal gasification and oil shale retorting zones to a nearby underground receiver. Transmitter and receiver for the Sandia system were outside combustion zones.

## Gasification

The passive detection technique offers the chance of getting a 3-D view of a burn in process. The active-seismic approach, on the other hand, offers a look at a burn on a 2-D (length and width) plane between the two wells.

This approach typically involves drilling two boreholes, one on each side of the burn, then setting off an explosive charge at the bottom of one and receiving (at the bottom of the other) the seismic signal it creates. The data received are transmitted to the surface for analysis. If the burn has created a void between the two boreholes, the signals will change.

"We're now working with DOE to exploit a non-explosive and much more sensitive version of that technology," says Paul. "Our geoscience effort includes an initiative on cross-well seismology. It's built around two systems: Harry Hardee's (6231) downhole seismic source, which creates a seismic signal with a compressed-air-powered piston [see "Petroleum R&D Projects Show Results"]; and our downhole receiver, which has been tested at the MWX project in Colorado" (see "Putting Gas Into Focus").

### Electromagnetics and Thermometrics

The electrical resistivity of coal is 1000 to 10,000 times greater than that of the hot carbon created at the edges of a burn zone. So an electromagnetic approach should be useful in defining the UCG burn process.

"The most promising technology here was surface electrical potential [SEP], which we first tried at Hanna," says Paul. "If the potential on the surface drops, say, from 3 to 2.8 volts, we should be able to relate that drop to the process occurring below."

(SEP is now used in enhanced oil recovery projects as a process-mapping tool and to help define reservoir characteristics — where to drill, where the fractures and seams are, etc.; see "New Facility Filled With Promise.")

In a sense, thermometry is the most direct, least ambiguous technology useful in defining a UCG burn. As the term suggests, it measures temperatures along boreholes near (sometimes in) the burn site — "if it's 700°C, you've got a burn," says Paul.

The measuring devices are obviously not traditional oven thermometers; they're thermocouples — two dissimilar wires (copper and copper-nickel alloy, for example) arranged in parallel; at their junction (thanks to the Seebeck effect), the voltage is precisely related to their temperature.

These thermocouples are arranged in strings, which are then grouted into the boreholes from top to bottom of the burn area. "The problem here, caused by the high temperatures and the chemically corrosive gases typical of UCG, was to keep the string of thermocouples operating after the top ones burned out, which is pretty typical," says Paul.

"We ended up with the concept of an inverted thermocouple, which means sending the signals downhole, not up to the surface. As developed by Thurlow Caffey [6258] and Milo Navratil [7120], the system includes a transmitter at the bottom of the borehole that sends the thermocouple data directly to a receiver at the bottom of a second borehole, then by cable to the surface."

The inverted thermocouple technique was used at Hanna, at Hoe Creek, and at Centralia.

"Developing this arsenal of instrumentation techniques and devices for characterizing a UCG site, mapping a UCG burn, and defining the underground void it creates would, in itself, justify the effort we put into our UCG program," says Virg Dugan (6200). "If and when UCG becomes an attractive option in exploiting our vast coal reserves, we'll be ready to provide the tools and talents needed."

"More important today, we're proving that many of those tools and talents are valuable in a wide range of fossil- and geothermal-energy programs." ●BH

**Explosive Landscape Tailoring****Cast-Blasting: Out of the Empirical**

You've seen (or seen photos of) the gargantuan draglines used in strip mining — the lumbering machines with a giant scoop at one end, an even larger engine compartment at the other, a boom like a horizontal oil derrick between them — and a human operator whose head doesn't reach the top of the crawler tracks.

Those draglines cost \$500 a minute to operate, but overburden has to be removed so the coal or other resource it's covering can be mined. That means breaking up overburden rock by blasting it into fragments, then moving it out of the way with a dragline. Maybe there's a better way . . .

Maybe it's "cast-blasting."

Cast-blasting is a way to rearrange landscape by setting off near-surface explosive charges so as to maximize the amount of overburden removed and to deposit that airborne overburden in just the right out-of-the-way place.

Performing that feat reliably and repetitively — optimizing it, in other words — demands a set of computational tools — a mathematical model — to specify where the holes for the charges are bored, how closely the holes are spaced, how deep they are, what angle they should be, how much explosive to bury in them, in what order the charges will be detonated, and what the time spacings between detonations should be.

"Answers to those questions depend, in turn, on a host of variables — the nature of the explosive detonation, the emanation of the shock wave it creates, how a rock formation fractures, and where hundreds of thousands of rock fragments will end up," says Paul Hommert, supervisor of Advanced Technology Div. 6258.

**Cooperative Cast-Blasting Customer**

"We certainly can't define all these variables precisely yet," Paul continues. "But, through the years, Sandia has developed a unique computational ability aimed at answering such questions, and we now have a most cooperative commercial customer for our cast-blasting product.

"Actually, our code was designed to predict fracturing patterns in shale reservoirs. But, at the request of Atlas Powder Company, it's taken off from there, and today we're applying our cast-blasting code to a wide range of blasting environments. We're funded by DOE's oil shale program and by Atlas, the largest manufacturer of blasting powder in the US, to perfect the cast-blasting model."

The model, applicable to all commercial blasting, will predict fragmentation and motion created by explosives in a variety of mining settings. "It should make a difference in the industry," says Paul. "Much of the blasting now is empirical — a blaster simply is doing what his or her father did."

