VOLUME 9 NUMBER 1

REVIEW

OAK RIDGE NATIONAL LABORATORY · WINTER 76

State of the Laboratory - 1975

THE COVER: In reporting on the State of the Laboratory to the staff at the end of 1975, Director Herman Postma called attention to the many new directions in which the ORNL efforts are turning: research in coal technology, energy conservation, social impacts of the new power plant installations, advanced energy systems, many others. His address, delivered in December, is complete in this issue, beginning on page 2.

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REVIEW

VOLUME 9 NUMBER 1 **WINTER 1976**

FEATURES

OAK RIDGE NATIONAL LABORATORY

OPERATED BY UNION CARBIDE CORPORATION • FOR THE ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

EDITORIAL

Margaret Mead, Listen to This

About ten years ago Margaret Mead, renowned anthropologist, gave a lecture at Oak Ridge. The high school auditorium was packed, and the audience was rewarded by one of Dr. Mead's interesting talks; but the fireworks did not really get under way until the question period following the lecture. In one of her responses Margaret Mead took Oak Ridge violently to task for failing its social obligations to the surrounding country—impoverished mid-Appalachia. She felt that Oak Ridge, with its vast store of scientists and engineers, had done nothing to raise either the economic or social standards of its neighboring counties. Oak Ridge was a city with blinders, set on its nuclear track, not much caring what went on around it and certainly not involved in the problems that seemed so blatant to Dr. Mead's trained eye. Members of ORNL, along with many others, have been wearing this hair shirt of guilt for years. The Laboratory bends every effort to solve major national problems, but when it comes to its neighbors it is not involved.

I have news for you, Dr. Mead. We can now doff the hair shirts, or at least line them with satin. The people at ORNL are indeed involved. I recently came across a memo (I come across memos all the time, but very few are designed to gladden the heart) that really surprised me. It lists Laboratory employees who hold elective or appointive city, county, or state offices. All the way from Azzi (Chairman, Mayor's Committee on Bike Ways) to Zacchi (Anderson County Election Commission), there are 124 ORNL employees holding every imaginable office. The ORNL staff includes a member of the Campbell County School Board (R. Burns) and Loudon County Tax Equalization Board (A. J. Smith)—just to mention its more distant outreach. Anderson County and the cities of Oak Ridge, Clinton, and Kingston predominate in numbers of ORNL employees, but the Lab can also boast a Knox County squire (R. M. Hill) and officials in Blount County as well as in Lenoir City and Lake City; a Sevierville alderman (A. H. Marshall); and a member of the Sweetwater City Commission (W. J. Mayott). There are City Council members, justices of the peace, deputy sheriffs, Republican and Democratic party officials, and members of environmental conservation bodies, school boards, water boards, beer permit boards, planning or zoning commissions, appeal boards, and many others.

Laboratory involvement in the surrounding communities is not limited to appointed or elected officials. Many Oak Ridge-based organizations, all heavily laced with ORNL employees or their spouses, reach out into the counties around us. Oak Ridge provides unique sorts of humanitarian institutions that do not appear spontaneously in our region. Obviously, we have been doing something right. Consider, for example, the Daniel Arthur Rehabilitation Center: Of the 325 children it serves, only 50 come from the City. The rest come from as far as Morgan County (34 children) and even Monroe County (9 children). Similarly, the Regional Mental Health Center treats about 2700 cases a year, of which a quarter comes from the City. Oak Ridge serves the counties around us in other health-related ways through the Planned Parenthood Association of the Southern Mountains, the Oak Ridge Hospital, etc. Beyond that are the cultural activities—drama, arts, crafts, music, dance—all of which are available to our neighbors.

The people of ORNL can at last be said to be part of the fabric of the country around them. They do care, and their imprint on the area will be felt for generations.—A. Z.

State of the Laboratory - 1975

By HERMAN POSTMA

A TRADITION has slowly crept into the State of the Laboratory address—that being to characterize the year by a single theme or descriptive term. In the past we have heard of the "year of transition" several times, the "year of fulfillment," the "year of the environment," and others. Because of the great complexity of events this year, I feel that no one-word label seems adequate to convey either the primary events or the most significant accomplishments of 1975. There have been, of course, elements of all of those earlier themes, plus others that reflect the special circumstances of a year in which we began a new life under a new sponsoring agency and even found ourselves, very shortly after the year began, with a new official name. I thought of calling it the "year of the Holifield," but now that only final Congressional approval and the President's signature on the ERDA authorization act stand between us and having our name back, perhaps it would be most appropriate to call this the "year of the restoration."

In the past the Laboratory has gone through a number of distinctive stages of development that were concerned primarily with the technical progress and commercial maturation of nuclear technology. More recently, we have found the physical- and life-science disciplines concerned with the environment coming into play very strongly in our activities. And now, the activities are again expanding significantly. Under ERDA we may embrace virtually the full spectrum of energy technologies and the many related and supporting areas of research, development, and demonstration.

This year, many external events that have occurred have shaped the Laboratory. We welcomed the formation of the Energy Research and Development Administration, which came into being on January 19 this year under the Energy Reorganization Act. At the same time, a separate Nuclear Regulatory Commission assumed the functions of the AEC related to the licensing of nuclear power and fuel-cycle facilities. These developments have been matters of great significance for the Laboratory. They have, first and most obviously, recognized our mission as an ERDA lab to be truly a national *energy* laboratory rather than a national laboratory concerned primarily with a single energy technology.

Another impact of this transition has been the need for us to learn the methods and philosophies of the new leadership within ERDA and its new team of program administrators. Some of our familiar ways of business have been changed as we deal with programs and personnel that have come into ERDA from agencies other than the AEC. I think now that the major portion of these adjustments is behind us and that ERDA now has established a foundation of policy and program priorities that will permit it to move ahead impressively to achieve the important goals that led to its creation.

Several principles are new. We find that ERDA is a neutral agency; it is an advocate only for energy research, development, and demonstration and has not selected as the energy salvation any of the individual components of its expanded mission—fossil, nuclear, solar, geothermal, fusion, or conservation—all of which are treated as options to be developed.

Another feature equally important, I believe, both to us and to the concept of ERDA, is the emphasis ERDA is giving to rapid movement of the results of the research and development it supports into the commercial world.

ERDA, in its initial planning documents, has established a system of ranking all the energy technologies to reflect judgments about the time frame in which it is realistic to expect their contribution to increasing energy supply, reducing demand, or providing a supporting role. These priorities are backed with varying degrees of enthusiasm in the Congress, and many new programs in ERDA have mandates for an aggressive start. Therefore, the difficulties presented by the uncertainty about appropriations this year have been especially troublesome.

But these problems will soon be resolved. Not so easily resolved are the effects of a number of external events in the marketplace. For example, despite considerable private investment, there are no commercial fuel reprocessing plants in operation, leaving completion of the nuclear fuel cycle with an uncertain outlook that must await the resolution of political, technological, and regulatory questions.

Another uncertainty concerning the nuclear option is that Gulf and Shell, partners in General Atomic (the commercial firm responsible for the marketing of the High-Temperature Gas-Cooled Reactor), have retrenched and, at least for the present, have determined to suspend the sale of HTGRs, an area of technology in which the Laboratory is heavily involved. The utilities financing problems have greatly slowed the purchase of reactors, causing the antinuclear movement to announce a de facto moratorium, to rejoice in victory, and even to look elsewhere for other technologies to oppose. (For example, a geothermal project has been delayed for 3 years in California.) As these external events have been evolving—and I shall return later to indicate what the effects may be—many achievements of great importance have taken place at the Laboratory during the year 1975.

To describe the important achievements at the Laboratory this year, I will draw on the themes from the ERDA report, "Creating Energy Choices for the Future," the national plan for energy research, development, and demonstration activities which was issued in June. Conspicuously absent from the ERDA plan are basic physical, life, and social sciences that are crucial to solving the problems. In my presentation, I will show how these research areas are vitally interrelated to solving the problems and why that relationship is essential. Such relationship is the strength of the Laboratory and the essence of the solution, and we are urging that the next version of ERDA's plan recognize that importance.

In the short time available, it is necessary to limit the scope of coverage. Because of the excellent wide coverage given to reports, news releases, etc., I will only briefly cover well-known areas since our own people and *The Oak Ridger* have done such a fine job in getting recognition for

NATIONAL RANKING OF R, D & D TECHNOLOGIES	ORNL PROGRAMS	FY76 ($M)
NEAR TERM MAJOR ENERGY SYSTEMS		
COAL-DIRECT UTILIZATION IN UTILITY/INDUSTRY	FLUIDIZED BED SYSTEMS	1.8
NUCLEAR-CONVERTER REACTORS	LWR FUEL CYCLE, NUCLEAR SAFETY AND REGULATION, HTGR SUPPORT	27.5
OIL AND GAS-ENHANCED RECOVERY		
NEW SOURCES OF LIQUIDS AND GASES FOR THE MID TERM		
GASEOUS AND LIQUID FUELS FROM COAL	COAL CONVERSION SUPPORT	3.2
OIL SHALE		
"INEXHAUSTIBLE" SOURCES FOR THE LONG TERM		
BREEDER REACTORS	LMFBR AND GCFR SUPPORT MSBR,	22.5
FUSION	CONFINEMENT, LARGE MAGNETS, BEAMS,	28.9
SOLAR ELECTRIC	PHOTOVOLTAIC MATERIALS	0.3
NEAR TERM EFFICIENCY (CONSERVATION) TECHNOLOGIES		
CONSERVATION IN BUILDINGS & CONSUMER PRODUCTS	END USE CONSERVATION	0.8
INDUSTRY ENERGY EFFICIENCY		
TRANSPORTATION EFFICIENCY		
WASTE MATERIALS TO ENERGY	BIOCONVERSION	0.4
UNDER USED MID-TERM TECHNOLOGIES		
GEOTHERMAL	LOW TEMPERATURE CYCLES	0.8
SOLAR HEATING AND COOLING		
WASTE HEAT UTILIZATION		
TECHNOLOGIES SUPPORTING INTENSIVE ELECTRIFICATION		
ELECTRIC CONVERSION EFFICIENCY	K-VAPOR CYCLE	1.2
ELECTRIC POWER TRANSMISSION AND DISTRIBUTION	SUPERCONDUCTING TRANSMISSION	0.5
ELECTRIC TRANSPORT		
ENERGY STORAGE		
TECHNOLOGIES BEING EXPLORED FOR THE LONG TERM		
FUELS FROM BIOMASS	BIOCONVERSION TO FUELS	0.4
HYDROGEN IN ENERGY SYSTEMS		

Priorities listed in the ERDA report, "Creating Energy Choices for the Future," showing Laboratory involvement. Technologies for energy supply, demand, and related supporting areas are ranked according to the time scales in which they might be important.

our achievements. I also will omit many areas and ideas that have been proposed for funding, or are just under way, so that I can concentrate on those many new areas in which significant results are already coming in.

Within the framework provided by ERDA-48, my intent is to provide an overall perspective and somewhat uniform treatment, but I have chosen to emphasize particularly this year the new and nontraditional programs at the Laboratory—those about which you have heard little or nothing in the past because of their very recent establishment or because only during this past year have they attained significant results. In such an emphasis, I recognize that I will be short-changing important accomplishments in our traditional areas, particularly in nuclear technology, and therefore I do not reflect much of the essential flavor and special skills that the Laboratory has. But I hope this route can be justified this year by the already significant results of our new work and its importance to our expanded role under ERDA.

In the nontraditional areas, our technology and applied programs have been growing faster than the more fundamental and scientfic programs. By contrast, in the latter areas, we have not received much additional money, but we undertook a broad reprogramming of existing work to go into a number of new areas. In so doing, we have been able to contribute effectively within a very short period.

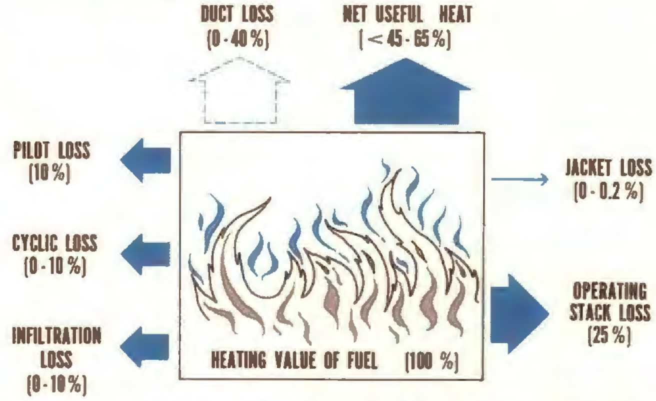
You should also note that I will couple the discussions of various energy technologies with the associated environmental questions. Energy and environment are intimately intertwined in practice, and it is, therefore, difficult to separate them. It is equally necessary for me to describe almost in the same breath the relationships of the technologies, the fundamental supporting sciences, and the environmental questions.

The Laboratory, in its planning, has chosen two major new areas for its significant comprehensive thrusts. These are end-use energy conservation and coal conversion technologies along with the associated physical, life, and social sciences. I will begin an examination of contributions and programs with a look at conservation.

Energy Conservation

At the Laboratory, our main contributions have been in end-use conservation practices and technologies, areas in which several significant events have occurred during the past year. One that has received considerable interest and attention is residential energy conservation. Here, the most important developments have been associated with a concept called the Annual Cycle Energy System, or ACES. This is new as a system, but one based on an idea originally proposed by Lord Kelvin more than 120 years ago. The ACES provides space heating, air conditioning, and domestic hot water for residences and small commercial buildings with the expenditure of less than half of the energy required by conventional all-electric systems. It has been developed by Harry Fischer, consultant; Gene Hise; John Moyers; and others in the residential conservation program in the Energy Division. The system uses a heat pump and an energy storage bin—in this case, a large insulated tank of water—to take advantage of the nearly equal balance between summer cooling and winter heating loads over much of the United States. It does so by extracting heat from the water in the winter, producing ice in the process, and then using that ice as a cooling system (without the operation of the heat-pump compressor) when it is needed for air conditioning in the summer. The system is presently being installed in a demonstration home at the Tennessee Energy Conservation in Housing project located on the UT farm between Knoxville and the airport. A much larger installation is

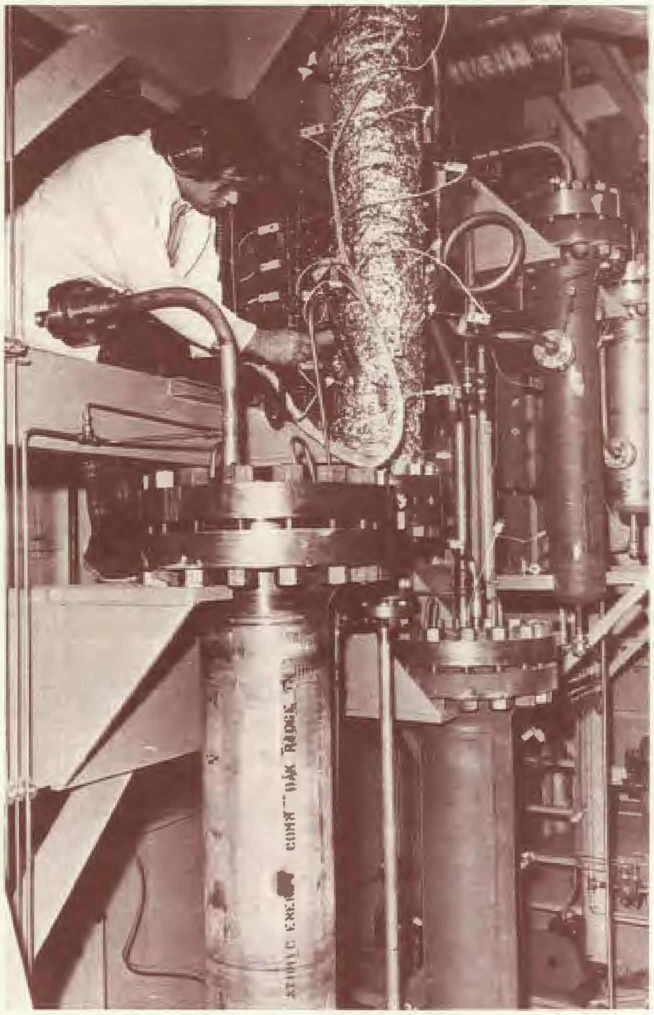
Significant improvements in the efficiency of gas furnaces can be made with fairly minor adjustments in their designs.



planned for a 60-bed nursing home to be constructed by the Veterans Administration in Wilmington, Delaware.

In addition to developing and demonstrating the concept, this group has also been working toward its commercialization—and an important step toward that goal was made with the announcement last month of one vendor's plans to market the system on a limited basis during the coming year. For the do-it-yourselfers, another firm has included some ACES components in the same catalog. Fischer and associates have worked directly with manufacturers to encourage introduction of a line of equipment to the marketplace, with consulting engineers and architects to show the advantages of the system and how it can be applied and with the housing financial community (mortgage bankers) to show that it has favorable life-cycle costs. This coupling of the technology development with the steps necessary to make it commercially available represents a direction in our work that promises to become increasingly significant under ERDA.

To be effective, conservation will result from the sum of many decisions and small improvements that take place. A realization that incremental small savings accumulate to produce rather large savings has caused the residential energy conservation group to examine conventional residential heating and cooling systems to determine what can be done to conserve energy with existing or newly designed equipment. Gene Hise, for example, has found that a 10% improvement in efficiency in gas furnaces in residences can be obtained by a simple adjustment in the cyclic operation of the fan. Another 15 to 20% improvement can result from redesigning new furnaces and replacing the pilot light with an



Hank Cochran is testing the experimental hydrocarbonization reactor for leaks with a high-frequency acoustic leak detector, which modulates the supersonic noise made by the leaks into audible range.

electric igniter. Significant further improvements can be made by eliminating leaks in duct work, etc., which indicates that rather large savings of that precious commodity, natural gas, can take place with relatively small changes or money.

Grimes Slaughter has found that reducing the thermostat setting of a standard electric water heater from 150 to 130°F reduces standby losses by 480 kWhr per year (or something like $10 presently in Oak Ridge) and that wrapping the heater with conventional insulation saves another 300 kWhr per year at that lower temperature.

Significant relationships result from the demand for electricity. Most of the existing studies of industrial electricity demand had found a relatively weak relationship between the consumption of electricity and the changes in the prices of suitable substitutes—natural gas and fuel oil. Gurmukh Gill, Charlie Chern, and others in the Energy Division have disaggregated the industrial data and have been able to identify strong relationships in many industries that are contrary to previous findings. Results show that if future prices of substitutes for electricity rise at a relatively high rate, the reduction in the growth rate of electrical demand because of increases in its own price will be significantly less. Such analyses are important inputs to policy to assure the desired result.

Fossil fuel

Aside from oil and gas exploration, the near-term technical portion of U.S. energy policy is concentrating on three essential components—conservation, coal, and nuclear energy. The first I have covered; so let's look next at coal and what is happening in areas involved with coal technology at the Laboratory.

