1975

Introduction

Sandia Laboratories is participating in the national effort to achieve energy independence, concentrating in those areas where its experience, expertise, and facilities permit a unique contribution.

The Labs' energy projects are concentrated in those areas where immediate, expert contributions can be made. The various geo-energy programs — coal gasification, oil shale development, hydrofracturing, etc. — draw on Sandia's remote instrumentation abilities developed during nuclear weapon testing. Contributions in nuclear fuel cycle work are based on experience and expertise stemming from the operation of powerful reactors and other radiation sources. Work on laser and electron beam fusion has a similar grounding in long-established radiation effects research.

Contributions in solar energy, such as Solar Total Energy Project, derive partially from systems analysis capabilities, which permit computer modeling and simulation to determine the most efficient and economical combination of components and subsystems. Photovoltaics work draws on the Labs' substantial materials research capabilities, as do several other projects — flywheel development, improved drill bits, and a better understanding of Synthoil catalysts.

By using these technical capabilities on a selective basis, Sandia expects to make a significant contribution.

An Energy Research and Development Administration (ERDA) multipurpose laboratory. Sandias' principal mission continues to be nuclear ordnance engineering. It is one of the largest research and engineering laboratories in the country, operating ERDA facilities worth approximately $350 million.

The headquarters laboratory is in Albuquerque; a smaller laboratory is operated at Livermore, California. The various installations include a complete range of lasers, nuclear reactors, particle and plasma generators, and electron beam accelerators; engineering development and testing equipment, including two large centrifuges, a rocket sled track, wind tunnels, and shock tubes; and a large computer facility.

Approximately 6,900 persons are employed at the Labs, including some 950 at the Livermore Laboratories. About half of these employees are in technical and scientific positions, the remainder in crafts, skilled labor, and administrative classifications. The Labs' broad capabilities in both engineering and research are reflected in the technical employee mix, which includes about 1,300 electrical, mechanical, aeronautical, chemical, and civil engineers, and more than 500 scientists – physicists, chemists, mathematicians.

Special competence exists in system engineering and management, component development, quality assurance, physical sciences, applied mathematics, explosives, electrochemistry, electromechanisms, materials and processes, earth sciences, electronics, aerosciences, safety and reliability assurance, biosciences, instrumentation, data systems, systems analysis, and testing. The Labs has also acquired considerable experience through the years in working with subcontractors, a capability which is particularly useful in conduct of various energy projects where it is desirable to secure the contributions of private industry.

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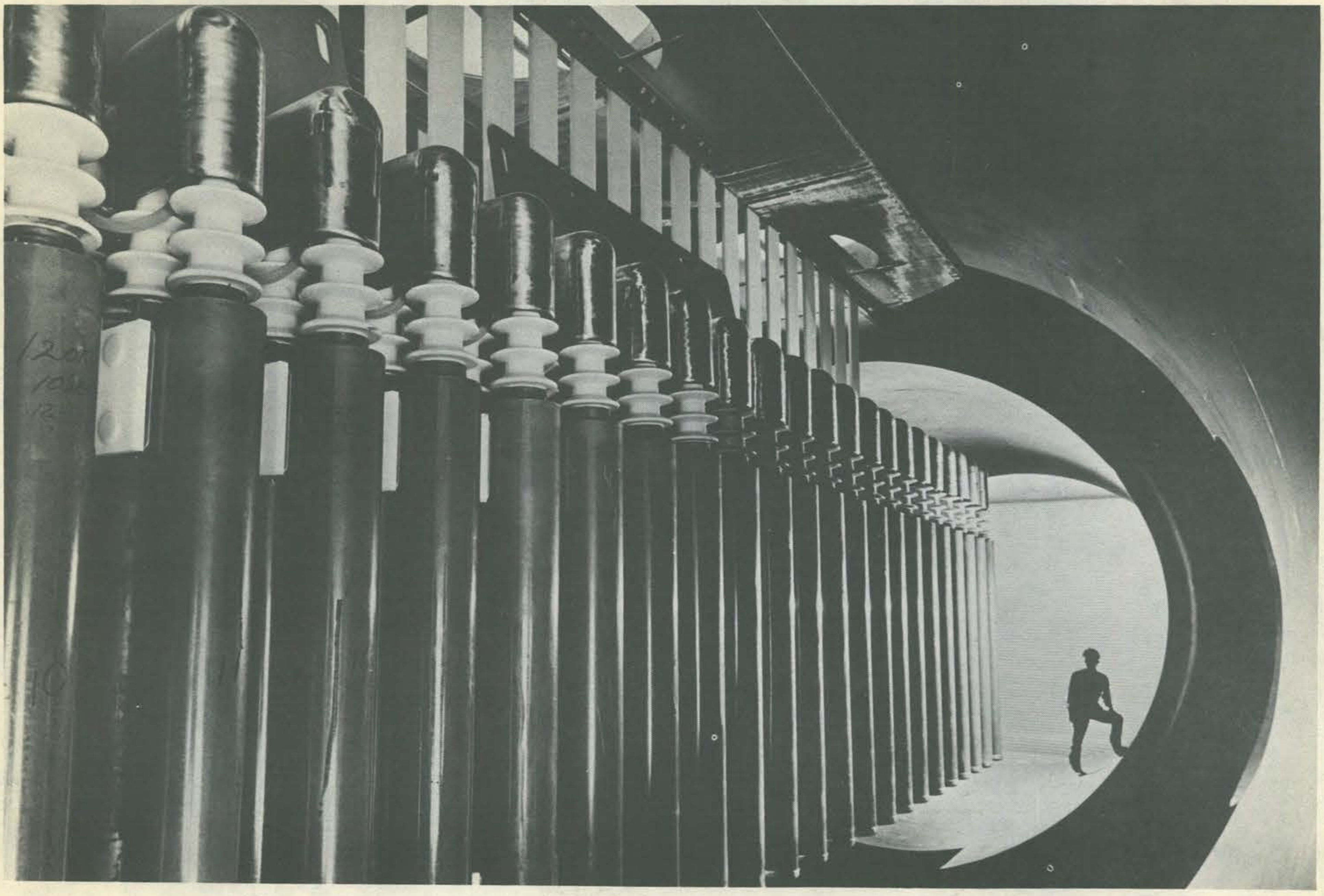
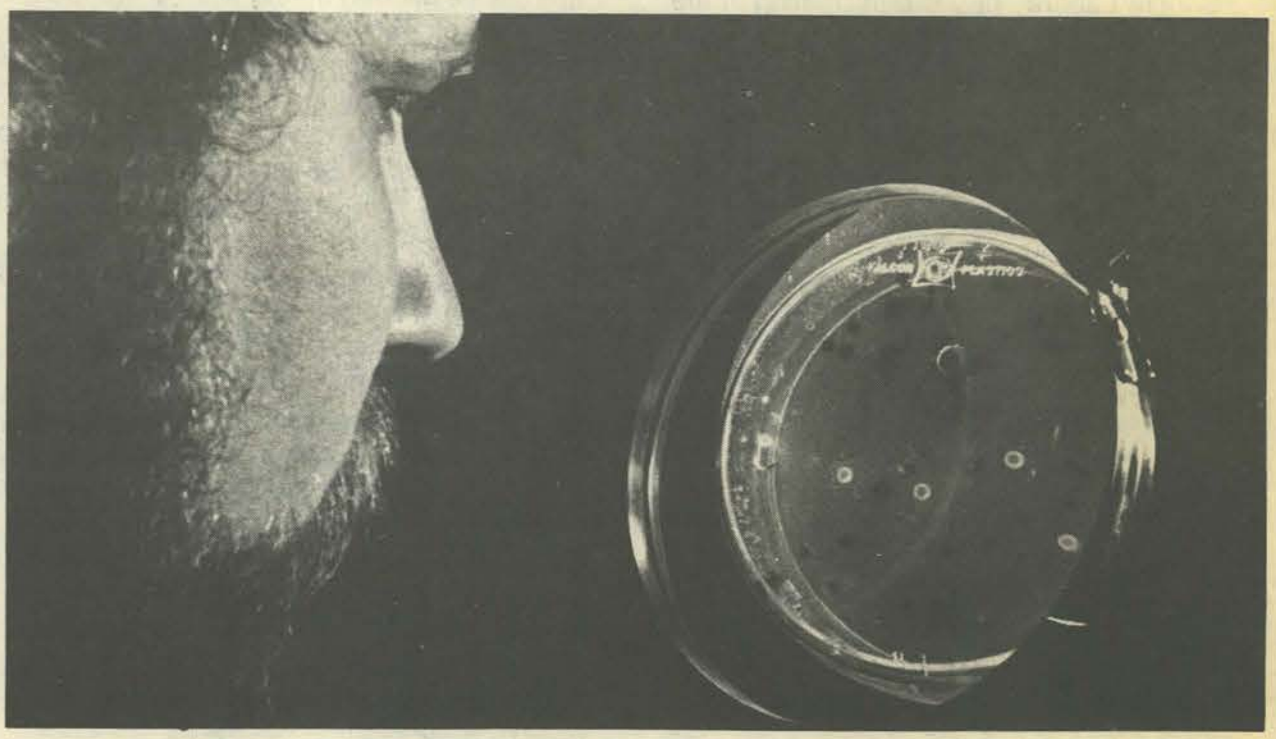
Capacitors in large electron beam accelerator.



NUCLEAR FUEL CYCLE

Nuclear fission is a relatively new means of generating electrical energy, and nuclear-electric power plants have many advantages. For example, they do not consume valuable hydrocarbons, emit large amounts of pollutants into the atmosphere or require the transport of vast quantities of fuel. (If all the atoms in one pound of Uranium-235 were fissioned, the energy released would be equivalent to that from burning three million pounds of coal.) But because radiation is released during the fissioning process and because radioactive waste and by-products (plutonium) are produced. The safety and security of the nuclear fuel cycle is an important issue. Work at Sandia addresses a broad range of nuclear safety concerns – safe design and operation of reactors, including breeders; safe transport of fuel and waste; and utilization and disposal of waste.



Beneficial uses of Radioactive Wastes

Although spent fuel from nuclear power reactors constitutes a severe disposal problem, this radioactive material contains isotopes which have a number of potential beneficial uses if they can be separated and utilized in a cost effective manner. A substantial research program to discover and develop such uses is under way at Sandia.

Currently the principal activity in the beneficial uses program is concentrated on treatment of sewage sludges which, themselves, are becoming a national "waste" disposal problem. The treatment of sludges utilizes a Sandia-developed technique known as thermoradiation — the simultaneous application of heat and gamma radiation. Applied simultaneously, heat and radiation have a synergistic sterilizing effect on bacteria and other microorganisms, permitting increased inactivation of the organisms with lower heat and radiation levels. A systematic analysis of the synergistic effect of thermoradiation was made by Sandia scientists during a study of possible means of sterilizing interplanetary spacecraft.

Because thermoradiation utilizes low levels of radiation and heat, Sandia researchers believe it will be possible to treat sewage sludge using isotopes — particularly Cesium-137 — from spent reactor fuel as a source of radiation and methane gas from the sludge as a source of heat. Such energy sources could be quite economical and efficient.

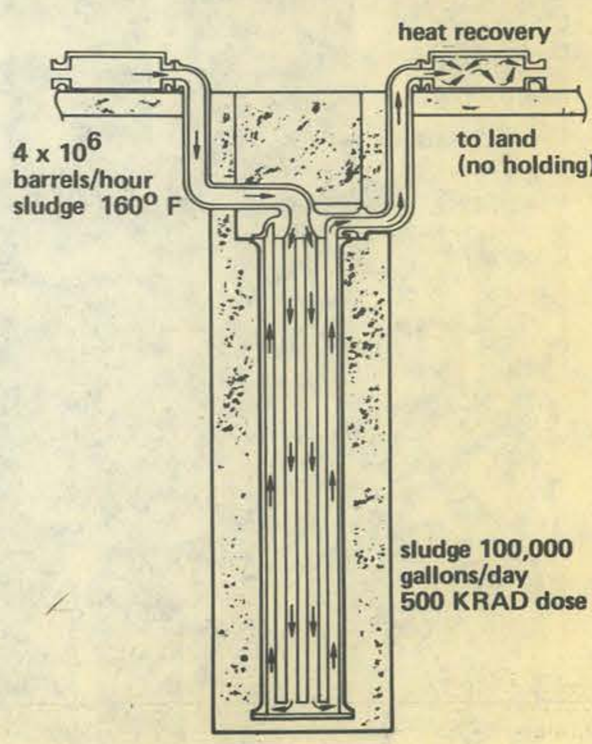
Sludge, which is a viscous residue remaining after treatment of sewage, contains various pathogens that must be sterilized before it can be used as a general-purpose fertilizer, soil conditioner, and possible food supplement for ruminant animals. Chemically, the nutrient value of the sludge appears to be equivalent to that of cotton-seed meal.

As part of the sludge sterilization program, Sandia and New Mexico State University scientists are working together to test the value of sludge as a fertilizer. Tests are also under way at NMSU to feed the material to experimental animals — rats and sheep — to determine its potential as range feeding supplement for livestock.

A pilot plant to more completely test the sludge treatment concept is being designed for operation in connection with a municipal sewage treatment plant in the Albuquerque area. The plant, which will use a 1.4-megacurie Cobalt-60 radiation source, can handle 20,000 gallons of sewage per day and is scheduled for completion in 1978.

below left–Studying effects of thermoradiation on sewage sludge bacteria.

below–Diagram of sludge treatment facility.



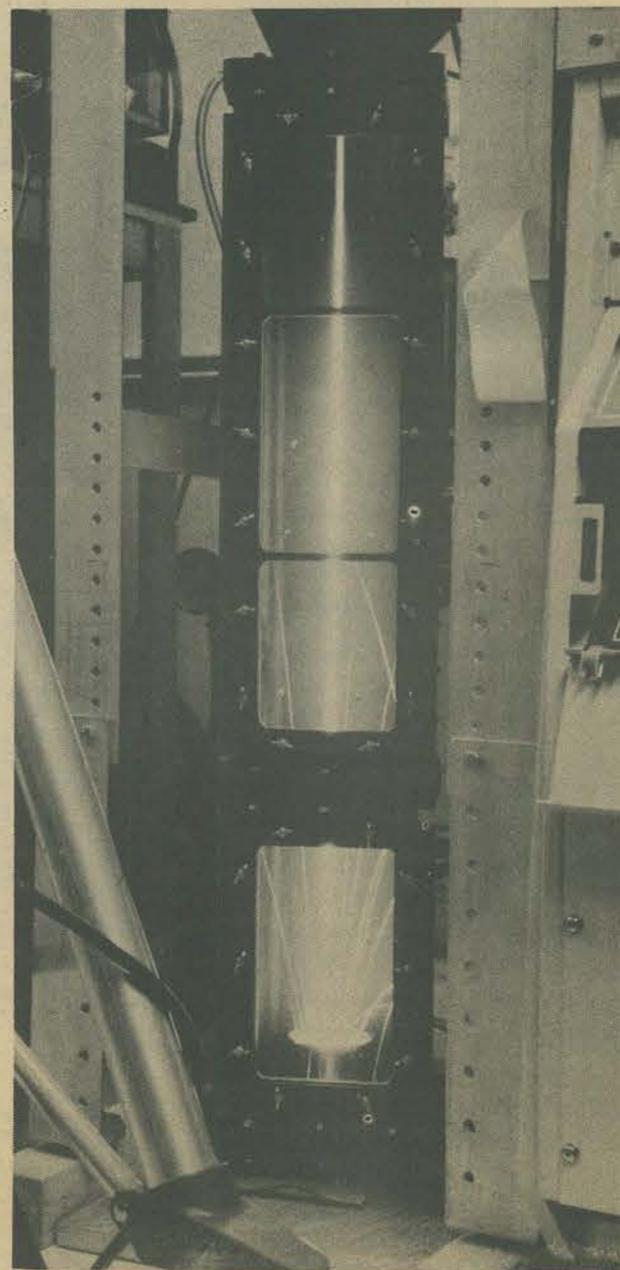
Nuclear Fuel Cycle Safety Research

Sandia is conducting many analytical studies for the Nuclear Regulatory Commission on the safety of commercial nuclear power reactors and other functions and facilities of the nuclear fuel cycle. These studies address possible accident initiation in nuclear power facilities, in-plant accident effects, and the public consequences of the release of radioactivity to the environment.

Modes of accident initiation that are considered include equipment failure, human operating error, sabotage, and external events such as tornadoes or wartime attack. Specific studies underway include application of reliability methods (event/fault trees) to determine reactor plant accident probabilities, assessment of the vulnerability of nuclear facilities to sabotage or attack, development of a methodology for the evaluation of plant safeguard systems, cost-benefit analysis of underground siting, and emergency responses to nuclear accidents.

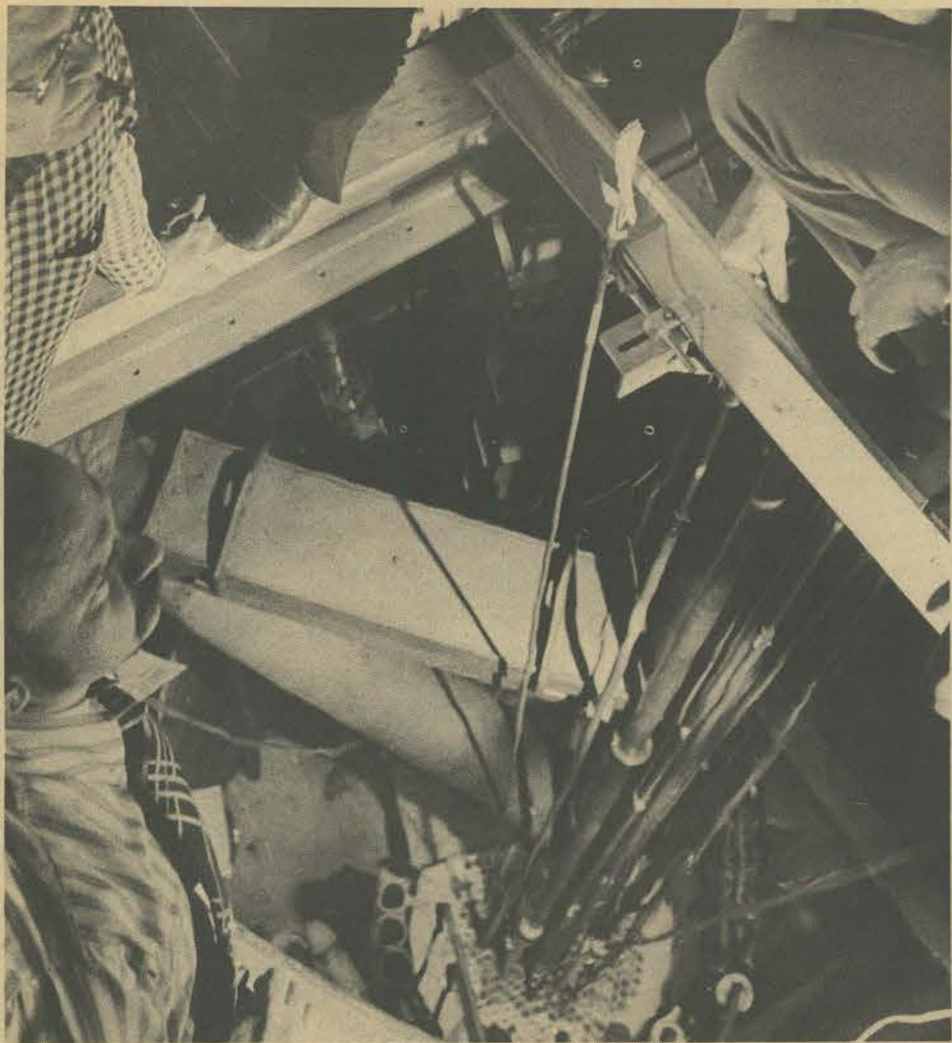
Combined theoretical and experimental studies are being carried out to investigate in-plant accident effects. These studies focus upon accident phenomenology and modeling, effectiveness of reactor safety systems, and containment of radioactivity. Hypothetical accident scenarios are being considered for both light-water and breeder reactors. Current projects include molten core-concrete interactions, steam explosion phenomena, analysis of fast breeder reactor safety experiments, statistical analysis of loss-of-coolant accidents in light-water reactors, and breeder reactor accident benchmark calculations.

Studies of the public consequences of radioactivity release to the environment require multidisciplined input from many fields. A variety of consultants are being employed to supply specialized knowledge, such as medical effects of radioactivity exposure. The effects of radioactivity release during normal operation or due to accidents are being considered for nuclear power plants, transportation, and the remainder of the nuclear fuel cycle. Property damage, public health hazards, and decontamination methods are being evaluated for hypothesized accidents. Probabilistic computer models are being developed to help quantify the consquences. Specific projects include calculation of reactor accident consequences, development of a methodology for the evaluation of waste processing and disposal, and the environmental impact of air transport of radioactive materials. Work is also beginning on risk assessment for both nuclear and fossil fuel power alternatives, thus providing additional data for comparing the public risk resulting from operation of various types of power plants.



above—Uranium-steam interaction experiment.

below—Rocket propelled car impacts simulated nuclear power plant wall to study tornado damage possibilities.



Breeder Reactor Safety

A projected shortage of uranium to fuel conventional water and gas cooled reactors has led to research and development on a new kind of reactor — the Liquid Metal Fast Breeder Reactor (LMFBR). The LMFBR, which is cooled with liquid sodium, produces or breeds plutonium in the course of burning its uranium fuel. Since plutonium can also be used as a reactor fuel, the breeder will produce more fuel than it uses and is being counted on to reduce the need for uranium near the turn of the century.

Sandia scientists are engaged in an extensive research program to produce information to help answer fundamental questions about the safety of the LMFBR. The LMFBR is being subjected to thorough scientific scrutiny because it is much different than present water cooled reactor systems. For example, accidents which lead to a loss of coolant or to movement of the fuel rods within the core could produce a marked increase in reactivity of the LMFBR.

Various aspects of the potential safety hazards are being studied at Sandia under contracts with the Nuclear Regulatory Commission. The research utilizes the Labs' unique reactor and electron beam accelerator facilities. In addition, the Labs' capabilities in radiation physics, reactor experimentation and high-temperature testing of materials are being used.