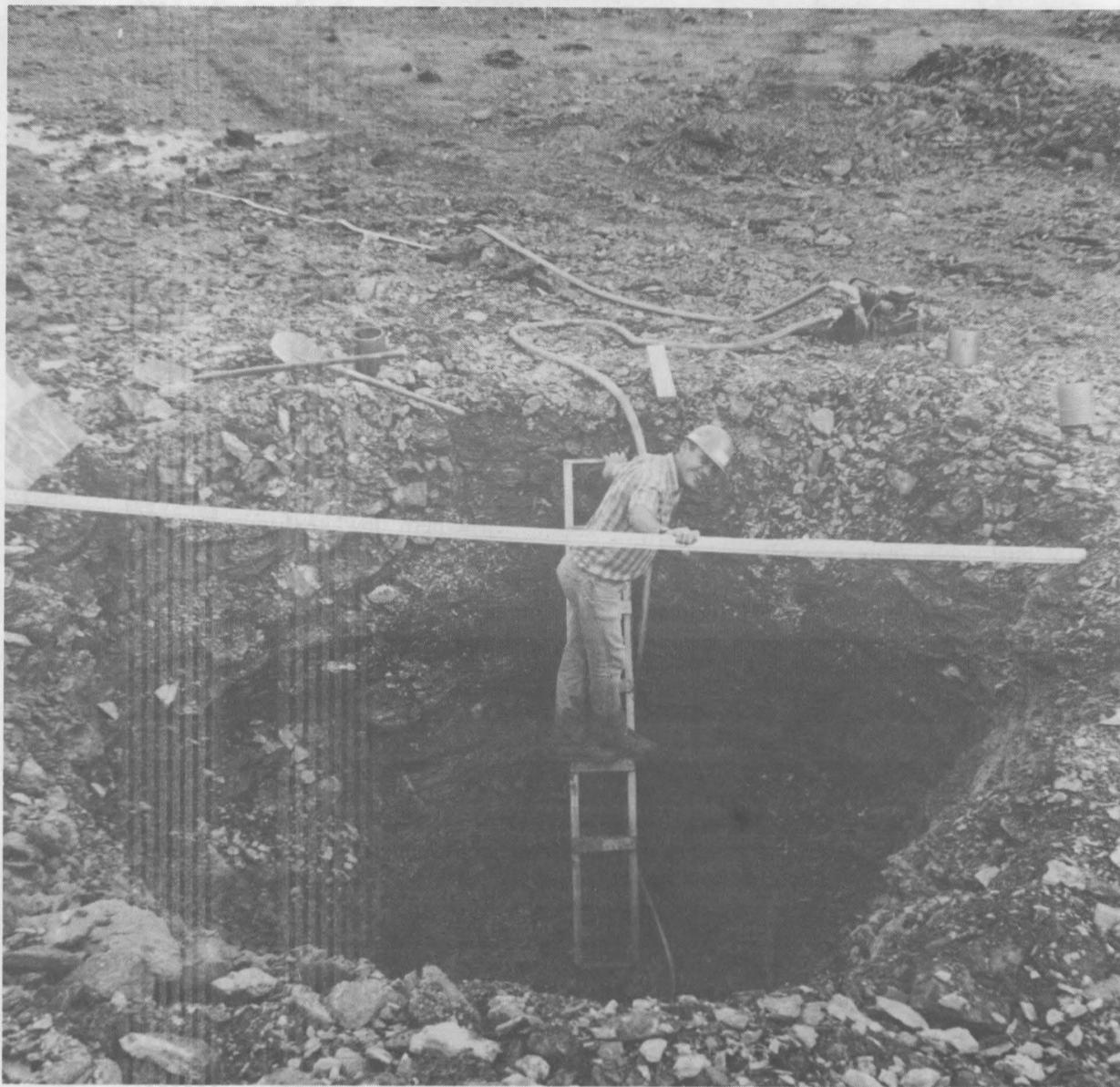
**Stiff Competition on World Market**

"So the big issue Sandia is addressing in this program, one underlying several other geoenergy programs as well, is 'How can we make the US mining industry more advanced, more competitive?'" says Dick Traeger, manager of Geoenergy Technology Dept. 6250. "In coal, both Australia and South Africa mine coal more cheaply than the US does, so we face stiff competition on the world market. We believe that computer modeling can increase the efficiency of domestic coal producers and thus make them more competitive worldwide."

The Atlas-Sandia relationship began in 1985. It was coincidental. "We were working with some Atlas people on an oil shale project," says Paul, "and when we began some model validation studies, they asked, 'What are you doing?'"

"When we told them, they said, 'Hey, we could use that model here — and here — and here.'"

Atlas then surveyed the US for computer-aided blasting talent. "They came back to Sandia and said, 'It's here,'" says Paul. "We really have no US com-



PAT DROZDA (6258) stands on a ladder in a 3-metre-deep, 4-metre-diam. hole formed during an explosive experiment in Kentucky's Straight Creek coal mine. The blast, one of a series last summer, is part of Sandia's program to verify mathematical models that can be used to plan cast-blasting operations.

petition. Canada, Australia, South Africa, and Sweden do some modeling work in cast-blasting, but we have a leg up, thanks to our advanced computers and a head start in modeling. The first Atlas funding arrived in July 1987, and by September we were rolling."

Work toward validation of the model took place in a Martin-Marietta granite quarry in North Carolina last January and at a Kentucky coal mine with a sandstone overburden last summer. Future experiments with more complex geometries and multiple blast holes are planned.

**Born at NTS**

Completion of the Atlas-Sandia project will likely take another year or two. "We've been using SLIFER [Shorted Location Indication From Electric

Resonance] — the device used to do shock wave analysis during underground nuclear tests at Nevada Test Site — to allow us to determine explosive detonation velocity," says Paul. "Velocity is closely related to the timing between detonations, and timing seems to have a more pervasive effect than we've been able to understand as yet. We have work to do."

Although the cast-blasting model might seem to be related to the Plowshare work of the 50s (involving nuclear explosions to excavate canals, for example), it really grew out of the shock wave code developed by Dennis Grady (DMTS, 1534) and Marlin Kipp (1533) to predict nuclear explosive containment. They later adapted the code for the early blasting studies in oil shale.

"It worked," says Paul, "but it wasn't nearly fast enough for the kind of work we're doing now in cast-blasting."

Another progenitor was the finite element code PRONTO, which was developed by Lee Taylor and Dennis Flanagan (both 1523) for determining how rock fractures in NTS tunnels during nuclear tests. They too adapted their code for oil shale.

"It's our Crays and PRONTO, which is vectorized for these supercomputers, that give us the high computational speeds we need — our edge on the rest of the world," says Paul.

Sandians involved in adapting PRONTO to the cast-blasting problem were Elaine Gorham-Bergeron (6413) and Joel Kuszmaul (now on educational LOA). Current members of the team, as it heads into a 3-D version of the model, are Dale Preece and Billy Joe Thorne (both 6258).

•BH



PAUL HOMMERT (6258)



# Snuffing Out Vulnerabilities, Sniffing Out Trouble

More security fences, new coded badges, automated badge readers, and an explosive-detecting dog are among the many security upgrades that have kept Sandia Livermore Security specialists busy this year.

"During 1988 we made great strides in reducing potential vulnerabilities, and we feel that employee security consciousness has been raised as well," says Don Charlesworth, supervisor of Physical Security Div. 8531.

Walking up to Bldg. 911, people will find a new entrance south of the building. Completed last month, the new entrance replaces the 30-year-old guard post in the 911 lobby. The new entrance includes handicapped access, a package search area, and two badge-reader booths for use by employees after hours and on weekends.