During the past nine months, several programs initiated under the former Office of Coal Research in the Department of the Interior have already achieved important results and are growing rapidly. There is now a significant involvement of the Laboratory in these areas. By the end of this year, we anticipate that these programs could reach a level of between $6 and $8 million per year. Last year, by comparison, we started with a few hundred thousand dollars, and it is especially significant that this growing involvement is not only in the area of technology but also in the physical, life, and social sciences. It already involves a transfer to industry of what we discover and close work with the Energy Research Centers—our new sister fossil energy laboratories that transferred from the Department of the Interior's Bureau of Mines.

The Laboratory has pursued three goals in its fossil-fuels program. One is to improve the methods available for direct clean combustion of coal (which is, of course, the best way to use coal). The second is to convert coal, as the most abundant fossil-energy resource, into clean products as substitutes for the diminishing domestic supplies of oil and natural gas. And the third is to improve the electrical generating efficiency through use of a postassium vapor topping cycle.

The main hardware involvement of the Laboratory in the fossil-fuels area is now in the coal-conversion liquefaction processes. There are several candidate processes available and under development. The one we have chosen to look at is a pyrolysis process that is conducted at elevated hydrogen pressures in a fluidized bed of coal, which then reacts to produce hydrocarbon liquids; gases that contain methane, hydrogen, carbon oxides, and other light hydrocarbons; and a residual char. During the past year, Hank Cochran and others in the Chem Tech Division have designed, and the Lab support services have constructed in a very short time, the experimental hydrocarbonization reactor now in operation. Initially, the reactor will be fed pulverized coal at a rate of about 10 to 50 lb/hr and hydrogen at up to 70 std ft^3/min, which then will react at temperatures up to 1200°F and pressures up to 300 lb/in.^{2} It is planned to later modify the apparatus to involve pressures up to four times as high as this figure. The work will provide important performance data that are sorely lacking for optimizing the hydrocarbonization process. In addition, a novel reactor design may produce significantly higher yields of lighter hydrocarbon liquids at milder conditions than previously has been possible. This area is particularly important because the largest planned coal-conversion demonstration plant, the $237 million Coalcon facility to be build by 1980 in Southern Illinois, will employ the hydrocarbonization process. This is to be a joint industry-government venture involving coal companies and other private industrial firms and including Union Carbide as one of the partners. The data are urgently needed for design purposes, and we expect our data to have considerable influence on that design.

I turn to another area—"separations technology"—also concerned with coal liquefaction, in which there has been an especially significant happening. The liquids produced in most of the methods of coal liquefaction contain a variety of solids in sizes down to almost a colloidal dispersion, and these solids must be removed. Ordinarily, expensive diatomaceous earth materials have been used as a coating on which to adsorb the solids from the coal liquefaction process streams below 450°F. It has been discovered by Bill Rodgers and Sid Katz that finely ground coal (at $20/ton) can be used as a replacement for this diatomaceous earth (at $200/ton). In addition, when coal is used in this manner, it enhances the value of the collected solids by converting what was once a waste product into a feed material, which then is suitable as a gasifier to produce hydrogen or as a plant fuel. In addition, by using techniques common at ORNL, they have done a parametric study of pressurized precoat filtration and on important effects of the solvents used for particle settling and agglomeration. Being able to optimize this type of process, coupled with the use of a recyclable solvent, has produced substantial potential benefits. For example, the estimated savings for a 100,000-barrel-per-day coal liquefaction plant could be as much as $16 million per year, or 45¢ per barrel of filtrate. This represents a factor of 8000 return on the investment in the program to this point for that one plant. Consider further that by 1985 we may have several such plants in the United States. This technology is being transferred to industry as fast as possible, and in

Richard Forrester of the Chemical Technology Division examines a lump of coal for heat transfer properties, information that will assist the country's research into in situ coal gasification processes.

February a run is planned to test these findings in a large plant in Tacoma, Washington.

In addition, we have been asked by ERDA to undertake engineering evaluations of coal-conversion processes. Many of our engineers in this program have backgrounds in process design, and some of them in the petroleum refining industry. This experience is proving to be very useful in the evaluation of two processes for the ERDA Division of Demonstration Plants. Presently, Royse Salmon is directing the evaluation of the "Synthoil" process, a product of the Energy Research Center in Pittsburgh, and John Holmes is directing a similar evaluation of the hydrocarbonization process. This is a relatively small program at present, but will be growing strongly, for, in addition to the engineering evaluation, we will be monitoring architect-engineer support and evaluating process development—all related to the national commitment to produce the equivalent of one million barrels per day of synthetic crude oil from coal and oil shale by 1985.

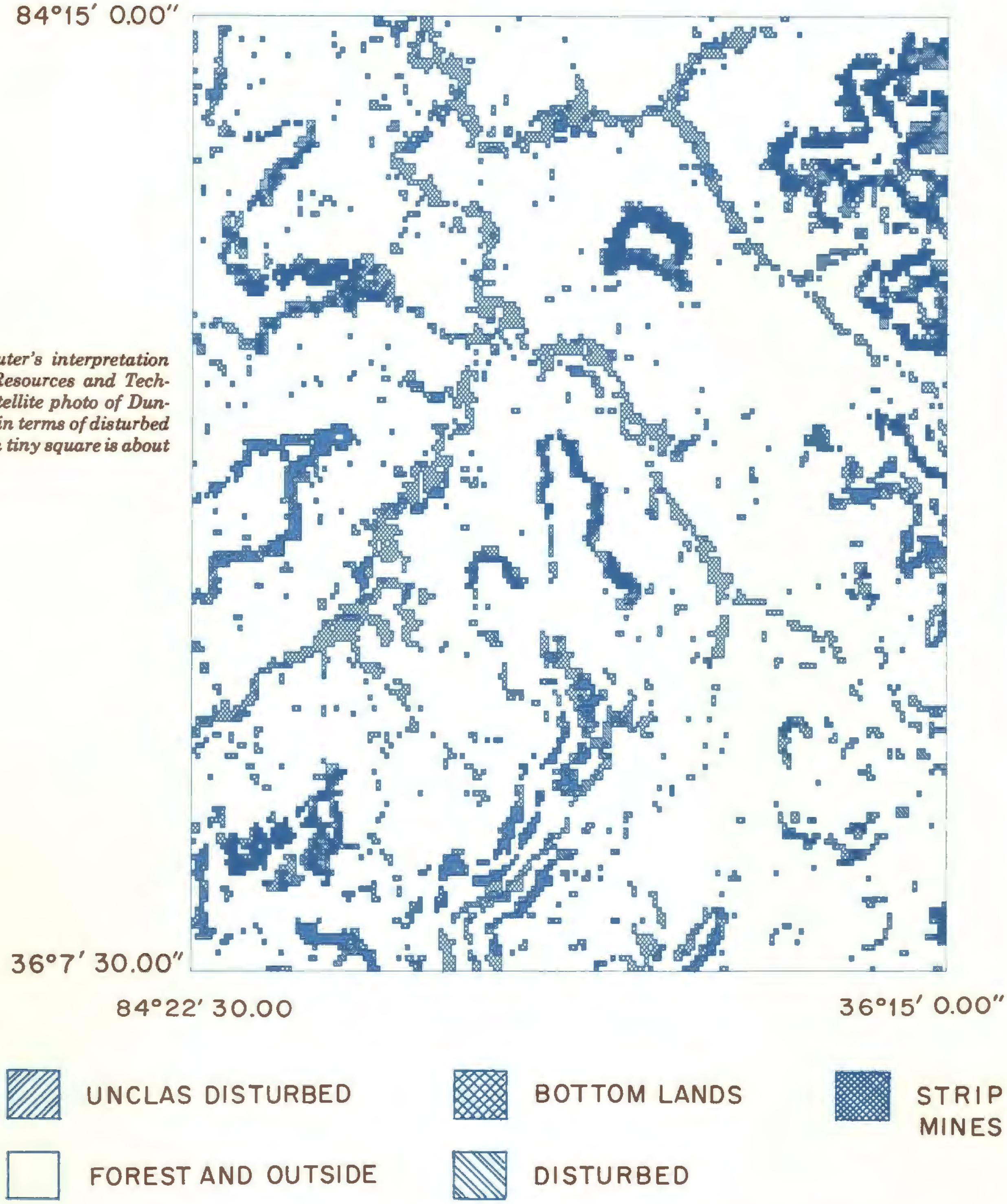
Just beginning are experiments with large blocks of coal for the purpose of in-situ gasification. These experiments study temperature profiles and the effect of moisture content (usually very high) on the rate of burning. Certainly if gasification of coal can be accomplished in place, costs can be reduced, and coal that would be difficult to mine can be put to use.

Much of our present work in coal has related to it a sophisticated supporting technology. In that area, too, we have made several interesting observations in the relatively short time that we have been looking at the chemistry of coal. Pete Smith and his colleagues in the Chemistry and M&C Divisions have been able to look at the physical structure of coal at the optical microscope level and, in the process, to develop an understanding of the chemistry and surface properties of coal hydrogenation catalysts. At 1000× magnification yellow material is seen. This derives from waxy matter in the original plant and is very reactive. Less reactive is a red material that derives from woody substances. The highly decayed black material is least reactive. Automating these processes will allow the petrographer to greatly speed up identification.

Using high-voltage electron microscopes, we have been able to discover something about coal that no one else has seen. We find a series of interconnected micropores approximately 500 Å in diameter. In each of these micropores are particles of an unidentified origin. Each of the particles is about 250 Å in diameter and gives the impression of a bug, dubbed by Pete Smith as a "coal bug," which has eaten its way into this golf-tee-shaped void and in the process has produced gas. An effort is now under way to identify these particles, which perhaps are catalysts, in order to discover whether nature has given us a better agent for gasifying coal than what we have been able to invent so far. This mystery, of course, will not be resolved simply, but through this work we expect to develop a more basic understanding of the structure of coal and of the nature of catalysts in coal.

The conversion of coal into clean products is an urgent national objective; but coal becomes a potentially hazardous substance when it is converted. Also, the ability to extract and transport coal, to build plants, to convert the coal into liquids, and to control emissions will represent at each step an important technological feat with significant environmental, public health, and social and economic impacts. Traditionally, the examination of such problems as related to the technology has been an essential part in the comprehensive development of ORNL programs, and coal is no exception.

The golf-tee-shaped voids in this micrograph of coal contain particles, dubbed "coal bugs," that appear to have eaten their way into the surface, creating a gas.

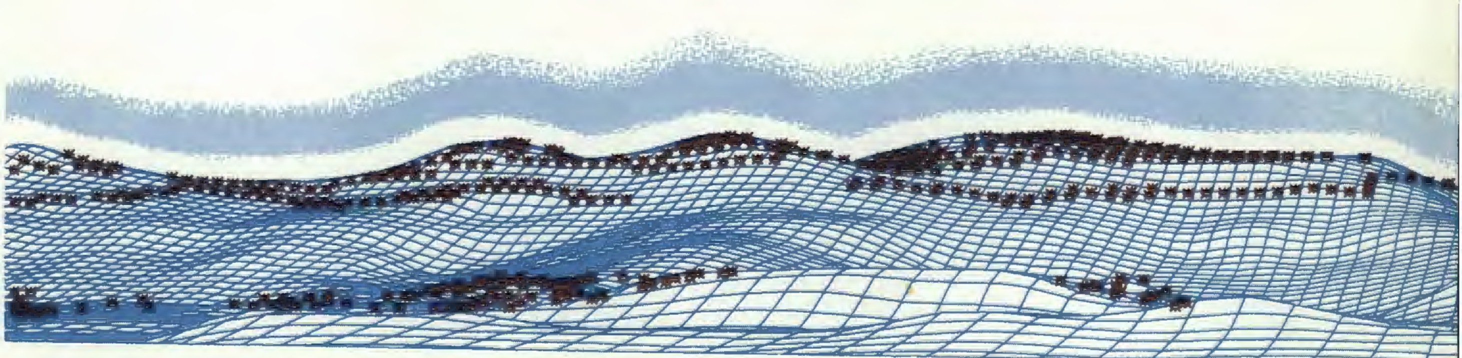


The computer's interpretation of Earth Resources and Technology Satellite photo of Duncan Flats, in terms of disturbed areas; each tiny square is about an acre.

As one significant example (and one close to home), we have been looking at the environmental effects of coal strip mining, with a concentration on the Appalachian region. These efforts under the direction of Bob Honea and Dick Durfee have concentrated on a small study area in the New River Basin in the Cumberland Mountains north of Oak Ridge. A major accomplishment by the Computer Sciences Division personnel has been the development of a technique that converts satellite data to a user-oriented classification of land cover—for example, hardwood forest, disturbed areas (strip mines), and open fields. The data transmitted by the satellite consists of light-reflectance values for each resolution element. Using techniques of factor and cluster analysis, these values are translated into specific land cover types, which can be verified through comparison with aerial photographs. By computer manipulation, it has been possible to identify those land areas that are greatly disturbed, the impact on the watershed and water quality, and the aesthetic impact. This method, of course, can be used for environmental assessments in a number of other areas as well (i.e., oil shale). It also permits assessments of changes every 18 days, the interval of the satellite's orbit. Manipulation of computer data is, of course, something that is a natural for the Laboratory to do. As these techniques are developed and validated for surface mining impacts, we are creating a handy method to permit the decision makers to assess readily what the impacts can be and how to minimize them.

The discussion so far of our new work with coal reflects not only the fact that the technological problems are difficult but also that, as the greater dependence on coal as an energy source evolves, substantial efforts in the understanding and control of related biomedical and environmental effects must occur. This past year has seen a concerted effort in organizing and developing an interdisciplinary effort in the life-science disciplines related to coal conversion. Eight divisions—Analytical Chemistry, Biology, Energy, Chem Tech, Health, Information, Health Physics, and Environmental Sciences—as well as a number of individuals from elsewhere in the Laboratory are involved. A large-scale effort must be expended in the area of biomedical and environmental research to ensure that coal conversion will be an acceptably safe technology. Potentially hazardous constituents in effluent and product streams will need to be identified and characterized, and methods for monitoring must be developed. Additional information on the carcinogenic, mutagenic, teratogenic, and toxic properties, as well as their potential environmental impact, are needed.

In a similar vein, Jim Epler of Biology and Mike Guerin of Analytical Chemistry have worked with the Pittsburgh Energy Research Center in obtaining synthetic crude oil for the identification, separation, and testing of biological effects in a program now under way. An excellent program has been developed this year, and some funding has already appeared. As one example, the polynuclear aromatic hydrocarbons in coal-conversion processes are a serious and well-known concern, but little is known about their fate in the environment. These compounds have been identified, and Sam Herbes in Environmental Sciences has been able to use yeast cells tagged with carbon-14 to simulate suspended organic materials in natural waters. The results are of value in two areas. First, they reveal the availability of this adsorbed material to aquatic organisms feeding on particulate matter and consequently encountering far higher concentrations than in the water itself. Secondly,



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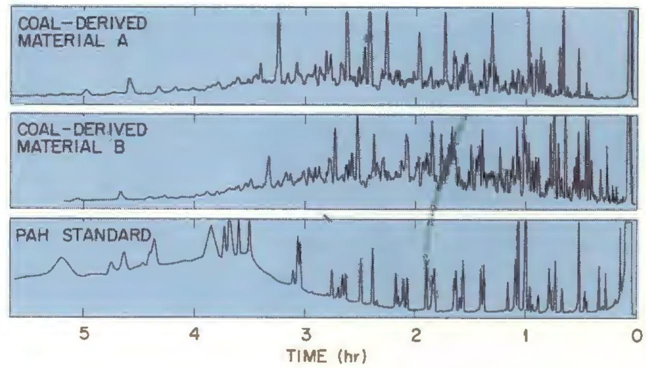
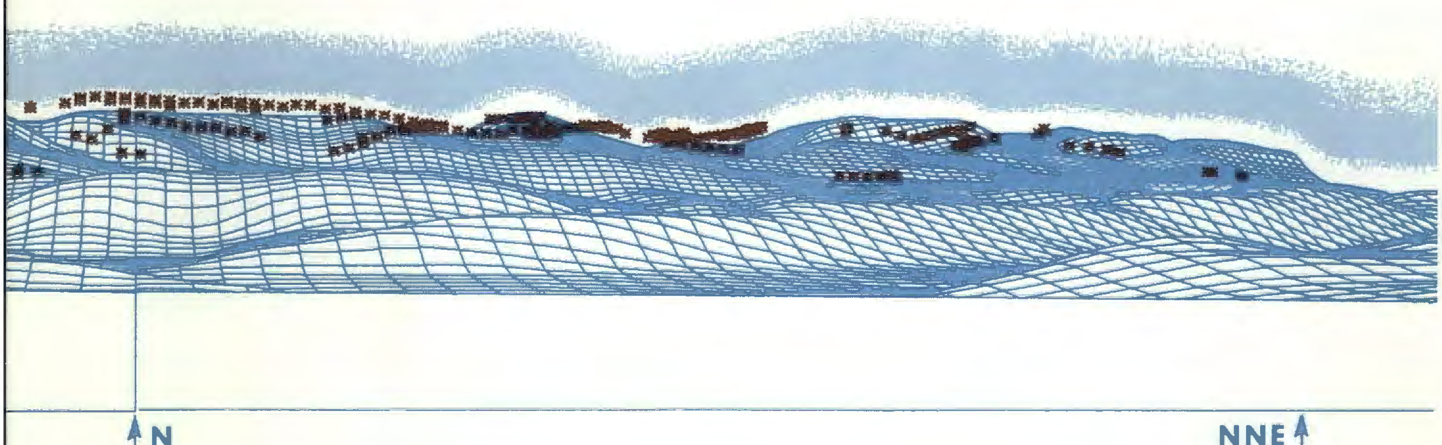
his finding of the high affinity of anthracene to the particulate organics suggests the possibility of its potential use in removal of the polynuclear aromatic hydrocarbons.

