REVIEW

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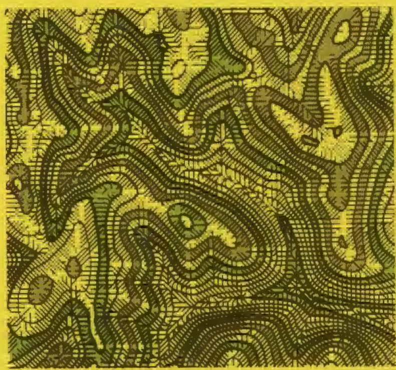
OAK RIDGE NATIONAL LABORATORY · FALL 75



THE COVER: Here is an aerial view of the Walker Branch Watershed as seen by the computer. The curved lines are isobars designating altitude, and the straight lines indicate direction of water flow. For a convincing statement of the value of this natural laboratory to the energy decision-makers, read the article by Gray Henderson and Dale Huff on page 27.

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REVIEW

Volume 8 Number 4 **Fall 1975**

FEATURES

OAK RIDGE NATIONAL LABORATORY

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

Bill Harms has undertaken to describe the LMFBR Program at the Laboratory and its relationship to the forthcoming Clinch River Breeder Reactor Plant nearby. Because the scope of the program is such that one article cannot do it justice, this is the first of two articles, the second of which will appear in the Winter 1976 issue. In this account he discusses the material research and development, the structural design methods effort, and the work on advanced fuels and absorbers. Harms, director of the LMFBR Program, holds the Ph.D. in physical metallurgy from the University of Minnesota. He came to the Laboratory in 1953 as a metallurgist and has been managing the LMFBR effort since 1968, when it was but a small fraction of its present breadth. Here he exchanges grins with Bill Foster, of the Metals and Ceramics Division, as the latter adjusts the controls on a device that detects flaws in welded joints of steam generators with x rays.

ORNL and the Clinch River Breeder—Part I

By W. O. HARMS

With plans now materializing for the beginning of construction next year and operation in the early 1980s of the Clinch River Breeder Reactor Plant (CRBRP) on a site less than 5 miles from the Building 4500 complex of the X-10 area, many questions have been asked in and around the Laboratory as to just what the role of ORNL is in this project. Such questions as, Is the Laboratory now or will it be involved in

- the design of the plant, particularly the reactor and balance of the nuclear steam supply system?
- the fabrication, installation, and inspection of the reactor and plant components (e.g., reactor vessel, valves, piping, heat exchangers, pumps, instrumentation and control systems)?
- the fabrication or processing of the fuel elements?
- safety analyses and licensability considerations?
- the operation of the plant at any stage, from approach to criticality through full-power operation?

The answer to each of these questions is, "Yes," with qualifications here and there regarding the kind and degree of involvement and, where it is more direct in nature, the levels of responsibility. A broader role is anticipated as plant construction gets under way and plans for the operational phases materialize. This commentary is set within the framework and context of a listing and brief description of the tasks in the Liquid-Metal Fast Breeder Reactor (LMFBR) Technology and Safety Support Program at ORNL—past, present, and proposed. It does not include LMFBR Fuel Recycle work, which recently received program status at the Laboratory under W. D. Burch.

First, however, to provide perspective for these considerations, we offer a few facts and comments about the CRBRP and its important role in the nation's total LMFBR Program.

The Clinch River Breeder

The CRBRP is a principal step in our national LMFBR Program, which aims at building reactors to breed plutonium as nuclear fuel to help stretch our nation's dwindling uranium supplies. The long-term objective of this program is to establish the technological and engineering base, with industrial involvement, for a competitive commercial breeder industry in the 1990s. The demonstration plant stage is necessary in the development of a power plant concept; it is that stage at which utility companies become deeply involved in proving the effectiveness of the concept as an integral part of the electric utility system. Thus, the objective of the CRBRP is to demonstrate the technical performance, reliability, maintainability, safety, environmental acceptability, commercial licensability, and economic feasibility of an LMFBR central station electric power plant *in a utility environment*. Corollary to this main goal are the objectives of focusing the development of systems and components and developing industrial and utility capabilities to design, construct, operate, and maintain an LMFBR plant.

The CRBRP design net electric power of 350 MWe (975 MWt) is between the 400-MWt Fast Flux Test Facility (FFTF) reactor at Hanford, Washington, for which construction is scheduled to be completed in 1978, and proposed near-commercial plants (1000/1500 MWe, 2500/3800 MWt). The primary system will include three loops or plumbing systems carrying the coolant, liquid sodium; the components of these systems are limited in size by consideration of the technical risk inherent in extrapolation from the base size represented by the FFTF components. The CRBRP components will be about 2.5 times as large as those in the FFTF (325 MWt/loop for CRBRP as compared with 133 MWt/loop for FFTF); a further increase in size of three to four times will be required for commercial plants.