"Even though there is no longer direct access to the tech areas through Bldg. 911, the badge office will remain there to process contractors and visitors, who can use a new side exit to the relocated Post 1," Don explains.

A redesigned badge is also part of the "new look." DOE policy requires that employee/contractor ID badges be redesigned every five years. The new credit-card-size badge has a magnetic stripe containing coded information that (with a badge reader; see below) allows authorized persons to enter the main tech area outside of normal working hours. It also allows access to special areas within the main tech area during business hours.

## More Badge Readers Planned

New badge photos are taken by a digitized video system that turns out a finished product in only two minutes. The system stores the photographic image for retrieval later if a replacement badge is needed. The new badge will be used at the many badge readers that will eventually be installed at every major building, exclusionary area, and vault.

Don says increased emphasis on more reliable badge-reader devices will reduce the need for personalized key service. "In addition to providing increased security, the automated badge readers will be more convenient for employees — no more phoning Security and waiting for an inspector to arrive and open doors."

A "bomb-sniffing" dog is another recent SNLL security addition. Trained to detect different types of explosives, the animal is funded by Sandia but housed by LLNL's security force, which has a trained handler. The dog is brought across the street to SNLL regularly for random vehicle searches and package inspections.

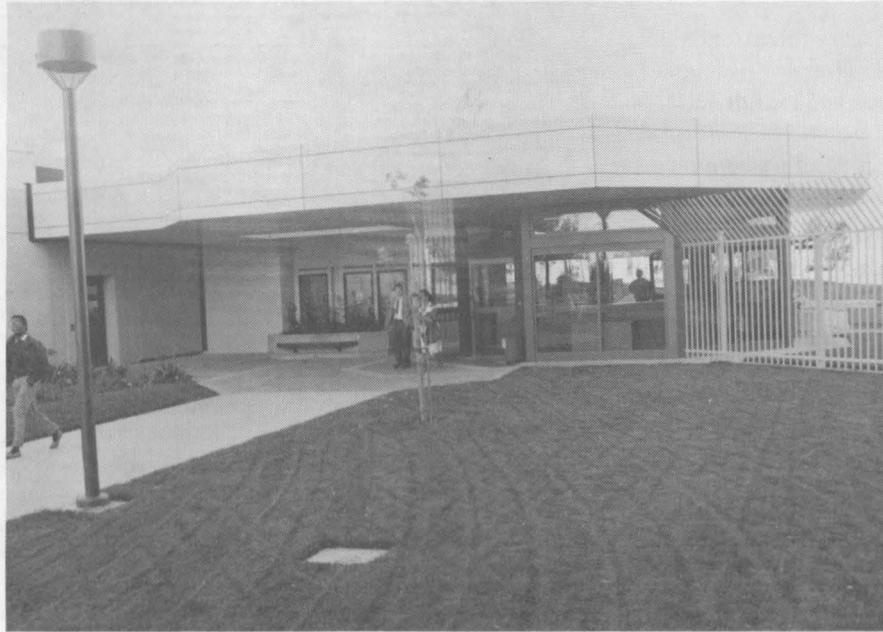
During the past few years, Sandia's site size has increased to 413 acres, about doubling the area that must be patrolled by Advance Security Inc., SNLL's contract protection force. The new buffer areas will eventually be fenced and equipped with surveillance cameras and lighting.

Visitors entering Sandia from East Avenue will notice the new cyclone fencing along the road — running all the way from Vasco Road, where new buffer zone land has been acquired.

Three new parking lot control points (guard posts) are staffed during normal business hours, with the main parking lot post by Bldg. 911 staffed 24 hours a day, seven days a week. Car window decals have been issued for employees, contractors, and credit union users; others must stop and obtain temporary permits to use the parking lots.

## Electronic Security Specialists Added

Corey Knapp, supervisor of Technical Security Div. 8536, has added two employees to work in electronic security areas. "This allows us to devote considerably more attention to the areas of technical

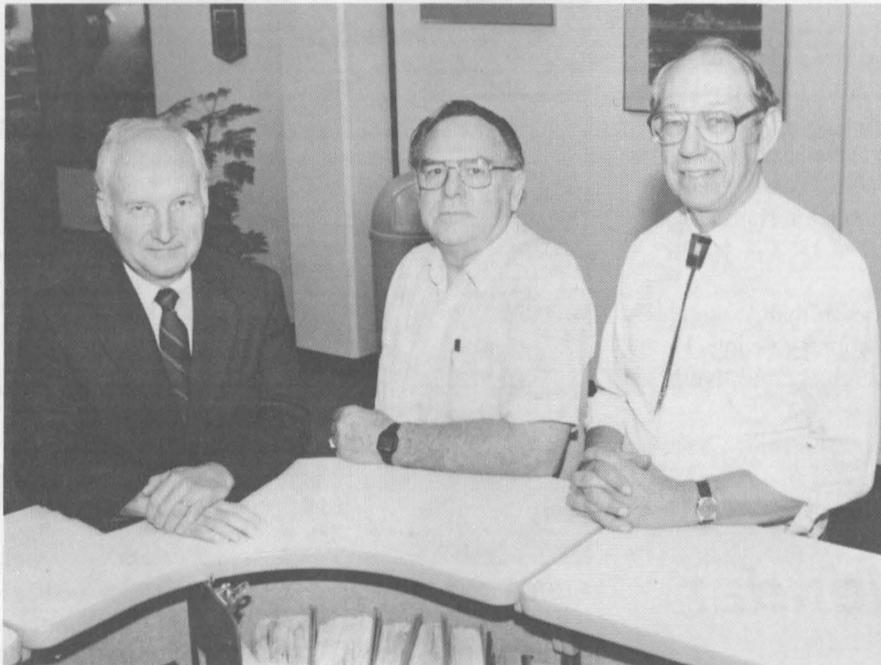


NEW FRONT ENTRANCE POST on the west side of Sandia is located south of Bldg. 911. Improvements include handicapped access, two badge-reader booths, and room for package searches.