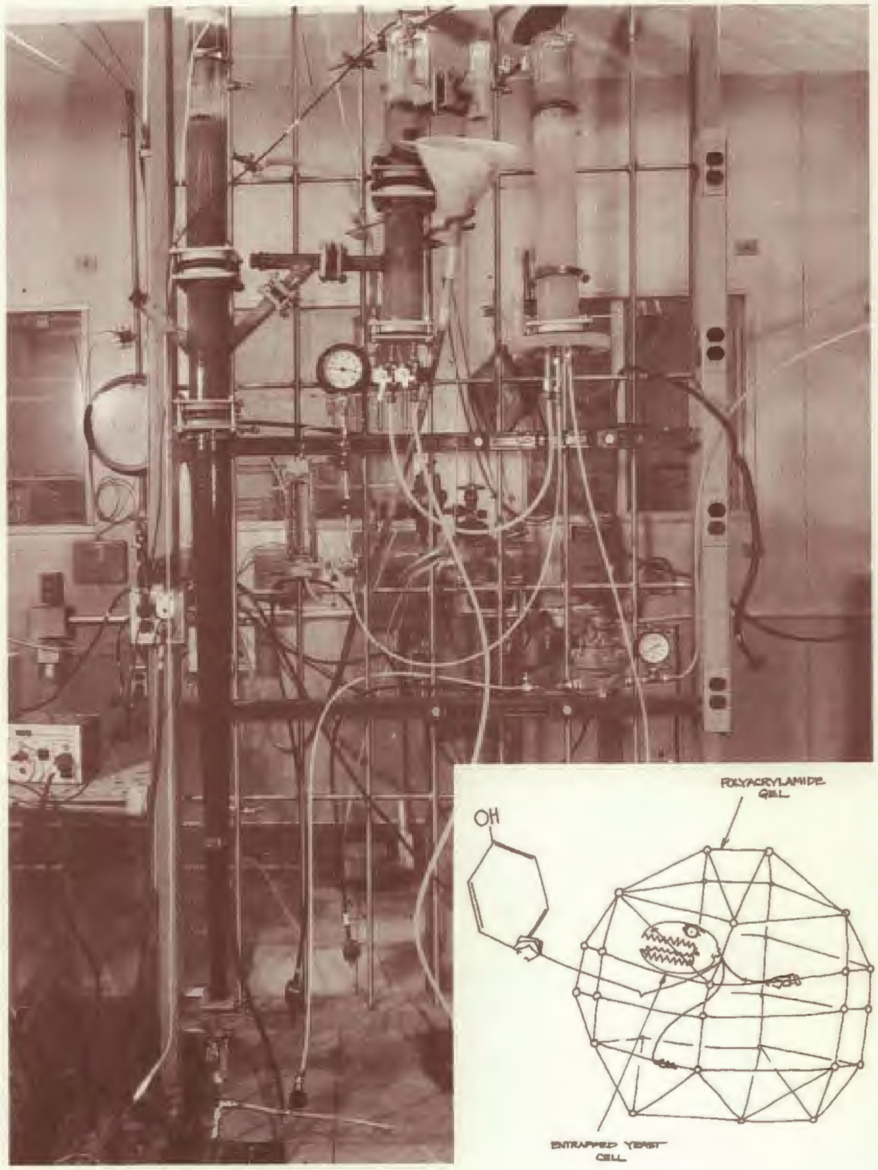
Chuck Scott, in his usual manner, has been working on this problem from a different point of view. In the past, most fermentation biological processes that utilize microorganisms in large tanks or ponds have had to use a significant amount of what is called "biomass." These activated sludge systems are essentially one-stage contactors that require residence times of many hours or days. (Bread takes only a few hours.) Recently, modern techniques in process development have begun to be applied to several potential bioprocess steps. For example, a tapered fluidized-bed reactor is now being used for the reduction of phenolic compounds in the aqueous waste streams of coal-conversion processes in the Chem Tech Division. In that system, Scott, Hancher, and Holliday have found that a fluidized bed of coal particles with adhering bacteria has been able to reduce phenol and related toxic and carcinogenic substances in various waste streams from 800 ppm to less than 25 ppb in less than one hour. These removal rates are 10 times as great as those that have been achieved in industrial activated sludge ponds. A small pilot plant is planned as part of our experimental hydrocarbonization development facility mentioned earlier for the treatment of that waste—not only allowing us to return a clean product to our waste streams at the Laboratory, but also developing a major step toward the ability to clean up commercial process streams. The accompanying photograph shows an engineering-scale, tapered fluidized bed of this type. On a commercial scale this will still be a modestly sized unit with significant cost savings.



Polynuclear aromatic hydrocarbons (PAH) from coal liquefaction products as visualized by gas chromatography. They can then be identified by mass spectrometry.

The computer-drawn view of the Cumberlands from the intersection of West Outer Drive and Morningside Drive. It is a panorama first projected on a cylinder, then opened out flat. Due north lies the valley of Poplar Creek coming around Walden Ridge (on the right), then Sassafras Mountain. Pilot Mountain lies on the ridge halfway between N and NNE, while Windrock Mountain is just to the west of N. This projection and drawing, plotted from data provided by the U.S. Defense Mapping Agency and Earth Resources Technology Satellite imagery as interpreted by R. B. Honea, was programmed for the Cal-Comp by Tom Tucker. The Xs represent stripmine locations.





The tapered column is a fluidized-bed reactor containing coal particles with bacteria on them that effectively reduce phenolic compounds from coal conversion waste streams in relatively short lengths of time.

Earlier, I mentioned that one of the best ways to utilize coal is to burn it directly. However, because of increasingly restrictive air quality standards for gaseous emissions, direct combustion is no longer possible in many areas. Therefore, one has the option of either cleaning up the coal during the process of burning or finally at some point as the gas moves up the stacks. One of the best ways of treating coal, we believe, is to burn it in a fluidized bed of limestone in which most of the sulfur and other pollutants are removed in the course of burning. Art Fraas is developing, and soon will be building, such a system with support from the Department of Housing and Urban Development and ERDA. A fairly detailed conceptual design has been prepared for a 6-ft-square, fluidized-bed coal combustion chamber coupled to a closed-cycle gas turbine, which will produce about 400 kW of electricity plus 600 kW of heat that can be used for building heating and domestic hot water. A fluidized-bed combustor of this type has potentially the greatest importance. The principal special problems involved have been attacked both experimentally and analytically, including the bed startup, flow, and pulsation characteristics.

We have also established a tie with The University of Tennessee in this program because of their desire to educate and train engineers in the area of clean combustion of coal. Perhaps in the future we will also be involved in a demonstration project with the Tennessee Valley Authority.

Art Fraas' other special favorite—the potassium vapor topping cycle—has just received new funding and should be moving along smoothly. Because it has been described thoroughly in past addresses, I will omit further discussion.

Solar and Geothermal Energy

Unlike conservation and coal conversion where we hope to play major and comprehensive roles, we anticipate a smaller base in solar and geothermal energy, where we tend primarily to play a supporting rather than a major programmatic role. It is not that we do not envision, in the long run, a great amount of activity or large involvement in either of these areas; indeed, we will supply various types of expertise in support of these programs wherever it is needed, but on a smaller scale.

In geothermal study, for example, we are able to contribute in the areas of scaling and corrosion due to our long-term expertise in the chemistry of brines. That type of work has evolved this year along with studies, under the Cold Vapor Program headed by Dick Lyon, of low-temperature conversion cycles. Here the emphasis is on the use of different heat-transfer fluids and heat-exchanger tubing configurations to achieve greater efficiency in the heat-transfer process from low-temperature resources. These measurements obviously have application at the low temperatures at which both solar and geothermal systems as well as ocean thermal gradients would be operating; they also apply to reject heat from most generating plants. The basic problem is the expense of the large heat-exchange equipment required. We have much to offer in solving that problem.

In the area of solar energy, it appears that few of the national laboratories will play a major role. There are several reasons for this, one certainly being the apprehension of some folks about giving any money to the "nuclear laboratories" for solar energy because of the fear that we cannot be objective. In addition, the ERDA solar energy group is waiting for final recommendations and decisions concerning the philosophy, location, and operating arrangements for the Solar Energy Research Institute—a new institute dedicated solely to solar energy and likely to be the largest recipient for solar research funds.

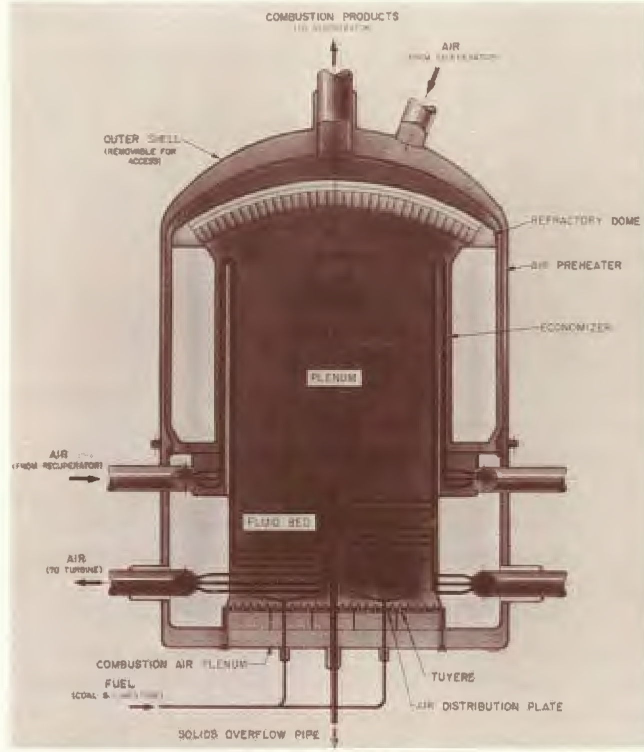
Nonetheless, during this past year we have appointed Bob Pearlstein as the Laboratory's solar energy coordinator. We have also just received support for a solar energy project in which we will assist ERDA in setting targets and evaluating solar energy systems.

One illustration of the Laboratory's ability to innovate in solar development, however, comes from the Solid State Division where, under our seed money program, there has been some effort in the doping of the semiconductor silicon used in photovoltaic solar cells. These cells require an electrical junction between crystal regions containing p-type (acceptor) and n-type (donor) chemical impurities. There is no known method of crystal growth that provides a uniform distribution of any chemical impurity dopant in semiconducting materials. However, the technique of nuclear transmutation of silicon-30 to stable phosphorus-31 by insertion of the material into a reactor has been used to introduce a uniform concentration of phosphorus, a standard n-type dopant, into large ingots of silicon. The performance of thyristors made from such materials has been significantly improved. Similar improvements may be attainable in the efficiency of silicon solar cells. J. W. Cleland and R. D. Westbrook have irradiated wafers and ingot sections of silicon in various reactor locales and have found that anticipated difficulties could be resolved. As a result, some of this nuclear-doped silicon is now being fabricated in other laboratories into photovoltaic devices for evaluation. The fearsome "nuclear laboratories" may still be able to help.

Fusion

Let me turn now to somewhat more familiar areas of research. We find that one of the biggest booms taking place at the Laboratory is the area of controlled thermonuclear research. The program has grown in the last few years from an annual budget of $7 to approximately $20 million, and we find Oak Ridge plays a leading role in the most important areas of the national program. For example, during the past year there has been considerable advancement in the physics and technology of the most promising method of confining and heating magnetically confined

On the left is a section cut through the furnace assembly of a fluidized-bed coal burner, showing the mixture of fuel and limestone enclosing the airflow tubes. On the right is the closed-cycle gas turbine that it will use, and inset is a 4-ft-square model used in cold flow tests.



plasmas—the neutral beam injection approach pioneered in Oak Ridge. Through detailed theoretical plasma physics investigations and experiments with the ORMAK device, a much better understanding of neutral injection technology has been achieved. In the last few weeks, temperatures in ORMAK have doubled to almost 10 million degrees through neutral injection heating. It is a significant step on the way toward the temperatures of 100 million degrees or so that will be needed for the thermonuclear break-even experiment. Under the leadership of Bill Morgan, Larry Stewart, and their associates, Oak Ridge has played a major role in the development of neutral beam technology, and the other laboratories involved in the fusion program are using the beams being developed here. Large beams are now available at a quarter of a megawatt each, and next year we will supply 1-MW models for use on the Princeton experiments.

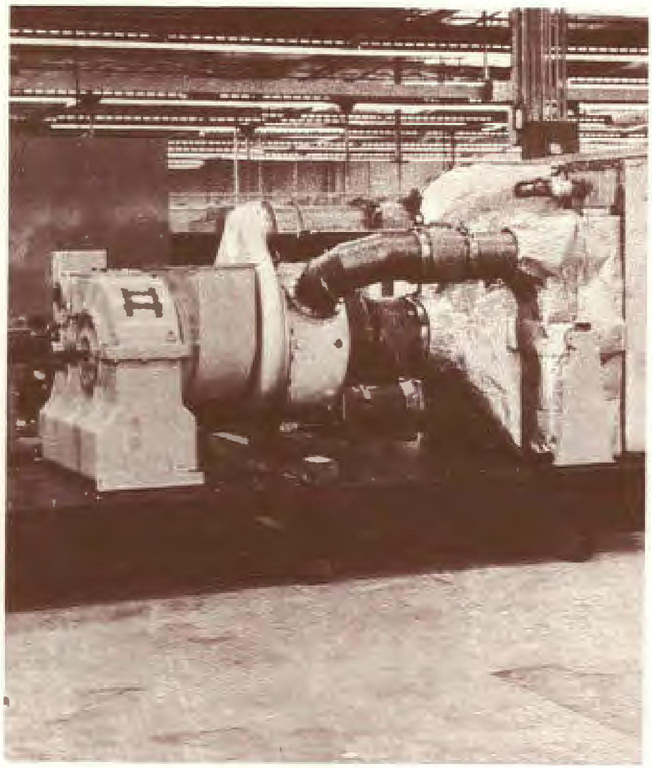
It is tentatively planned that when this current work on ORMAK ends, in about a year, it will be replaced with a new device having twice the present plasma current and eight times the present injection power. This facility will be called ORMAK Upgrade and will be operational in about two years. It will be the first facility for neutral injection heated plasma experiments designed on the basis of actual operating experience. In the meantime, the $2.5 million Impurities Study Experiment is now under construction with completion expected in early 1977.

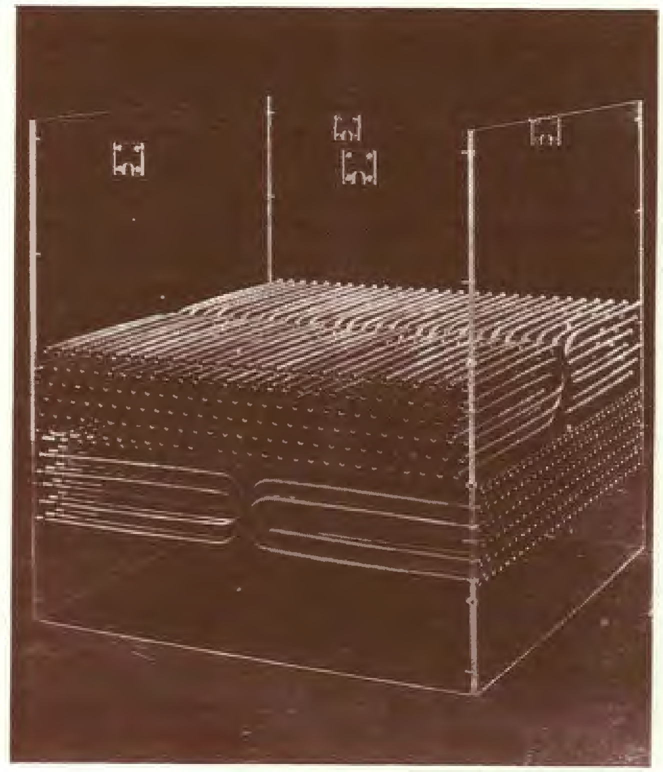
In addition, Oak Ridge is playing the leading role in the development of immense superconducting magnets. As this program evolves, we will be reporting to you about the large magnets that will be necessary for the next generation of thermonuclear devices.

One awesome problem for future thermonuclear devices is the first wall of the reactor, which undergoes severe neutron bombardment. One of the greatest concerns has been that this wall would last only a short time and that there were inadequate ways to determine what this lifetime might be. However, during the past year, Everett Bloom, Bill Wiffen, and P. J. Maziasz of the Metals and Ceramics Division have undertaken radiation experiments on the type 316 stainless steel under conditions that simulate the first wall of the fusion reactor and have obtained very encouraging results. Samples were irradiated to simulate six years' operation at a normal thermonuclear reactor radiation level. They found very low swelling and higher-than-expected ductility. These good results, combined with the metallurgical advantages of conventional stainless steel, mean that type 316 stainless steel is the structural material tentatively selected as the first-wall material for small power-producing thermonuclear devices. In addition, simulation via this route seems to be good enough to permit materials development to be carried forward before 14-MeV(d,t) neutron generators capable of producing thermonuclear energy neutrons become available.

Fission Reactor Development

The research and development efforts in our fission program in the past year have resulted in extremely important results, but I will spend only a brief time on them because of my decision to focus particularly on the work of a nonnuclear, nontraditional nature. Perhaps the biggest

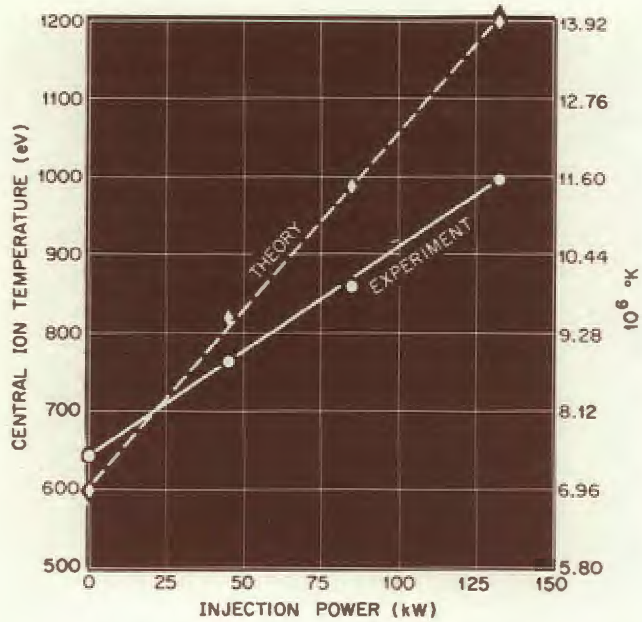




nontechnical event that has occurred this year is that there is great uncertainty with respect to the future of most programs on gas-cooled reactors. Presently, ORNL has $16 million in this area, prompted primarily by the large number of sales of High-Temperature Gas-Cooled Reactors by General Atomic over the last three years. Most recently, however, cancellation of these contracts has eliminated sales of this reactor type, and the operation of the chief prototype HTGR, the Fort St. Vrain plant in Colorado, has been long delayed by startup problems and additional regulatory requirements. General Atomic and its parent companies, Shell and Gulf, are now reassessing their ability to continue this program, and they have requested that ERDA undertake heavy commitments to fill the gap until they are again in a position to enter the marketplace. Thus, the future of gas-cooled reactors will depend upon the directions and decisions that industry itself makes, together with whatever stance ERDA takes in response to the anticipated industry action. As you are all aware, these events will have important consequences for Laboratory programs. Program participation could increase, or it could be cut off entirely if industry and ERDA are not prepared to continue. One of the major consequences this year has been that the HTGR fuel recycle program, about which we spoke last year, has already been reoriented toward the objective of providing an ERDA-funded, but delayed, HTGR fuel-recycle demonstration plant.