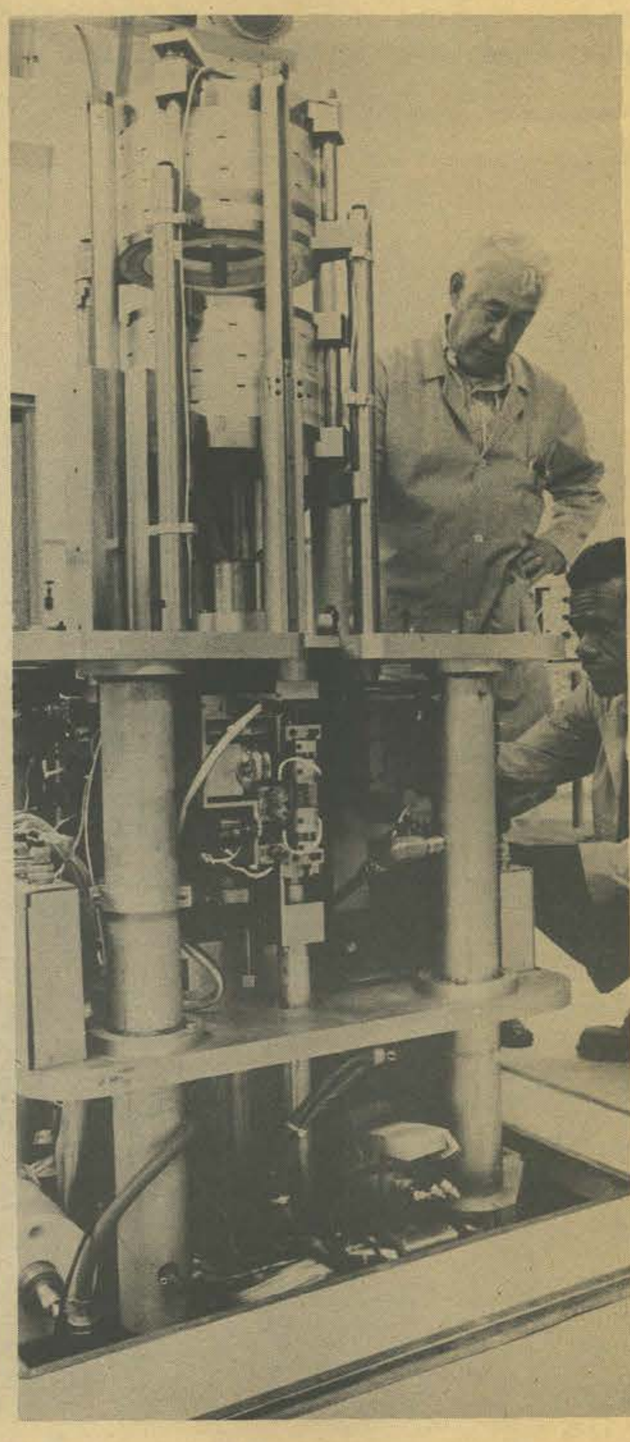
One of the Sandia reactors, the Annular Core Pulsed Reactor (ACPR), is undergoing major modification in order to produce the high temperature, high neutron fluence environments necessary to simulate conditions which might arise in a power reactor excursion or accident. The modification, expected to be completed in 1977, will increase ACPR's neutron fluence about three-fold, from 2.7×10^{15} neutrons per square centimeter to 8×10^{15} per square centimeter during a 5-millisecond burst, generating temperatures up to 6,000°F. Incorporated into the new facility will be a sophisticated diagnostic system, employing x-rays, laser beams or other advanced imaging devices to trace the movement of LMFBR fuel rods as it occurs during a simulated accident. Development of fuel motion diagnostic instrumentation for ACPR and for other reactor safety experiments is a major part of the Labs' breeder research program.

Using ACPR in its present configuration, various LMFBR fuels are currently being subjected to radiation bursts to determine the consequences of fuel movement or failure under reactor excursion conditions. Other reactor and electron beam facilities at the Labs are being used for very rapid heating of fuels to obtain equation-of-state data to predict how the LMFBR fuel will react to such heating.

In addition to fuel motion studies, the Labs is conducting an intensive investigation of post-accident heat removal (PAHR) for breeder systems. PAHR deals with means of cooling the reactor core should an accident occur. Although the reactor would be shut down, the disrupted core would continue to produce heat through decay of fission products, and this heat would need to be extracted in order to minimize safety hazards. Labs scientists are using the ACPR to heat fuel debris beds to determine whether the molten fuel would melt the steel and concrete container around the reactor core. In addition, diagnostics studies are being conducted to characterize the thermal and kinetic behavior of internally heated molten pools of fuel materials.

Data from the fuel motion and PAHR studies will permit the Labs to make significant inputs into the Nuclear Regulatory Commission's program to determine the safety of breeder reactors well in advance of their use.

above—Annular Core Pulsed Reactor viewed through the 30 feet of water shield, the right photo shows the glow from Cerenkov radiation. below—Sandia Pulsed Reactor III.



Nuclear Waste Management

The use of nuclear reactors produces radioactive waste, posing disposal problems at the back end of the nuclear fuel cycle (from the point where fuel rods have been removed from the reactor until the reprocessed plutonium is again made into new rods and the remaining material disposed of). The material must be isolated from the biosphere and human activity for sufficient time for waste constituents to decay to acceptable levels. This isolation is achieved by using a series of both man-made and natural barriers to decrease or halt the migration of the radionuclides for the desired time period.

The first barrier, which Sandia is studying, is the solidified waste form. A new method of solidifying aqueous radioactive waste is the Sandia Solidification Process (SSP). This ion exchange process results in a ceramic waste form with the long term stability and refractory properties associated with crystalline ceramics. The process basically involves passing a stream of liquified waste through a column or bed made of a new type of inorganic ion exchange material. The solids concentrated in this manner are then heated and pressed to form a highly stable ceramic. The ceramic has a very low leach rate and remains stable without emission of high level radioactive materials at temperatures up to 1,000°C.

Another barrier or set of barriers for isolation of the radioactive material might be the geology in which the waste is placed. In a search for suitable disposal sites, both on land and in the floor of the sea, Sandia has three investigations under way. The first is a study of the salt beds in southern New Mexico, where a site survey is under way. After a thorough drilling and seismological survey of the southern New Mexico area and the identification of a suitable location, a pilot plant operation will be initiated to assist in exploring feasibility of the concept.

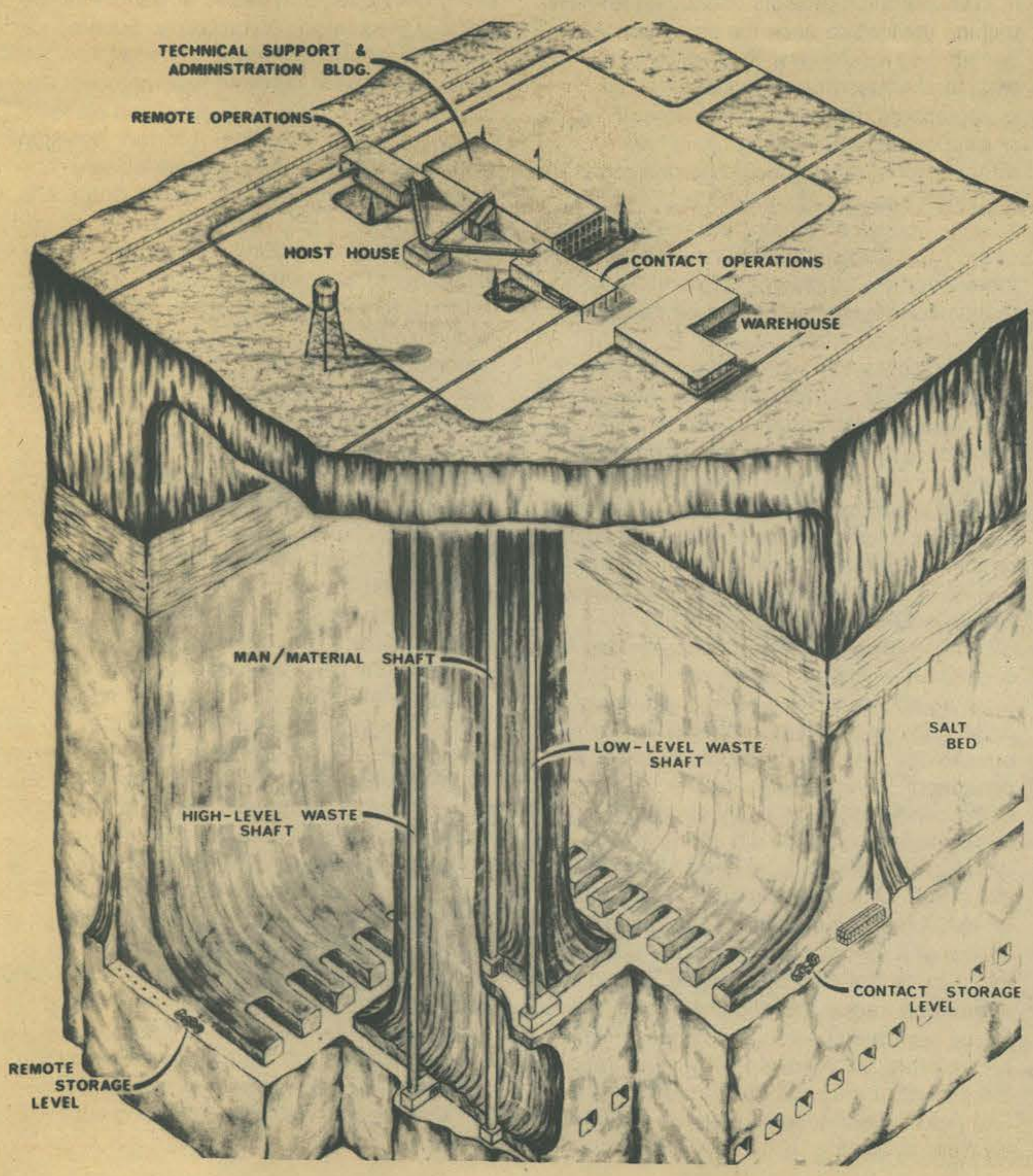
The second geologic container option currently under study at Sandia Laboratories is the disposal of nuclear waste in geologic formations at the bottom of the sea. A long-range feasibility study has been under way for the last three years directed by Sandia, with both Sandia and university scientists and oceanographers participating. The stable mid-plate and flank of ridge regions at the centers of the great ocean gyres have been found to be the most geologically and climatologically stable areas of the world. These resource-limited, inaccessible areas are now being studied in some detail with a goal of understanding the transport mechanisms of nuclides through the different geologic containers (the basement rock, the sediments, the benthic boundary layer, and the water column).

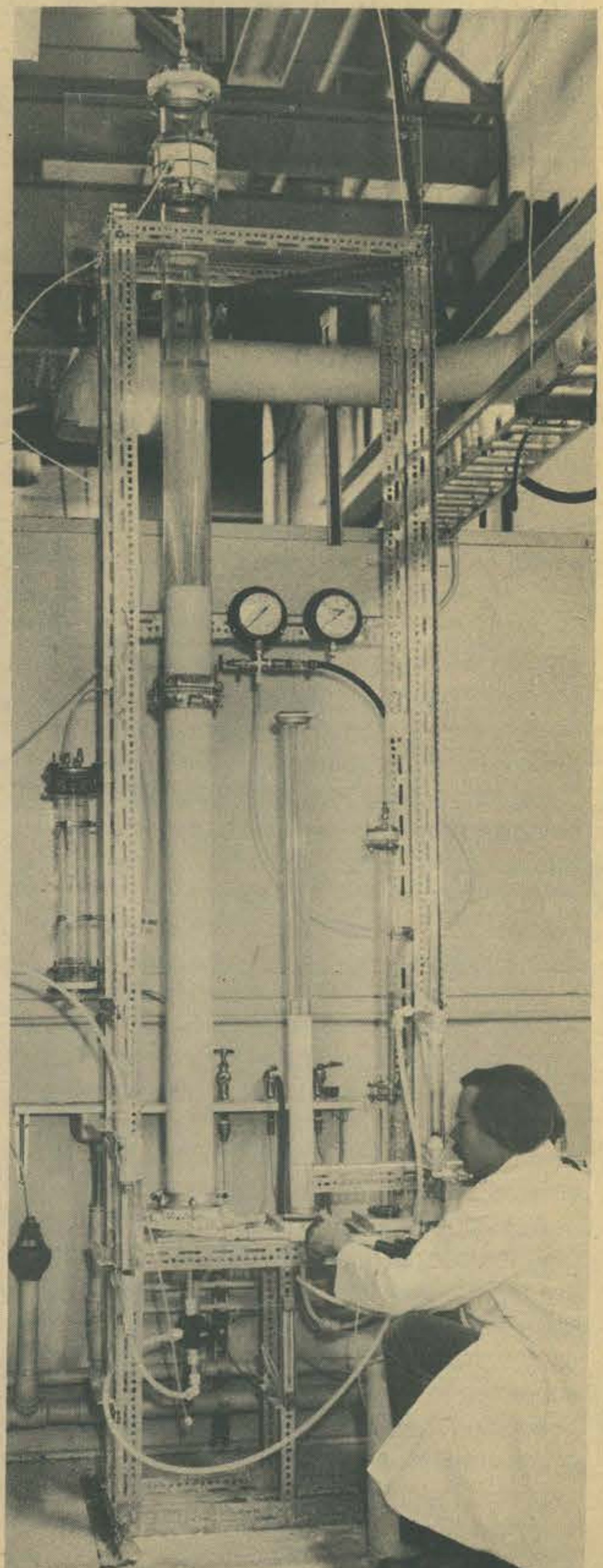
The third geologic formation being proposed and considered by Sandia for long-term containment of high level radioactive waste is emplacement deep in the basement rock underlying land masses. The waste would be either in a contained form or in canisters. With appropriate engineering of the package, the radiogenic heat could either melt both the canister and the surrounding rock to form a solid plug permanently emplaced thousands of feet below the earth's surface or just melt a specially designed material placed around the canister, such as a low melting glass which would form a solid impermeable plug in the drilled hole.

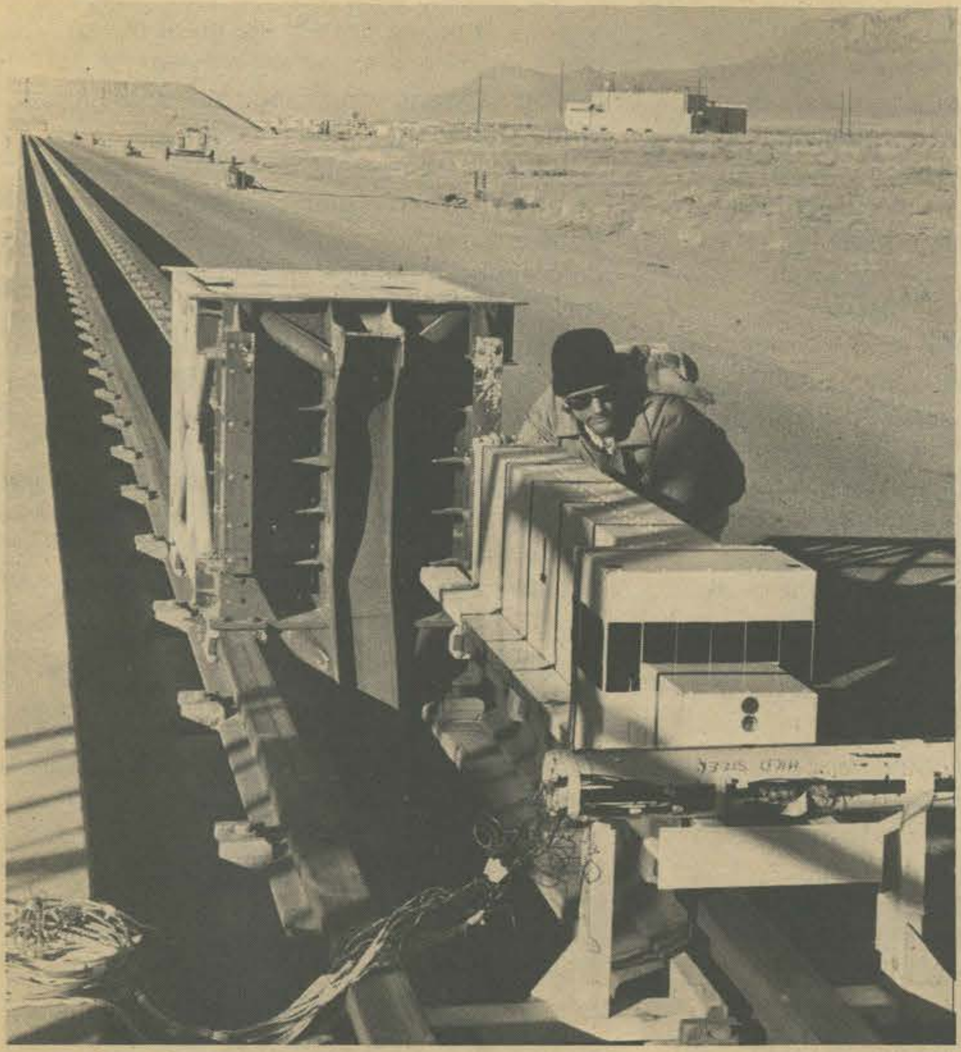
Results from these studies will be combined with information from other studies at Sandia and other laboratories to yield a complete research development package for the back end of the nuclear fuel cycle.

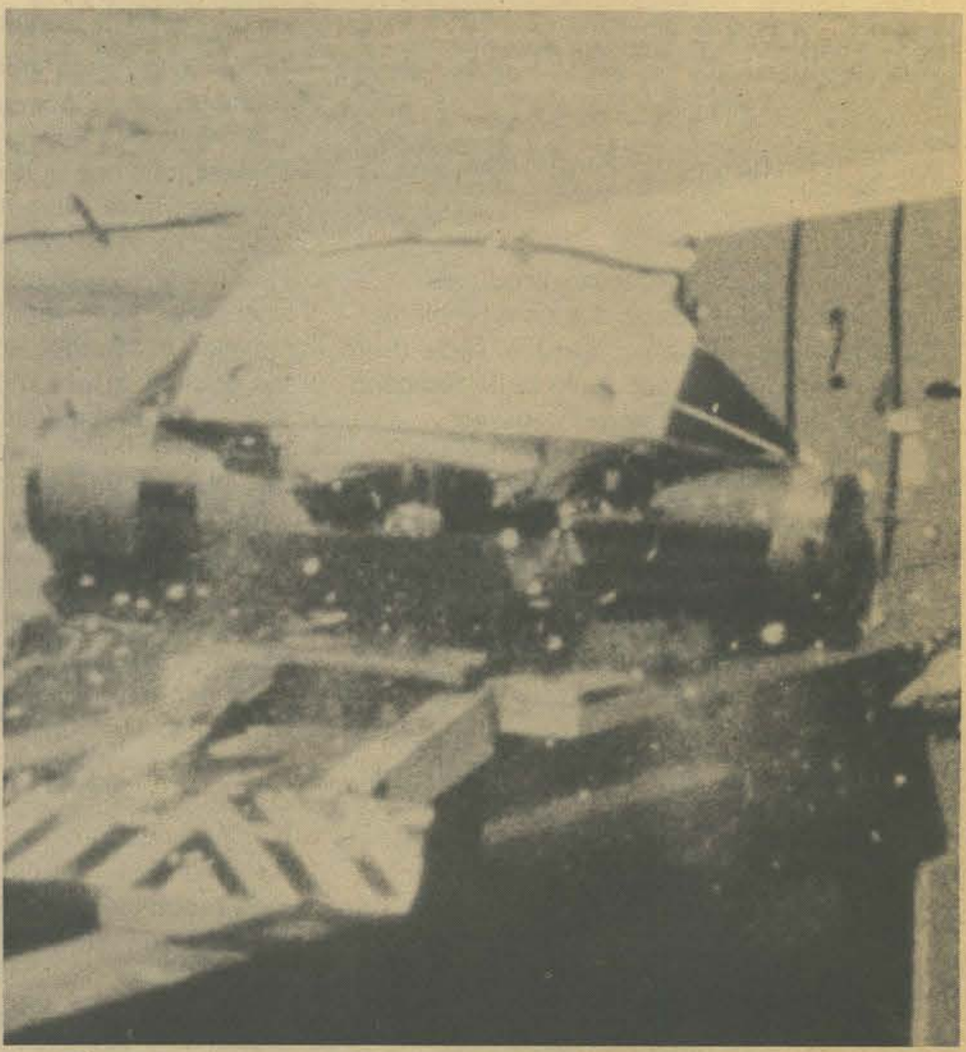
right—Laboratory solidification experiment.

below—Artist concept of nuclear waste storage proposal.









above—Rocket sled test simulates impact of locomotive into plutonium fuel shipping cask.

Technology Development

Development of the technology upon which new standards and concepts may be based as a part of the effort to improve the safety of the entire nuclear fuel cycle, including reactors, processing plants, and the transportation sector, is a major part of Sandia's nuclear fuel cycle programs. Work is being conducted for both ERDA and NRC drawing on the Labs' years of experience in complex systems analysis, structural design, environmental testing, nuclear reactor operation, and design of special containers for both nuclear weapons and radioactive materials.

Aid in the development of standards, primarily for NRC, focuses on studies and tests of reactor equipment and components, their aging characteristics, and their ability to withstand severe environments produced by abnormal power plant conditions, such as fire. Design performance characteristics of high temperature gas reactors (HTGR) and liquid metal fast breeder reactors (LMFBR) are also being compared in order to determine the licensing review requirements for these advanced concepts. Included in this effort are non-destructive tests being conducted to determine the response of materials and structures to the high temperatures and other environments encountered in these reactors.

As part of the standards development studies, a substantial effort is under way to determine synergistic effects, if any, of combined environments which could be created should a severe accident occur in a nuclear power plant. Various environments — high temperatures, radiation, high pressure, live steam, caustic spray — have been identified, and components, such as electric cables, motors, pumps, and relays, are being subjected to these combined environmental conditions to determine the possible existence of synergisms which might not be detected by simple, single environment testing. Other tests to evaluate existing standards are directed toward determining the adequacy of cable tray separation as a factor in protecting control and instrumentation cabling against massive destruction caused by spread of fire from one cable tray to another.