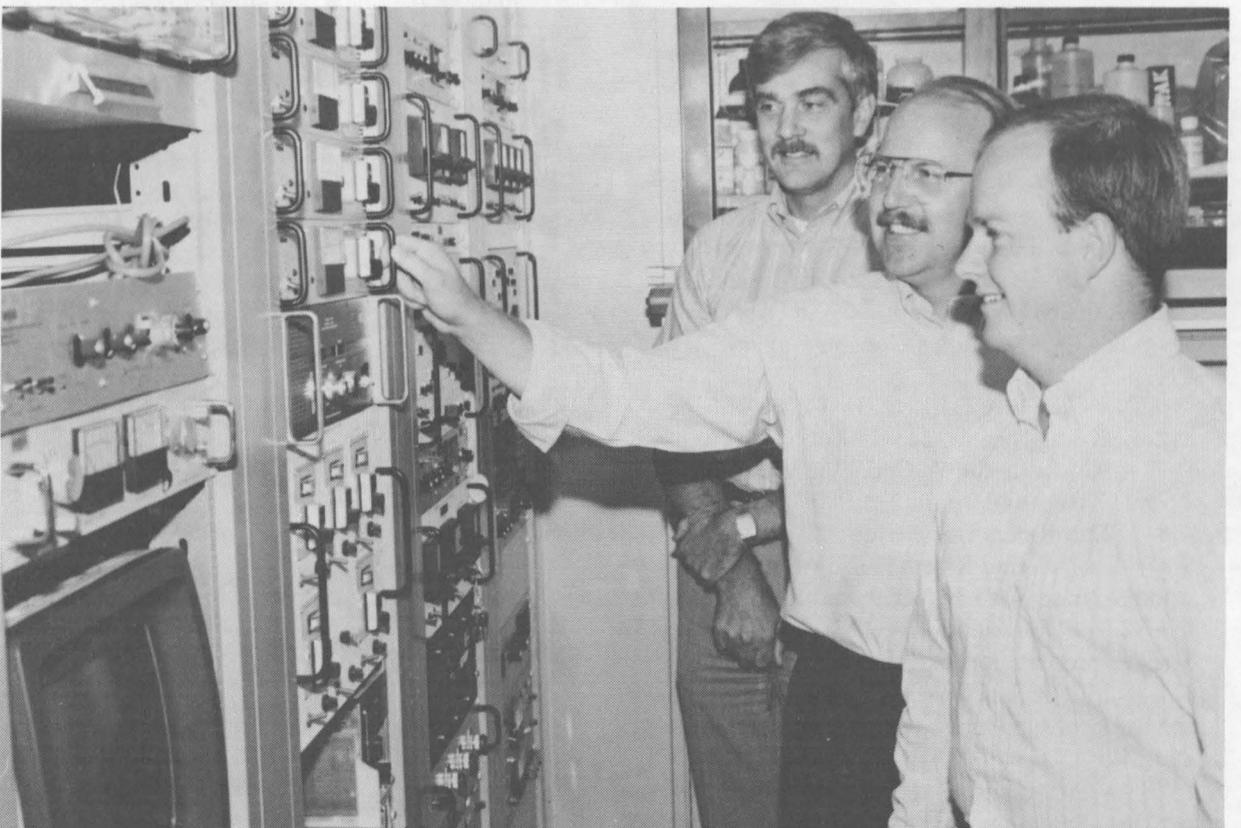
surveillance countermeasures [checking for electronic bugs, for example] and to the computerized access-control system," says Corey.

Seminars on espionage presented recently at SNLL explained how spying is carried out and discussed telltale signs of employees who may have sold out to foreign governments. "The seminars are an

example of our increased concern over the insider threat," says Corey. "Ten years ago we concentrated on protecting our employees and site assets from terrorists; now we are also directing efforts to the potential espionage agent on the inside — a disgruntled employee, someone who is being blackmailed, or just a person spying for money." ●BLS



RECENT RETIREES at Sandia Livermore (from left): Lou Selder (8511), Bill Byroads (8445), and Dale Irving (8285).



NAVY ENSIGN Pat Steele (right) spent the past three months at Sandia Livermore as part of a new Service Academy postgraduate program in which science and engineering graduates will work with Sandians on temporary duty assignments in R&D. Pat, the son of Rex Steele (8446), is shown with Rich Behrens (left) and Larry Thorne (both 8357) looking at the Thermo Analyzer Modulated Molecular Beam Apparatus in Rich's solid propellant lab. Pat worked with Rich on the molecular materials program and with Larry on low-pressure flame studies before reporting to nuclear power school in Orlando, Fla.

# Ortiz Named Director

Nestor Ortiz, formerly manager of Reactor Systems Safety Dept. 6410, became Director of a new organization, Environment, Safety, and Health 3200, effective Dec. 16.

"The new directorate affirms Sandia's commitment to the safety and health of our workplace and to the protection of our environment," says Dennis Roth, Vice-President of Administration 3000. "The DOE and Congress are moving toward a new era that places significant emphasis and value on the need to respond to an increasing number of appraisals designed to ensure compliance with DOE orders. To support our vital national mission, it is imperative that we have a Labs-wide course of action that meets these emerging challenges."

The ES&H directorate includes the Health and Safety Department (formerly ES&H Dept. 3310), the Environmental Protection Group (formerly Environmental Programs Div. 3314), and a Planning Staff to be formed later.

Nestor joined Sandia in 1977 as a staff member with the reactor safety organization. The following year he was promoted to supervisor of the Nuclear Fuel Cycle Risk Assessment Division. He became manager of the Nuclear Fuel Cycle Systems Safety Dept. in 1984.

Nestor received a BS in EE and an MS in nuclear engineering from the University of Puerto Rico. He earned his PhD, also in nuclear engineering, from MIT. Before joining the Labs, he was a department head with a Puerto Rican public utility and worked for the AEC in Germantown, Md.

Nestor is a member of the American Nuclear Society. He is on the Technical Advisory Board of the Engineering Research Center for Hazardous Waste Control, recently created at UCLA by the National Science Foundation.

In his spare time, Nestor enjoys softball, country-and-western dancing, and cross-country skiing. He and his wife Regina have two daughters and live in the NE Heights.



NESTOR ORTIZ, Director of newly formed Environment, Safety, and Health Org. 3200, and Phyllis Pei, a member of the Environmental Protection Group in 3200, check barrels of waste being prepared for shipment to licensed disposal sites.



SUPERIOR PROGRAM PERFORMANCE award has been presented to Sandia by the US Small Business Administration (SBA). The award, SBA's highest national award for federal government prime contractors, recognizes Sandia's efforts during FY88 to award contracts to three categories of firms — small, small disadvantaged, and women-owned businesses. The award is displayed after the Dec. 12 presentation ceremony by (from left) Dennis Roth (3000); Monica Edwards Harrison, SBA Assistant Administrator; and Bruce Twining, DOE/AL Manager. Only nine of the awards were presented throughout the nation.