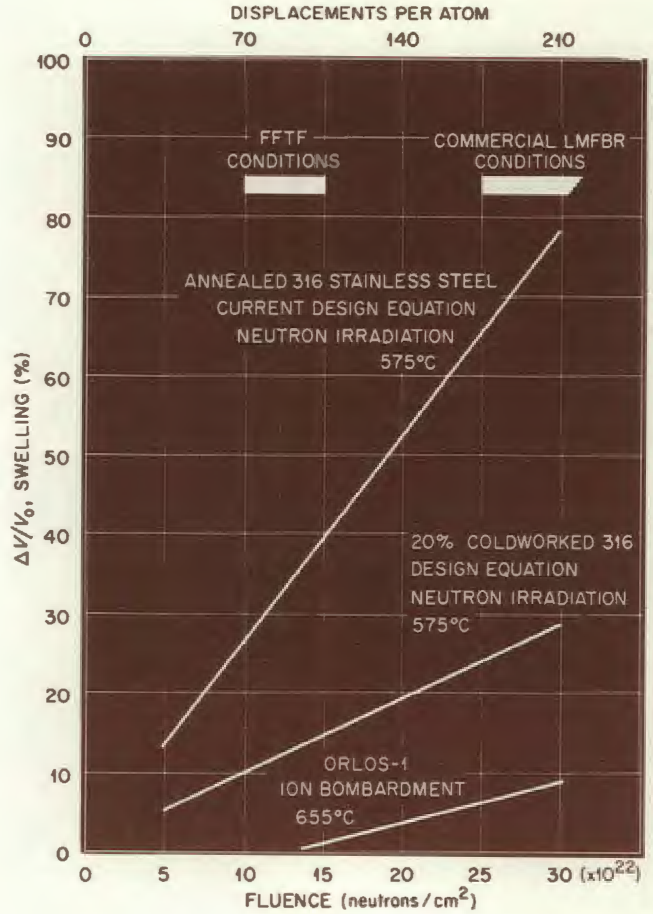
One of the technical highlights of the past year in the HTGR program was the encouraging results from the development of a process that in the reprocessing of the fuel would absorb one of the radioactive gases. This is the KALC process, an acronym standing for krypton absorption in liquid carbon dioxide. This past summer, concentration factors greater than 1000 and decontamination factors greater than 100 were obtained in an experimental verification of the KALC process in a pilot plant stage at K-25. This work has been carried on by A. B. Meservey and Karl Notz of Chem Tech Division and at K-25 by Mike Stephenson.

Another important finding this year has been the discovery of the cause and effective prevention of cracking in molten salt reactor materials. As you will recall, when the molten salt reactor was shut down the Hastelloy N material, which is the chief construction material within the reactor, was found to have suffered cracking within the grain boundaries due to the concentration of the fission product tellurium. The observed concentration is sufficient to account for



Ion heating with neutral beam injection. Reasonable agreement is obtained between theory and experiment within the uncertainties introduced by incomplete information on plasma parameters.

This graph shows the improved performance of the new, low-swelling stainless steel developed through the cooperation of Metals and Ceramics, Solid State, and Physics Divisions this year.



the embrittlement that was found, and modifications have taken place which indicate that additions of niobium are very effective in reducing the extent of intergranular cracking. Perhaps soon the new material will be qualified for reactor use.

The Laboratory is becoming increasingly involved in the LMFBR program. This issue and the last (Fall 1975) issue of the *Review* detail much of that involvement. This is reflected not only in our diversity of experiments and programs and in a growing association with the Clinch River Breeder Reactor demonstration plant itself, but also in our role as the lead laboratory for the development of reprocessing techniques for LMFBR fuel.

Perhaps one of the most important contributions made during the past year (one of our advisors said "perhaps the most important development at ORNL in 10 years") has been the development of a low-swelling alloy for breeder applications. Last year, I gave a preliminary report of the discovery of a class of stainless steels that would have low-swelling characteristics under the fast-neutron bombardment characteristic of LMFBR cores. This quality has been found through ion bombardment over a wide range of radiation temperatures and at exposures likely to be those of a commercial LMFBR. The additions of silicon and titanium were shown to be responsible for the good swelling resistance. The composition of the initial low-swelling alloys is in the range in which precipitation can be induced. Small changes in chromium and nickel contents were shown to promote stability. A new alloy has shown equally low swelling behavior and excellent phase stability. In addition, mechanical properties are equal to those of the best heats of 316 stainless steel, and the low-swelling formula appears to hold for a wide range of compositions of iron-chromium-nickel alloys. This development now can proceed within this range to produce alloys optimized for swelling, strength, ductility, corrosion resistance (including fission product this new addition looks promising enough to be considered for one of the later cores of the Clinch River reactor. As you will recall, because of the characteristics of this low-swelling alloy, it is estimated that for 200 fully developed LMFBR reactors this achievement alone could produce a benefit, discounted to its present worth, of $20 billion. Thus, the program arising from the interaction of M&C, Physics, and Solid State Divisions of the Laboratory and involving both basic and applied constituents, has saved enough money in less than a year to pay for the entire ERDA physical research program (exclusive of high-energy physics) for the next 50 years.

As you may remember from the newspapers earlier this year, several of the boiling-water reactors made by General Electric were experiencing trouble due to vibrations within the core and fuel elements that were eroding away cladding in some areas. To ascertain the degree to which these reactors could be run, an assessment needed to be made. An extremely quick response of the I&C Division—particularly Bert Ackermann, Dwayne Fry, and Bob Kryter, who went on a whirlwind tour of the affected reactors—was made to determine the power levels at which these reactors could operate safely. It was found, using processes developed by I&C, that these reactors could continue at certain levels of operation. Savings from this work alone were millions of dollars per day in generating costs, showing again that the Laboratory can indeed respond quickly to real-life situations and that money saved in such programs repays the initial investment many times over. I omit many significant safety program results that have appeared this year.

Perhaps one of the most important events to occur in the nuclear area was not technical but administrative, involving the establishment of the new Division of Nuclear Fuel Cycle and Production within ERDA. This division has responsibility for assuring the supply of nuclear fuel, closing the fuel cycle, and transporting and disposing of the wastes generated by power reactors. Because of technical as well as regulatory problems, nuclear fuel reprocessing plants are not being operated. Thus, the ability of the industry to close the fuel cycle, that is, to take fuel out of the reactor, reprocess it, and refabricate it (after separating out the waste) to fuel forms useful in other reactors, was not being taken care of. The recognition by ERDA of industry's plight and the reinsertion of ERDA into a role in which it will attempt to solve problems that have arisen will have important bearings on ORNL and on the Nuclear Division here in Oak Ridge.

Basic Research

Throughout this talk, I have tried to weave the concerns, the planning, and the results, where appropriate, of the physical and life sciences efforts at the Laboratory as they relate to specific technologies. It is the particular strength of the Laboratory, I believe, that we can bring together those things that Washington has been dividing among agencies and within agencies in ways that are useful for budget reasons but that are not always conducive to solving a broad problem. The Lab puts these diverse elements together as comprehensive tasks, which, if fragmented, would never achieve results. I have tried to indicate these as we have gone along—in fossil energy, fission, and fusion. However, there are a number of things that have happened during this past year that stand out not because of their present contribution to any technology, but because of their intrinsic value or future importance. I would like to talk a few minutes about those basic research areas that have produced important results.

Many of you may not know that ORNL runs a satellite laboratory in Rockville, Maryland, under the direction of John Gerin. Its main supporter is the National Institute for Allergy and Infectious Diseases. During this past year, John and his coworkers have created a vaccine for hepatitis-B. The vaccine is now ready for human testing. They have isolated viral antigens from human carriers of hepatitis and used them to prepare a vaccine that has proved successful in chimpanzees. Hepatitis-B is a debilitating disease characterized by the inflammation of the liver, fever, weakness, loss of appetite, muscle pain, etc. It is most frequently transmitted by the infusion of blood from the infected individuals and also by intimate association with infected individuals. It is considered the most dangerous form of hepatitis because many of those exposed to it are already ill; about 7500 cases are reported each year. John has purified the antigen by centrifugation and has injected the vaccine in six chimpanzees. These animals have been shown to be resistant; none of them developed hepatitis, whereas animals in the control group did. The next step is to get Food and Drug Administration approval for limited testing with humans. This process will take about five years, and once this vaccine is found safe and effective, it will find many uses, particularly for those individuals who process blood or work in blood banks and hospitals and for doctors as well.

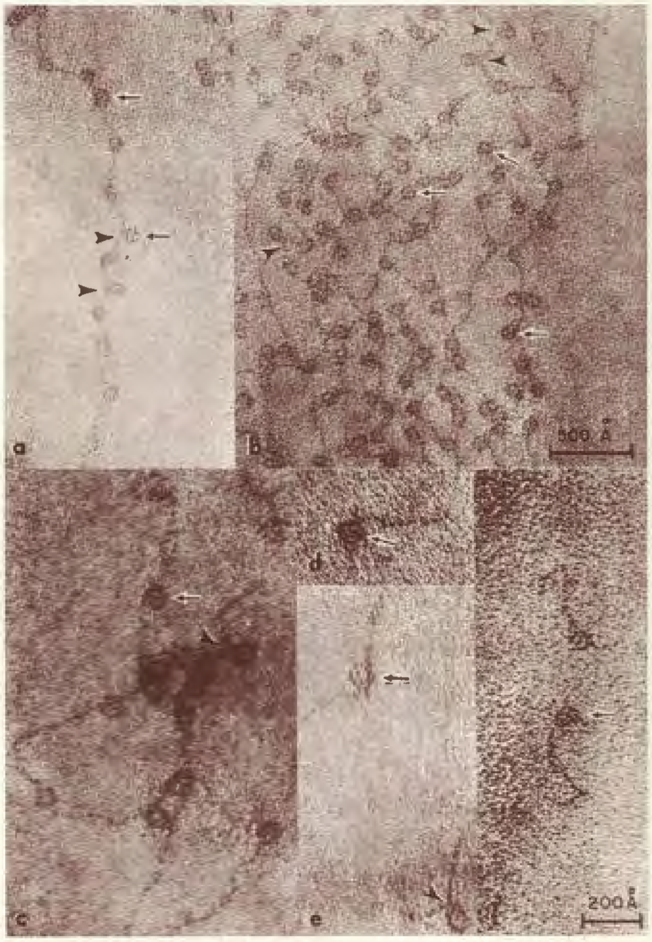
Since May of this year, there have been four editorial articles on chromatin structure in *Nature*, *Science*, and *New Scientist* referring to the pioneering and excellent work of a husband and wife team in the Biology Division, Don and Ada Olins. A little over a year ago, they published the first electron micrographs showing the "string of beads" structure of chromatin. Since then, they and others have obtained much valuable information about "DNA folding" within the nucleosome. Many researchers have adapted the string-of-beads model in preference to the supercoil model. A study of this particular structure and how it interacts within cellular machinery is important because they believe that some aspects of the structure of composition of chromatin (i.e., of DNA and its associated proteins) affects the expression of genes in cells of higher organisms. Nobel Prize winner Francis Crick states that the most cogent models for chromatin are based upon the original observations that the Olinses made last year, together with more recent evidence from them and other workers in the field.

An important discovery, which I described in a preliminary way last year, has reached fruition. A new type of molecule spectroscopy has been developed by Sam Hurst and Gay Payne of the Health Physics Division. This new method, called resonance ionization spectroscopy, allows the determination of the absolute numbers of an extremely small concentration of gaseous and atomic species in ground or excited states. The principle is the selective ionization of a given species through stepwise photon absorption with the use of the laser.

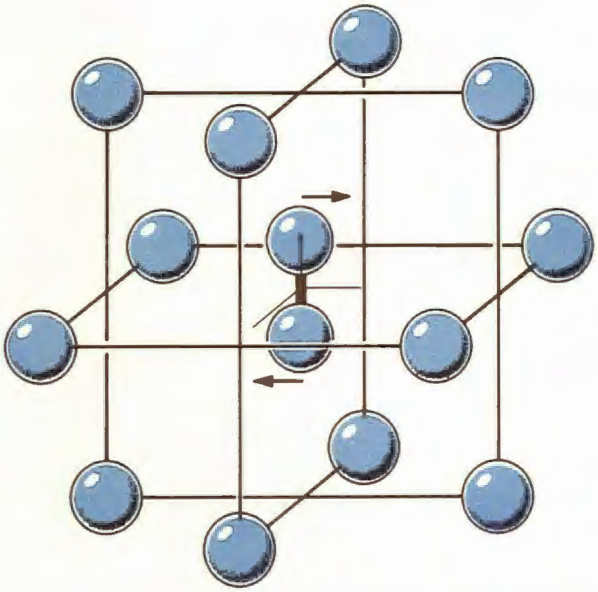
The experiment described as "quick draw" was demonstrated by Sam Hurst and his coworkers using the 1 J/pulse tunable dye laser. They have been able to detect as few as 10 metal atoms residing in the intersecting laser beams. This may be one of the most important experiments that has come out of the Laboratory in many years because of its implications for detection of very low concentrations of material.

In a presentation before Robert Seamans by the materials group in Washington, the three best fundamental discoveries in ERDA-sponsored materials science research made within the United States during this past year were described. Two of

The beads in these electron micrographs are DNA, complexed with histones, a special group of proteins called chromatin. The clusters are strung out at regular intervals and are believed to be a way of condensing or packaging the DNA.



those occurred at ORNL, and I have mentioned one of them already—the low-swelling alloy development. The second was the understanding of the dynamics of the lattice of interstitials in copper. It is well established that the irradiation of crystals at low temperatures produced vacancies in the crystals as well as interstitials. However, the basic questions concerning the stable structure of configurations and the location of some of these extra atoms remain. One important conclusion of recent theoretical work was the prediction that in certain kinds of interstitials there existed a stable structure in copper and that it possessed a certain low-frequency vibrational mode predicted by members of the Solid State Division. Dick Wood



This schematic drawing of the self-interstitial in copper shows the nature of the internal, low-frequency, vibrational mode, which was first predicted, then discovered by ORNL physicists.

and Mark Mostoller have shown that these modes can undergo strong resonance hybridization at very low concentrations. To seek this out experimentally, Robert Nicklow did neutron scattering experiments at the HFIR to search for these particular modes. The copper crystal was irradiated at very low temperatures, and Nicklow was able to detect very small perturbations (a factor of two better than previously done in neutron scattering experiments). The results show quite clearly that perturbations exist even though the results are more complicated than expected. It is clear, however, that this direct observation of a resonance mode will provide valuable information about the structure within crystal lattices.

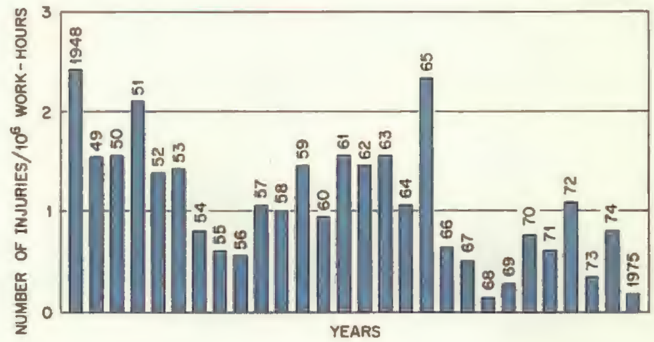
Other basic research areas at the Laboratory are concerned with the social impact of what we do. Two quite different research studies have been under way this year to seek answers to very perplexing problems of the social costs and benefits raised by the siting of large energy facilities. Because all the cheap ways to produce energy have disappeared, we are faced in the future with the construction of very large, capital-intensive projects for energy generation or conversion. Each one of these facilities involves hundreds of millions and even up to billions of dollars in capital costs and, therefore, uses rather large construction forces with the consequence of serious impacts upon nearby communities.

The first study undertaken this year by Elizabeth Peele and associates was a social impact assessment of what happened in two New England communities—Plymouth, Massachusetts and Waterford, Connecticut—where nuclear power reactors are located. In these particular cases, because of the proximity of an ample, skilled labor force, there are few construction period impacts. They found, however, that the augmentation of a tax base offered new options for the local decision makers by changing the relative cost of private and public sector services and that this altered the relationships of those communities with the neighboring towns and communities. That has raised the growth/no growth controversy in the community.

Their second study was designed to test what would happen when large construction forces came into a small rural community. The proposed Hartsville Nuclear Power Plant near Nashville was taken as the case study. During this last year, two attitude surveys were undertaken using 350 randomly selected residents, prior to the issuance of the construction permit. A model was developed for predicting the tradeoff for construction workers between commuting or moving to the construction site. The survey in Hartsville found much greater acceptance for the power plant location than people had anticipated. In fact, it predated the now-famous Ebasco Services study, which indicated that nuclear power was more acceptable than either the politicians or the Naderites would believe. We plan to follow the Hartsville situation as the construction of the nuclear power plant occurs in order to trace changes in social and political structures, population attitudes, economic activities, etc.

Internal Events

There have been many important internal events during this past year. For example, the Laboratory has achieved the best safety record since 1969. These safety results are due to the efforts of everyone at the Laboratory, and this speaks well for your concern for a safe work environment. During the course of this year, a 25-year record without a disabling injury was achieved by the Reactor Division and is notable



The number of disabling injuries at ORNL reached the record low in 1975.

not only for that particular record but also for the achievement of the Reactor Division in being around for 25 years.

During this past year, we decided to change out the beryllium reflector within the HFIR. This changeout took place without a hitch and in a much shorter time than anticipated; much credit is due to the efforts of Jim Cox and others for effecting, in such an expeditious manner, the restoration of one of the most valuable research tools in this country.

We have seen ground broken for the Environmental Sciences Laboratory, a two-unit structure that will be the first environmental-studies-related building in ERDA. Ground also was broken for the ACES experiment at the UT farm, in which the Laboratory is cooperating with the University and TVA. The Heavy Ion Laboratory project got under way with a groundbreaking, award of a contract for the 25-million-volt tandem accelerator, site preparation, and completion of the overall design by the architect-engineer.

We have seen an increase in space for the growing population in Thermonuclear and Reactor Divisions located at Y-12. We see dimly in our crystal ball a new building for the X-10 site as well. In addition, extensive modifications are being made in the Biology Division to accommodate the growing chemical carcinogenesis and mutagenesis studies related to our nonnuclear activities.

During this past year, we have seen excellent benefits from our seed money programs; at least three of the ideas seeded earlier by this money have grown to be important enterprises and achieved results in a very short time. Specifically, I refer here to the work of Dave Novelli on the transfer factor, Loucas Christophorou on gaseous breakdown, and Elizabeth Peele on the socioeconomic effects of power plants on neighboring communities. I have already mentioned the micropore and doped silicon programs.