Transportation projects conducted for NRC include the testing of plutonium shipping containers to determine their ability to withstand transportation accident environments. Based on these data, low-cost, accident-resistant shipping containers for transport of plutonium could be designed. The structural analysis of complex fuel shipping cask designs is also being pursued in support of the NRC licensing activity. Another facet of these efforts is studies of the damage to reactor elements which might be caused by the normal shock and vibration to which shipping casks are subjected on rail cars or truck transport. Complementing these efforts are investigations into the probability of radioactive materials being released from shipping containers and casks as a result of accidents during shipment, and evaluation of the magnitudes and consequences of such a release under varying external conditions.

Transportation projects being conducted for ERDA include analysis of accidents to determine the environments experienced by containers — impact, crush, puncture, thermal, and immersion — and the use of these findings to aid in the development of qualification test standards for shipping containers. A variety of container tests are being conducted to evaluate existing packages as well as to aid in the development of new containers. As a part of this effort, full scale tests are being conducted on spent fuel shipping casks, including the impact of a locomotive traveling at 80 mph into a truck-mounted 30-ton cask stalled astride the tracks; the derailment of a 100-ton rail car-mounted cask and its impact into a bridge abutment followed by severe fire; and the impact of a 25-ton truck-mounted cask into a concrete barrier at a speed of 80 mph. Similar studies are being conducted on full scale casks to determine their resistance to damage by malevolent attack.

A plutonium shipping container which can survive an aircraft crash and resulting fire is being developed and tested at Sandia for the Nuclear Regulatory Commission. Such a container would be used to transport plutonium dioxide between fuel reprocessing plants, storage sites, and fabrication plants.

Known as the Plutonium Accident Resistant Container (PARC), the container closely resembles a commercial 65-gallon drum. It is about four feet high, two feet in diameter, and weighs about 400 pounds. Its capacity is 2¼ kilograms of fissionable material.

PARC is being developed to withstand a sequence of "worst possible accident conditions" so that it will be resistant to any and all transportation accident conditions that can occur. Throughout that sequence of environments — crash, puncture, crush, fire, and deep water immersion — the inner container must not release any nuclear material.

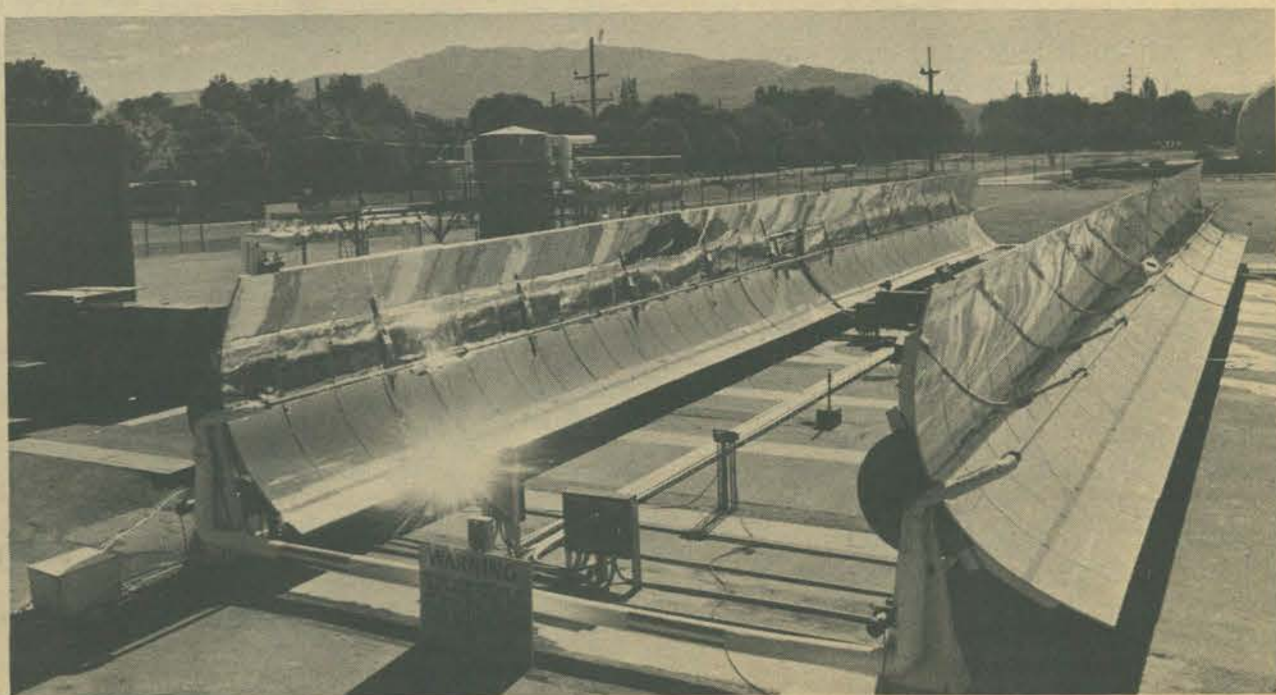
PARC consists basically of a double-thick shell of stainless steel filled with laminated redwood whose grain is oriented perpendicular to the outer surfaces of the package. Sandwiched within the redwood is an aluminum layer which spreads impact loads throughout the wood. Within the inner-most wood section is a high strength stainless steel vessel, closed by bolts and a gasket. Nested within this vessel is the steel can in which the plutonium is carried.

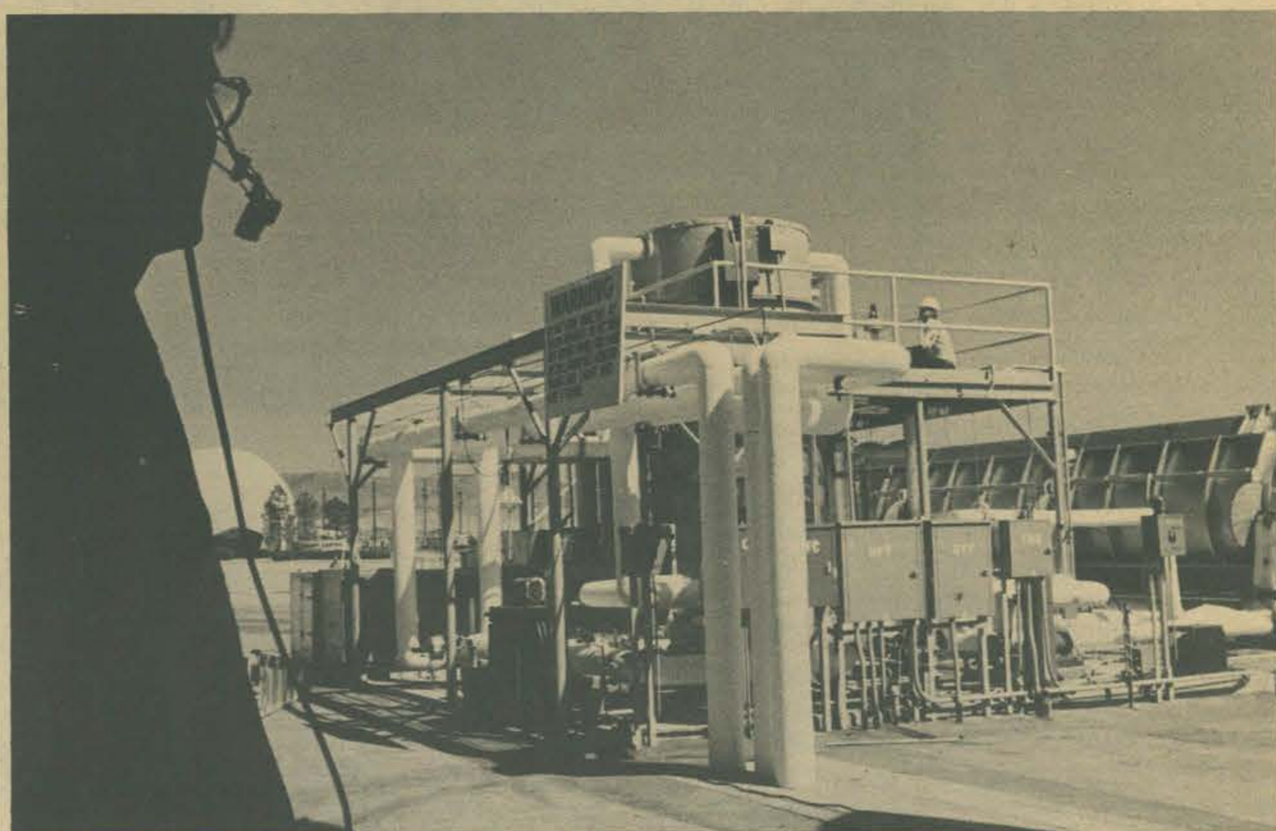
Redwood has two characteristics which make it an ideal material for use in the container. It displays the highest specific energy absorption characteristics of any shock-mitigating material presently known and when it burns, the char becomes a carbon insulation similar to the heat shield of a space vehicle. PARC is an outgrowth of Sandia's past work on development of accident resistant containers for transporting nuclear weapons in aircraft.

SOLAR

As one solution to the worldwide energy crunch, solar energy has a number of notable advantages. It is free and already distributed; it is environmentally clean; and it is, for all practical purposes, inexhaustible and in abundant supply. For instance, assuming a 10 percent efficiency in conversion of sunlight to electricity, the total electricity consumption of the United States could be supplied by the solar energy falling on less than one percent of the U.S. land area. But solar energy has notable disadvantages, too. It is very diffuse and frequently must be concentrated, particularly for power generation. Concentrators are expensive. Solar energy is also intermittent, so storage systems are necessary, or a backup source of energy must be used. These are requirements which further increase solar energy costs. Wind energy – a form of solar energy – is also intermittent. Several efforts are underway at Sandia to make both solar and wind energy more competitive with conventional energy souces.

Solar Total Energy





above—First 2000 square feet of parabolic collectors.
below—High-temperature storage tank.

Sandia's Solar Total Energy concept involves development of a system that could supply as much as 60 percent of the total energy needs for a community of 100 to 2,000 units — apartments, residences, or small businesses. Solar total energy is made more competitive with conventional energy sources by using energy that is normally wasted during the generation of electricity.

The solar total energy concept is the outgrowth of studies begun by Sandia scientists in 1972 to construct computer models in which solar energy components and subsystems are manipulated in a realistic economic context. In these studies, which are continuing, system costs are calculated on a 30-year life-time, accounting for capital outlay, cost of financing, maintenance, operation and other factors that govern the economics of any energy supply system. Up-to-date technical inputs are provided by Labs' studies of collectors, reflective and absorptive materials, heat exchangers, turbines, generators, etc.

Using ERDA funds, Sandia is constructing a complete Solar Total Energy Systems Test Facility. The installation consists basically of 8,000-square feet of parabolic solar collectors, storage tanks, and a 32kW turbine/generator. Electricity and hot water from the system will be used to heat, cool, and provide power for a 12,000-square foot building. When completed late in 1976, the facility will constitute the country's largest operating solar energy plant, and will permit testing of new components and subsystems developed by industry and university experimenters.

The collectors initially being used in this testbed are parabolic mirrors surfaced with polished aluminum. These collectors, which use small electric motors to track the sun, focus solar radiation onto a black receiver tube running the length of the collector. The tubes are sealed into an evacuated glass jacket at 3mm of pressure, allowing incoming long waves to enter freely, but trapping shorter waves re-radiated by the tube.

A high-boiling-point fluid, Therminol-66, circulated through the tube, is heated to about 600°F by radiation. Some of this fluid is stored to meet startup requirements, while the remainder is pumped through a heat exchanger where toluene is boiled and superheated to drive the turbo-generator. Fluid exhausted from the turbine while it is still hot enough to heat water to about 200°F. will be used for spaceheating, domestic hot water, and air conditioning in an absorptive system like that used in Servel refrigerators. Conventional gas and electrical sources will be used during periods of extended cloudiness.

The test facility should begin providing operating data early in 1977. Subsequent accumulation of data should provide a basis for determining the competitiveness of the concept with other energy sources. Development of a successful system would permit general commercial applications by industry, thus relieving the load on power generating plants fueled with uranium, coal, and oil.

In addition to operating its own solar total energy facility, Sandia is managing the solar total energy portion of ERDA's National Solar Thermal Program. The objective of this portion of the program is to demonstrate the technical, economic, and institutional feasibility of the solar total energy concept and to transfer this technology to the private sector. To accomplish this goal, the Labs will use sub-contractors, supplemented by in-house technical effort. The Labs will monitor the progress of the R&D contracts and provide technical direction, administration, and evaluation.

A key part of the effort will include applications studies and analyses to identify preferred users of solar total energy, preferred geographical locations, and optimum sizes and configurations. Systems engineering studies, pilot and demonstration plant designs, and construction tasks are also a part of the effort. Components and subsystems will also be reviewed, developed, tested, and made available for use in pilot plants and demonstrations.

Central Solar Receiver

Sandia is playing a key role in the nation's Central Solar Receiver Project, which envisions the use of solar radiation to produce electricity from central power plants. Sandia's laboratory at Livermore, California, is serving as technical manager for this long-range program, while the laboratory in Albuquerque is the site of a large facility to test components for a pilot plant to evaluate the concept.

The concept is relatively simple, involving the use of tracking mirrors, or heliostats, to focus solar radiation on a boiler located atop a tower. Steam generated by the boiler would be used to drive turbines to produce electricity. If the concept proves sound, plants capable of generating tens of megawatts of electricity may ultimately be constructed in those areas of the country, particularly the Southwest, which receive large amounts of sunlight.

Construction of the Albuquerque test facility, expected to cost approximately $20 million, began early in 1976. It will consist basically of a central tower, 200 feet high, surrounded by about 300 tracking-mirror arrays. Various receivers (boilers) will be tested atop the tower.

Water in the boiler will be heated to about 1850°F., and the facility will have a maximum output of approximately five megawatts of thermal energy, making it the world's largest solar-powered facility. A one megawatt plant at Odeillo, France, where focused solar radiation is used in high temperature research, is now the largest such facility. The Albuquerque installation is scheduled to reach one megawatt output in April 1977 and be at full power by the end of the year.

The facility will produce steam, but no electricity, since the boiler will not be connected to a turbine. (If a turbogenerator were installed, one to one-and-a-half megawatts of electrical power could be produced from the five megawatts of thermal energy.) The primary purpose of the facility is to test boiler designs and materials, mirrors, and other components designed by ERDA contractors for use in a central receiver pilot plant which will produce 10 megawatts of electrical energy (30 to 50 megawatts thermal). The pilot plant is to be operational by 1980 and will be followed by larger plants if the concept proves economical.

It is expected that the Albuquerque facility, under Sandia management, will continue to be used as a general purpose test bed for solar energy system components. As use of solar energy becomes more widespread, new ideas for mirrors, control systems, and other components are expected to require testing under actual operating conditions. The University of Houston has been designated as the lead university to coordinate this phase of testing activity for the universities.

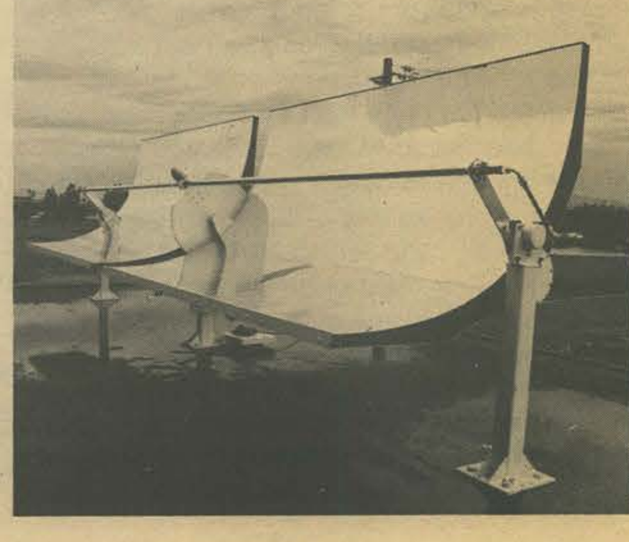
One of 320 heliostats which will focus sun rays on a boiler atop a 200 foot tower. Each heliostat consists of 25 four-foot-square mirrors.

Solar Irrigation

Natural gas is expected to be in increasingly short supply in the future, and thus its widespread use throughout the Southwest to power irrigation pumps is a cause for some concern. Sandia and New Mexico State University have begun design and development of a solar powered water pumping system to demonstrate use of solar energy as an alternative to natural gas.

The new system, which will be located on an irrigated farm in the Estancia Valley east of Albuquerque, will consist basically of a small solar collector field, an insulated storage tank, a heat exchanger, and a heat engine which will power the water pump. A fluid will be circulated through the collectors where it will be heated by the sun to temperatures ranging from 200 to 420°F.

The fluid will be pumped to the thermal storage tank and then to the heat exchanger where its power will be transferred to a working fluid — a low boiling point liquid, such as Freon, to drive the heat engine. Present designs call for 6720 square feet of collectors, which would produce enough energy to pump 880 gallons of water per minute from a 75-foot-deep-well. This output would be sufficient water for 100 acres. Current plans are to operate the system continuously while the sun is shining, storing excess water in a surface reservoir.



Photovoltaics

Photovoltaic cells that convert sunlight directly to electricity, like the silicon cells that have powered on-board instrumentation in many space satellites, may provide electrical energy for domestic and industrial use if their present prohibitive cost can be reduced. The goal of ERDA's National Photovoltaic Conversion Program is the establishment, by 1986, of an industrial capacity which can produce solar arrays with an annual total output of 500 million watts (megawatts) of electricity at a sales price of less than $500 per peak kilowatt.

Present photovoltaic systems employing silicon cells produce electricity for a cost of about $20,000 to $25,000 per peak kilowatt, with about 10-square meters of cell area required to produce one kilowatt. Reducing the cost of photovoltaic arrays to $500 per peak kilowatt of output would make them competitive with power from conventional generating systems.

As part of this national program, Sandia is managing the Systems Definition Project. The Project, funded for the first time in late 1975, consists of two major tasks: photovoltaics systems definition and analysis and development of tracking and concentrator subsystems. As a part of this work, Sandia will work closely with the Jet Propulsion Laboratory, which has been assigned responsibility by ERDA for the Low Cost Silicon Array Project, and with NASA-Lewis Research Center, which will manage ERDA's Photovoltaic Test and Demonstration Project.

The systems definition and analysis task requires that Sandia and its subcontractors provide new system design concepts for photovoltaic applications, evolve preferred system configurations from these concepts, then produce preliminary and final design specifications for these systems. It is also necessary to provide system performance characteristics based on analytical models.

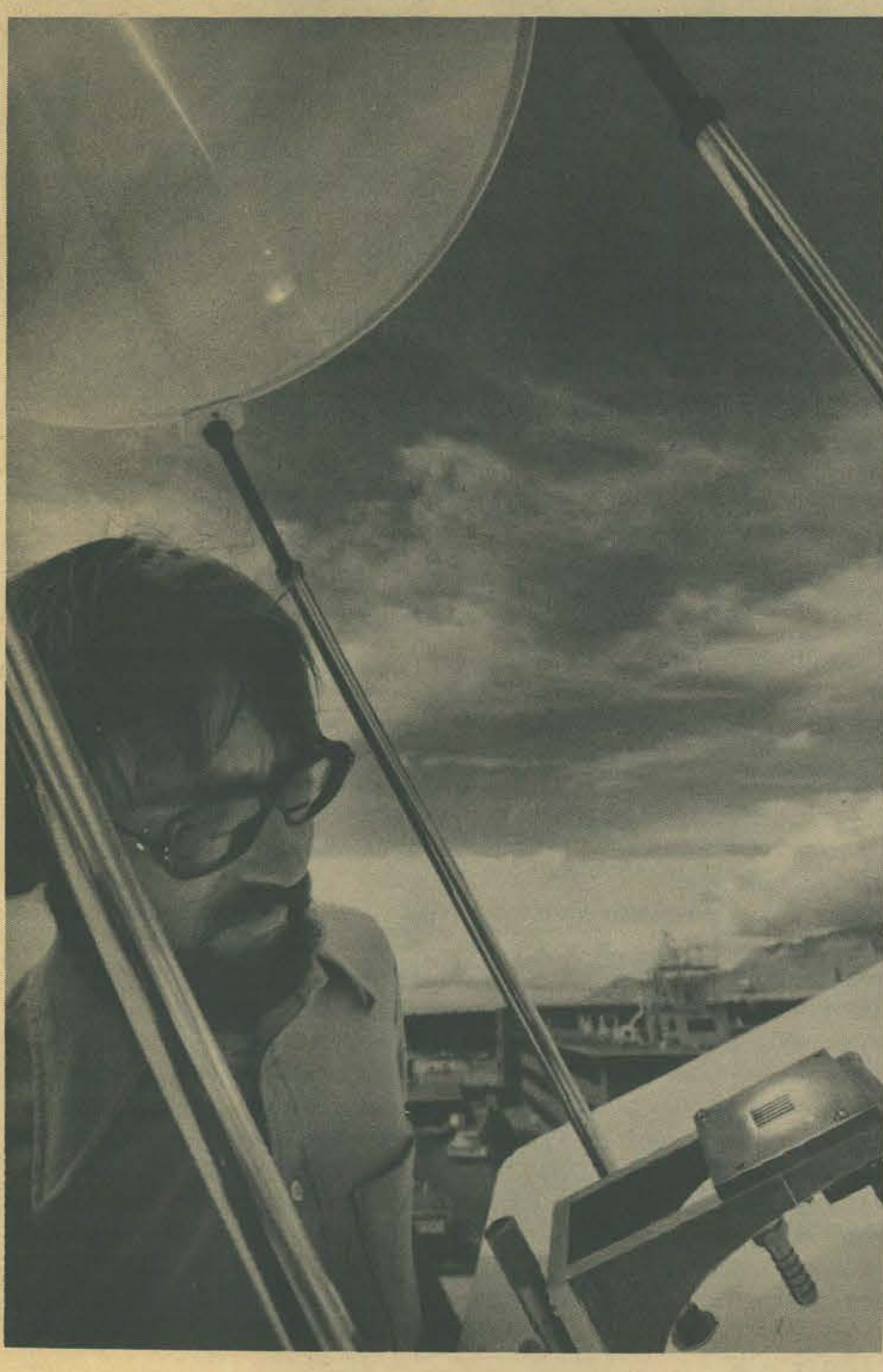
The second task, which includes work which the Labs has had underway since 1973, involves the development of alternatives to fixed, flat-plate photovoltaic arrays. Such arrays simply face the sun, but do not track it and do not focus its rays with curved reflectors or other devices.