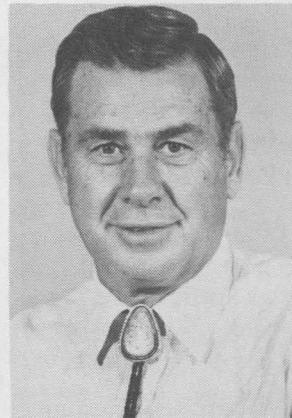
## Events Calendar

- Dec. 23 — Christmas concert, presented by the Musica De Camara Ensemble; 8 p.m., First United Methodist Church (4th & Lead SW), 243-5646.
- Dec. 23-24 — "Much Ado About Nothing," comedy by William Shakespeare, performed by the New Mexico Repertory Theatre; 8 p.m., KiMo Theatre, 243-4500.
- Dec. 23-Jan. 1 — "Peter Pan," Albuquerque Civic Light Opera presentation; 8:15 p.m., 2:15 p.m. Sun.; Popejoy Hall, 345-6577.
- Dec. 23-Jan. 20 — Exhibit, "Alexander Masley: Calculated Abstractions"; 9 a.m.-4 p.m. Tues.-Fri., 5-9 p.m. Tues. evenings; Jonson Gallery, 277-4967.
- Jan. 6-7 — "Talking Dance," by Celeste Miller; 8 p.m., KiMo Theatre, 243-4500.
- Jan. 7 — Concert, the A Cappella Vocal Band; 7 p.m., Kiva Auditorium, 275-0807.
- Jan. 8 — Trail Riders Horse Club All-Breed Horse Show, 9 a.m., Trail Riders Horse Arena (Maplewood & Niese NW), 873-0699 or 877-2585.
- Jan. 11-22 — "Roosters," New Mexico Repertory Theatre presentation of contemporary Hispanic play by Milcha Sanchez-Scott about a father-and-son battle for supremacy; call for time, KiMo Theatre, 243-4500.
- Jan. 13 — Crownpoint Rug Auction: 3-6:45 p.m. rug viewing, 7 p.m. auction; Crownpoint Elementary School, 786-5302.
- Jan. 13-14 — "Master of the French Horn," classical concert, the New Mexico Symphony Orchestra w/guest Philip Myers (New York Philharmonic principal horn player); 8:15 p.m., Popejoy Hall, 842-8565.

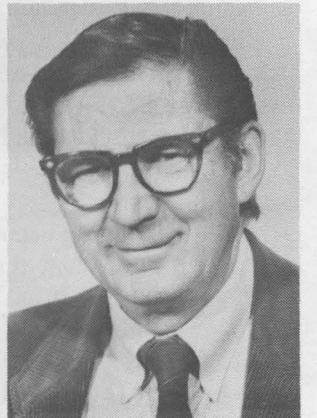
## R e t i r i n g



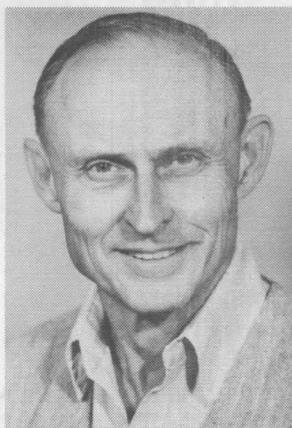
Boney Vigil (7841)  
Dee Vigil (122)



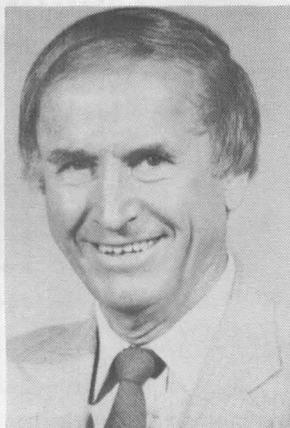
32 Don Markwell (3313) 34



Lyle Porter (5248) 37



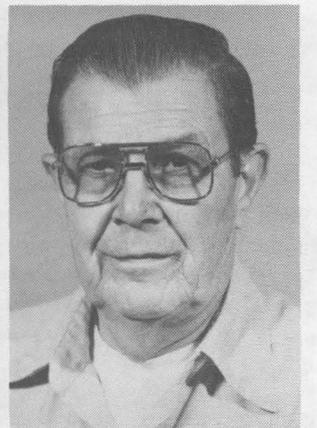
Ralph Fox (5113) 37



Earl Simonson (122) 36



Dick Andes (120) 30



Willard Flowers (7412) 38

# You Don't Have to Be Jane Fonda

You may think that aerobics is just for the "hard bodies" down at the health club. Not so, according to Sandia's TLC (Total Life Concept) program — specifically, program manager Pete Egan, aerobics instructor Bobbie Bartberger (7845), and substitute instructor Dave Bushmire (7252).

The TLC program views aerobics as a good way to reduce the primary risks of coronary heart disease: high blood pressure, high serum-cholesterol levels, and high body fat.

What you need for safe, successful participation in an aerobics class is a physician's approval and advice on safe levels of exercise, plus an instructor who knows how to minimize risk while maximizing gain.

Dave was recently certified as an instructor by the International Dance-Exercise Association (IDEA). As he studied for a rigorous four-hour test (only 60 percent of the candidates passed), he was impressed by what he was required to know both about keeping aerobics safe and about the range of possible benefits. Some possible gains in addition to the reduction of cardiac risks:

- Low-impact aerobics can help those with arthritis remain flexible and keep their full range of motion;
- Increased aerobic fitness raises the activity threshold at which asthmatic symptoms occur;
- Low-intensity, long-duration exercise (along with the proper diet) can reduce obesity;
- Aerobic exercise can increase bone density and thus help prevent osteoporosis;
- Aerobic exercise reduces mental stress and decreases swings of depression; and

• A moderate exercise program can increase the uptake of glucose from the blood, possibly reducing insulin needs for people with adult-onset diabetes (but diabetics should reduce dosages only in consultation with a doctor).

## Something for Everyone

Although aerobics is not a cure-all, Dave would like Sandians to view this type of exercise as a possibility for them. He has taught aerobics for eight years, while certified locally by the YWCA.

The certification by IDEA took a major commitment. "At times I felt like I was studying for pre-med," says Dave about the months of work he put in to get ready for the four-hour test.

Bobbie is preparing for IDEA certification and plans to take the exam in a few months. She's now certified by the YWCA. Like Dave, Bobbie is interested in making aerobics a form of exercise suitable for as many people as possible. She describes the TLC classes as low-impact but high-energy.