Future

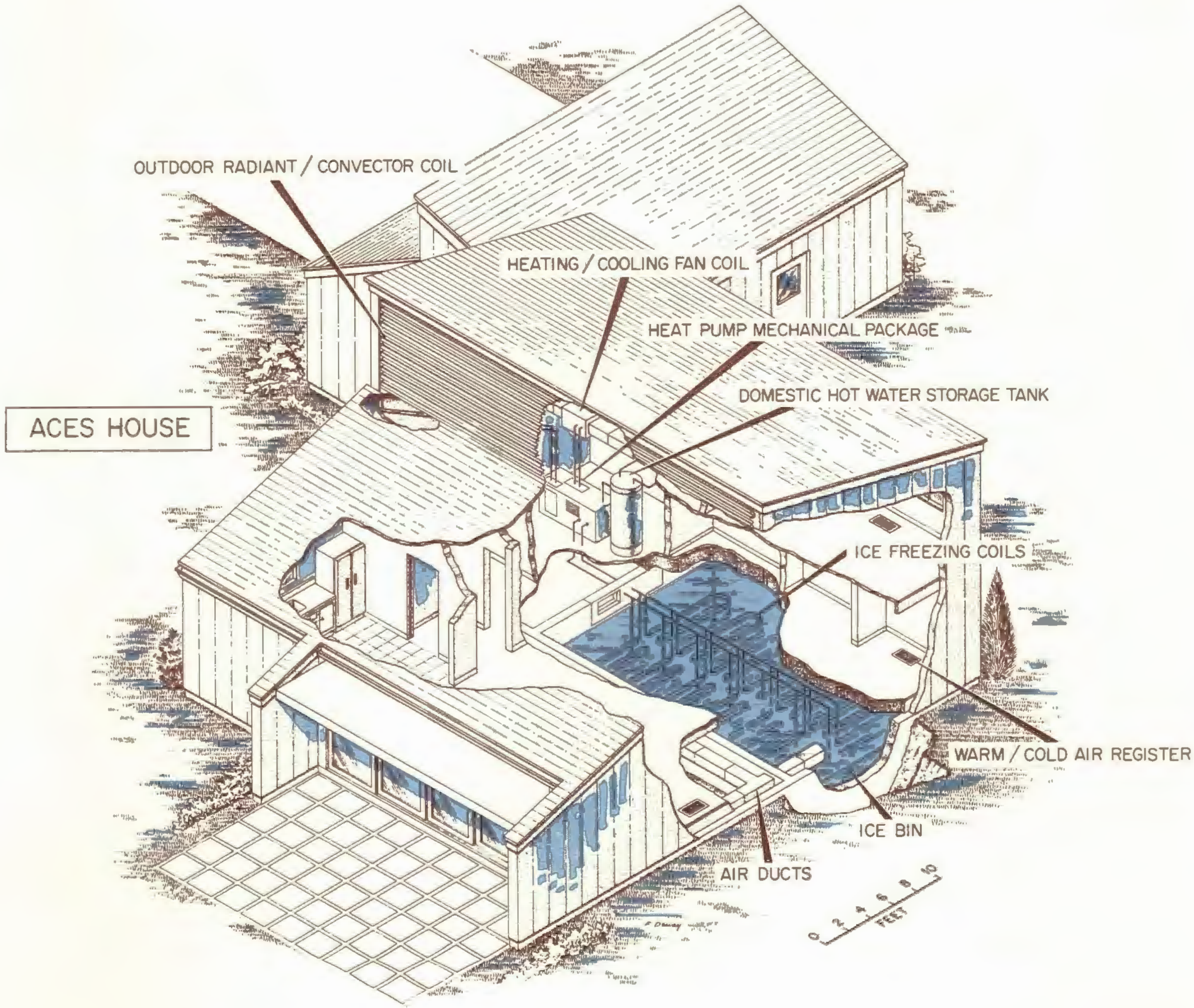
We should now take cognizance of some of the forces that are moving the Laboratory in new directions. Remember, for example, that ERDA's specific policy is to remain neutral about pushing any particular technology. The technical options will be kept open as long as possible by ERDA so that choices can be made as to which of the technologies require significant increases for commercialization.

The second significant aspect of the ERDA policy which differs from that of the past is in the area of commercialization—the rapid transfer of technologies to the market and the involvement of industry in many of the activities that in the AEC days were solely confined to in-house laboratories or to silence.

We have formulated stronger associations this year with ORAU and The University of Tennessee. Likewise, our relations with TVA in cooperative environmental undertakings have also been strengthened. We are presently involved as partners in the East Tennessee Cancer Research Center. We have formed a user's group composed of many universities and other laboratories to utilize the Heavy Ion Accelerator. And we find ourselves becoming increasingly involved with our sister multiprogram laboratories and also with new members of the ERDA family—the Energy Research Centers, Pittsburgh, Morgantown, and Laramie. I have already mentioned several commercial liaisons.

Another noteworthy development is our interaction outside the Laboratory to a greater extent and on a wider basis than before. We have had briefings for State and legislative groups, including the Tennessee Legislature, the National Conference of State Legislatures, the Council on Environmental Quality, the Committee on Environmental Quality and Natural Resources of the Southern Legislative Conference, the Council of State Governments, the state energy offices in the southeastern region, the Illinois Atomic

The ACES experimental house is under construction on UT land in a joint project undertaken by UT, ORNL, and TVA.



Energy Commission, Natural Resources Committee of the North Dakota Legislative Council, and many individual political aspirants. This reflects our concern that the evolution of the energy policy in this country not suffer from the lack of available relevant facts with respect to energy issues. There is an equal concern on the part of the visiting groups with the impact of the Federal energy initiatives on the states and with what the new energy technologies might be, in what time frame they will be developed, and what the effect would be on their constituents or institutions.

We see ERDA evolving to an agency quite different from AEC. ERDA has questioned everything that has been done by any of its member agencies before incorporation. Out of this, I expect will come a larger role to be played by the national laboratories. At the same time, there will be increasing use of industry and other institutions in the country to carry out energy research, development, and demonstration activities. I expect that the work that will be coming to the Laboratory will be less involved with job shop tasks and small packages, but rather will delineate larger areas in which we will play a more significant role with less control from Washington. We find that there will be an increasing emphasis on technology, but that supporting research will be funded out of the major technology programs as well as out of the physical and life sciences areas. There will be an increasing concern for the economic and social impacts.

The formation of the ERDA Division of Nuclear Fuel Cycle and Production will have a great impact. And the recognition of the problems that have not yet been solved in these areas will be perhaps the greatest influence in the future upon directions at the Laboratory and in the Nuclear Division. It is becoming widely recognized in ERDA that the Nuclear Division in Oak Ridge is unique in its capabilities. It possesses within the Laboratory a range extending from basic research to strongly developmental work and, in the rest of the Nuclear Division, there are the capabilities for large demonstration and engineering projects and handling of architect-engineers as well as the actual production of materials. Such a gamut exists nowhere else, and that strength will be used by ERDA.

Finally, as I speak of the future of the Laboratory, I remain optimistic. Although there is a cloud concerning what will happen with the gas-cooled reactor program that may hang over us for some time, recognition of the great capabilities of the Laboratory has certainly been important in the establishment of our contacts with the new agency. The new factors of commercialization will undoubtedly cause us to look at things in a different way than we have in the past. The local impact of the location of the Clinch River Breeder Reactor project, of course, will have a major impact upon the Laboratory as we seek to find modes of working with them to solve problems.

All in all, 1975 has been a magnificent year. We look back on the accomplishment of balancing the uncertainty and the strangeness of being part of a new agency against the challenge and opportunities of an expanding and vital mission. There has been a solid record of significant achievement by the Laboratory both in its traditional areas of nuclear research and development and in many newer, nontraditional areas on which the nation will depend greatly for its future well-being.

It has once again been an immense pleasure for me to work with you this year and to be able to present and to recount to you so much of great value that has been discovered at ORNL. My only regret is that so many other remarkable achievements have been left out because of the pressure of time.

Staff quote:

"One of a laboratory's largest investments is in its computing facility, and the operation of this affects the productivity of an appreciable fraction of the staff. The Jülich IBM 370/168 computer is comparable to our 360/91; however, the peripheral equipment at Jülich makes their facility immensely more useful than ours. Their equipment is user-oriented: for example, 15 cathode-ray communication terminals are available in the computing center, and for the Institut alone (about 20 regular users) there are a remote card reader, remote printer, two typing and two cathode-ray communication terminals. At ORNL there are no cathode-ray terminals available to users, nor are remote reading and printing devices available. Only a few teletype terminals exist. Such equipment is indispensible for optimum efficient use of our computer, and I suggest that the Computer Services Division be encouraged to make it available here. Indeed, in this connection an assignment to Jülich of one of our Computer Services Division staff might be beneficial to the Laboratory researchers."—**Gayle Painter,** *discussing a recent assignment to the Institut für Festkörperforschung der Kernforschungsanlage Jülich, West Germany.*

Take A Number.....

BY V. R. R. UPPULURI

SEQUENCES OF SQUARES

The number 49 is a perfect square (= 7^2). Take 49 − 1 = 48. If we insert 48 between 4 and 9, we obtain **4489**, which is a perfect square (= 67^2). If we insert 48 between 44 and 89, we obtain 444889, which is also a perfect square (= 667^2). If we insert 48 again in the middle of this new number, we obtain 44448889, which is also a perfect square (= 6667^2). It is rather fascinating to note that, if we continue the process of inserting 48 in the middle, we always find a perfect square at every stage.

This property is also true for 16. Take 16 − 1 = 15. Insert 15 in the middle at each stage to obtain 1156, 111556, 11115556, 1111155556, ... This is the sequence of squares 34^2, 334^2, 3334^2, 33334^2, ...

However, there are no other numbers between 11 and 99 with this property.

ONE THROUGH NINE COVERED IN SQUARING

Take a three-digit number, and square it. For example, 123^2 = 15,129. We see only five distinct digits 1, 2, 3, 5, 9 in this display. If we square 567, we obtain 567^2 = 321,489; note that the integers 1 through 9 appear exactly once in this display. Are there any other numbers with this property? It is of interest to see that 854 is the only other number with this property.

John Huckabee, a research associate in the Environmental Sciences Division, is a product of the American West. He moved at the age of 25 from his native Texas to the University of Wyoming, where he earned his Ph.D. in Zoology and Physiology. From there he joined the Laboratory in 1971, where he has worked in the ecology of heavy metals since that time. His extensive work in identifying mercury content in animals and fish made him a fitting candidate to respond to a request by the Spanish government to examine the impact on its environment of the Almadén mercury mine, the largest in the world. He is shown here, in front, with ORNL technician Sherry Janzen and Spain's contribution to the expedition, ecologist Paco Sanz, during Paco's training period in Tennessee. They are collecting on the North Fork of the Holston River. (Photo by Jay Story.)

Quicksilver Quest

By JOHN W. HUCKABEE

STUDIES AT ORNL concerning mercury in the environment, which have been under way for the past six years, have now culminated in a full-scale ecological project at the world's largest mercury mine, located in Almadén, Spain, about 250 km southwest of Madrid.

The mercury deposit at Almadén is one of the most remarkable mineral occurrences on earth. Exploitation of the ore—cinnabar and quicksilver—began with the Carthaginians at least two centuries before the Christian era, was expanded by the Romans, and was continued by the Moorish caliphs and the Spaniards until the present. At least 2.8×10^8 kg of mercury have been taken from the mine, but the ore body—a vertical bed of quartzite in the flank of a great plunging syncline—still shows no indication of exhaustion.

The Almadén mining operation generates the oldest and possibly the most extensive case of mercury pollution of land and air in the world. The flora and fauna of the region are exposed to elevated levels of environmental mercury deriving both from rock weathering and from the mining-smelting processes. Effluents contaminate both the terrestrial and the aquatic ecosystems, but neither the extent nor the effect of this contamination is known.

Although mankind has been aware of the unique and peculiar properties of mercury for millennia, concern about the metal's environmental effects is a comparatively recent phenomenon. It has been only two decades since the first manifestations of the Minamata tragedy in which over 50 Japanese died of eating fish contaminated with mercury released to Minamata Bay by the Chisso Corporation's acetaldehyde factory. This sorry occurrence, along with the similar events at Niigata, Japan, the decrease in Swedish bird populations because of bioaccumulation of mercury derived from agricultural and industrial sources, and accidental poisonings from the misuse of mercury biocides in the United States and Canada, has now become litany for environmentalists and antipollutionists. Americans in this decade became acutely aware of the mercury contamination problem when high levels were found in some brands of canned tuna and later in frozen swordfish by Dr. Bruce McDuffie, professor of analytical chemistry at State University of New York at Binghamton. (Dr. McDuffie is a brother of Fritz McDuffie, director of ORNL's Information Division.)

All these events were found to be preventable, and it is unlikely that similar cases will ever occur on such scales again. Overt effects of the noxious element are still present in some instances, however, serving to warn us against the misuse of mercurials and of their environmental persistence.

Mercury is one of the rarer elements in the earth's crust, but it is so widely disseminated by natural processes that it can be found in practically everything, including the tissues of biota. Indeed, mercury in trace quantities has been detected in virtually all organisms in which it has been sought, indicating that, in spite of the low solubility of naturally occurring HgS, mercury is mobilized and absorbed by plants and animals, whether it is derived from natural or cultural sources.

There are four main reasons why a study of mercury cycling and transport in the environment at Almadén is a unique opportunity. First, the release is continuous and long-term, meaning that cycling processes would tend to be at steady state; second, the effluents are from a virtual point source, at least on a regional basis, meaning that transport gradients and rates are easier to measure; third, there is apparently no other significant source of mercury or any other pollutant within a radius of hundreds of kilometers; and fourth, the region is semiarid so that cycling processes are not speeded up through excessive leaching.

Oak Ridge involvement in the Almadén studies began in May 1974 although other studies at the mine by EPA and the University of Rochester Medical School had been under way for a year or so. The Almadén Mine Council, the government's administrating agency, was expressly interested in an ecological study, but it employed no ecologists at that time.

The NSF Office of International Programs was administering the American involvement in both the medical and the potential ecological projects; and the program manager for Spain, Duncan Clement, requested that Stan Auerbach and I go to Almadén as part of the NSF site visit team that would advise NSF in the matter of an ecological survey. I was in Spain at that time for the First International Mercury Congress in Barcelona and, when that meeting was over, I met the rest of the site visit team in Madrid; we then proceeded to Almadén. The Mine Council considered us as guests and gave us rooms in the VIP chalet, a baronial mansion with, among other accoutrements, velvet draperies, inlaid hardwood floors, and formal gardens. During the next three days we acquired a reasonable qualitative grasp of the possible environmental impacts of the mining-smelting operation. In addition to observations and discussions, we managed to mist-net some house sparrows, but failed miserably in our attempts to trap rodents.

The most obvious, and probably the most important, mercury source at Almadén is the 30-m stack from which mercury vapor and sulfur dioxide generated in the ore-roasting ovens are released. Another source of mercury vapor is the forced ventilation of the mine. Air is blown through the shafts and galleries by large fans and is dissipated to the atmosphere through a stack very near the main shaft. There are other discharges of mercury vapor to the atmosphere such as that from the flasking operation, but compared with ore roasting and mine ventilation, they are probably minor. Particulate matter (such as road dust) containing mercury is distributed to

unknown distances from the mine by wind and vehicular activity. Because the ore is not carried more than a few hundred meters on the surface, transportation is not an important factor.

The liquid effluent from mine and smelter is little more than a trickle, but it is nearly constant and probably contains very high concentrations of mercury, as evidenced by beads and pools of metallic mercury accumulating in the discharge channels. The effluent from the smelter flows into trapezoidal sludge ponds that collect most of the mercury-containing particulates, but the ponds do overflow. The overflow is released into a small stream called Arroyo Azogado, which runs for 7 km until it joins the Rio Valdeazogues (*azog* is Arabic for mercury). The Rio has large fish populations, some of which are used for food by the local residents.

The Arroyo Azogado also receives an unknown quantity of dissolved mercury leached out of the tailings by rain and groundwater. The average annual rainfall at Almadén is about 50 cm, but it falls mainly during January and February. This means that mercury contributions to the aquatic environment from the tailings may vary widely, reaching maximum levels following the seasonal rains.

The upshot of our site visit was a request by the Spanish government that I return in October 1974 to conduct a preliminary survey of mercury in the environment and, based upon the findings of this survey, submit a proposal to NSF-OIP for a full-scale ecological study during 1975-1976.

Meanwhile, the Mine Council hired a biologist, Paco Sanz, to work with us and sent him to ORNL for training in the summer of 1974. Additionally, the house sparrows collected in May 1974 were analyzed in due time in ORNL's Analytical Chemistry Division, and mercury concentrations were seen very clearly to be a function of distance from the mine. By previous agreement, all data taken in this study are proprietary; they will be published in an appropriate forum agreed to by both the American and the Spanish groups.

It became apparent that we needed two ecologists for the October survey, and Steve Hildebrand was the logical choice for the second man. I journeyed to Almadén in early October 1974, and Steve followed two weeks later. On this

Site of the Almadén mercury mine, with the town of Almadén in the distance. The buildings of the centuries-old mine are at the left, with the new laboratory, "La Pagoda," showing white just left of center.

trip, we were quartered at another domicile, where most of the mine's younger professional staff, including Paco, lived. The quarters were less commodious than the chalet, but the ambience was much livelier.

Stresses and strains of a sociocultural nature occasionally cropped up; indeed, certain situations were almost Cervantean. Americans, for instance, take hot water for granted, by heritage and by right, and usually suffer when unexpectedly deprived of it. One character-building night the hot water went off, and stayed off. And stayed off. To the Spaniards, the normal way to cope with this contretemps was to regard it as inconvenience, not disaster; our daily (and exponentially intensifying) plaints summoned no relief. I'm a natural poikilotherm, so it was in melancholy that I soon perceived that immediate restoration of heated water was indeed an Impossible Dream. Paco ultimately realized our strait and saved the day—and certainly my equanimity—by taking us to the facilities at the mine, where the showers were still hot. It turned out that Paco and his cohorts frequently (but furtively) went to the mine, also. The Spaniards' legendary propensity for helping foreigners to cope (and for coping themselves) still prevails.

Paco, Steve, occasionally Bob Wilson of the University of Rochester, and I would venture out each morning in the mine's well-traveled Land Rover (named Rocinante, of course) to collect samples. Lunch was at 3 PM, so the mornings were long. About 5 or 6 PM, we went back to the field until dark; dinner was at 10. Paco's—well, *mercurial*—enthusiasm extended to his driving; he referred to himself as "Fittipaldi" (Numero Uno on the Grand Prix circuit at the time). Each trip, then, was an adventure; but by early November we had managed to collect for mercury analysis more house sparrows, four species of fish, and many plants. We also sited the sampling stations and devised a schedule and routine for the proposed ecological study.

Upon returning to Oak Ridge in mid-November, we set about the details of preparing the proposal for NSF-OIP. We planned to conduct an ecological survey of mercury in both the terrestrial and the aquatic ecosystems in the vicinity of Almadén with the objectives of defining the range of mercury concentrations in critical ecosystem compartments, identifying indicator species (if they exist), and charting the distribution of environmental mercury away from the mining area. These tasks, including the onerous sample preparation, obviously required more personnel than did the survey; thus, technician Sherry Janzen was recruited to accompany Steve and me on the fall trip of 1975.

Our sample collection and analysis at Almadén followed the same rationale used at ORNL for the acquisition of our two other data sets on environmental mercury: the Holston River (polluted by a chloralkali plant) and the Great Smoky Mountains (unpolluted oliogotrophic streams). In all these studies we followed an ecosystem approach, in which all major compartments of the system were sampled at a given time. The information obtained in these field studies and supporting laboratory experiments will make possible a synthesis of the behavior of mercury in widely differing environments.

At Almadén, our sampling included both the terrestrial and the aquatic ecosystems. The terrestrial sampling stations are within a radius of 25 km from the mine-smelter complex. By field examination, we located stations as nearly equidistant from the mine as possible along north-south and east-west transects. The distances and directions vary with the local differences in topography, geology, cultural activities, and ecology, but the stations are about 2, 6, and 20 km from the mine. There is no station 2 km east because of disruption of the ecosystem in the form of an urban garbage dump, nor at 2 km south because of range fires two years in a row. Thus, there are ten terrestrial stations, at which we have collected the following samples for mercury analysis: soil cores; plants that include *Quercus rotundifolia*, *Asparagus acutifolius*, *Centaurea hisopifolia*, *Cistus sp.*, *Avena fata*, *Ephedra sp.*; and a composite sample of moss species.

Collection of small mammals was not possible during the first two trips, but rodents and carnivore scat were seen. Some plants known to accumulate mercury (*Labiatae* and *Caryophyllaceae*) could not be found in October and November, but will be sought in the spring. Because mosses have been shown to be reliable indicators of airborne mercury contamination, we

Closeup of La Pagoda, showing the characteristic architectural lines that earned it its nickname.

collected composite samples of several species, some as far as 5 km from the mine.