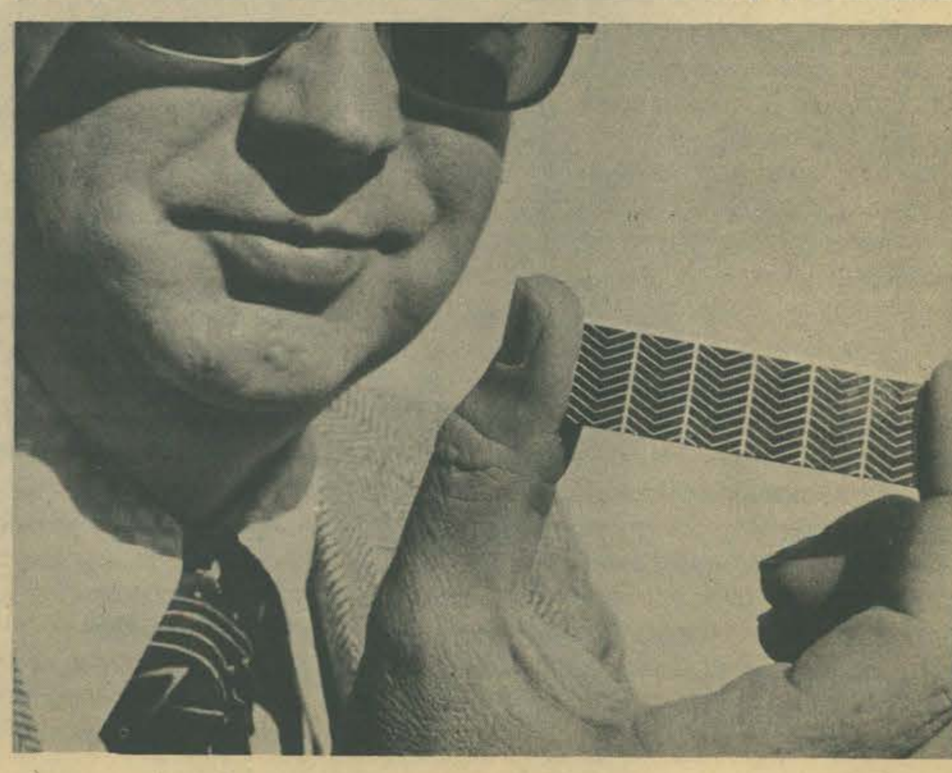
Sandia has developed an alternative approach to array design in which silicon cell output is increased with a "multiple suns" technique. This approach is based on the fact that, in general, the more intense the light striking a cell, the more electricity it produces. If sunlight is gathered by lenses or curved (parabolic) collectors and focused on the cells, their output increases. This effectively lowers the cost of electricity by generating more kilowatts per unit of cell.

Using computer modeling techniques and materials research, Sandia scientists have demonstrated that silicon cell efficiency under multiple sun illumination can be raised to 12 percent or higher if means can be developed to control the heat which accompanies high illumination levels and to control the internal resistivity losses resulting from higher currents. The heat generated by concentrated sunlight is a particularly serious matter, since the cells work most efficiently at very low temperatures. In one solution to cell heating, Labs scientists are mounting the cells on the back of receiver tubes of parabolic collectors such as those used in the Solar Total Energy Systems Test Facility. Fluid flowing through the tubes cools the cells to about 100°C., permitting acceptable electrical efficiency even at high illumination levels of 50 suns, yet the fluid temperature remains high enough to be used for heating, air conditioning, and hot water.

Labs scientists are also working with private industry on a long-range research and development effort to produce very inexpensive solar cells by spraying thin films of cadmium sulfide/copper sulfide on plate glass. Inexpensive solar cells costing only a few cents per square foot would eliminate the need for lenses and concentrator systems.

left—Fresnel lens focuses sunlight on cell.
right—Reflection of cells mounted on back of receiver tube and close up of photovoltaic cell.





Vertical Axis Wind Turbine

Like sunlight, the wind is freely available, but its variability, the cost of energy storage, and the capital investment necessary to construct large systems have made windpower economically unattractive in comparison with more conventional power sources. Sandia's wind project is directed at demonstrating the economic advantages of a vertical axis wind turbine (VAWT) in power grid applications.

The VAWT is not new, having been invented in 1925 by a Frenchman, D.J.M. Darrieus. The VAWT consists basically of two or three curved airfoil blades attached to the top and bottom of a vertical shaft. A 15-foot model has been in operation at Sandia since early 1974.

The VAWT's primary advantages, when compared to the more common horizontal (propeller) wind systems, are economic. The VAWT extracts about 35 percent of the energy from passing winds, compared to 38 to 40 percent for horizontal designs. However, the VAWT is a simpler system. It needs no yaw control to bring it into the wind, since it accepts wind from any direction. It requires no pitch control to reduce rotational speeds in high winds; an important advantage in power grid applications where the input to the power line must be in phase with the 60 cycles per second alternating current system. The VAWT automatically stalls at high wind velocities, so that a synchronous generator will not be overpowered at higher wind levels.

The VAWT is also lighter than propeller systems, thus may be somewhat less expensive, and its generator can be attached at ground level, reducing the cost of the support tower. The light construction of the VAWT results partially from the unique shape of its airfoil blades. Referred to as a "troposkien" (Greek for "turning rope"), the shape is that assumed by a skipping rope or any flexible member whirled about a central pole. The principal stresses on the blades are along their axis — their strongest dimension. A Sandia modification of the troposkien shape simplifies manufacture of the blades by permitting them to be fabricated in three pieces — two straight members at the ends of a curved center section.

It appears that the best application of the VAWT is to feed the output of large models into the nation's central power grid, although smaller turbines may provide power to farms and other isolated areas. Studies of wind in the U.S. indicate there is sufficient energy available — particularly in coastal areas and the Western High Plains — to ultimately provide up to 10 percent of the nation's electricity.

The present Sandia VAWT produces one kilowatt of electricity in a 15-mile-per-hour wind. A 55-foot-diameter system is being installed to produce 60 kilowatts; this model will be followed by design of a 100-foot diameter, 100 kilowatt system, to be operational in 1978. These systems will provide practical operating experience and improvements in wind technology which may eventually help windpower to become a significant source of energy.

Geothermal

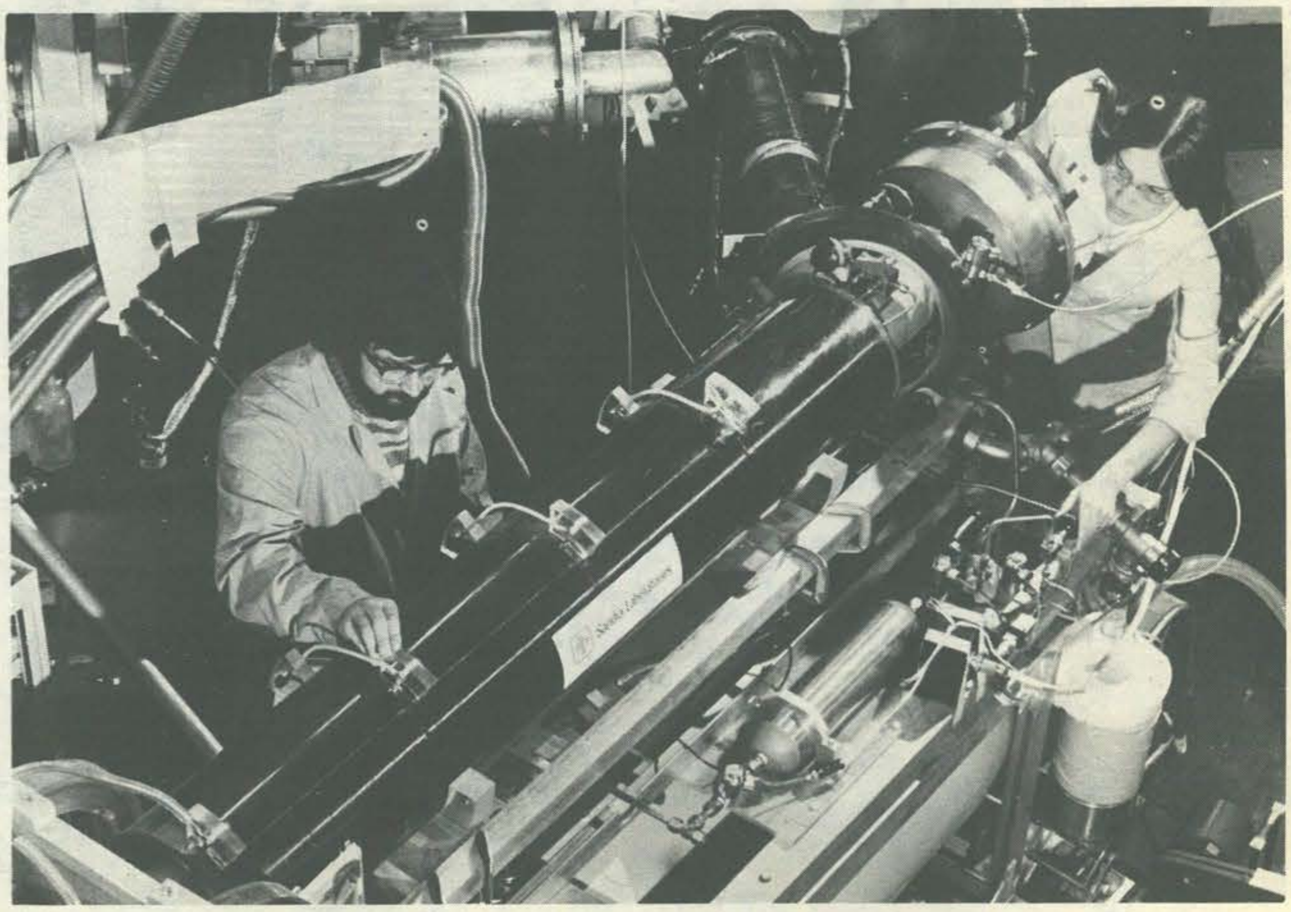
A small generator powered by heat from hot springs is being developed at Sandia to provide electricity in remote areas of the world. The generator would be suitable for use in any locale which has adjacent sources of heat and cold to satisfy boiler and condenser functions.

The Small Geothermal Electric Generator (SGEG) is designed to operate in 145°F. hot water — the temperature of water in many hot springs. Its boiler is immersed in the water, vaporizing a low boiling point organic fluid — Freon 12 — which drives a heat engine expander. The expander rotates at about 1,800 rpm., powering a small generator. Freon vapor exhausted from the turbine is then condensed in cold water (45° F.) or air and pumped back to the boiler to complete the cycle.

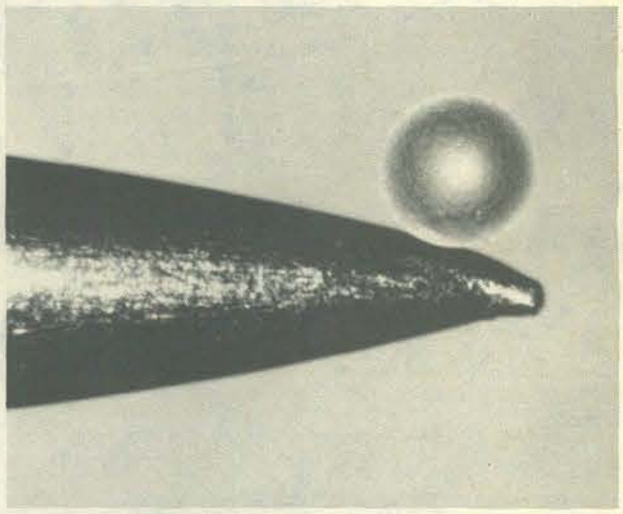
A prototype generator produces five kilowatts, and a second generation system is being designed which will produce 40 to 50 kilowatts. The relatively high capital cost of the generators per kilowatt of capacity would be offset by lower operating costs since no fuel would be required.

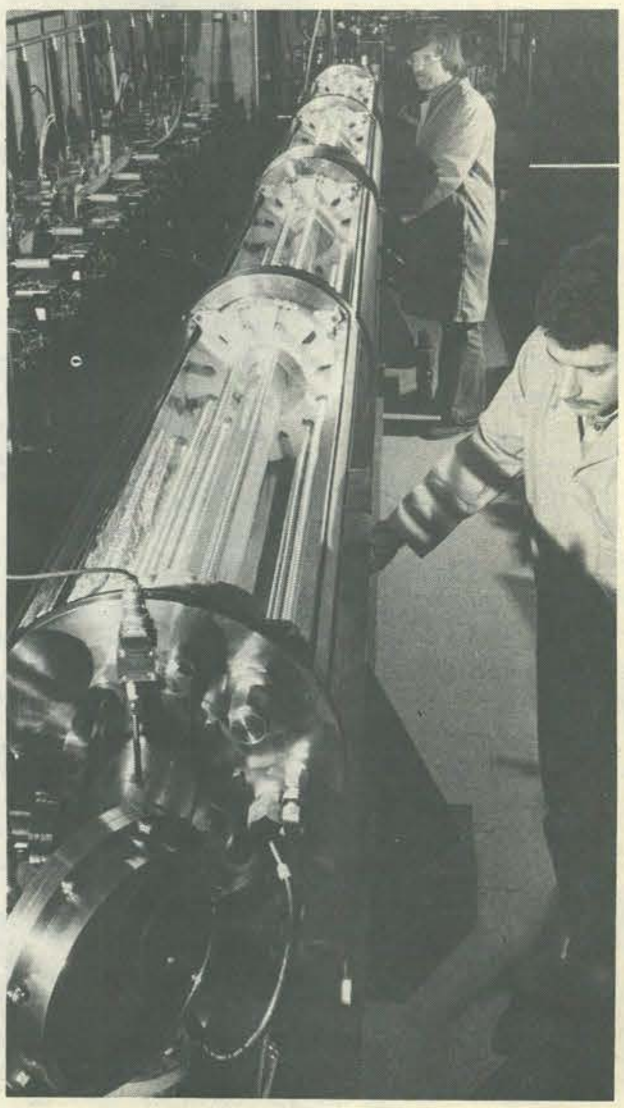
FUSION

Controlled thermonuclear fusion is considered one of the most attractive of all long range energy resources because it is a safe, clean process that uses fuel - deuterium and tritium - which can be obtained in almost inexhaustible quantities by all nations. Deuterium occurs in minute amounts in all water, including seawater, while tritium is produced during the course of the thermonuclear reaction. A pound of deuterium can release fusion energy equivalent to three million pounds of coal, with the cost of separation estimated at about one percent of the present cost of coal. However, harnessing the tremendous energy produced by a thermonuclear reaction is still beyond today's technology, although progress continues on several fronts. Magnetic confinement fusion attempts to confine a hot ionized gas in a powerful magnetic field until temperature rises to the point where an efficient reaction occurs. Inertial confinement schemes, using lasers and electron beams, attempt to implode tiny fuel pellets, triggering a reaction before the pellets fly apart.



above—Electron-beam excited laser.
below—Deuterium fuel pellet on a pin point and Iodine laser.





Laser Fusion

Sandia has been a participant in the nation's laser fusion program since the late 1960's and is one of the leaders in the search for new lasers which can be used in advanced laser-fusion research and in the fusion power plants of the future. No laser exists today which is precisely suited to high energy pellet experiments or which is powerful enough to be used in power plants.

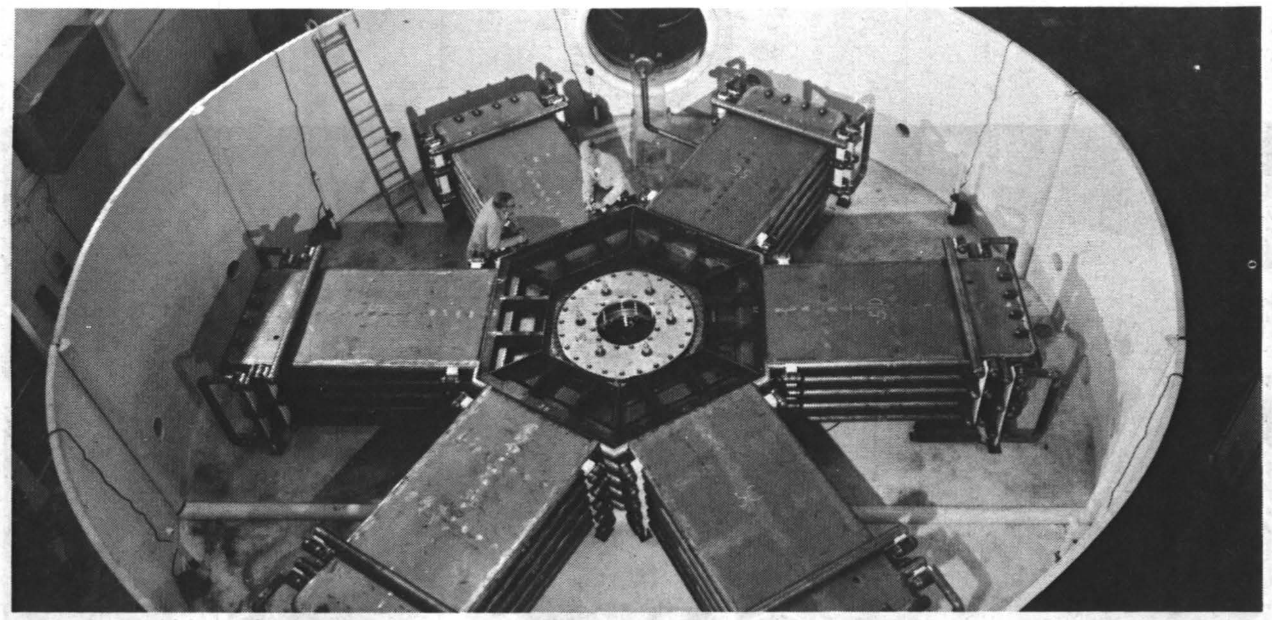
Laser fusion is an alternative to the better known magnetic confinement fusion system in which a hot hydrogen gas (plasma) is confined inside a magnetic field until temperature and pressure reach levels sufficient to cause atomic nuclei in the gas to fuse, releasing great amounts of energy. Problems of confining the plasma within the magnetic field have caused researchers to consider laser fusion, an approach in which tiny fuel pellets are imploded with intense pulses of laser light. Fusion would occur before the pellets fly apart, thus solving the confinement problem.

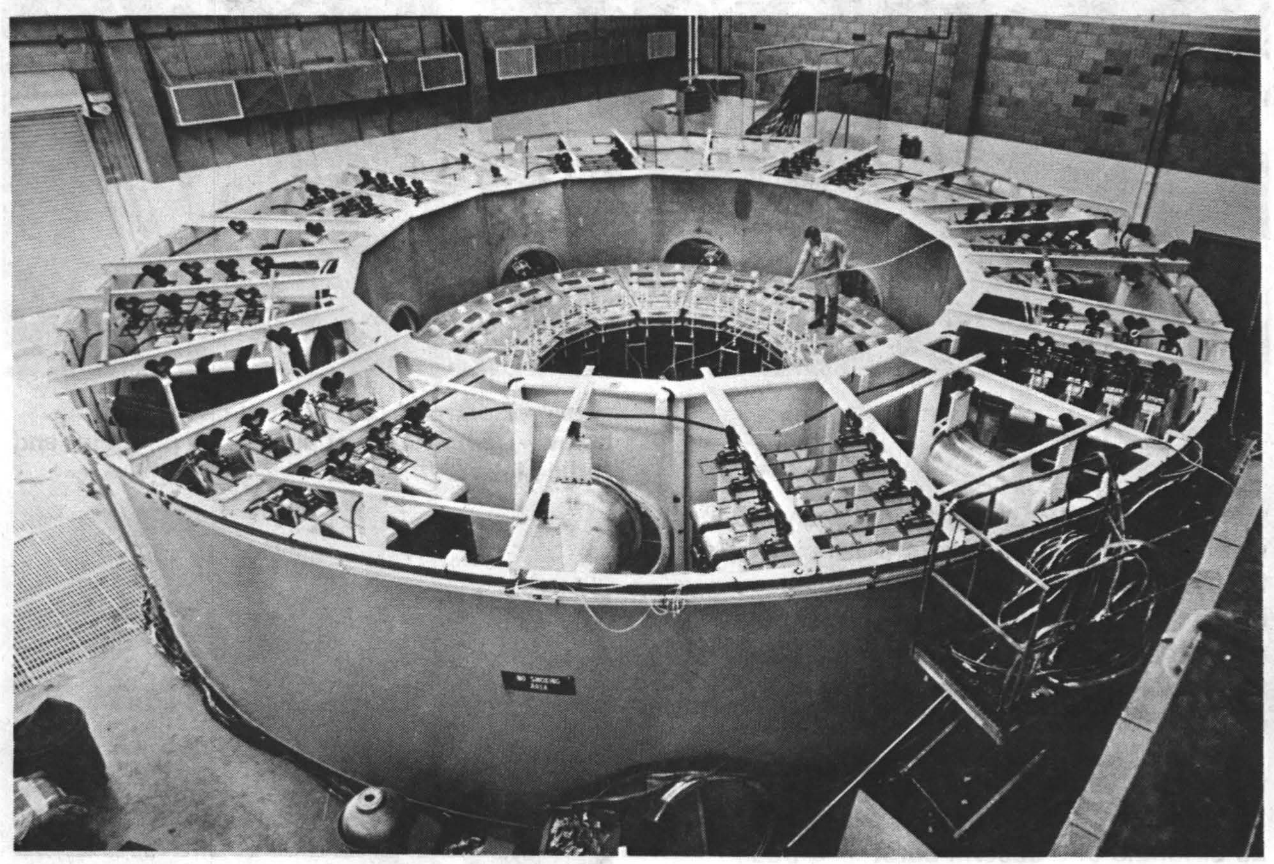
Computer calculations indicate that if the deuterium-tritium pellets, which are about the size of a grain of sand, can be uniformly irradiated with a short, powerful pulse of laser light, small thermonuclear explosions can be triggered. These microexplosions would occur perhaps 100 times a second, with each releasing energy equivalent to explosion of 50 pounds of TNT. The resulting heat would drive a conventional steam turbine to generate electricity. An operating system will require an efficient laser capable of producing an estimated 100,000 joules (a joule is a watt expended for a second) of energy in a pulse lasting about a billionth of a second or less. Present calculations indicate that laser light in the visible region of the spectrum should be best for laser fusion.