Dave points to himself as the sort you might expect to avoid aerobics classes. "I'm 54 years old, I'm a division supervisor who has to travel a lot, I have the stresses of dealing with engineering problems in the weapon program — but for me, aerobics is not just something I want. It's a need."

Besides aerobic-dance classes, emphasizes Pete, TLC offers fitness classes such as walking/jogging and swimming. Anyone enrolled in the TLC program may choose to enroll in one of these fitness classes.

The TLC fitness staff orients the enrollees on principles of safe exercise. They learn the how, what,



BOBBIE BARTBERGER (7845) and Dave Bushmire (7252), TLC aerobics instructors, demonstrate stretching exercises that help students increase their range of motion. By keeping within a comfortable limit, say Bobbie and Dave, anyone in the TLC classes can safely do stretches.

and why of exercise and are screened for cardiovascular risk factors. Some are asked to take exercise stress tests before starting the exercise program.

Pete notes that exercise yields perceptible benefits. "Before and after the 12-week fitness program, the TLC staff measures body composition, blood pressure, aerobic endurance, and flexibility. For most of our participants, we see significant improvement in all of these."

## UNCLASSIFIED ADVERTISEMENTS • UNCLASSIFIED ADVERTISEMENTS • UNCLASSIFIED ADVERTISEMENTS • UNCLASSIFIED ADVERTISEMENTS

**Deadline: Friday noon before week of publication unless changed by holiday. Mail to Div. 3162.**

### Ad Rules

1. Limit 20 words, including last name and home phone.
2. Include organization and full name with each ad submission.
3. Submit each ad in writing. No phone-ins.
4. Use 8½ by 11-inch paper.
5. Use separate sheet for each ad category.
6. Type or print ads legibly; use only accepted abbreviations.
7. One ad per category per issue.
8. No more than two insertions of same "for sale" or "wanted" item.
9. No "For Rent" ads except for employees on temporary assignment.
10. No commercial ads.
11. For active and retired Sandians and DOE employees.
12. Housing listed for sale is available for occupancy without regard to race, creed, color, or national origin.

### MISCELLANEOUS

- NINTENDO ACTION SET w/Super Mario Brothers II, \$60; Thomas Playmate organ, \$500. Ratcliff, 255-737.
- PORTABLE SEWING MACHINE, \$55; 8mm movie camera, \$10; ski boots, size 10, \$15; lamps, \$15; clothes. Schowers, 822-8494.
- CANON EOS 650 CAMERA, w/50, 35-105, 100-300 lenses, EZ300 flash, hoods, remote cord, \$750. Granoff, 345-0711.
- KING-SIZE HEADBOARD and 7-1/2' armoire, handmade by George Sandoval, \$1000. Dossey, 823-9306.
- "POWER WHEELS" JEEP, riding toy, 1 year old, \$110. Macha, 298-6583.
- SEARS CAR-TOP LUGGAGE CARRIER, vinyl cover, fits automobiles w/gutter, \$25 OBO. Treadwell, 884-4221.
- DP EXERCYCLE, speedometer, 12 miles on odometer, \$40; doghouse, new, carpeted, \$25; Regina Electric broom, \$25; Amerec rowing machine, 600 series, \$150. Snodgrass,

- 268-8820.
- GAME TABLE, folds, \$100 OBO. Mason, 281-3052.
- SOCCKER SHOES, size 5, \$7.50; Girl Scout uniform (dress & pants), \$7.50. McMillen, 881-6077.
- OLYMPUS OM-10 CAMERA, w/manual adapter, T-20 flash, 35mm and 50mm lenses, \$50. Pei, 275-9033.
- MICROWAVE, Sears Kenmore, \$200. Hunter, 865-5745.
- TWO PAIR CUSTOM LINED DRAPES, w/Austrian valances, foam green, ceiling to floor, 92" x 90" and 57" x 90", sell separately. Chavez, 298-7969.
- GE COLOR TV, 25", w/remote control, \$160. Subramanian, 821-1705.
- ZENITH TV, 19", \$75; Hammond organ, spinet, 2 keyboards w/base pedals, \$400. Hole, 255-1444.
- FIREPLACE INSERT, w/blower, \$150 OBO; fur-like 3/4"-length coat, size 10, \$35 OBO. Campbell, 889-0961.
- IBM TYPEWRITER, correcting Selectric II; microfiche reader; mauve mini-blinds, 55" x 55"; Composite computer monitor; oil paintings. Hudson, 821-3968.
- HEADER (MUFFLER) SYSTEM, fits dual-port 1600 VW engine, \$20. Schuster, 822-8969.
- PUNCHING BAG, Everlast, used once, \$45; exercise bike, \$35. Miller, 281-4397 after 6.
- SHORT-BED CAMPER SHELL, \$65. Casares, 877-0369.
- HAM RADIO EQUIPMENT: Kenwood TS-1405 transceiver, Astron 35A power supply, 1-KW Ameritron AL-80A linear amplifier, NYE Viking 3000-W tuner, half price. Wayland, 299-2587.
- HEAVY-DUTY TIRE CHAINS, can be adjusted to fit 16" or 16.5" tires, \$60. Danneels, 292-1548.
- '75 FORD PICKUP BED, slight damage on one side, you pick up, \$15. Chavez, 842-6374.
- NATURAL CORDUROY MINK JACKET, worn 8 times, has been cleaned, glazed, and stored, cost \$1850, sell for \$600. Smith, 384-5182.
- MAN'S 3-PIECE SUIT, light tan corduroy, jacket R38, pants 34 w/wide-cut bottom, \$45. Nickerson, 888-4159.
- COMMODORE VIC-20 COMPUTER

- w/tape drive, games, TV adapter, serial programming books, learning aids, \$95 OBO. Atkins, 298-5762.
- LOCKING SKI RACK, gutter mount for full-size vehicle, \$30 or make offer. Lane, 884-4566.
- WOMAN'S DOWN SKI JACKET, green w/navy trim, misses size 12, \$35. Tremi, 266-5412.
- MATCHING LEATHER CHAIRS, chocolate brown, Brazil Contempo, w/foot-rests, cost \$1540, sell all for \$590. Johnson, 298-1011.
- MAYTAG WASHER & DRYER, \$300 OBO. Holmes, 897-0916.
- CAMPER SHELL, insulated, fits long-wide bed, \$250 OBO. Eisenberger, 877-7041.
- BACH STRADIVARIUS TRUMPET, model 37, medium large bore, 3 mouth pieces, mute, reconditioned, \$495. Thorne, 884-4870.
- COMPUTER PRINTER, Star Gemini 10x dot-matrix, \$75 firm. Knapp, 294-6359.
- KEROSENE HEATER, 10,000-Btu, \$75; Sears humidifier, 10-gal., new belt and motor, water purification tablets, \$35. Owyong, 294-1884.
- THREE PICKUP REAR WINDOWS, all '85 Nissan, 1 sliding, 2 solid, \$30/ea. OBO. Chavez, 243-9530 after 6.
- TWIN-SIZE BED, bookcase headboard, complete, \$50; 6-drawer credenza, \$30. Baker, 888-0792 leave message.