House sparrows are another species that are collected on an independent basis because of unique characteristics. They occur abundantly in the Almadén area. Because of their wide distribution (Europe and North America), small home ranges, and well-known population genetics, house sparrows constitute an ideal study species. Responses of species with small home ranges to gradational changes in the environment (i.e., mercury levels) can be detected at greater resolution than can those with larger home ranges. There is also adequate opportunity with the ubiquitous house sparrow for intraspecies comparison, thus providing an approach to the study of its adaptive capacity to elevated levels of mercury. We collected house sparrows in nets at the mine, the chalets, and a control site 20 km from the mine.

We organized aquatic sampling so as to measure the distribution of mercury downstream from the effluent; we included control stations upstream. Other control streams farther from the mine may be selected later. The samples we collected include water, sediments, stream-bottom biota where available, and at least ten each of three species of fish.

The liquid effluent from the ore processing plant drains into the Arroyo Azogado, which also receives sewage from Almadén. Water, sediments, aquatic macrophytes, and whatever macrobiota were in evidence (little or none) were sampled, and measurements of pH, alkalinity, and temperature taken, at selected points between the effluent and the Rio Valdeazogues.

Because mercury flux through the environment probably varies with weather changes, we collected samples during two distinct seasons: April, when it is cool and dry, and late September, when it is warm and dry.

We froze the samples upon collection to keep them until Paco could analyze them. The new laboratory at Almadén, called "La Pagoda" for its distinctive architecture, was completed just before the September 1975 trip. It is located at the absolutely worst spot on earth for a mercury analysis lab—that is, within meters of the ore-roasting ovens, condensers, stack, and main mine shaft of the largest mercury mine in the world. Of course, these seemingly Herculean obstacles will be overcome, we hope, by maintaining the laboratory room at positive pressure, filtering the incoming air, and monitoring continually.

Paco's analysis for mercury content will be performed by standard cold-vapor atomic absorption spectrophotometry, as will ours. Because the volume of samples is high (about 3000/year), two of us must spend one to two months in Almadén each trip working on specimens collected during the scheduled sampling periods. Between 5 and 10% of the samples are divided for analysis at both Almadén and ORNL for quality control purposes.

We are performing methylated mercury determinations on selected samples by gas-chromatographic techniques at ORNL. ORNL's Analytical Chemistry Division has developed a high level of expertise in measuring methylated mercury in biological samples, a very difficult analysis. This is the most complete environmental methylated mercury survey yet attempted. Methylated mercury is the most toxic form of mercury and is ubiquitous in fish tissue. The origin of methylated mercury in fish probably involves microbes somewhere in the aquatic ecosystem, but the argument is by no means settled. Samples of terrestrial organisms also contain some attack), and neutron economy. The composition of methylated mercury, although apparently less (on a percent basis) than do fish.

Last September's trip commenced with four days' advance notice that we were going for certain. Steve, Sherry, and I arrived in Almadén in our rented Renault and set about collecting the aquatic samples. The work progressed swimmingly, and we finished the task in one week.

Paco was completing his Army service, so when Steve returned home, Sherry and I were on our own. We set 350 mousetraps at three locations, the maximum number we could run in a period short enough to keep ahead of ants stripping the bait. Four weeks later, we had caught just enough mice for statistical significance of mercury content in the population. Fortunately, the number of animals caught was about the same at each of the three locations and more or less evenly split between two species. One of these was the house mouse, a cosmopolitan species that will provide the same kind of data for small mammals that the house sparrow provides for birds.

For some reason, the sparrows were harder to trap this year than in 1974, and Sherry and I could not find enough time to handle bird nets and mammal traps simultaneously. However, the person in charge of the analytical lab and our chief contact, Juan Pablo Garcia Frades, provided us with a helper who was an expert at trapping birds. This man, Bernardino, kept for food any excess over our needs, so he gladly worked for us, even before and after normal hours. In addition to sparrows, he caught blackbirds and numerous small songbirds.

When the bird sampling was completed, Sherry and I were invited to the neighboring pueblo (Chillon), where Bernardino and some

From l., Juan Pablo Garcia Frades, Sherry Janzen, Steve Hildebrand, and the author confer around one of the gondolas outside the mercury mine. (Photo by the author, he says.)

other lab workers lived, for sparrows and pitarra. Bernardino's wife cooked the birds (at least 4 and 20) in a garlic sauce and they were, believe it or not, very good. Pitarra is a local vintage made only in Chillon that varies in quality from egregiously inferior to nearly excellent. We were in luck that night, and we hope Bernardino catches many birds during our next trip.

The presence of women at all professional levels in the United States is a fait accompli, but in the macho-dominated Spanish culture, male prevalence in physically active outdoor work is virtually one hundred percent. Sherry, as part of our field research team, then, was Almadén's cause célèbre of the year.

When Sherry and I made it known that we would like to go down in the mine, the chief of underground operations, Juan Grande Gil, asserted his authority and invited us to go with him on a personal tour. I had been down a couple of times before—once, in fact, with Juan Grande. That time, however, had been strictly business.

We put on the bright orange uniforms, hard hats, and rubber boots, switched on our battery-powered head lamps, and rode the elevator (with no sides) down to the 500-m level. Juan Grande showed us everything—the galleries with their beautiful, brick-red swaths, seams, and veins of cinnabar, the droplets and puddles of liquid quicksilver seeping out of the rocks. At the height of activity on one of the working faces, he stopped two of the miners as they were boring holes for the dynamite charges with their oversized, stuttering air drill, and called Sherry to come and take hold of it, just so. She complied without hesitation, and he switched the air on! Juan Grande and the miners, who had respirators and ear protectors, then stepped aside, well back, while Sherry drilled away.

Unlike miners in the United States and elsewhere in Europe, the Spanish mine workers apparently do not subscribe to the superstition that proscribes admitting women to the mine. This was not the first time a woman had been down in the Almadén mine; Fran James of NSF had gone down during the site visit trip in 1974. But it was, I daresay, the only time in the mine's 2000 years of operation that a woman had drilled for mercury on a working face in Almadén! After such an event, the elevator trip back up was, in a sense, a step down; back to our less than epochal business.

Ordinarily, collecting vegetation is not very exciting compared with mining, but in southern Spain, the flora resemble that of the American Southwest in that every plant either "sticks, stings, or stinks." We persevered, though, and finished the plant sampling in a couple of weeks despite thorny defenses.

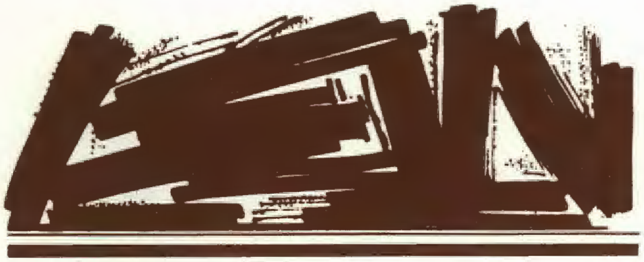
Juan Pablo told us that we were in Spain during the most significant two weeks (early October) since the Civil War. Although the Spaniards were very preoccupied and concerned with the political situation, we were directly affected only once. The Federal Police (Guardia Civil) had seen us coming and going to tend one of the traplines and had become suspicious. I thought it was a routine check as we approached their roadblock. We showed them the official papers and permits, but they searched the car anyway. Apparently my explanation satisfied them, and we were not detained for long. However, we realized it had not been a routine check at all because they left immediately after releasing us.

If the transfer of power to King Juan Carlos goes well in both Spain and the European community, we expect to remain on schedule and complete this project by late fall of 1977. Upon or before completion of this study, it may be desirable to expand the program into more specific research problems that we identify during the current work.

If the most optimistic predictions on cooperation between the two governments and funding levels are realized, ORNL-ESD may have a Spanish connection for some time to come.

CORRECTION

An item in the Summer issue of the *Review* announced publication of the third volume in the series "Advances in Molten Salt Chemistry" and erroneously cited it as the last in the series. Jerry Braunstein, one of the editors of the series, asks that we correct this to call it the *latest* volume, with, it is hoped, more to come.



BOOKS

***"Portrait of Nature,"** by Alan Cottrell, Charles Scribner's & Sons, New York (1975). 231 pages; $9.95. (Reviewed by Arthur H. Snell)*

SELDOM HAS THE GRANDEUR of nature been painted on a scale such as has been chosen for this short book. The scope is almost breathtaking, and to convey some concept of it, I can do no better than to attempt a partial listing. It starts with astronomy and the universe and passes to a chapter on relativity and cosmology, including the Schwarzchild radius, and black holes. Then we go to angular momentum, the Coriolis forces and their effect upon the earth's ocean currents and weather cycles, energy, the second law of thermodynamics, the "arrow of time," and the expansion of the universe. Then we enter atomic physics—electric charges, the structure of matter, and light and radiation. This subject leads naturally to molecules, crystals, nuclei, and the origin of the elements, and further to the quantum theory. Then the statistical nature of things is discussed, followed by the wave-particle duality, uncertainty and complementarity. There follows more about radioactivity, parity nonconservation and the subnuclear particles, and something about information theory. After that, we venture into chemistry and the structure of molecules and solids, introducing geochemistry and plate tectonics and the history of the earth. This brings us to a fine chapter on the origin of life, evolution, the structure of the cell, mitosis, and genetics. With the groundwork already laid, the reader is then taken into the energetics of the cell, its enzymes and proteins, and of course the marvels of DNA and RNA. Viruses are presented as simple self-replicating organisms in which the genetic message that has to be conveyed is simple and brief and austere, leading to symmetric forms and a crystalline appearance. The viruses raise the question: What is life?, and the background has been prepared for a chapter on the probable biochemical origins of life and its evolution into all of its manifold forms through the ages to the present. Then we go to man, his brain and his mind, with the portrait of nature finally merging into the unknown.

That is the nature of Sir Alan Cottrell's book. Sir Alan himself is Master of Jesus College, Cambridge, and previously was Chief Scientific Advisor to Her Majesty's Government. Perhaps the experience of the latter post gave him some of the facility and conciseness and drama of his language and his ability to present scientific concepts to the general reader. But what a challenge—to present all of that great, awe-inspiring story in less than 250 pages without being trite, with a continuing rationale, and with enough depth for conviction!

So you and I are physically simply the result of mechanistic, interatomic and intermolecular forces, refined as they have been through the last billion years. Only the laws of probability (and mutations) introduce variability. Is this disillusioning? Does it take some of the mystery and magic out of life? To my mind, no. The mystery has been modified through understanding, but the magic is still there, if anything, greater in majesty because of the wonder that comes with the knowledge. But what of the mind, the emotions, behavior, free will? Does the logic of the inheritance of the physical extend into that realm? "Instinct"? But how then is "instinct" transferred on the molecular level? Just how do mind and matter meet? Perhaps, the suggestion is, there is a duality or a complementarity here; if we examine it with instruments, the mind is the brain, and neural events are conceptually subject to observation and measurement. But if we analyze the signals that get to our own minds through our own neurons, we sense something absolutely different. Furthermore, the act of self-analysis modifies the signals. There seems then to be a duality and a limitation to our powers of observation reminiscent of the nature of light; the mystery stands.

In Sir Alan's opinion, the portrait of nature has no end. Knowledge will be gained, the details of the portrait will be filled in, and its limits will be extended; but there will always be something beyond. There will always be a "first cause" unexplained, and despite all our knowledge of mechanisms, there will always be room for a God. Meanwhile, man, in his insatiable curiosity, will always ask further questions, and if the questions are well formulated, nature will respond.

The *Review* has been notified of the 1976 publication of "Photoelectron and Auger Spectroscopy" by Thomas A. Carlson. Publisher in Plenum Publishing Corporation, New York; the book has 417 pages, and its list price is $32.50.

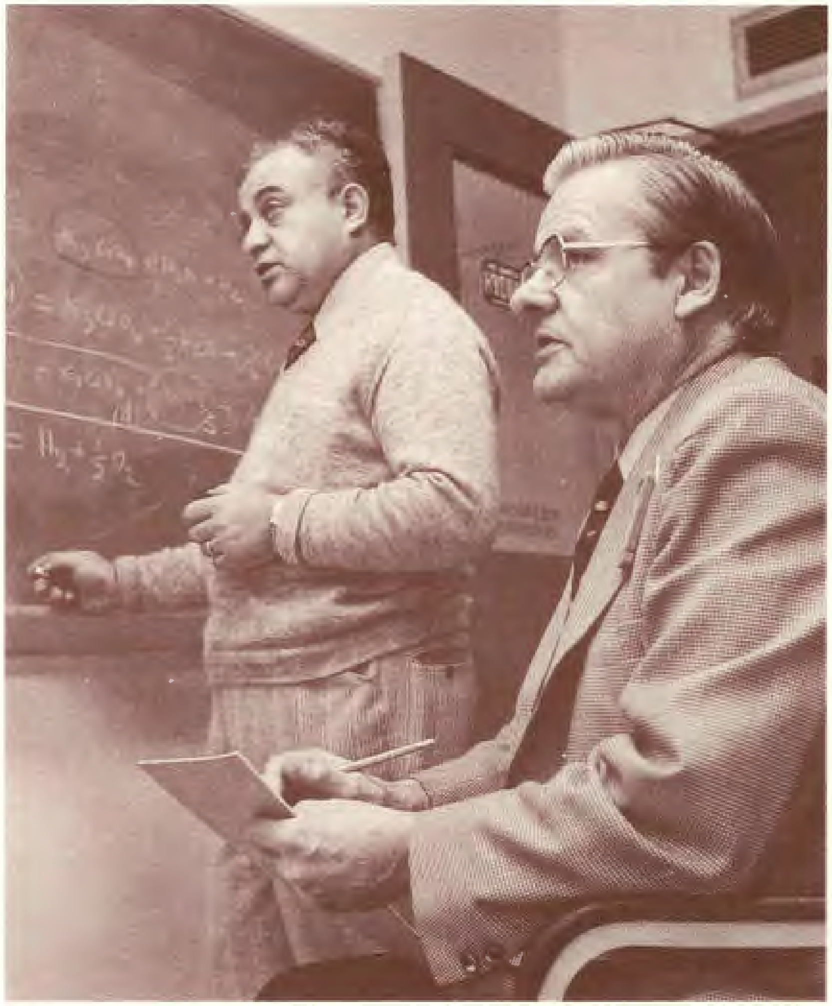
"H. G. J. Moseley; The Life and Letters of an English Physicist 1887-1915," by J. L. Heilbron, University of California Press, Berkeley (1974). 312 pages; $15.00. (Reviewed by Curtis E. Bemis, Jr.)

HENRY GWYN JEFFREYS MOSELEY, nicknamed Harry by his family, seemed destined for an eminent career in the physical sciences. The son of an Oxford zoologist, grandson of a fellow of the Royal Society and clergyman, Harry Moseley was reared in the late Victorian era and breezed through a traditional education at Eton and at Trinity on scholarships. In the first three chapters of his book, Heilbron documents these aspects of Moseley's early life and education and carefully traces the gentle nurturing of Harry's interests in science. Clearly, Moseley's two-year apprenticeship in 1910 under Ernest Rutherford at Manchester was a milestone in his scientific career as this was his introduction to the phenomenon of radioactivity and the world of the atom. He distinguished himself in radioactivity investigation under Rutherford's close supervision and became convinced during this period that x-ray diffraction would be the key to understanding atomic structure. The interaction with such greats as Bohr, von Laue, and Bragg clearly influenced Moseley's research, and in 1913 he left Manchester to pursue independent research on the nature of x rays at Oxford. Within a few months he had observed characteristic x-ray line structure and developed the empirical relationship between x-ray wavelength and atomic number now known as Moseley's law. This provided the fundamental basis for the ordering of elements in the chemical periodic table and had immediate applicability in establishing the correct order of the chemically similar rare earth elements and in identifying the then existing gaps in the periodic system as elements 43, 61, 72, and 75. Moseley's research won instant international acclaim, and he traveled to Australia in June 1914 at the invitation of the British Association to present his work. The patriotic fervor instilled in him from his Eton days led to his early return to England to enlist in the Royal Engineers when World War I broke out. Commissioned as a signals officer in the 38th Brigade of the First Army, he was sent to the Dardanelles, and on August 10, 1915, he was shot through the head during a charge of 30,000 Turks at the battle of Sari Bair in the Gallipoli Campaign. At the age of 28, his brilliant research career of only 40 months' duration was ended.

Heilbron's description of Moseley's personal and scientific life is extremely interesting and eminently readable; certainly it will remain as the authoritative work on the life and research of H. G. J. Moseley. About one half of the book consists of all known correspondence written by and to Moseley. Heilbron has painstakingly documented the book by these letters, conversations with associates and acquaintances of Moseley, and liberal references to previously published works.

Heilbron has taken the liberty in an epilogue to speculate on what Moseley's life and research would have been were it not for his untimely death. Clearly, Moseley would have provided some more of the research that would have aided in the development of the theory of atomic structure and perhaps might have even discovered one of the then missing or controversial elements. Heilbron feels, as I do, that a most fitting tribute to Moseley would be the attachment of the name "Moseleyum" to an appropriate transuranium element. Characteristic x rays have always provided, and will continue to provide, clues to the placement of elements in the chemical periodic table—a great Moseley legacy indeed. I highly recommend this book to those who wish an enjoyable glimpse into the life of a great scientist.

Carlos Bamberger and Don Richardson have been reexamining methods of extracting hydrogen from water by thermochemical reactions, designed to take advantage of the large heat resources available from nuclear power plants. Carlos came to the Laboratory from the AEC of Argentina in 1961 on a two-year IAEA fellowship. In 1966 he returned to permanent employment, working principally on molten salt technology. His doctorate was earned at the University of Buenos Aires. Don, who has been with the Laboratory since 1944, has been working with Carlos on the current problem for just two years. Both are in the Chemistry Division.



Thermochemical Production of H_2

. . . *A new look*

By CAROLYN KRAUSE

HYDROGEN, THE SIMPLEST of the elements, is now being examined for its potential to help solve the nation's, and even the world's, complex energy problems. Technologists are talking about a "hydrogen economy" in which hydrogen, a clean-burning gas, will serve as a multipurpose fuel; as a means of storing and transmitting energy; and as an industrial chemical for making ammonia, producing steel, and for creating liquid and gaseous fuels from coal. Although free hydrogen is found only sparingly on earth, it can be obtained in large amounts by the decomposition of water, 11.19% of which is hydrogen and 88.81% of which is oxygen. The current challenge is to determine the most efficient, economical method of separating the hydrogen and oxygen of water. The conventional method used to decompose water is electrolysis—that is, passing a current between electrodes immersed in a water solution of an electrolyte such as potassium hydroxide. However, this method, used since the beginning of the century, may not be the best of keys for unlocking hydrogen from oxygen.

Thermochemical Cycles

Carlos Bamberger and Don Richardson, ORNL chemists, are enthusiastic about the potential of thermochemical cycles for production of hydrogen from water. A thermochemical cycle is a series of reactions, carried out at high and low temperatures, involving water and other compounds. These reactions, which consume only water and energy (mainly as heat) to yield hydrogen and oxygen, are called cycles because the same reactants used at the beginning of the series are regenerated at the completion of the series. Bamberger and Richardson, who have identified half a dozen promising thermochemical cycles, say that such cycles are potentially more efficient in their use of energy than is electrolysis for the production of hydrogen from water.