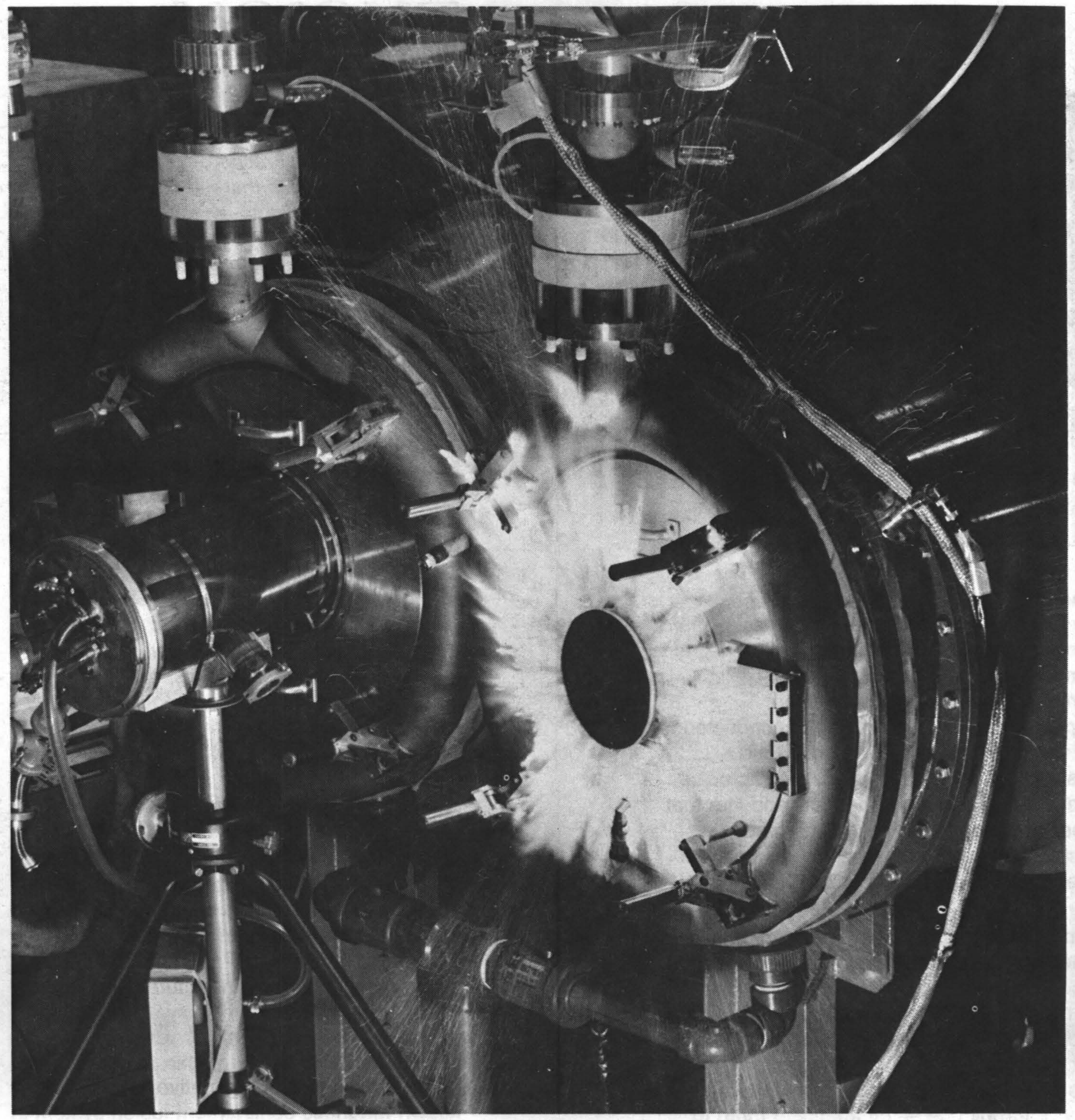
Sandia's research is presently focused on such lasing media as hydrogen fluoride (HF), iodine, xenon, oxygen, and noble gas halides, such as krypton-monofluorine. Several of these lasers are pumped with powerful electron beams, an excitation scheme pioneered by Labs scientists. It is uncertain whether any of these lasers will be suitable for use in a fusion power plant, but investigation of them is providing information on methods of improving efficiency, shortening pulses, and developing new excitation schemes.

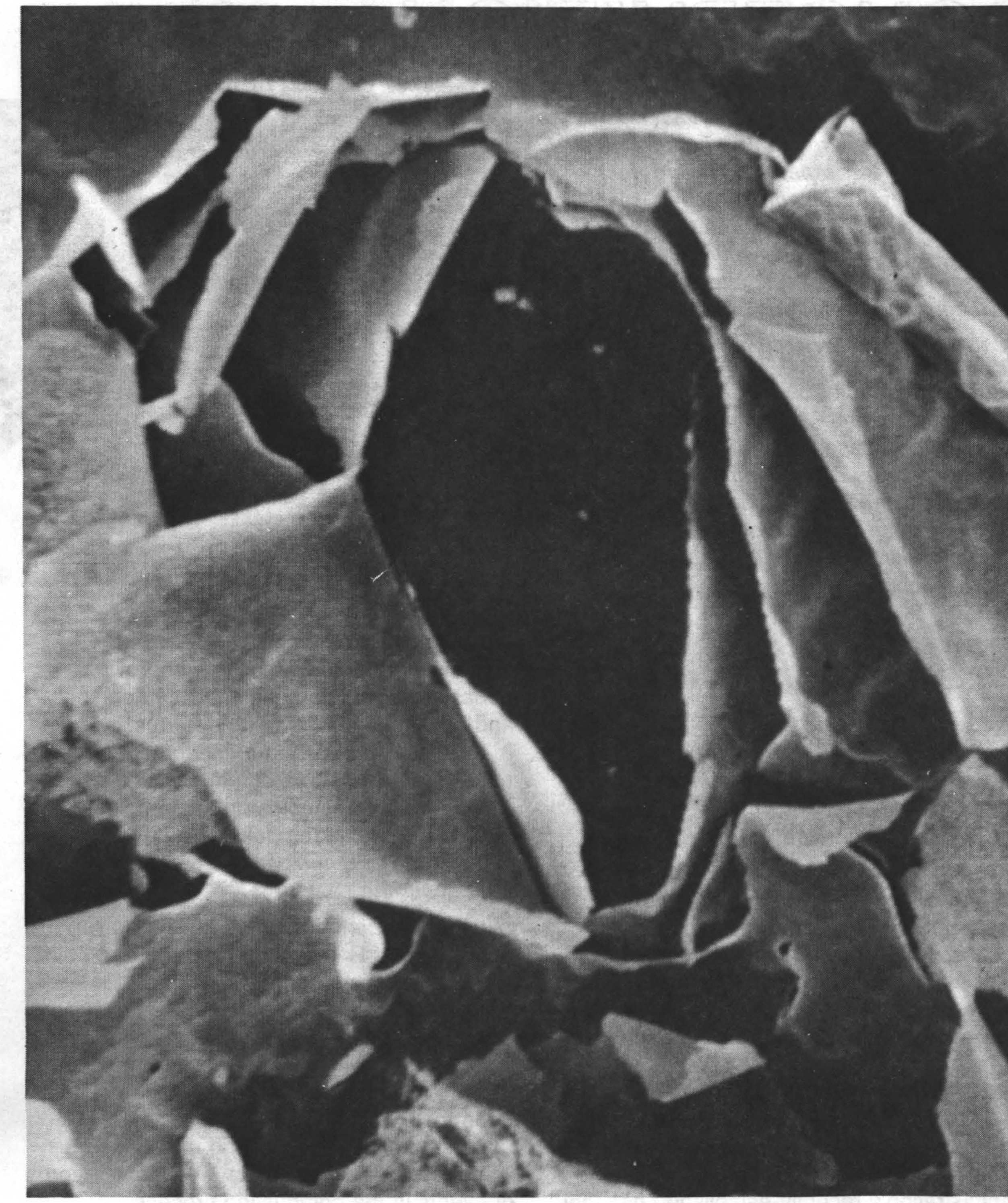
The Labs' electron-beam-driven HF laser is the most energetic short pulsed laser yet announced, producing 4,200 joules in a 25-billionths-of-a-second burst — a peak power of about 200 billion watts. It appears that HF lasers can be rapidly scaled up in size — perhaps to energy levels approaching 100,000 joules — so that they could be used to perform critical, interim fusion experiments. Sandia's efforts are now directed to shortening the laser's pulse width to a range of one to five billionths of a second by increasing the pressure of the lasing medium and by a novel pulse shortening scheme.

The Labs' iodine laser is the largest of its kind in the U.S., and is being used for exploratory research. It is ultimately expected to produce about 100 joules in a pulse lasting a few hundred trillionths of a second, with an efficiency of about one percent. Efficiency — laser beam energy divided by energy deposited in the lasing medium by the pumping source — is a critical requirement for laser fusion because today's experimental lasers consume far more energy than they can produce by fusion energy from a microexplosion. Most lasers, for example convert less than one per cent of their pumping energy into laser energy, although the HF laser has an electrical efficiency up to 200 percent and a chemical efficiency up to 10 percent. A new Sandia laser which uses krypton fluoride has recently demonstrated about 3½ percent efficiency, and other lasers at the Labs, such as xenon fluoride, have demonstrated one percent efficiency.It is presently believed that the laser for the power plant of the future must be at least 10 percent efficient in order to produce electricity economically.









Electron Beam Fusion

Electron beams are being used to pump high power lasers, thus contributing to laser fusion. However, the beams can be used in a more straightforward manner by irradiating fuel pellets directly with electrons. This approach to controlled release of thermonuclear energy is called electron beam fusion, and Sandia is a major experimenter in the field.

A key advantage of electron beam fusion is the efficiency of accelerators used to produce the beams. These machines can convert up to 50 percent of their electrical input into beam energy, compared to only a few percent for the most efficient of today's lasers. However, electron beams are much more difficult to focus to the diameter of fuel pellets than are laser beams, and short pulses are harder to achieve. The fuel pellets are somewhat larger than those used in laser fusion, but are made of the same elements — deuterium and tritium, with outer shells of lead, gold, or other heavy metals.

The electron beams used in fusion experiments are ultra-powerful versions of the beams used in TV picture tubes, dental x-ray machines, and other common devices. These low-power beams are of fairly long duration and have outputs of only a few thousand watts. The electron pulses needed to achieve fusion are estimated to require 100 trillion watts of power delivered in 10 to 20 billionths of a second.

Sandia experimenters are presently testing the electron beam fusion concept on two large accelerators — Hydra and Proto I. A third machine, Proto II, will become operational in 1976. These machines are used in experiments to demonstrate focusing of high power beams in short pulses, to study uniformity of pellet irradiation, and to investigate thermonuclear reactions during implosion experiments. Data from these experiments will be used to complete the design of an Electron Beam Fusion Facility for further evaluation of the fusion concept at much higher energy levels.

Experiments on Hydra, an accelerator which was originally designed for irradiation studies of materials and components, have demonstrated that high-power electron beams are gas-like in nature when focused. This permits symmetrical irradiation of a pellet with either single or dual beams. Using two beams, Hydra can subject a pellet to about 800-billion watts of power in a pulse lasting about 80 billionths of a second.

Proto I, which became operational in 1975, is the first high power, short pulse accelerator expressly designed to irradiate pellets. Using oil as a dielectric in which the final electrical charge is momentarily stored, the machine discharges two 400,000-amp beams onto a fuel pellet in a pulse lasting about 24 billionths of a second. The beams have a combined maximum power of about two trillion watts.

Proto II, to be completed by late 1976, is designed to deliver about eight trillion watts in two simultaneous beams lasting about 20 billionths of a second. This machine will represent a substantial advance in accelerator design since it will use simple, but extremely fast water switches within water-insulated pulse forming lines.

The accelerator for the Electron Beam Fusion Facility will also use water as a dielectric, with disc-shaped pulse forming lines energizing vacuum diodes where the pellet will be placed. This machine, being designed for use late in this decade, will subject a pellet to about 40 trillion watts of power in a pulse lasting 20 billionths of a second.

Sandia is also conducting preliminary studies of ion beam fusion, using electron beam accelerators. Recent studies on pellet design indicate that beam currents could be reduced if ions were used for pellet implosion rather than electrons. It also appears possible to generate ion beams using the technology developed for electron beams.

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left—Proto I above and Proto II below.
above—Hydra accelerator striking target plate.

above right—Magnified view of reactor wall degradation.

Thermonuclear Reactor Material

Research on reactors which can confine and heat a hot ionized gas (plasma) for periods sufficient to create a controlled thermonuclear reaction for generation of electricity has been underway at several laboratories in the U.S. and abroad for a number of years. Sandia is supporting this effort by evaluating materials for use as the so-called "first wall" or inner wall of one of these reactors, the toroidal Tokamak device developed by Russian researchers.

The Tokamak, as well as other experimental fusion reactors, uses a powerful magnetic field to confine the plasma until sufficient energy can be pumped into the gas to cause fusion to occur. This approach to fusion is known as magnetic confinement fusion, as opposed to the inertial confinement principle used in lasers and electron beam fusion.

Although the heated plasma will not touch the wall of the reactor, the wall must be able to withstand energized nuclear particles and other radiation emanating from the controlled thermonuclear reaction. Experiments conducted by Sandia researchers show that some first wall materials rapidly blister or exfoliate under this bombardment of hydrogen-isotope ions and helium ions. In addition, the particles eroded from the wall and gas ions implanted in the wall and later re-emitted into the reactor may contaminate or poison the plasma, reducing or extinguishing the reaction.

Sandia experimenters are using high voltage ion accelerators to bombard prospective first wall materials, then observing the damage as it occurs with a scanning electron microscope connected to a video tape system. Damage to conventional wall materials is severe, and it is apparent that this problem must be solved before experiments with "working" plasmas can begin. The problem is more immediate and possibly more serious than the one of radiation damage to reactor structures, another area which Sandia researchers are studying. One possible solution to the first wall problem which Sandia personnel are investigating is use of coatings or liners made of low atomic number materials such as aluminum and beryllium.

The Sandia studies have also revealed that stainless steel can be used for interim fusion experiments in which wall materials will be bombarded only with hydrogen ions. Stainless steel performs satisfactorily in room temperature hydrogen environments, but will not be usable when thermonuclear burns, which produce large numbers of helium ions, are achieved. A number of theoretical calculations are under way at the Labs to understand the behavior of helium in metals and the cause of blistering and flaking during helium bombardment.

CONSERVATION

Development of technology which permits new sources of energy to be economically exploited is one approach to solving the country's energy problems. Another approach, which often receives less attention, is conservation - more efficient use of energy. It has been estimated that the nation could be saving up to 20 million barrels of oil per day by the year 2000 if conservation efforts were aggressively pursued. The automobile is one of the biggest consumers - and wasters - of the nation's energy resources. Sandia has several programs - development of a variable displacement engine, development of flywheels and combustion research - aimed at making automobiles more efficient energy consumers.

Combustion Research

Combustion — the burning of fuel to release energy — is a poorly understood process. The transient nature of combustion and the severe environment in which it occurs have prevented many of the fundamental studies of this process. To conduct and manage such studies, which could have significant, long-term impact on conservation of the nation's energy resources, Sandia Livermore Laboratories is contributing to the Energy Research and Development Administration's recently-established national combustion research program.

The combustion research and management activities are concentrated in four areas:

1. Development of diagnostic instrumentation, particularly high power optical devices employing lasers, for use in basic combustion studies.
2. Conduct of fundamental combustion process studies, including application of computer modeling techniques.
3. Application of new information from these studies to the solution of current combustion problems, such as improving performance of internal combustion engines and advanced coal burning systems.
4. Assisting ERDA in management of the national combustion program, which includes a wide variety of studies on auto engines, gas turbines, coal burning power plants, and other combustors at a number of locations throughout the country.

Much of the combustion work will involve application of Raman spectroscopy and other laser diagnostic techniques in which the Labs has specialized. These techniques are based on the fact that when laser beams of known wavelength are directed at a given material, their light is selectively scattered, depending upon the instantaneous state and composition of that material. By collecting the scattered light, it is possible to obtain a dynamic record of events in the combustion process.

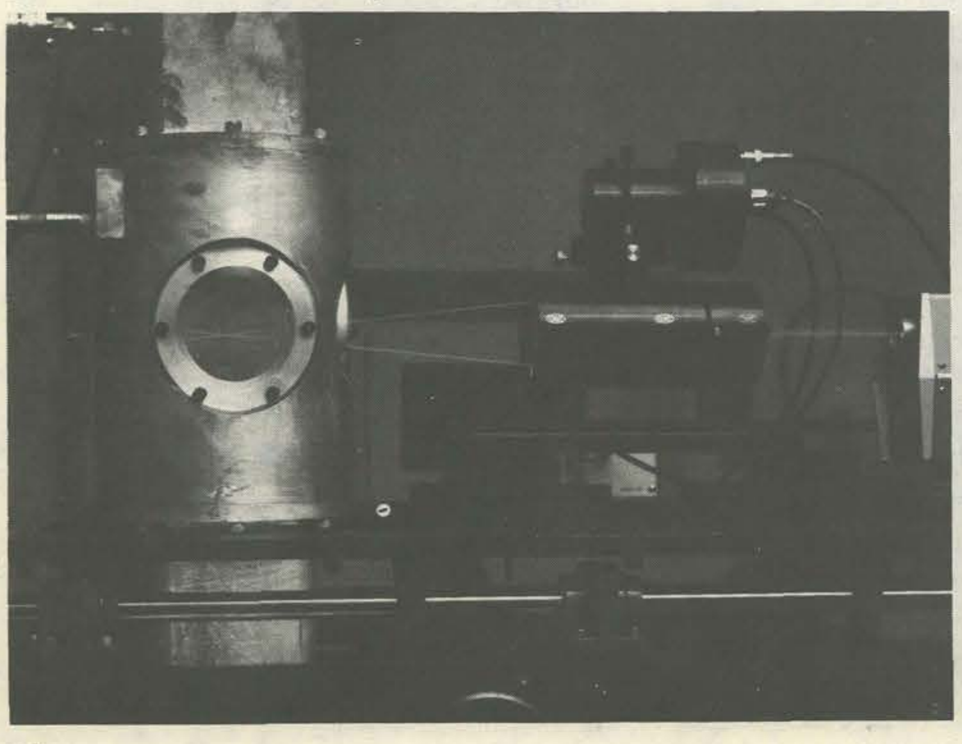
Since the amount of light scattered is typically very low, the resulting signal is often obscured by system noise, presenting problems in interpretation. The Labs is being equipped with a number of high power lasers — both pulsed and continuous wave — to increase signal strength in such experiments. A recently patented ellipsoidal reflector which increases signal strength by a factor of up to 100 is also playing a key role in many of the studies.

One of the first uses of the Labs' laser spectroscopy involves directing a laser beam into a cylinder of an engine to measure gas temperatures and chemical specie concentrations during combustion. Experiments have already been conducted to determine whether system noise and obstructions to the optical ports will preclude use of these techniques. It now appears that these techniques will permit the first systematic studies of transient combustion phenomena within an operating engine.

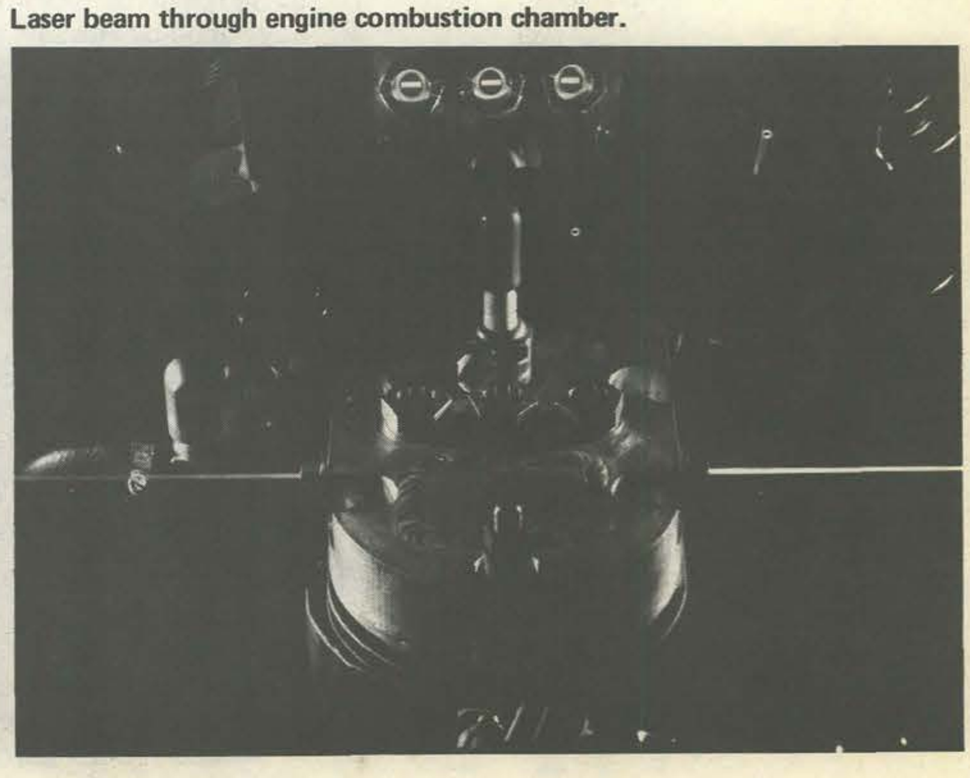
In addition to laser scattering spectroscopy, Sandia personnel are developing or improving other tools and techniques for combustion research such as emission spectroscopy sampling probes and hot wires. A significant improvement has already been made in use of hot wires — thin, charged wires inserted into a combustion chamber to measure gas flow or turbulence — by attaching them to computers to obtain real-time data.

These diagnostic devices, as well as computer codes and analytical models developed by the Labs, are ultimately expected to influence the design of engines and combustors. Better designs and rapid application of new information to solution of combustion problems have the potential to improve fuel utilization by five to 10 percent — a substantial contribution to the nation's energy conservation effort.