### Deadline Notice

**The next issue of the LAB NEWS is Jan. 13. Deadline for ads and other submissions is noon on Jan. 6.**

### TRANSPORTATION

- '78 DATSUN 280Z, 2x2, new paint, tires, and radio, \$3000. Martinez, 296-6184.
- '83 YAMAHA VIRAGO 750, \$1500; '84

- 23' gooseneck trailer, \$3500; '84 Chev. 1-ton Dully, 4-WD, \$13,500. Rodriguez, 296-3277.
- '88 FORD RANGER XLT, 5-spd., 4-cyl., PB, PS, AM/FM, sliding rear window, 6K miles. Gibson, 888-0603.
- '79 PORSCHE 924, red, 5-spd., AC, sunroof, Australian sheepskin seat covers, \$10,000 OBO. Jacobs, 275-8335 after 5.
- DUNE BUGGY, Pinto engine, sand tires, street-legal, extras, \$2600. Castillo, 294-0624.
- '86 TOYOTA MR2, 5-spd., PW, PL, tilt, cruise, sunroof, tinted windows, \$9350 OBO. Whelan, 265-2836.
- '58 FORD UTILITY TRUCK, V-8, standard, needs some work, \$250 OBO. Dickenman, 892-9561.
- '85 TOYOTA SUPRA, fully loaded, leather seats, power sunroof, 5-spd., 27K miles, silver, blue book. Soo Hoo, 294-0268.
- '81 CUTLASS SUPREME BROUGHAM, 2-dr., split-bench seat, V-8, AM/FM 8-track, cruise, AC, below NADA. Maestas, 292-6409 evenings.
- '83 TOYOTA CRESSIDA, white, 4-dr., 41K miles, leather, sunroof, one owner, \$7000. Loeppeke, 299-7338.
- '79 CHEV. PICKUP, 4-spd., have every maintenance bill. Rutledge, P.O. Box 520, Tijeras, NM 87059.
- '82 VW RABBIT, 4-dr., gas-powered, \$995 OBO. Campbell, 889-0961 or 275-0795.
- '72 OLDS. CUTLASS SW, \$700 OBO. Brigham, 293-6914.
- '69 CHEV. C-20 PICKUP, V-8, 4-spd., w/shell, \$1100. Reynolds, 298-1434.
- '78 CHEV. PICKUP, \$2200 OBO. Chemistruck, 281-9434 after 5:30.
- '87 PLYMOUTH VOYAGER SE, loaded, 19K miles, \$12,000 OBO. Strasburg, 291-9212.
- '87 TOYOTA PICKUP, AT, AM/FM cassette, white, camper shell, truck-bed mat. Smith, 275-8185.
- '88 FORD FIESTA, take over payments. Campbell, 888-3135.
- '76 TOYOTA CELICA, 4-spd., AM/FM, AC, 85K miles, one owner, \$1850. Anderson, 299-1628.
- '84 CUTLASS SUPREME COUPE, V-8, AT, PW, PS, moonroof, all extras, \$6500. Ater, 822-9697.
- '85 TOYOTA PICKUP, 1-ton, long bed,

- 5-spd., PS, 30K miles, \$4750 OBO. Rowe, 299-0961.

### REAL ESTATE

- 4-BDR. TRI-LEVEL HOME, 2070 sq. ft., on cul-de-sac, vaulted ceilings, open floor plan, new carpet, east of Tramway & Lomas, \$121,000. Reinhardt, 296-1815.
- 3-BDR. HOME, LR, DR, den, sunroom, 1-1/2 baths, garage, masonry construction, landscaped yard w/sprinklers, \$77,000. Clauss, 266-9319.
- 3-BDR. HOME, NE, 2 baths, den, LR, FP, double garage, pitched roof, security iron, storm windows, assumable FHA, \$83,900. Beck, 294-6868.
- 3-BDR. CUSTOM HOME, American Quality Craft, great room, DR w/atrium, French paneling, tile work, Heritage East, \$131,000. Barr, 294-9034.
- 1600-SQ.FT. HOUSE, NE Heights; sell or trade for 4-bdr./den home, in Bosque Farms area, \$30,000 equity. Baker, 888-0792 leave message.

### WANTED

- ROTTWEILER, AKC-registered, female to breed w/AKC Rottweiler male. Chavez, 839-9830.
- 410-GAUGE SHOTSHHELL RELOADER, rent or buy; glass bottom for microwave, 13" x 15" maximum. Yingst, 884-3812.
- APPLE IIe for use in a school, reasonable price and good condition. Warpinski, 884-8791.
- POLE LAMP, good condition. Brigham, 293-6914.
- BOAT, 18' to 20', fish/ski, closed bow cuddy preferred, good condition. Young, 884-7836.

### LOST

- GOLD CHAIN, 20", rope chain w/barrel clasp, lost Dec. 6 around 11:30 a.m. between Personnel/Benefits Bldg. 832 and front parking lot. Campbell, 299-2556.

## Say Goodbye to '88, Hello to '89: You Gotta Race to Save Your Place — Because It's Deadline Time

IF YOU PUT OFF 'TIL TOMORROW what you should do today, you'll be in a state of deep despair (and we don't mean New Mexico) — at least if you plan to be at the C-Club's New Year's Eve celebration. That's because today is the last day you can buy tickets for the barn-dance bash on Dec. 31. The \$38/couple tab includes a prime rib or fried shrimp dinner (served from 7 to 10 p.m.), a bottle of champagne served with continental breakfast at midnight, and plenty of noisemakers and party favors. Those well-known Poor Boys from south of town belt out the sagebrush-shuffle tunes (plus Auld Lang Syne!) from 9 p.m. to 1 a.m.

LIKE THE REST OF US, that hard-working Club crew will take a much-needed vacation between Christmas and New Year's. There's still time to wish them all a merry Christmas though. Tonight, the main lounge is open from 4 to 8 p.m.; stop by with your friends for the last hurrah of 1988.