Although the efficiency of electrolysis is 30 to 35%, researchers believe that the efficiency of thermochemical cycles is potentially greater than 50%—recovering as much as half the thermal energy from the hydrogen as is invested in the processes. The net efficiency would be lower because of the inherent mechanical and electrical energies consumed in handling the chemicals. Because the separation of reaction products in general, and of gases in particular, is an energy-intensive operation and has not yet been applied to the mixtures resulting from thermochemical cycles, the subject deserves further research.

The most efficient thermochemical cycles are those involving three basic reactions, Bamberger says. He and Richardson have identified several three-step cycles using compounds containing such elements as potassium and chromium, iron and sodium, barium and chromium, and strontium and chromium. The two most promising of these cycles are those using strontium and chromium and barium and chromium; of these, the strontium–chromium cycle is considered better so far, Bamberger says, because the end products can be separated in solution where they recrystallize so that the cycle can begin again. Another advantage of the strontium–chromium cycle, which was invented (and its reactions demonstrated) at ORNL, is that the reactants involved are not as corrosive as those in the barium–chromium cycle. The chief drawback of the barium–chromium cycle, Bamberger notes, is that one of the end products containing barium is an insoluble solid that is not easily isolated. The cycles also differ in that the strontium–chromium cycle requires steam in the hydrogen-evolving step. The two cycles are compared below.

Each cycle consists of three chemical reactions that take place in a temperature range of from 100 to 850°C. The reactions that constitute the two proposed cycles have been demonstrated. The first cycle involves the oxidation and reduction of chromium compounds by barium hydroxide and the hydrolytic disproportionation of (IV) chromate and barium chromate (V). In the reactions below, (s), (l), (g), and (d) refer, respectively, to the solid, liquid, gaseous, and dissolved states. The three following reactions,

$$Cr_2O_3(s) + 4Ba(OH)_2(l) \xrightarrow{650°C} 2Ba_2CrO_4(s) + 3H_2O(g) + H_2(g)$$

$$2BaCrO_4(s) + Ba(OH)_2(l) \xrightarrow{850°C} Ba_3(CrO_4)_2(s) + H_2O(g) + \tfrac{1}{2}O_2(g)$$

$$2Ba_2CrO_4(s) + Ba_3(CrO_4)_2(s) + 5H_2O(l) \xrightarrow{100°C} Cr_2O_3(s) + 2BaCrO_4(s) + 5Ba(OH)_2(d) ,$$

give a net reaction,

$$H_2O \longrightarrow H_2 + \tfrac{1}{2}O_2 .$$

The second cycle involves the oxidation and reduction of chromium compounds by strontium oxide and steam; oxidation—reduction is required because $Sr(OH)_2$ is thermally unstable at the reaction temperature. The hydrolytic disproportionation of strontium chromate (IV) and strontium chromate (V) completes the cycle. The three reactions,

$$Cr_2O_3(s) + 4SrO(s) + H_2O(g) \xrightarrow{700^\circ C} 2Sr_2CrO_4(s) + H_2(g)$$

$$2SrCrO_4(s) + \tfrac{4}{3}Sr(OH)_2(l) \xrightarrow{500^\circ C} \tfrac{2}{3}Sr_5(CrO_4)_3OH(s) + H_2O(g) + \tfrac{1}{2}O_2(g)$$

$$2Sr_2CrO_4(s) + \tfrac{2}{3}Sr_5(CrO_4)_3OH(s) + 5H_2O(l) \xrightarrow{100^\circ C} Cr_2O_3(s) + 2SrCrO_4(d) + \tfrac{16}{3}Sr(OH)_2(d) ,$$

give a net reaction,

$$H_2O \longrightarrow H_2 + \tfrac{1}{2}O_2 .$$

The end products, $Sr(OH)_2$ and $SrCrO_4$, are soluble in water and easily separated from the solid Cr_2O_3 formed in the third reaction. The two dissolved compounds are separable by fractional recystallization.

To make thermochemical cycles go, a great deal of heat is required, preferably with an upper temperature limit of 1000°C. Bamberger and his colleagues have examined such possible sources of heat as solar energy, coal-fired, and nuclear power plants. They have concluded that solar energy plants would require prohibitively expensive equipment and collectors to supply 1000°C heat and that it is cheaper to get hydrogen from coal by reacting steam with incandescent coal than to use coal as a heat source for thermochemical hydrogen production. However, to the extent that coal's availability for this purpose may be limited, Bamberger believes that nuclear energy is the best bet as a source of heat for thermochemical cycles. Says Bamberger: "High temperature gas-cooled reactors right now look like the best prospect for thermochemical cycles. The Liquid Metal Fast Breeder Reactor and the Molten Salt Reactor would also be useful if the operating temperature could be increased." Bamberger says that the best HTGR presently available for this use is one developed by the Germans.

In determining how efficient a themochemical cycle is, Bamberger and Richardson try to measure the heats of formation of some of the compounds used to determine how much heat will be needed for the endothermic reactions. Heats of formation and other thermodynamic properties can be determined only by time-consuming and difficult measurements. Because this information is sometimes unavailable or in error, Bamberger and Richardson prefer the experimental demonstration of reactions and cycles over computer programs used by some researchers. As Bamberger puts it, "We claim we have an edge on many pieces of work you see in the literature because we do our work experimentally. It is more time-consuming to run an experiment than to sit down at a calculator; but while we are doing research on thermochemical hydrogen, we are also doing basic research on inorganic chemistry."

In addition to the two-man effort at ORNL, thermochemical hydrogen studies are also being conducted at Argonne, Los Alamos, General Atomic, and the Institute of Gas Technology in the United States; in Japan, Germany, and France; and by EURATOM.

Bamberger says that the next step at the Laboratory will be for chemists to seek collaboration of chemical engineers in determining what amounts of heat and mechanical energy are required and what materials problems are involved in building a small-scale thermochemical plant, which could be a forerunner of a pilot plant should ERDA decide to fund one. Chemical engineers would be needed to look into such questions as temperature vs. recycling—that is, how much more energy would be required to recycle reactants of partially completed reactions if lower temperatures were used. In considering the cost of such a plant, analysts will have to factor in such information as the price of the reactants. For example, barium, chromium, and strontium compounds are promising for thermochemical cycles because, although not the cheapest of chemicals, they fall in the medium price range and are relatively easy to handle. A thermochemical cycle (identified by Bamberger et al.) involving iron and sodium compounds would be cheaper to run considering the prices of the reacting materials alone; but they have determined that this cycle is not practical now because it would require too high a temperature. Richardson says that a drawback of thermochemical plants on a commercial scale will be their prodigious size, but he still feels that they may be more efficient and less costly than the large-scale electrolysis plants using existing technology.

The idea of thermochemical cycles was first suggested in 1924, but it was not until 50 years later that scientists began looking seriously at the feasibility of thermochemical cycles for producing hydrogen. The groundwork for thermochemical studies was laid by Funk and Reinstrom in 1966 in a study for the U.S. Army, and several years later DeBeni and Marchetti at EURATOM started a vigorous experimental program. Alvin Weinberg, as director of ORNL, had talked to Marchetti about his work and subsequently stimulated studies at ORNL to evaluate Marchetti's reactions using calcium, bromine, and mercury. Another earlier involvement of ORNL with hydrogen was the assembly of a panel under John Michel in 1971 to prepare a report on hydrogen and other synthetic fuels for the Federal Council on Science and Technology R&D Goals Study. Several ORNL staff members contributed, and the report was released in September 1972. The present thermochemical program at ORNL was initiated and directed by Warren Grimes in 1973.

Toward a Hydrogen Economy

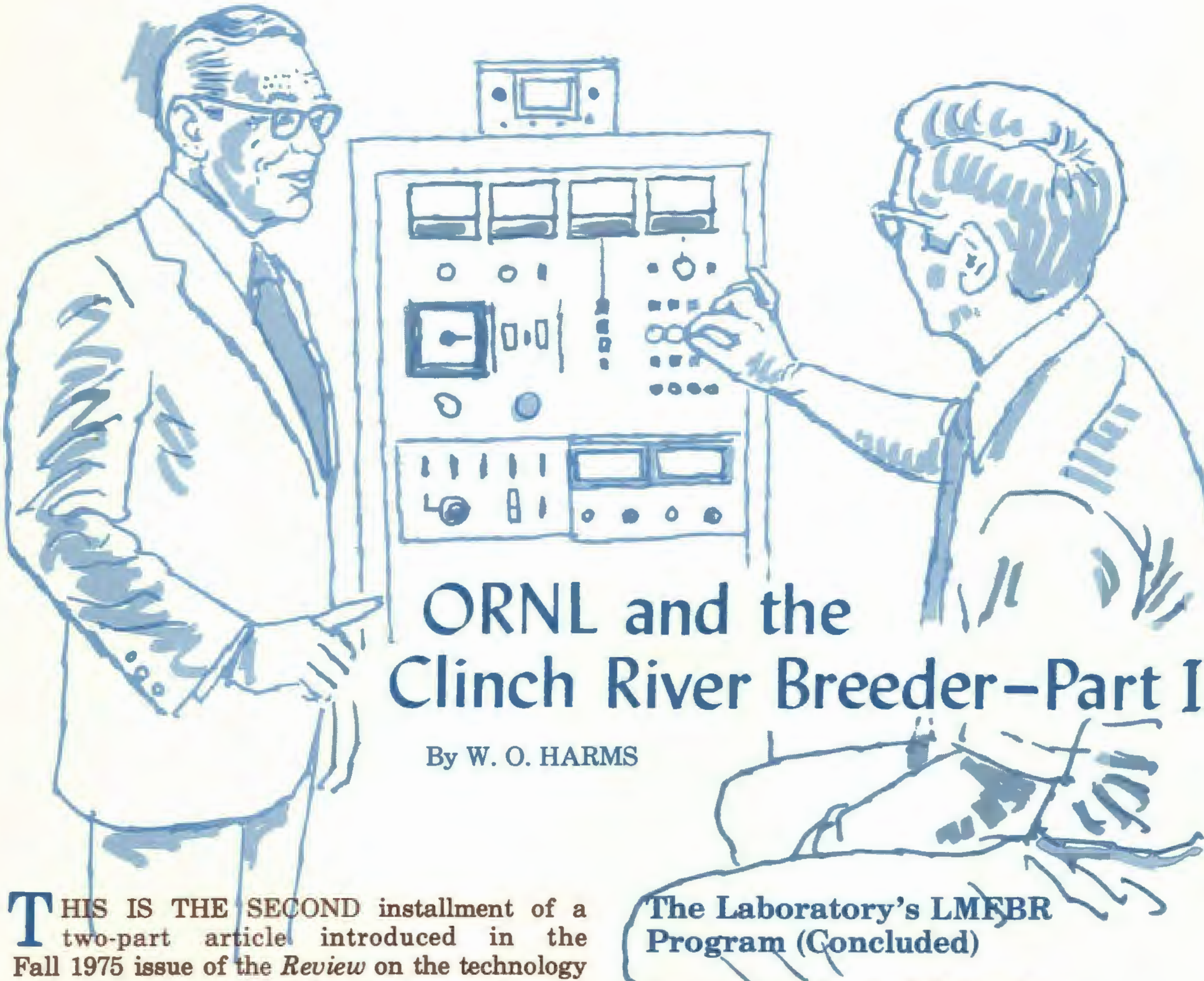
Hydrogen is currently used by industry for the manufacture of fertilizers based on ammonia (NH_3), production of petrochemicals, and organic synthesis and hydrogenation of oils and fats, according to a recent article coauthored by Bamberger and Jerry Braunstein. The article, "Hydrogen: A Versatile Element," appeared in the July-August 1975 issue of *American Scientist*. In it, Bamberger and Braunstein contend that hydrogen may be used in the future for energy transmission; coal liquefaction and gasification; reduction of iron ore to produce steel; fuel for industrial furnaces, domestic appliances, and transportation; and energy storage (using electricity to produce hydrogen when demand for power is down).

Bamberger says that the most important use of hydrogen in the near future will be for making ammonia, which is vitally needed for manufacturing fertilizers in a world faced with increasing food shortages. "About 90% of hydrogen used to make ammonia comes from natural gas, and we are running out of that," says Bamberger.

Another important use for hydrogen in the near future will be for the production of steel, Bamberger contends. Steel is made by removing oxygen from iron oxide ores by reaction with coke. However, coke is becoming increasingly costly, making hydrogen appear more attractive economically as a reductant for iron. Thus, the day may come when it would be feasible to locate hydrogen-producing facilities adjacent to steel manufacturing plants.

Hydrogen is a clean fuel because it burns by reacting with oxygen, producing harmless water vapor. It could be used as a fuel for jet aircraft or for making methanol to mix with gasoline to fuel automobiles. It can be transmitted safely by pipeline for use as fuel for industrial furnaces and for heating homes and commerical buildings. Hydrogen is also needed for coal gasification and liquefaction, processes that require the addition of large amounts of heat and hydrogen to coal.

Like other sources of energy, hydrogen is not perfect. It can be a hazardous explosive when ignited in the presence of oxygen. When hydrogen is burned as an automobile fuel, the exhaust may contain traces of hydrogen peroxide, which, although a health hazard, can be dealt with easily. A third problem is that hydrogen can embrittle metals and alloys used in containers and pipelines (HEE, or hydrogen environment embrittlement). But Bamberger sees these as technical problems that can be overcome without investing too much money, thus making the use of hydrogen economical in the long run.



ORNL and the Clinch River Breeder—Part II

By W. O. HARMS

THIS IS THE SECOND installment of a two-part article introduced in the Fall 1975 issue of the *Review* on the technology and safety research and development under way and planned at ORNL in support of the country's Liquid Metal Fast Breeder Reactor (LMFBR) Program and on the relationship of this effort to the Clinch River Breeder Reactor Plant (CRBRP) Project.

Background information, including a brief description of the CRBRP and its organizational structure, was presented in Part I along with detailed accounts of the program segments on materials, high-temperature structural design, and advanced fuels and absorbers, which constitute about one half of the Laboratory's total LMFBR Technology and Safety Support Program. The program segments on instrumentation and controls, physics, and safety and core systems are covered in this final installment. The total program framework showing the various technical areas and tasks is presented in diagram form for reference purposes in the Fall issue.

The Laboratory's LMFBR Program (Concluded)

Instrumentation and Controls

Success of the CRBRP and subsequent commercial LMFBR plants will depend upon a well-conceived, -designed, and -executed control and protection system for orderly and safe operation. The tasks of this ORNL program segment, directed by Les Oakes of the Instrumentation and Controls Division, are providing important input to this end.

Surveillance and Diagnostics. This task produces tools for continuously monitoring the plant for any departures from normal performance and for clarifying such possible deviations by special diagnostic measurements. The measurement schemes being developed by Bert Ackermann, along with Bob Kryter and John Mihalczo, include systems for

- delayed neutron triangulation for detecting and locating failed fuel elements;

- subcriticality measurements;
- monitoring for at-power reactivity anomalies;
- noise signature analysis and automated pattern recognition.

The delayed neutron triangulation system, if demonstrated to be reasonably accurate, will be attractive for commercial reactor applications and less expensive and simpler to implement than the "gas-tagging" method currently adopted for both the FFTF and the CRBRP. The triangulation system uses signals from neutron detectors located near the exit junctions where the three primary sodium coolant circuits connect with the reactor vessel. If failure occurs in any fuel subassembly, the delayed neutrons from certain leaked fission products that enter the sodium pass the detectors at each of the coolant exit ports. By triangulating the times of arrival of the streams of delayed neutrons at these detectors, it is possible to locate the "failed" fuel subassembly quickly and with accuracy. It is apparent that for this method to be feasible there must be less than complete mixing of the sodium coolant in the upper plenum of the reactor vessel; such feasibility has been demonstrated for the FFTF reactor system.

To guard against accidental criticality, we need to be able to measure the extent to which a nuclear reactor is subcritical during the initial fuel loading operation and also during subsequent reloadings. At ORNL, engineering support has been provided for the CRBR in the planning, analyzing, and testing of the capability for monitoring subcriticality with proposed low-level neutron flux monitors. In addition, for determining the level of subcriticality during initial loading of the fuel, special measurement methods employing californium-252 have been evaluated.

Methods for monitoring at-power reactivity anomalies are important for early detection of failures and anomalous behavior of reactor components and systems. A slow variation in predicted reactivity at steady power operation can indicate the existence of a safety problem; this anomalous reactivity (i.e., any unexplained change in the process of the nuclear chain reaction) may return at a rate that cannot be handled by the plant protection system. To preclude such an event, a reactivity monitoring system has been proposed for use during startup and power range operation, and experimental and analytical support has been provided by ORNL for the design and implementation of this system for the CRBRP.

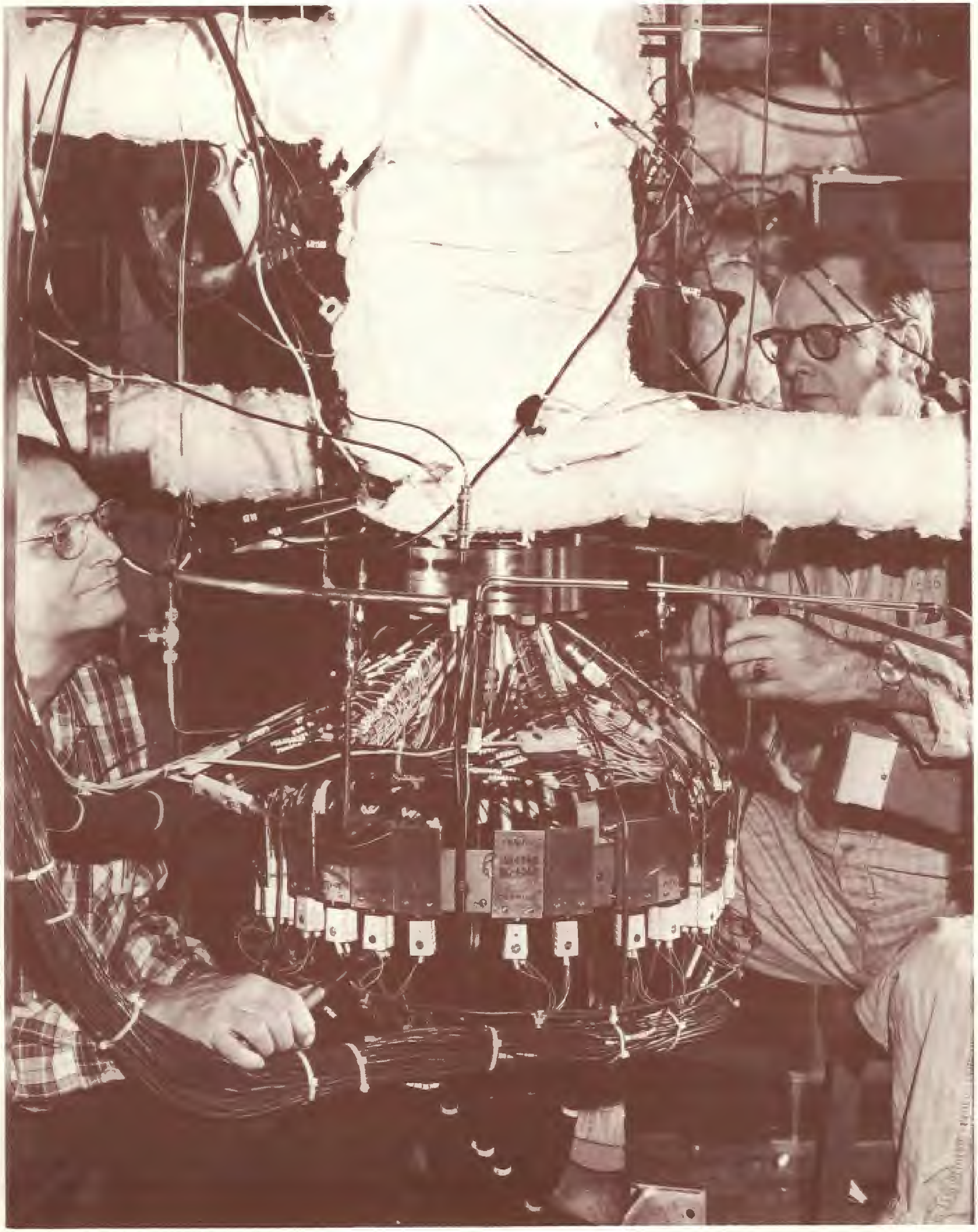
Robert Guice (l) and Edward Pollard (r) making final instrumentation connections on an electrically heated fuel-simulating experimental assembly installed in the Fuel Failure Mockup Facility. Nineteen power lines and nearly two hundred thermocouple leads are shown. Sodium flow and temperature distributions in LMFBR fuel assemblies are investigated in this facility under a wide range of normal and accident conditions.