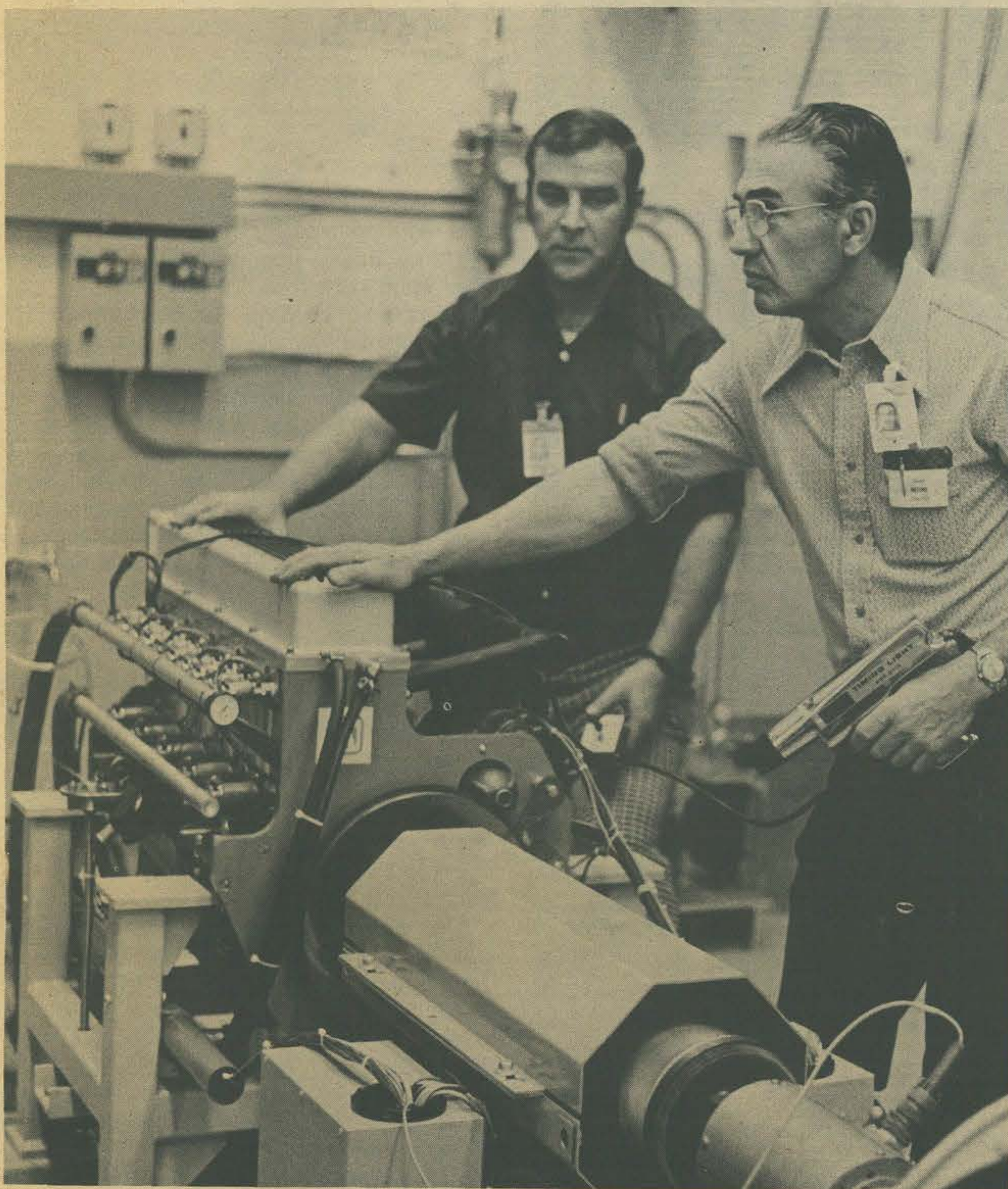
Laser measures turbulence in premixed flames.



Laser beam through engine combustion chamber.

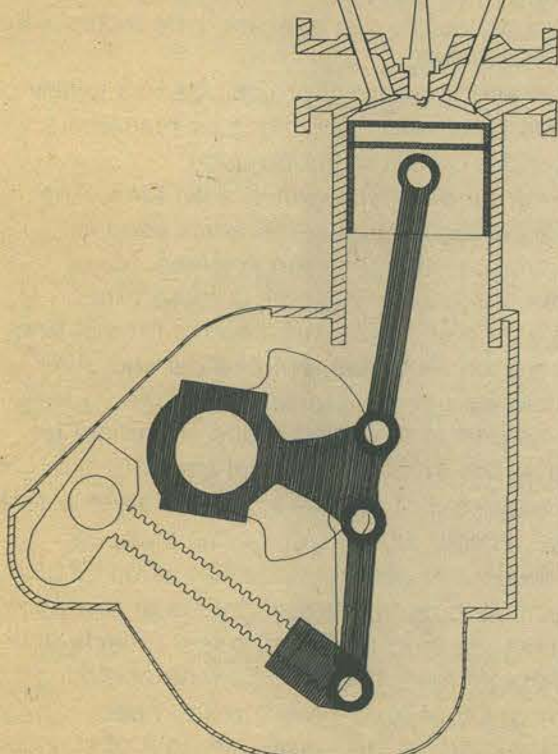


Variable Displacement Engine

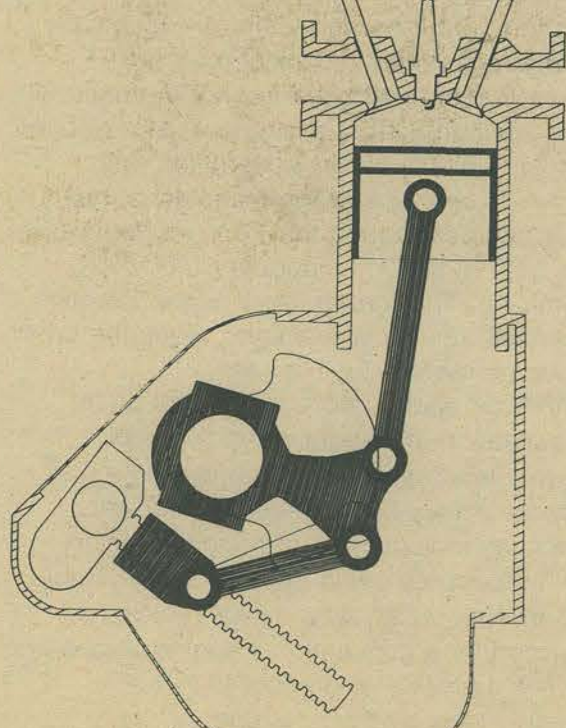


Five-cylinder Pouliot variable displacement engine

Increased stroke



Decreased stroke



Engineers at Sandia Livermore Laboratories have designed and are testing a variable displacement engine which shows promise of improving gas mileage in automobiles. Successful development of the engine — invented at Sandia by Harvey Pouliot, but similar in some respects to an engine originally patented by Joseph Pierce in 1914 — could cut gasoline consumption significantly.

Engine displacement — the volume created when a piston is drawn down a cylinder by rotation of the crankshaft — determines an engine's horsepower to a considerable extent. In general, the larger the displacement, the more fuel and air drawn into the chamber, and the greater the energy released as the mixture is compressed and ignited. Because displacement is fixed in a conventional engine, it is necessary to select a displacement which will adequately power a vehicle under the greatest load it will encounter.

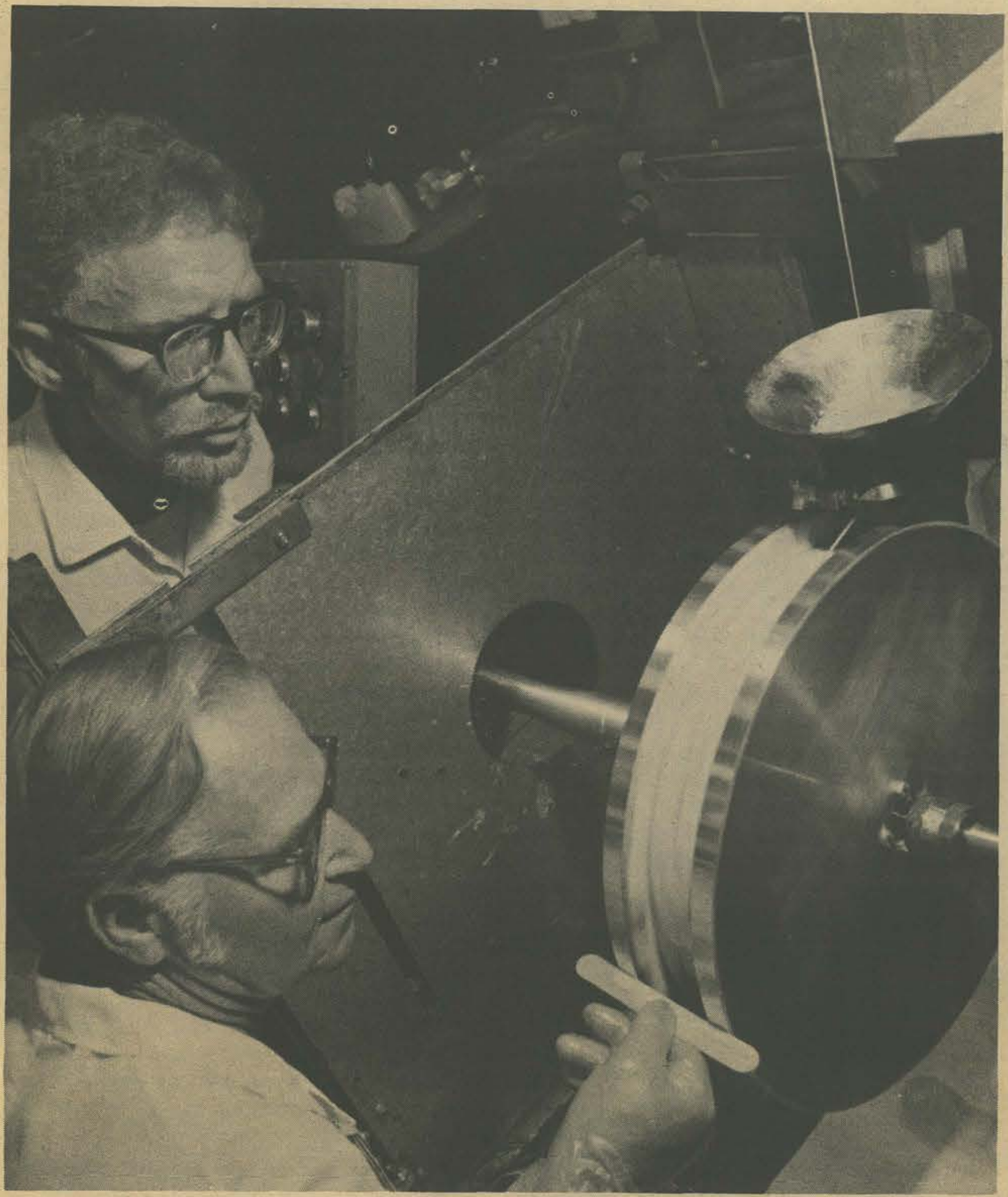
Under maximum loading — such as climbing a steep hill or accelerating rapidly — a fixed displacement engine performs reasonably efficiently. About 90 percent of the time, however, the engine is lightly loaded, as when maintaining cruising speed. At such times the engine is overpowered and its efficiency is decreased because fuel intake is reduced by throttling the air/fuel mixture admitted to the engine to pressures which are a fraction of an atmosphere.

Except when idling, the Pouliot variable displacement engine runs at full throttle, greatly reducing throttling losses. Power is regulated by varying the length of the piston stroke, increasing it when the load increases and decreasing it when the load decreases.

The piston stroke — and thus the engine displacement — is varied by means of a jointed connecting rod whose end can be swung, in an arc, along a controlled path. Movement of the rod, which can be achieved mechanically, electrically or hydraulically, shortens or lengthens the stroke smoothly, varying power output rapidly.

Preliminary calculations indicate that reduction of throttling losses and the improved matching of load to power availability could increase average gas mileage of a typical automobile up to 40 percent. Piston-cylinder wall friction should also be reduced in the engine because the pistons travel a shorter total distance during the life of the engine and because thrust from the connecting linkage and crankshaft is principally along the axis of the cylinder.

Extensive computer simulations and analyses have been conducted to refine engine designs, solving material stress and intertial loading problems. A five-cylinder, 110-horsepower model of the engine is undergoing laboratory dynamometer tests to determine gas mileage, wear, vibration, noise, emissions, and such performance characteristics as response to load and speed changes. Displacement in the engine can be varied from 43 to 190 cubic inches, with compression ratios ranging from 7 to 1 to 9 to 1.



Winding flywheel from Kevlar filament

Energy Storage

Better utilization of the nation's energy resources requires development of improved energy storage systems. Such systems would help make autos and power generating plants more efficient and speed utilization of wind, solar, and other alternative energy resources. Sandia researchers are working on several energy storage systems, including flywheels and insulated tanks.

Storage of hot fluids in tanks has been extensively investigated at Sandia Livermore Laboratories in connection with development of a storage system for the Solar Total Energy Project (Page 7). Product of this developmental effort is a specially-insulated tank which stores 2,000 gallons of oil at 600°F. and 450 PSI pressure, with an energy loss of only one to two percent in 24 hours. The tank employs double-wall insulation, with a vacuum in an inner wall next to the stored fluid and alternate layers of aluminum foil and glass cloth in an outer wall to prevent radiation and conduction losses.

The tank also employs the thermocline principle to prevent energy degradation because of constant mixing of hot and cold fluids as they flow in and out of the tank. Sandia experiments, using lucite tanks and colored fluids, show that thermal stratification, hot fluids at the top of the tank and cold at the bottom, can be maintained by adding and removing fluids with a minimum of vertical turbulence. This is done by means of baffles or plates attached at right angles to the inlet and outlet pipes so that fluid movement is always in a lateral direction. Utilization of thermoclines in a single tank obviates need to construct separate tanks for hot and cool fluids.

Sandia Livermore is also surveying other high temperature energy storage techniques for ERDA and has technical program management responsibilities for the national thermal energy storage program as it applies to solar thermal power generation. In its survey of energy storage techniques, the Labs has determined that two — chemical and heat of fusion — appear particularly promising. The former involves the initiation of reversible chemical reactions, while the latter concerns melting fusible salts.

Another energy storage concept under investigation at Sandia is the flywheel. Flywheels store energy kinetically in a disk rotating at very high speeds. Preliminary estimates indicate that the supplementary flywheel energy could approximately double gas mileage of an intra-urban vehicle powered by a conventional engine. It does not appear desirable at present to power a vehicle solely by flywheel energy.

One approach to improving gas mileage would be to operate the vehicle's gasoline engine at a nearly constant speed and load, thus reducing throttling losses and improving efficiency. Energy from the flywheel would be used when extra power is needed for accelerating or climbing hills. Energy would be fed into the flywheel from the engine and from a regenerative braking system which uses energy dissipated during braking.

The energy storage capacity of a flywheel is governed by its mass, diameter, shape, and speed of rotation. The limiting factor in energy storage is the specific strength (strength divided by density) of the flywheel material. The Sandia projects will initially use steel flywheels. But more advanced wheels will be wound from high strength filament-reinforced composites, using technology derived from development of missile nosecones.

Composites, which consist of resin reinforced with glass, graphite or organic fibers, are the engineering materials which presently have the highest specific strength in required directions. They are formed by winding filaments onto a mandrel while resin is applied. The material is then cured until a solid rotor is formed.

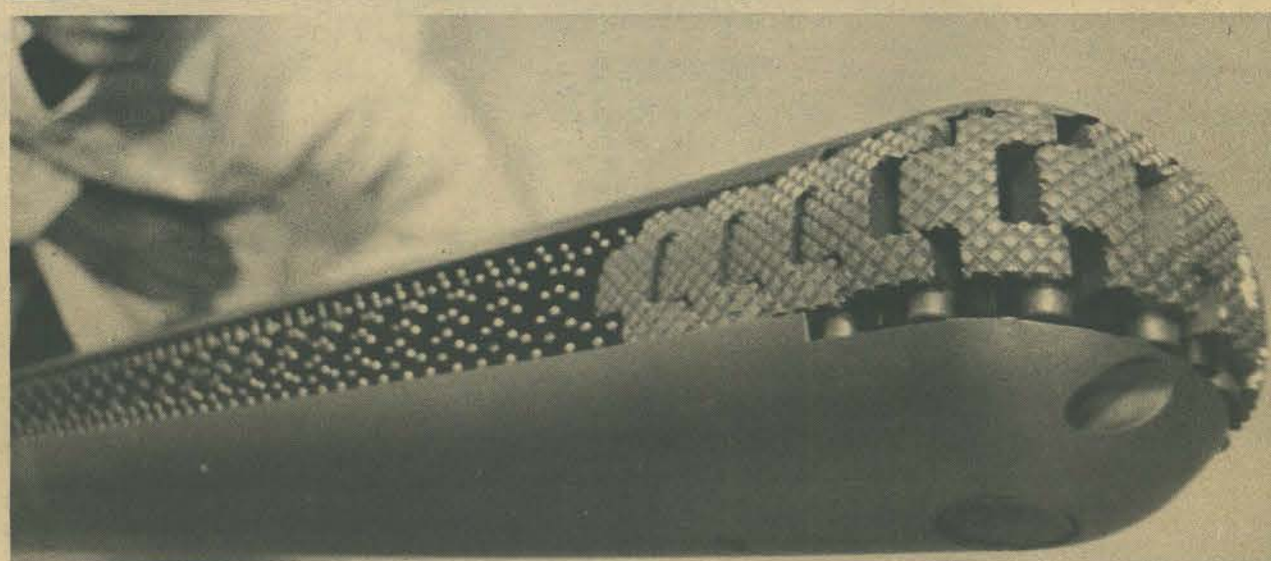
The most advanced wheels fabricated to date at the Labs have been made of Kevlar fibers, an organic material developed by DuPont. Wheels up to 16 inches in diameter have been made and are being tested at high rotational speeds. At speeds of 40,000 rpm — as yet unattained — a wheel 20 inches in diameter, two inches thick and weighing about 25 pounds would store approximately 40 watt-hours per pound of material. This would be three to four times the energy storage capacity of a lead-acid battery. The maximum storage capacity of this material appears to be 50 to 70 watt-hours per pound, four or five times that of steel flywheels. Sandia designers believe that wheel systems occupying about the same amount of space as a spare tire can eventually be incorporated into vehicles.

In another energy project, Sandia Livermore Labs has conducted materials research on hydrides which might be used for storage of hydrogen in solid form. The Labs is also studying materials used in hydrogen transportation systems. Major concern in such systems is leaks and catastrophic failures which might result from hydrogen embrittlement of steel and other materials used in pipelines.

As part of this effort, Labs personnel are operating an 80-foot model pipeline constructed of standard pipeline steel to test its behavior when hydrogen is pumped through it at pressures up to 1,000 PSI. Various experimental segments or modules within the loop are used to test defects and marginal materials to determine operating limits. Other tests have already been conducted on the tensile strength of stainless steel to determine crack growth in a hydrogen environment.

GEO ENERGY

Many energy resources are located below ground. Improved methods of discovering and recovering these resources would have a significant impact on increasing energy supplies worldwide. Discovery, for example, could be greatly facilitated by improved borehole drilling and logging methods. In situ techniques for recovering coal and oil shale might greatly reduce the cost and environmental problems associated with mining these energy resources. Development of massive hydrofracturing techniques could aid in freeing natural gas trapped in impermeable underground rock formations. A significant, long-range source of energy might be developed if magma pools could be located and tapped efficiently. A number of these geo-energy projects are being investigated at Sandia.



top—Spark drill bit. bottom—Continuous chainbit.

Drill Bits

Although drilling technology has been refined through the years, basic methods of cutting boreholes to reach underground energy and mineral resources have remained largely unchanged. Yet, during this same period, drilling environments have grown much more difficult. Oil, gas, and uranium, for example, are being recovered from greater depths than ever before, and newer energy resources, such as geothermal, tend to be situated in formations that are harder than the sedimentary rocks normally drilled.

Sandia scientists are attacking these problems by developing new drills designed to speed cutting of drill holes by increasing bit life and penetration rates. The drill bits — spark drill, terra drill, and chain bit — are compatible with present rotary drill rigs, a fact which would speed application of the bits if their development proves successful.

The spark drill involves generation of high voltage sparks — up to 40 per second — across electrode gaps located on the bottom surface of the bit. Sparks are generated around the circumference of the bit to chip — spall — rock as the bit makes contact with the bottom of the hole. The sparks create high pressure shock waves in the drilling mud used in the hole. Shock waves are followed by stress relief (bubble formation) and cavitation (bubble collapse). It appears that bubble collapse produces a high pressure jet of fluid which further chips the rock.

Only low-energy, low pulse rate laboratory models of the drill have been operated to date. Shock pressures of 2,000 to 10,000 times atmospheric pressure have been measured. Immediate objectives of the program are to increase energy output of the drill to about 25 horsepower, to demonstrate penetration in rock, to solve insulation and other materials problems so that a long-life bit can be developed, and to continue studies of the physics of the drilling phenomena.

The chain bit has a cutting surface located on the face of a continuous chain circulating between two sprockets — one at the bottom of the bit, the other several feet distant. The chain links are studded with diamonds. The hole is cut by that portion of the chain wrapped around the lower half of the bottom sprocket. As the bit is rotated in the hole, the inserts scrape the bottom and sides of the hole, gradually deepening it. When the cutting surface at the bottom of the hole becomes dull, another segment of chain is stepped into place without removing the bit from the hole.

Sandia designers feel that the two sprockets can be located about five feet apart, permitting use of a chain about 10 feet long. This would provide some 20 separate cutting segments, allowing a substantial improvement over conventional bits in terms of bit life. Initial laboratory tests of the bit have been encouraging, and an improved model is being designed.

The terra drill, which fires projectiles between the spacings in a standard tri-cone roller bit, is based on the observation that highly fractured rock can be drilled more rapidly than unfractured, homogenous rock. Projectiles launched from a magazine located above the roller cones penetrate and weaken the rock ahead of the bit, which then pulverizes the fractured segments and cuts the hole to the proper diameter.

Supplementing the development of new drill bits are four new projects recently undertaken by the Labs' Drilling Research Division. These include the investigation of new hard surfaces for drill bits, design and development of drilling fluid test equipment, high temperature materials studies, and development of high temperature borehole instrumentation. The projects are sponsored by ERDA's Divisions of Fossil Energy and Geothermal Energy.

The investigation of hard surfaces for drill bits will focus on the application of such materials as General Electric's diamond Compax to new bit configurations. One of the main problems attacked will be improving the bonding of Compax to their mounting studs.