SPEAKING OF THE MAIN LOUNGE, special events there in early January include video nights (and free popcorn) on Jan. 4 and 11; entertainment starts at 6 p.m. Import Night on Jan. 12 offers your favorite foreign beer for just \$1.25 from 4 to 8 p.m. And don't forget — Mondays are Mug Nights; bring your own mug from home (up to 24 ounces), and Marlon (the friendly bartender) will fill it up with

beer for only 50 cents.

BINGO FANS get their next chance to hit the jackpot on Thursday, Jan. 5. Cards go on sale at 5:30 p.m., and the Early Bird game starts at 6:45; regular gaming begins at 7. Plan on scuttling the scullery stint that night, because a nice variety of food is available at very reasonable prices.

WHOO IT UP at Western Night on Jan. 6. Two-for-one chow-line specials that night are filet mignon or scallops; sounds like mighty fine home-on-the-range food (and the cost is just \$19.95 for two). Afterwards, the Isleta Poor Boys — recovered from New Year's Eve (we hope) — strum the c/w music for your dancing pleasure. Make your reservations early for this first Friday-night fling of the year (265-6791). Remember: Members receive a \$1 discount on meals every Friday night (\$2 maximum per family).

FIRST GAMING SESSION of the new year for those sharp sharks of the T-Bird variety is set for Thursday, Jan. 5, starting at 10 a.m. As usual, that means card games of every description, good conversation (probably *also* of every description!), and free refreshments and door prizes. With a deal like that, you can't go wrong.

## Welcome

### Albuquerque

Peter Boissiere (1414)  
Nanette Briscoe (144)  
William Buller (1111)  
Frederick Helsel (7554)  
Judd Herman (2826)

### Illinois

Richard Wetzel (9235)

### Iowa

Lynne Schulter (7851)

### Louisiana

David Pace (7842)

### Wisconsin

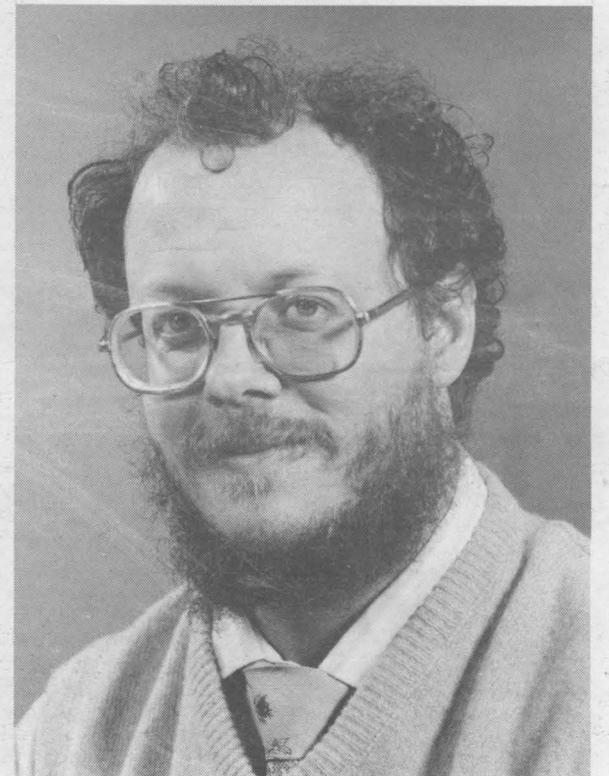
Steven Deibele (2343)

## Congratulations

To Vickie and Duane (2625) Garrison, a son, Casey Allen, Nov. 28.

To Terry and Richard (1141) Blake, a daughter, Kristen Micheala, Dec. 5.

To Martha and John (9211) Gaona, a son, Kenneth Ryan, Dec. 14.



DR. KRIS LEE SPERRY

## Increasingly High-Tech

# Forensic Pathology Specialists Have Vital Role in Death Investigations



The phrase "a tough job, but someone's gotta do it" is often used jokingly, but it applies very seriously to some professions — including that of forensic pathologist, who

identifies deceased persons and establishes causes of death.

Sandians can learn how forensic pathologists use science and technology in their work at the next Community Focus lecture at 12 noon, Tuesday, Jan. 10, in the Tech Transfer Center.

Kris Lee Sperry, M.D., of the UNM School of Medicine will present "Whodunnit? The Challenge of Contemporary Forensic Medicine." Dr. Sperry has a dual appointment at the medical school — assistant professor in the Pathology Department and medical investigator for the State of New Mexico, Office of Medical Investigator (OMI).

His presentation will explain the normal duties of his profession, how cause/manner-of-death determinations are made, and how subtle findings revealed during an autopsy are interpreted. He plans to present details from OMI files to illustrate several points.

Dr. Sperry says his profession is using more high-tech devices and techniques today to accomplish its mission. "For example, we're now using a special laser to detect trace evidence like fingerprints, fibers, and hairs. And new DNA hybridization techniques allow us to connect blood and body-fluid samples to criminals and victims. These devices and techniques give us added capabilities for solving some violent crimes that previously were very difficult, sometimes impossible, to solve."

### Often Difficult Conditions

Cause and manner of death must sometimes be established under difficult conditions. The forensic pathologist must identify deceased persons who have been exposed to the elements for prolonged periods or disfigured from fires and extreme trauma. And,

of course, some murderers go to great lengths to cover up the true cause of death.

Dr. Sperry received his M.D. from the University of Kansas in 1978. He served as a commissioned general medical officer for two years in the US Public Health Service, Indian Health Service branch, Red Lake, Minn. He joined the UNM Med School as a pathology resident in July 1981. Among other professional activities, he is serving as program director for the pathology/biology section of the American Academy of Forensic Sciences annual meeting in Las Vegas in February.



PHONE BOOKS — more than 24 tons of them — are not the problem, even if they arrive at the Mail Room by the truckload. And the mail distribution system works well, even if most customers don't show up at the Mail Room to do the toting personally. The problem — one that top management is becoming concerned about — is incoming personal mail (the magazines, advertisements, letters, etc. that should go to employees' homes.) But, this time, the personal-mail problem was not the purpose of President Welber's visit — he came to receive the ceremonial first phone book; Isabel Vigil (3154) did the honors. Fourteen members of the Mail Room crew distributed the other 7703 pairs (white and yellow pages) last Saturday. If you were missed, drop by Bldg. 824 and pick up a set. And if you get personal mail at the Labs, cease and desist. Stop too.