A noise signature surveillance system and an automated pattern recognition system also are being developed for use in the detection of anomalous performance and incipient failure of reactor components and systems. Noise signature analysis works like an electrocardiogram does for a human being. In automated pattern recognition, a computer, programmed to learn all the normal noise signature patterns, is used to detect any variations that might indicate anomalies in reactor behavior.

Related to this task in the ORNL program is the development of neutron sensors for high-sensitivity and high-temperature application under Vic Paré. In EBR-II testing, a development model has worked satisfactorily at 400°C, sustaining radiation equivalent to three years of operation in the FFTF reactor. Ultimately, it is planned to extrapolate this design to 590°C operation.

Temperature Sensors. Determination of the thermal power level of a nuclear reactor is dependent on measurement of the temperature change in the coolant from inlet to outlet and the rate of coolant flow. Temperature measurement devices in the primary system of LMFBRs have to operate under far more severe environmental conditions than those in water-cooled reactors. Bob Shepard and Meyer Herskovitz are developing temperature sensors that can respond fast enough to measure significant core exit temperature variations; they are also determining the long-term stability of platinum resistance thermometers for use in primary sodium temperature measurements and are providing a complete procurement service for high-reliability Chromel/Alumel thermocouples now being used in all aspects of the national LMFBR program.

An important development in this task has been the demonstration of a technique based on the Johnson Noise Thermometer concept, which



provides an absolute measure of temperature that is not subject to drift or decalibration in a reactor environment. Cas Borkowski and C. V. Blalock developed a thermometer system in which temperature is determined by measuring the thermal noise power spontaneously generated in a sensing resistor made of rhenium. The Johnson Noise Thermometer concept makes use of the principle that the noise power generated in a resistor is proportional to temperature and independent of the magnitude of the resistance. This latter property makes the concept particularly attractive for application in reactor environments in which transmutation effects may significantly alter the resistance of the sensing element.

Shutdown and Control Systems. Steve Ditto and John Anderson are working directly with the CRBRP designers in an advisory capacity to transfer applicable parts of the Laboratory's reactor instrumentation and controls technology to the CRBRP. With Paul Rubel, they are also providing technical support to the CRBRP reliability program to demonstrate that the CRBR has adequate shutdown response capability through (1) the application of classical system and component reliability methodology and (2) the development of methods for more accurately quantifying and coping with the relatively elusive common-mode failure mechanisms.

Physics

The objective of the physics effort is to provide accurate nuclear data (such as neutron cross sections) and experimentally verified analytical methods for both core physics and shielding so that LMFBRs can be designed for optimal breeding performance, safety, and economics. All the ORNL tasks for this part of the program, which is managed by C. E. Clifford of the Neutron Physics Division, are directly related to the CRBR design.

Analytical and Experimental Shielding. The shielding analysis effort under Ward Engle of Fred Mynatt's section is in direct support of the CRBR design, and close communication is maintained with the project design team. This activity interacts extensively with the shielding experiment analysis work led by Dick Maerker so that the analytical methods developed and the data used in the shielding design calculations can be verified on a timely basis. The work includes the evaluation of uncertainties in shielding design calculations by means of integral experiment analysis and the propagation of uncertainties from basic data by sensitivity analysis.

The basis for the analytical shielding work is an interacting set of computer codes that have been developed for predicting neutron and gamma-ray transport, both in deep-penetration shields and in complex-geometry systems. These codes—ANISN, DOT, MORSE, AMPX, and SWANLAKE (a sensitivity code)—have become well known in the worldwide shielding community. Calculations using these codes in support of the CRBR design provide for design flexibility, capital cost savings, and, best of all, shielding design accuracy and adequacy.

The experimental program is carried out under Clifford's direction at the Tower Shielding Facility where quantitative assessments can be made of the ability of various shield materials and configurations to attenuate nuclear radiation of the type generated in LMFBR cores. A specially designed small nuclear reactor there serves as the source of the nuclear radiation required for the experiments.

The program in support of the CRBR includes experiments to evaluate

- radiation heating (i.e., the heat generated in shielding materials when exposed to CRBR core irradiation);
- deep penetration neutron transport in stainless steel and sodium;
- the effect on shielding requirements of storing spent fuel elements within the reactor vessel;
- neutron streaming in the complex labyrinth formed by the intermediate-heat-exchanger pipeways and in the nitrogen-filled cavity adjacent to the reactor vessel;
- secondary gamma-ray production and transport in the reinforced concrete used as a reactor shield and structural material;
- the adequacy of low-level neutron flux detectors outside the reactor vessel for subcriticality measurements during reactor shutdown periods.

Important to the total ORNL shielding effort, including its relationship to the CRBRP, is Betty Maskewitz' Radiation Shielding Information Center where shielding information—including nuclear data and computer technology—is acquired, organized, and distributed as a national technology resource. In addition, computer codes and cross section libraries are evaluated, tested, and improved. Assistance and advice in implementing the best technology available is provided to engineers throughout the nuclear community. As a measure of the magnitude of the total RSIC operation, more than 2700 separate letters of request were processed in 1974, with an increase in 1975 of about 10%.

Reactor Methods and Sensitivity Analysis. Support for the CRBR core physics analysis is provided in this task. This work, mainly the responsibility of George Flanagan, includes

- design support analysis and integral experiment design and analysis for the low-level-flux-monitor system which employs ex-vessel detectors;
- analysis of complex core physics problems such as the reactivity effect of fuel-assembly bowing caused by thermal expansion interaction with the core restraint system;
- evaluation of criticality problems in ex-reactor fuel storage;
- analytical problems concerned with monitoring the initial fuel loading.

Calculations of complex three-dimensional problems associated with the analysis of critical experiments and core design are also performed. The diverse advanced techniques available at ORNL are used to complement the design-oriented (i.e., less complicated) methods used by designers.

Cross-Section Measurements and Evaluations. The nuclear data used for the design of the CRBR are derived from the Evaluated Nuclear Data File (ENDF). Version IV of this file, which is now being tested against a wide selection of critical experiments, will form the main base for the CRBR design. Early design studies used Version III. Version V, which will be available in about 1978, will doubtless be used to check the final CRBR design.

The nuclear data program at ORNL under Bob Peelle and Francis Perey has had a strong impact upon the ENDF. For example, data determined at the Oak Ridge Electron Linear Accelerator for uranium-238 have been combined with those from other parts of the world to form the accepted best capture cross-section estimates for use in LMFBR core designs. The objective here is to determine as accurately as possible the probabilities that neutrons from the fissioning plutonium fuel will be captured by the uranium-238, principally in the blanket, for the breeding of more plutonium. The ORELA-based information has played a dominant role in the total evaluation process for plutonium capture and fission. In addition, the ORNL group has led the way in estimating and making available uncertainties and correlations in data sets. These correlation estimates are essential to evaluation of the nuclear performance of the CRBR and subsequent commercial LMFBR plants.

Safety and Core Systems

This program segment is managed by Mario Fontana of the Reactor Division, but the work is performed in three other divisions as well—Instrumentation and Controls, Neutron Physics, and Chemical Technology. This effort represents an important part of the national LMFBR safety program, the purpose of which is to develop that base of understanding and data that will give assurance that the hazardous material associated with the fission process—plutonium and fission products—will not reach the environment and the public. It is addressed to the second and third levels of safety that comprise the "defense-in-depth" approach to reactor safety. These levels are (1) the prevention of accidents in the first place through integrity of design and quality assurance; (2) protection against accidents that could lead to damage of the core; and (3) assurance that even the extremely unlikely occurrences that could damage the core do not hurt anyone. (Essentially all the other segments of the Laboratory's LMFBR technology support program are addressed to the first level of safety.)

Core Thermal Hydraulics (Fuel Failure Mockup Facility). The principal aim of this task is to provide detailed knowledge of the temperature and flow distributions in LMFBR fuel subassemblies under normal and abnormal operating conditions. This information is important for understanding the behavior of the reactor core with respect to

- subassembly distortion as it affects the design and functioning of the core restraint system;
- development of hot spots;

- effects and detectability of partial blockages resulting from inlet debris or fuel pin failure and propagation;
- temperature and flow in the natural circulation mode (i.e., without the pumps);
- void (bubble) growth during sodium boiling and limits to cooling capability during power/flow mismatch conditions that give rise to boiling.

The work is centered in the Reactor Division, the analytical portion under John Wantland and the experimental phase in the Fuel Failure Mockup (FFM) Facility under Paul Gnadt of Bob MacPherson's section. Dwayne Fry of the Instrumentation and Controls Division is in charge of development and implementation of methods for detecting anomalous thermal-hydraulic behavior in FFM experiments through analysis of thermocouple signal noise, pressure-transducer response, and acoustic signals using hydrophones.

The FFM is a large-scale, pumped sodium loop in which LMFBR fuel subassemblies are simulated by using electric heaters. These heaters

This newly acquired, minicomputer-based Fourier analyzer is essential to many of the LMFBR development areas: subcriticality measurement, reactor surveillance and diagnostics, and high-temperature neutron sensor design and proof-testing, among others. It has been transported to several experimental sites for on-line trouble shooting and is also useful for laboratory data processing. Gathered around the digital genius are, l to r, John Mihalczo, Bob Kryter, and Vic Pare.

have the same dimensions, configuration, heat flux, heat generation rate, and temperature capability as actual fuel pins in LMFBR cores. The heaters are developed jointly with private industry. So far, relatively small subassemblies containing 19 fuel pins and up to 190 thermocouples have been used. The power generation and heat rejection capability of the FFM is being increased to 2 MW so that experiments can be performed on larger subassemblies. An adjunct to the experimental effort has been a larger, dynamically similar water mockup facility for (1) investigation of local heat transfer and coolant velocities in the vicinity of the blockages by using aqueous salt solutions and (2) development of theoretical models for applying the results to the analysis of sodium-cooled subassemblies.

Of this work, the base thermal-hydraulics experiments pertinent to the CRBR fuel design concept have demonstrated

- absence of significant hot spots during normal operation;
- acceptability of operating under the reduced flow rate that would result during operation of "pony motors" (relatively small auxiliary pump motors that operate on emergency power);
- possibility of reducing flow streaming near the inner wall of the hexagonal subassembly containers through modification of the wire-wrap spacer configuration, thereby enhancing the breeding performance; and
- validity of Wantland's theoretical model as represented in his computer code for predicting flow and temperature distribution in the subassemblies.

The safety-related investigations have demonstrated

- tolerance of fuel subassemblies to inlet flow blockages that are many times larger than any obstruction that could pass through the inlet flow slots;
- acceptability of credible heated zone blockages (this, an extrapolation of water mockup tests, will require confirmation in sodium tests, but the indication is that in-core blockages of up to 60% of the cross-sectional area of the subassembly can be tolerated);
- capabilities of the subassemblies to sustain stable local boiling without failure;
- ability to detect boiling by acoustic means.

Results of the blockage tests figure prominently in the CRBRP Preliminary Safety Analysis Report. Future plans include, in addition to testing larger simulated subassemblies, experiments to determine the dynamic voiding behavior under loss-of-flow conditions and the regimes of stable boiling for evaluating the consequences of an unlikely loss-of-pipe-integrity accident.

Aerosol Release and Transport. This task is supported by the Reactor Safety Research Division of the Nuclear Regulatory Commission. Tom Kress of the Reactor Division is in charge, and portions of the analytical and experimental work are conducted by members of Tony Malinauskas' section in the Chemical Technology Division. The object is to determine the quantity and characterize the behavior of aerosols containing fuel, fission products, transuranic elements, and sodium that could be generated and released in the very unlikely event of a core-disruptive accident (CDA). This work clearly is associated with the third level of safety mentioned above, and information developed in it will be very important if for licensing purposes it becomes necessary to design the CRBR or subsequent commercial plants on the basis of a CDA. Initiating events that could lead to a CDA are (1) simultaneous loss of all pumps and failure of the shutdown systems ("loss of flow without scram") and (2) transient overpower resulting, for example, from some sort of catastrophic mechanical failure such as ejection of a control rod or failure of the core support structure or core restraint system. The postulated consequence would be melting of the fuel subassemblies, with the development of a rapid power excursion leading to temperatures and pressures that would reverse the transient by hydrodynamic disassembly of the core. The question then arises as to the amount, properties, and behavior of the hazardous aerosol that would be released and, if it gained access to the secondary containment, how much, if any, could possibly leak out.

In experiments performed in this program, aerosols characteristic of those released in a CDA are generated in nonnuclear systems by vaporizing oxide fuel, stainless steel, and sodium by electrical capacitor discharge. The feasibility of this technique has been demonstrated by using a bank of capacitors in a facility at Arnold Engineering Development Center in Tullahoma, Tennessee, that was designed initially for generating shock waves for use in wind-tunnel experiments.

Neutronics of Disrupted Core. This relatively new task under George Flanagan of the Neutron Physics Division has a twofold purpose: (1) to test and verify neutronics methods by means of existing computer codes for analysis of disrupted LMFBR cores and (2) to develop a three-dimensional neutronics capability based on Monte Carlo techniques for use in analyzing CDAs in large cores where accident geometries might not be reasonably approximated with two-dimensional codes. This work can contribute significantly toward improved estimation of the total and maximum energy release in CDAs.

Data Base for Safety Codes. This is another recent undertaking by the Neutron Physics Division. Fred Mynatt is in charge of the effort to define, develop, coordinate, and maintain a centralized data base for LMFBR safety computer codes, including those used for the CRBR. As these codes, which are widely used in accident analysis, have become increasingly more complex and widely distributed, the need for the use of the best evaluated data, use of consistent data between codes, and maintenance of an up-to-date data bank has become urgent. These codes require input data ranging from high-temperature materials properties and thermophysical properties to biological dose factors and meteorological information. The system under development here will perform the functions of collection, evaluation, and dissemination of data for the entire national LMFBR safety program.

In brief summary, the Laboratory's relationship to the CRBRP project has been and continues to be both significant and important. Although our LMFBR work is oriented more toward "technology" than "direct design," the results of it have been or will be applied to the design, operating philosophy, and licensing considerations for the CRBRP in a manner similar to that which has been followed for the FFTF. To be sure, the technology to be applied in the design and early operation of the CRBRP largely is that which exists today; important exceptions in areas where ORNL is involved are structural design methods and materials properties, shielding design, surveillance and diagnostics, and safety (the latter principally in consideration of hypothetical core disruptive accidents).

For the next decade at least, the LMFBR program will be geared toward commercialization of the concept by the 1990s. To this end, most of our research will continue to be aimed at enhanced breeding performance, economics, safety, and reliability. The results of some of these long-range efforts (e.g., the development of advanced fuel systems based on qualified swelling-resistant cladding and duct alloys) may find direct application in the CRBRP several years after it has been in operation.

The Laboratory is committed with a high level of dedication to the cause of the Clinch River Breeder and the ultimate commercialization of LMFBRs. This subject was addressed in a recent information meeting by Herman Postma, who put it this way:

"The presence of the CRBRP Project in Oak Ridge presents both a tremendous opportunity and an obligation to the Laboratory. As a chief demonstration of the nation's highest priority nuclear program, the Clinch River Breeder Reactor Plant gives us the opportunity to be intimately involved with a crucial national program, to see first hand the fruits of work done years ago at the Laboratory, and to note the continuity of an important technology from the research bench to commercialization, as well as to focus our own directions toward those problems of great importance. But along with that opportunity there is a strong obligation to make the project succeed. Whatever facilities, resources, and capabilities the Laboratory possesses need to be applied when requested; and we must be available instantly for problem solving. The Laboratory has a commitment to do whatever is possible and necessary to aid in the success of the CRBRP and to show how the large investments in the past in R&D can be made to pay off in a realistic and rapid manner.

"As we have done many times in the past, we can again show how the name Oak Ridge can mean success, and the Laboratory looks forward to aiding in the early success of the CRBRP Project."

Awards and Appointments

William A. Arnold has been awarded the Charles Reid Barnes Life Membership by the American Society of Plant Physiologists for his contributions to the understanding of photosynthesis.

William L. Marshall has been selected to be a member of the standards working group of the International Association for the Properties of Steam. He has also been appointed member of the American Chemical Society's newly formed National Steering Committee on High School Teacher Training, as well as member of the National Council of ACS. Elected as alternate member of the National Council is **H. Fritz McDuffie.** Secretary of the East Tennessee Section of ACS is **J. Kenneth Poggenburg.**

T. A. Carlson will chair the Gordon Research Conference on Electron Spectroscopy next July.

George D. Kerr and **J. A. Auxier** have been appointed Consultants to the Radiation Effects Research Foundation.

Jerry Braunstein has been selected as cochairman of the International Symposium on Molten Salts to be held in conjunction with the Electrochemical Society Meeting in Washington, D.C., next May. He has also been invited to be Course Director for a three-day Short Course on Molten Salt Technology at the Center for Professional Advancement in New Brunswick, N.J., also in May.

Jeanne S. Carver has been appointed News Editor for the *Health Physics Journal.*

M. K. Wilkinson has been elected to the Executive Committee of the Southeastern Section of the American Physical Society for a four-year term.

G. S. Hurst has been elected to the Main Committee of the Gaseous Electronics Conference, sponsored by the American Physical Society; he has also been appointed Consultant to the National Science Foundation's Committee on the Use of Accelerators for Atomic Physics.

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Neutron counters are used inside an LMFBR to monitor such parameters as low-level neutron flux (subcriticality) and delayed neutrons that signal failed fuel. Because they must operate at high temperatures (up to 650°C), they are first tested in a furnace. Here Bob Kryter, John Mihalczo, and Vic Paré, l to r, check out just such a furnace. *(See article, p. 37.)*