The drilling fluid (mud) test equipment will be used to measure drilling fluid properties under high temperatures and pressures. Equipment design is being preceded by studies to learn exactly what environmental parameters — viscosity, flow properties, etc. — need to be measured to characterize mud degradation in deep oil, gas and geothermal wells.

The high temperature materials studies will be conducted to determine the effect of temperature, pressure and corrosive environments on steels, elastomers and other materials used in borehole drilling. Such environmental factors have a serious adverse effect on bits, pipe, and tools, particularly those containing elastomer seals.

The high temperature borehole instrumentation which will be developed will include primarily a logging truck and tools for logging geothermal wells. An advisory committee will decide what tools would be most useful to the geothermal well drilling industry.

Uranium Borehole Logging

above—Uranium logging probe.
below—neutron generator.

Knowledge that Sandia has gained from development of neutron generators for nuclear weapons is being used to produce a more precise instrument for logging uranium boreholes. Funded by ERDA, Sandia is developing prototypes of a neutron generator logging device to determine if it would be a useful supplement to conventional logging instruments.

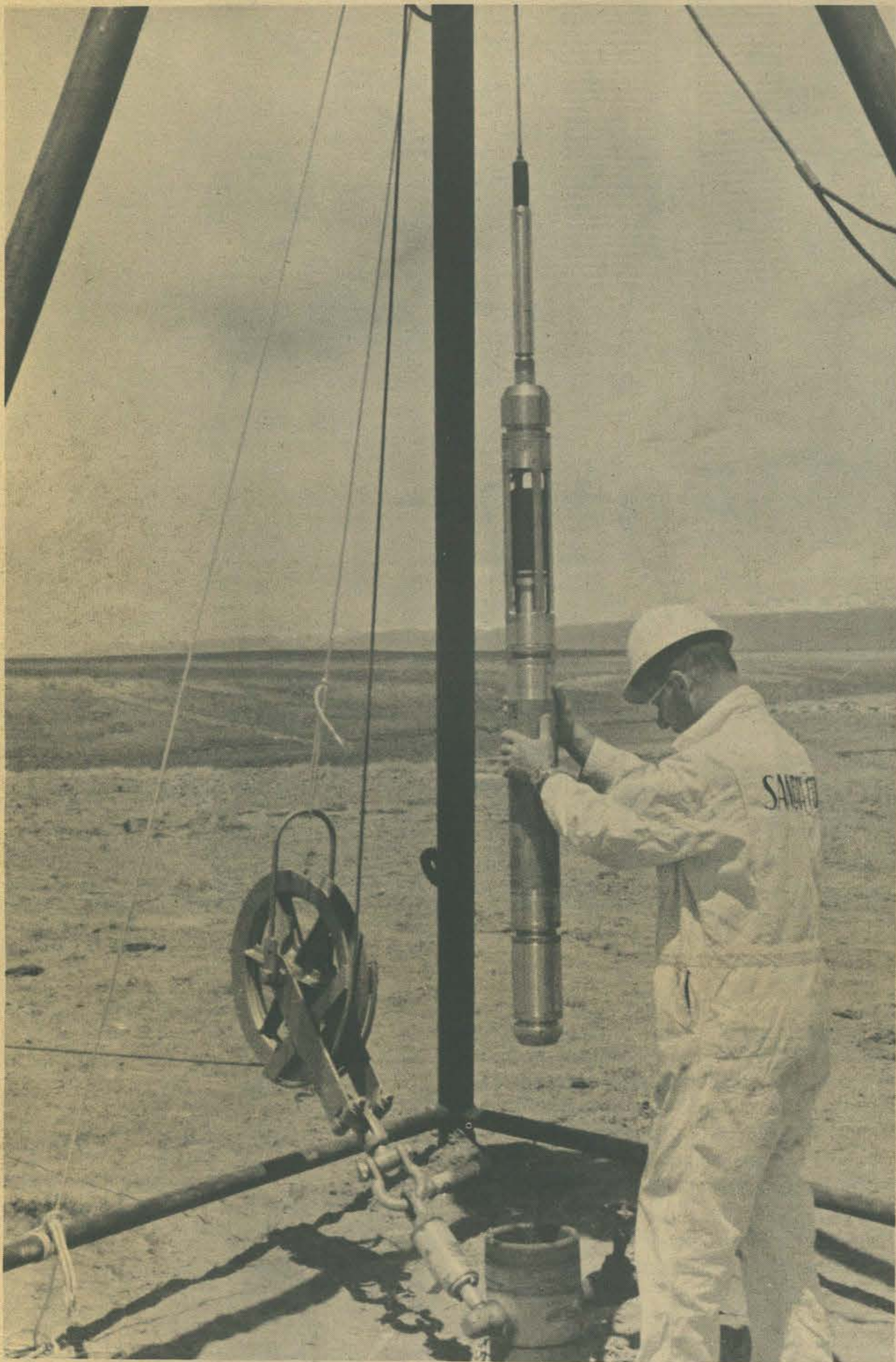
Most uranium drill holes are presently logged with a gross count gamma ray probe. The probe is lowered into a drill hole and counts the gamma rays emitted by radioactive decay of uranium, thorium, and potassium intersected by the hole. The count is recorded on a graph or log which is correlated with the amount of uranium at each level in the hole.

While these instruments give reasonably accurate counts under most conditions, they do have limitations. For instance, they do not measure very low concentrations of uranium — 0.05 percent or less — with great reliability, and they can give misleading measurements when, for various geological reasons, the gamma ray emission does not match the amount of uranium actually present in the hole. Since it does not rely on a count of gamma rays for accurate measurement, the neutron generator logging device is not affected by this geological condition.

The new device produces pulses of neutrons which split or fission atomic nuclei in the uranium ore around the borehole. Neutrons produced by the fissioning process can be identified and counted to give a fairly precise estimate of uranium concentration. If the neutron output of the device is high enough, the fissioning process can be maintained at a sufficient level to permit accurate detection and count even in the presence of low grade uranium ore.

Feasibility of the new logging concept has been proven, and prototype development and testing are underway. The prototype produces 500-million neutrons per second in a series of 100 pulses. Design of a prototype which will produce even more neutrons per second and be satisfactory for measuring very low concentrations of uranium will follow. The pulses of neutrons are produced by accelerating deuterium atoms against a tritium target.

The neutron logging instrument may also be a superior tool for logging holes intersecting silver, copper, and other minerals, although such applications are not being investigated under the present program. A variation of the instrument may also be useful in undersea pollution analysis.



left—Lowering seismic instrument package into well. below—Geophone used in hydrofracture experiments.

Massive Hydrofracture Instrumentation

Sandia is participating with private industry in experiments designed to extend fracture zones around natural gas wells to increase the permeability of surrounding rock and thus improve the flow of gas. Using expertise gained in underground instrumentation for weapons tests, the Labs is attempting to map the extent and orientation of the fractures as they extend out from the drill hole.

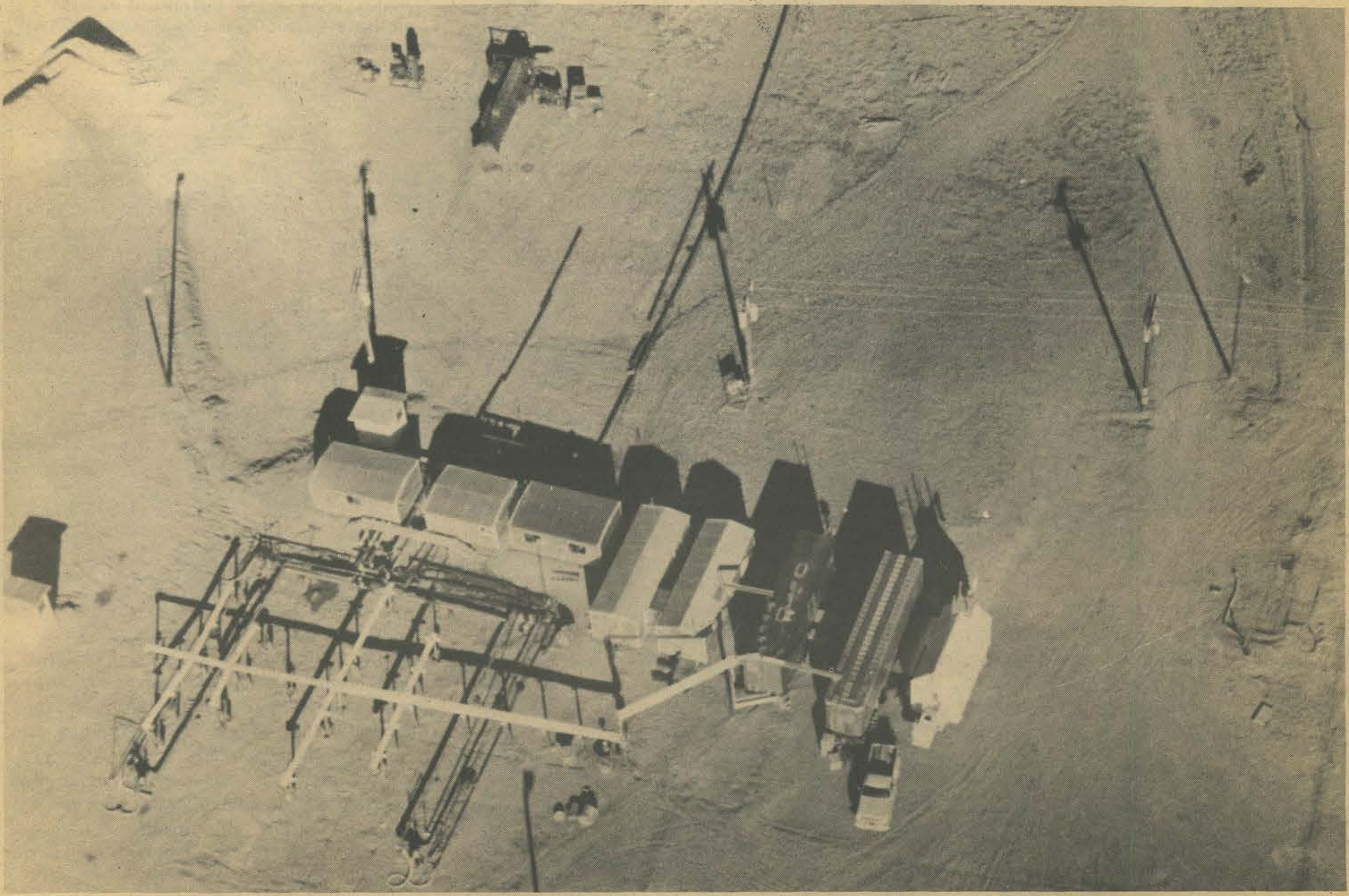
The fractures are produced by a standard technique known as hydrofracture in which fluid is pumped under high pressure into the drill hole, producing cracks which extend outward from the hole hundreds of feet. The experiments in which Sandia is participating involve the pumping of greater quantities of fluid into the hole and are thus known as massive hydrofracturing experiments. Cracks will hopefully be extended for distances up to 2,500 feet, thus stimulating flow throughout a greater portion of the gas-bearing zone.

The Sandia instrumentation is being used to determine whether the technique is actually fracturing the rock to the extent desired. Labs' scientists and engineers are using two types of instrumentation — seismic and surface potential — to obtain the required data.

The seismic instrumentation consists of an array of geophones and hydrophones, located on the surface and in wells adjacent to the borehole. These instruments record the arrival time of seismic signals produced during fracture propagation. Recorded data are then reduced by computers in an attempt to calculate the location of the cracks.

The surface potential technique uses the electrically conductive path formed by the well casing and the hydrofracture fluid as it fills the new cracks created in the rock formation. Surface measurement of the potential field change caused by flow of current along the path indicates the extent and orientation of the longitudinal fractures.

The techniques have been tested in several experiments in Wyoming and Colorado. Different gas producing zones were fractured in each of the tests. Data gathered on both tests are still being analyzed. The surface resistivity method is showing great promise. Success of the massive hydrofracturing technique on these drill holes could eventually lead to recovery of millions of feet of natural gas now trapped in impermeable rocks throughout the world.



Coal gasification test site near Hanna, Wyoming.

Coal Gasification

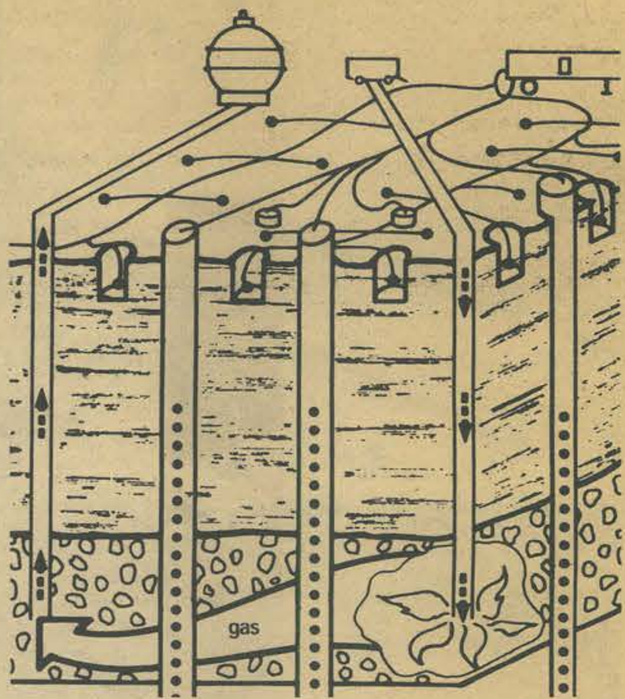
The nation's large coal reserves can be put to much greater use if methods can be developed to extract energy from these deposits without having to mine them. One such approach being tested by ERDA's Laramie Energy Research Center at a site near Hanna, Wyoming is *in situ* or underground coal gasification. In this process, a portion of the coal is burned to produce heat which allows other reactions, such as decomposition or reaction with water, to occur. The combustible product gas, chiefly hydrogen and carbon monoxide, could serve as fuel for an on-site electrical power plant, be used as a chemical feedstock, or could be upgraded to substitute natural gas.

The underground gasification of coal consists basically of providing access to the coal reserve by drilling wells, establishing permeability in the coal seam between wells, igniting the seam and sustaining gasification by the injection of air and oxygen and withdrawal of the product gas from neighboring wells. This process is environmentally attractive since the energy of the coal is extracted without mining, and most of the potentially polluting ash and sulfur contaminants remain underground.

Commercial development of such *in situ* processes will require the understanding and development of positive process control systems. Sandia Laboratories is supporting the underground coal gasification experiment at Hanna by using expertise gained in nuclear weapons testing to develop instrumentation and process control techniques. Such techniques will be required because the burn, hundreds of feet below ground, can be made to proceed more efficiently if factors affecting combustion can be detected and adjusted. It is important, for example, to pinpoint the burn front as it proceeds through the coal seam, thus permitting changes in operating conditions to maximize gas production.

Sandia is presently active in three areas of the gasification project:

1. Development and application of subsurface instrumentation to obtain detailed information about the process itself. Extensive thermocouple arrays provide temperature information as well as a spatial description of the process. Gas sampling canisters allow gas samples to be taken for analysis and local pressures to be measured.
2. Development of surface or remote instrumentation which would not require additional costly boreholes. These techniques will provide an overall picture or map of the continuously changing process and form the basis for a process control system. Several techniques appear promising. In one, changes in the electrical resistivity due to the burn are measured. In another, acoustic techniques determine the location of the sources of noises made by the burn. Finally, seismic techniques, which measure variations in small explosive signals which pass through or are reflected from the changing gasification zone, are being evaluated.
3. Measurement of earth movement or subsidence caused by the underground burn to examine these environmentally important effects. Tiltmeters, displacement gauges, and acoustic techniques are employed for these measurements.



The initial phase of the Hanna experiment has demonstrated the practicality of igniting and controlling burns between two linked boreholes drilled into a 30-foot coal seam at a depth of 300 feet. During this test, the site produced about 2-million cubic feet per day of gas with a heating value of 150 BTU/cubic foot for a 60-day period. The 300-million BTU's per day from this limited test would have been sufficient to power a 1½ MW electrical power station. Future experiments at the Hanna site will determine the effect of oxygen enrichment, well spacing, and coal seam depth on the gasification process and the practicality of extending a burn laterally along a broad front in order to improve the recovery of energy from the coal reserve.

Oil Shale Retorting

The Western United States contains vast deposits of oil shale which can supply the country's oil needs for hundreds of years if satisfactory means of freeing the oil from the shale can be devised. Sandia is investigating various aspects of *in situ* (in place, underground) retorting of the shale, an approach that may be less expensive than surface retorting, would require less water for processing, and would reduce disturbance of the environment.

Typically, oil shale has been mined, crushed, and heated in surface retorts to release the oil from the nearly-impervious stone. More recently, a modified *in situ* technique has been devised in which tunnels are driven into the shale, and portions of the remaining shale fractured in place with explosives and ignited with the initial aid of combustible gas. This approach extracts the oil, but still requires removal of about 20 percent of the shale from the ground, increasing mining costs and environmental impact.

True *in situ* retorting, the approach in which Sandia is primarily interested, represents an effort to process the shale completely in place. One proposed plan is to enlarge a borehole in the deposit with explosives, torches, or cutters, removing a small amount of rock to the surface. The surrounding shale is then fractured and collapsed into the hole, creating a porous, permeable zone filled with shattered rock. Propane would then be pumped into the zone and ignited. Supported by injected air, combustion would begin at the top and burn downward, driving the oil before it. About two-thirds of the oil in the shale (each ton of shale contains up to 30 gallons of oil) could be freed and pumped to the surface.

The technique is still in the experimental stage, however, with a number of complex problems yet to be resolved. It is not known, for example, how much porosity is required for efficient combustion — estimates range from one to 20 percent — or how the porosity can be distributed through the rock most effectively. If satisfactory oil recovery cannot be achieved with fracturing and burning, it may be possible to free the oil by introduction of hot gases, brine, or steam into the rock mass.

Sandia scientists are presently working in three areas of *in situ* oil shale technology:

1. Advanced instrumentation — Efforts are underway to develop sensors to evaluate the underground retorting process, chiefly employing acoustical techniques to determine fragment size, the extent of the fracture zone, and the degree of porosity.

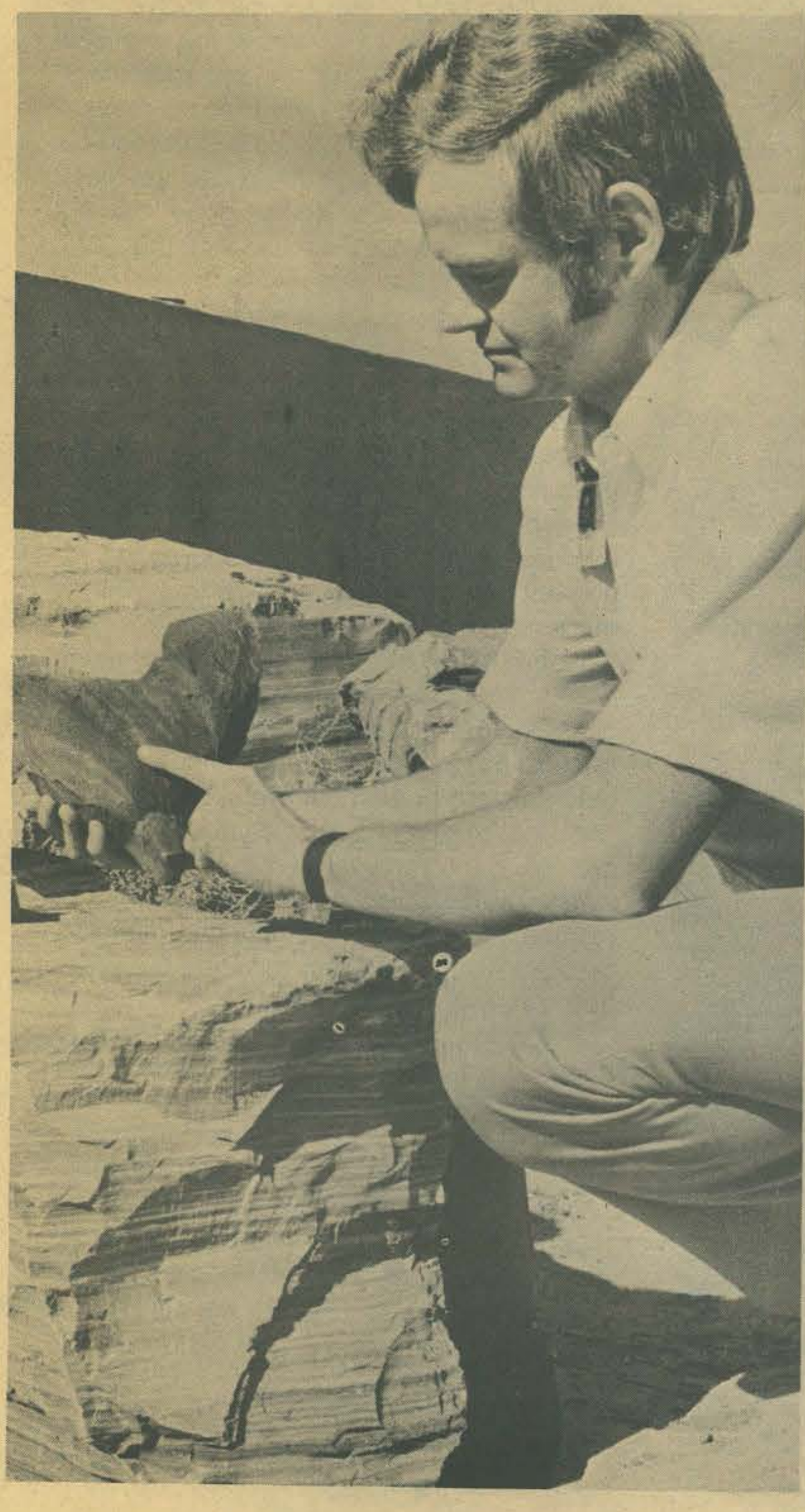
Sandia is also developing a solid state electrolytic probe that provides absolute measurements of oxygen in the retort. A small, rugged instrument, the probe should be extremely useful in monitoring process control remotely.

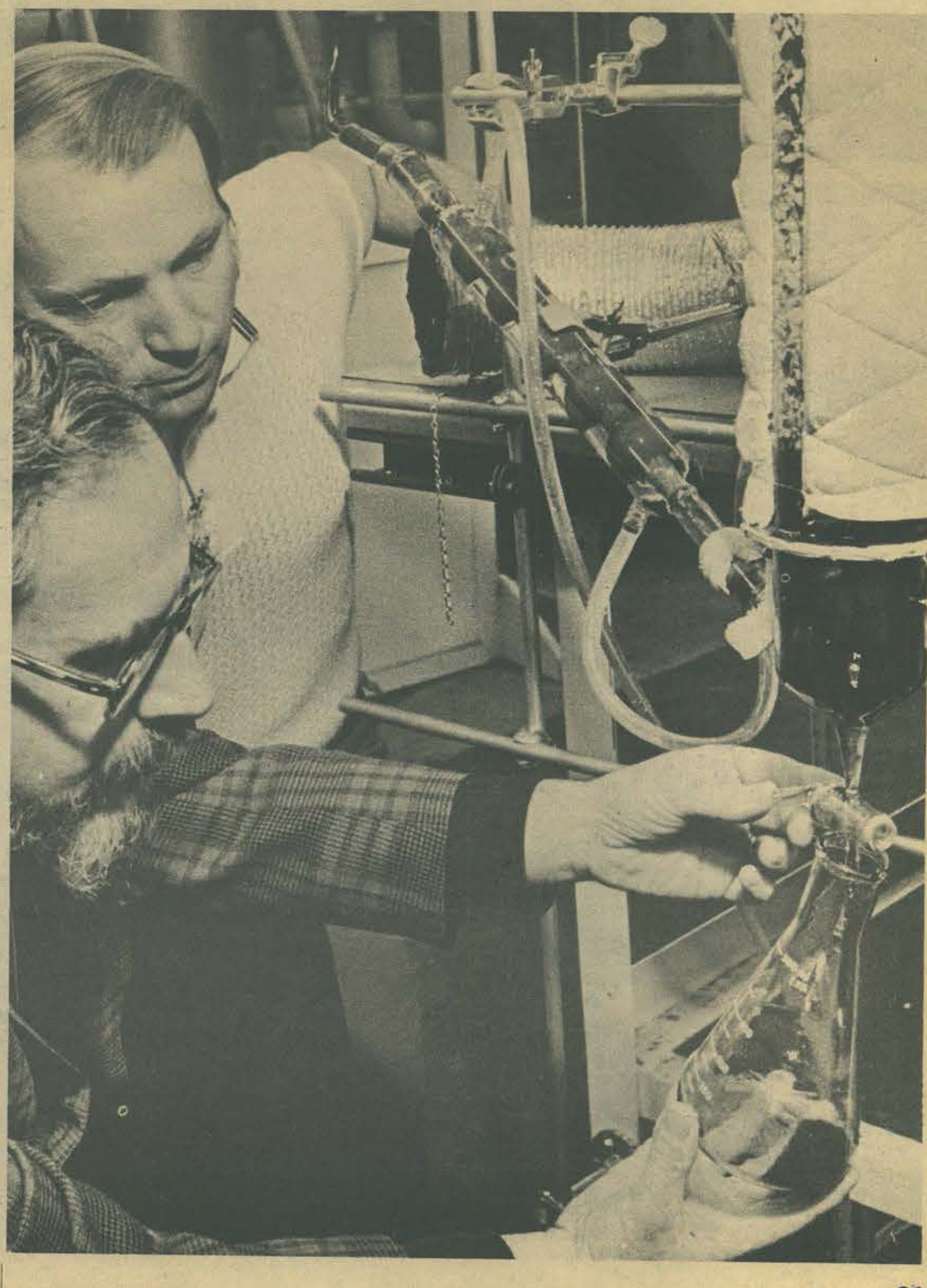
2. Rock mechanics and numerical modeling — The mechanical and chemical properties of oil shale are being determined in the laboratory, and computer models of shale beds are being constructed. These models will be used to predict effects of experiments before field tests are conducted.

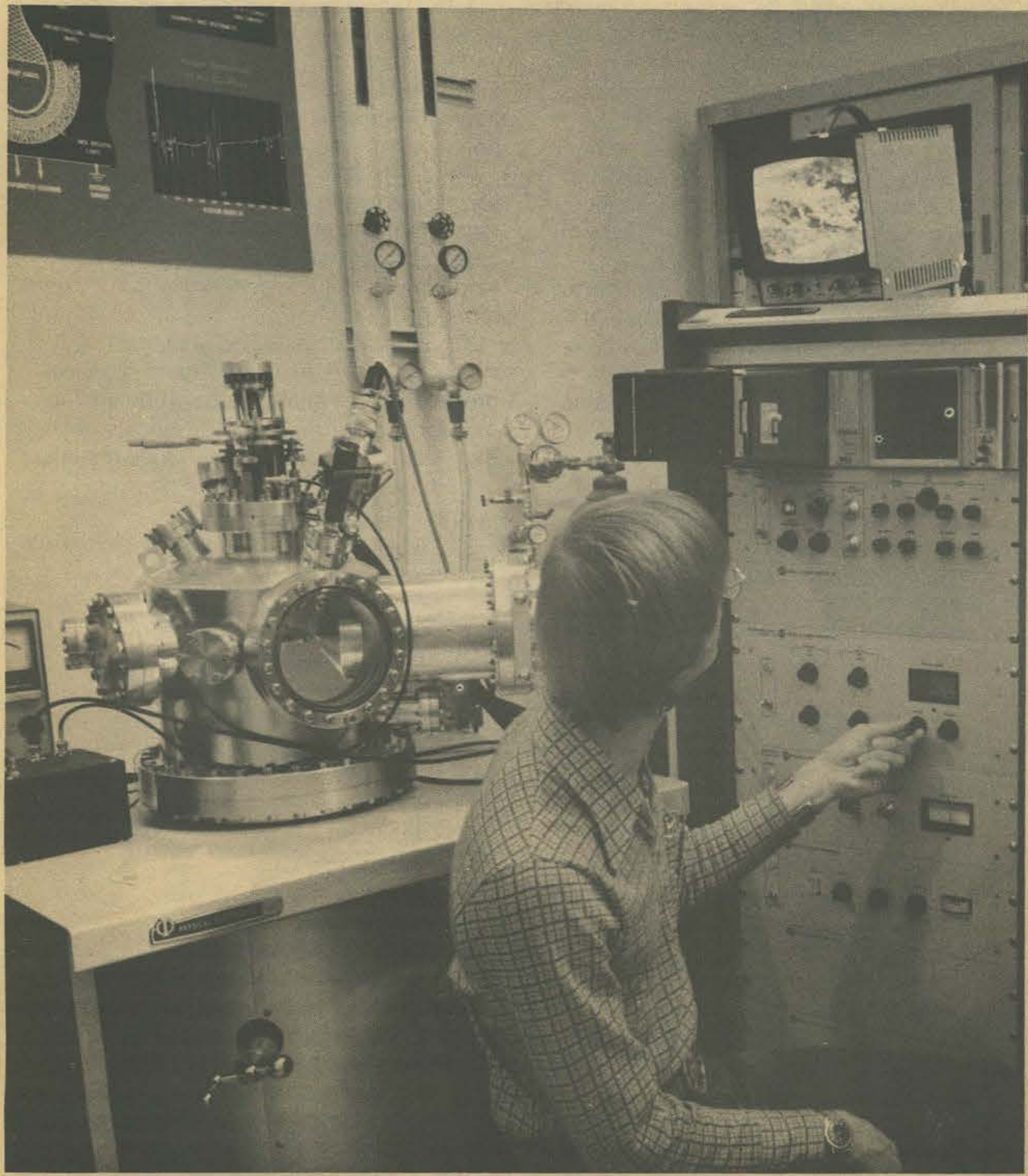
3. Field experiment assistance — ERDA's Laramie Energy Research Center is conducting *in situ* retort experiments near Rock Springs, Wyoming, and Sandia is providing rock mechanics and diagnostic instrumentation support for the test.

Success of the *in situ* retorting technique would help provide the country with a long-term supply of low-sulfur, low-nitrogen crude oil which could be processed by conventional means into a wide variety of petroleum products.

below left—Oil shale.
right—Extracting oil in a laboratory retort.







Synthoil Analysis

A two-year study whose objective is to provide information that will make the production of synthetic oil — "Synthoil" — more economical is underway at Sandia. Synthoil is the product of a process developed by ERDA's Pittsburgh Energy Research Center in which coal, in a slurry with recycled oil, is converted to liquid fuel oil by heat and pressure in the presence of a catalyst, cobalt molybdate.

During the process, sulfur is combined with hydrogen and removed as gaseous hydrogen sulfide. Removal of the sulfur — a major constituent of pollution from power plants and furnaces — makes the Synthoil process a comparatively clean and convenient method of making greater use of the nation's extensive coal reserves. However, the process still has several unresolved problems, which presently limit Synthoil's use as a competitive fuel.

Under contract with the Pittsburgh Energy Research Center, Sandia is using its capabilities in surface physics and analysis of special materials to advance understanding of the Synthoil process in three areas:

1. Determination of the causes of catalyst deactivation. Sandia scientists are attempting to develop techniques that will lengthen the useful life of the catalyst, cobalt molybdate. Catalysts are not consumed in the chemical reactions which they initiate, but secondary chemical activity during the process may attack the catalyst and limit its effectiveness. In addition, the surface of the catalyst and its pores become coated and plugged, thus preventing necessary contact with the reacting materials.

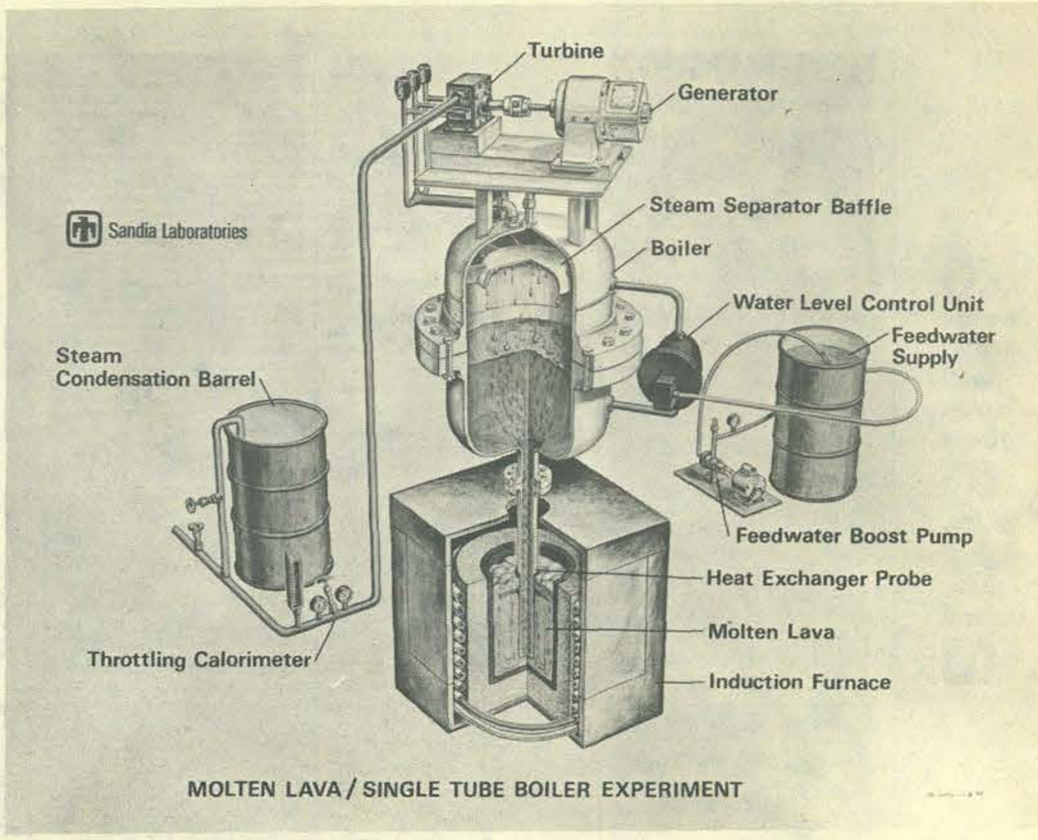
As part of the study, samples of fresh and spent catalyst are being examined to determine their structure and the nature of contaminants, using such techniques as x-ray photoelectron microscopy, scanning electron microscopy, and secondary ion mass spectroscopy. Findings will provide the basis for recommendations on procedures to prevent catalyst deactivation or to permit efficient recharging of the catalyst.

2. Investigation of the role of minerals in the Synthoil process. Many different minerals occur in coal in quantities ranging from a trace to a major constituent. Some of these materials are natural catalysts, such as iron and zinc, that may aid the Synthoil process by promoting the removal of sulfur through hydrodesulfurization. Effects of these materials on the process may be optimized to take advantage of them, reducing the cost of both catalyst and hydrogen.

3. Design, construction, and operation of a bench-scale Synthoil reactor system. As information is developed on the practical nature of the process and its performance with various raw materials, the process itself can be modified to optimize production. The test model, which will create up to 5,000 pounds per square inch of pressure and temperatures up to 1700°F., will permit detailed experimentation with process control and operating variables.

Analyzing Synthoil catalysts.

Magma Energy



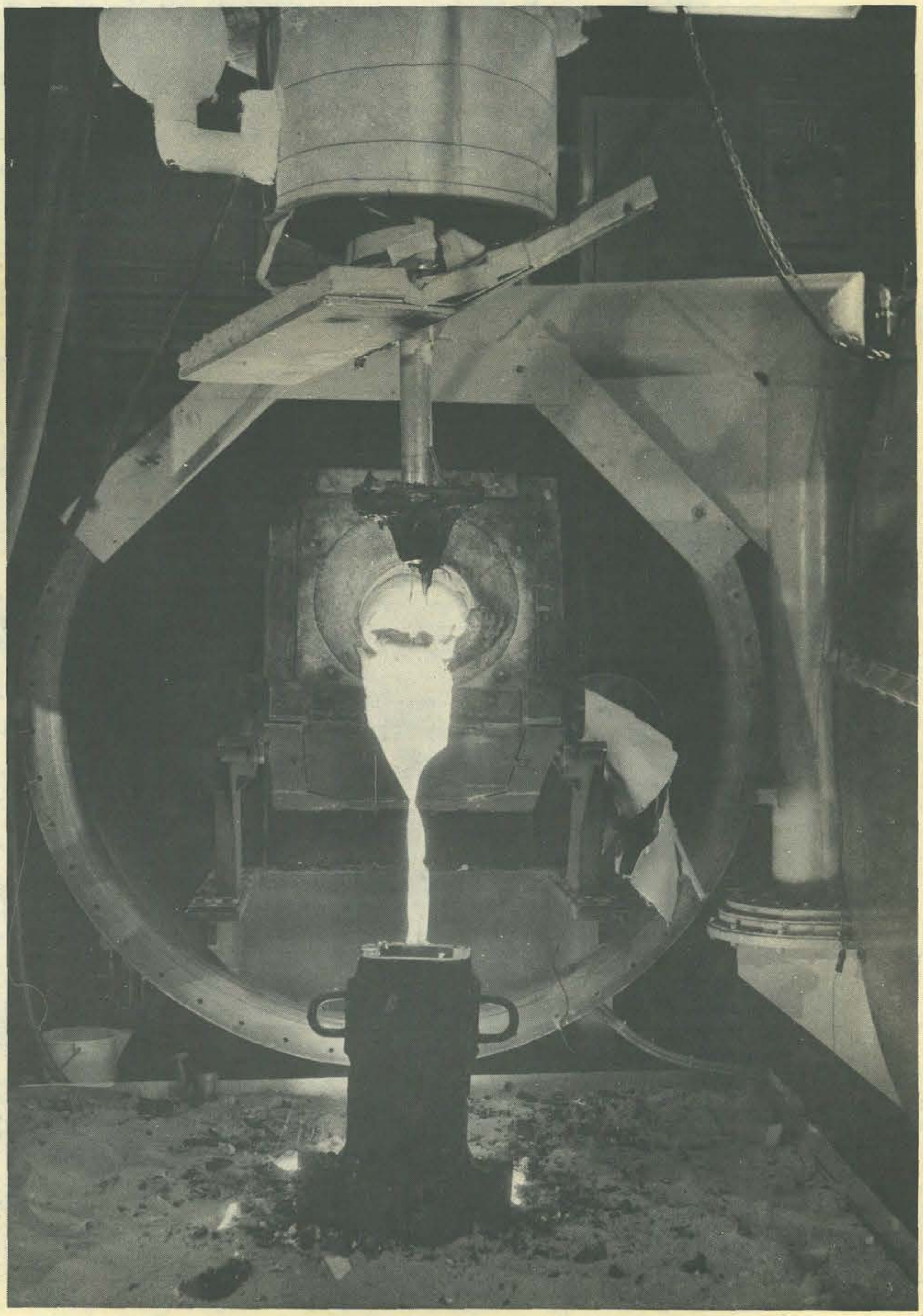
Sandia's magma energy research project is a long-range program to determine the practicality of tapping the virtually limitless supply of energy contained in molten rock (magma) located miles beneath the Earth's surface by emplacing heat exchangers directly in the rock. Such energy extraction would have minimal environmental impact, since it has been estimated that the heat in magma could keep society operating at its current level of energy consumption for millions of years without measurable effect on the environment.

Feasibility of the magma energy concept is predicated on the yet unverified occurrence of magma chambers within two to 10 miles of the surface at a number of points around the Earth. Volcanoes are presumed to be outlets for some of these deposits, which are thought to exist under the island of Hawaii and at 15 or more sites in the western states, including Yellowstone National Park. Locaton and identification of such chambers, using differential seismic and thermal measurements, are major objectives of the magma energy program.

A second principal objective is determination of the chemical and physical properties of magma and its response to insertion of heat exchangers. Flow motion in the magma is of particular importance, because a heat exchanger would operate far more efficiently in an environment where temperature is evenly maintained by convection. Equipment is being prepared for insertion into surface laval pools as they occur to obtain data on magma convection and composition. Sandia materials scientists are also studying the composition and characteristics of magma in the laboratory.

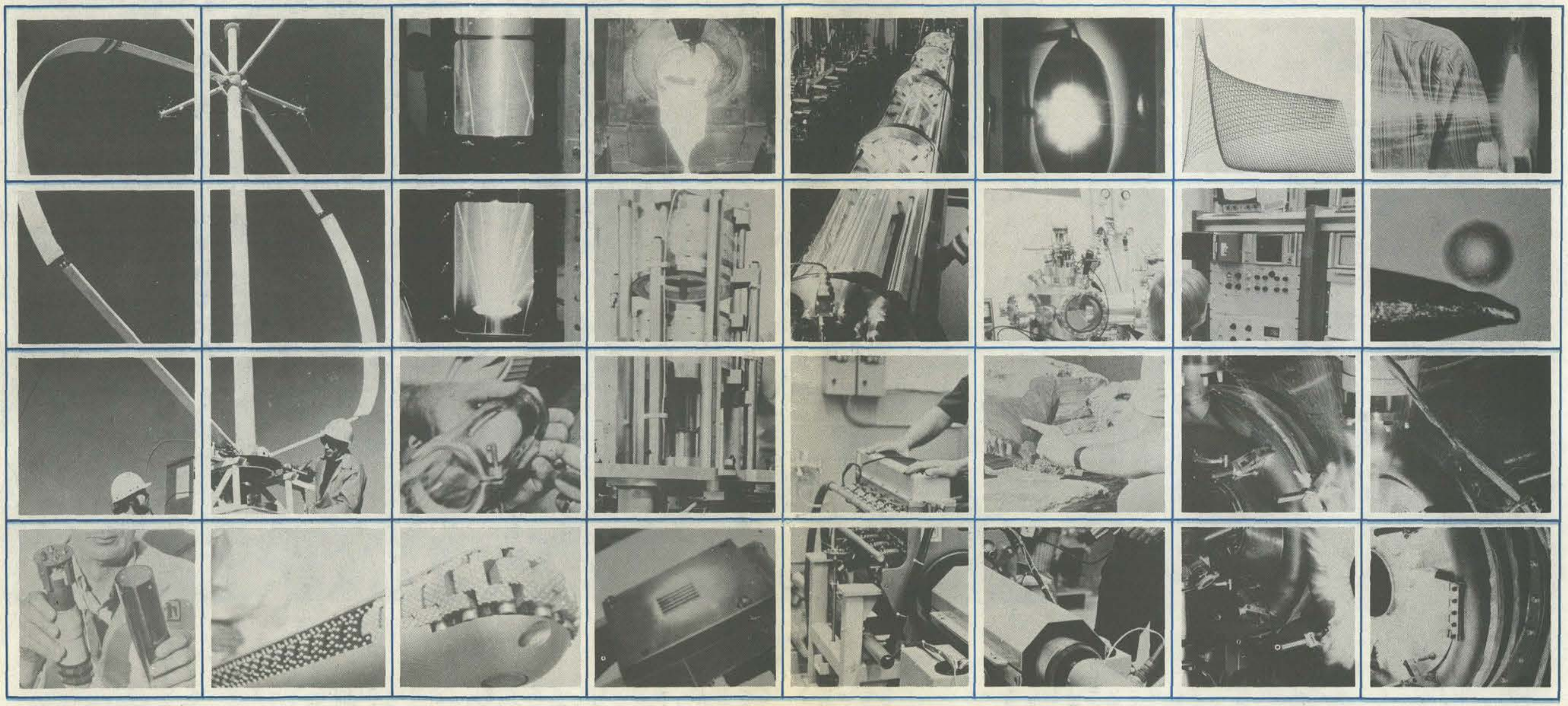
Development of heat extraction systems which can withstand the heat and corrosion of molten rock is presently being studied, with the goal of determining if it is possible to fabricate a heat exchanger which will operate for an economically useful life of 30 years. A small-scale heat exchanger/turbine system with a two-foot probe has been operated in a lava pool created in an electric furnace. Hawaiian lava was melted at temperatures measured up to 2650°F., well above the 2000°F. to 2200°F. estimated for naturally occurring magma.

Water was circulated through the model to maintain probe temperature at a safe level and to provide high quality steam for the turbine. Heat extraction rates of 170 to 314 kilowatts per square meter of heat exchanger surface were measured during the test. Typical rates for coal-fired boilers are 100 to 200kW per square meter. Corrosion damage to the probe was insignificant, suggesting that an exchanger might survive in a magma chamber if such deposits can be located and successfully penetrated.



top—Single tube boiler experiment.
bottom—Molten lava used in tests of heat exchanger probe.

energy programs at Sandia



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