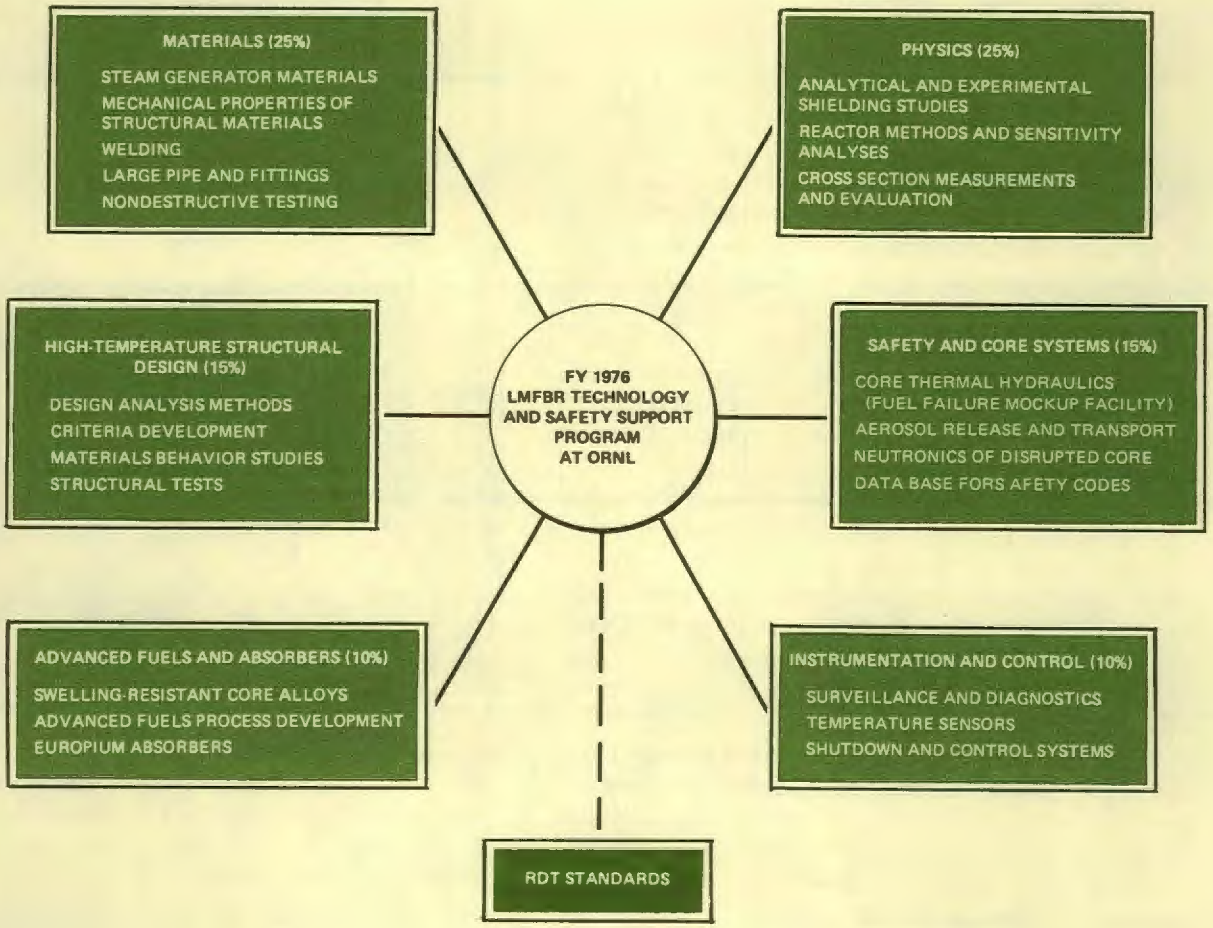
The management structure for the project is relatively complex because of the involvement of ERDA (which has lead management responsibility), three reactor manufacturers, architect-engineering firms, public and private utilities, the national laboratories, and a multitude of subcontractors and component suppliers. National laboratories are not directly involved in the management function, which is to be performed by a single, integrated organization with offices in Oak Ridge, composed of both ERDA and industry/utility personnel. A project steering committee, consisting of one representative each from ERDA, Commonwealth Edison, and TVA, serves as a tripartite review board.

Project Management Corporation, a nonprofit organization formed especially for this project, represents the utility industry in the day-to-day project work with the responsibilities for project monitoring, dissemination of information, arranging participation by utility personnel, and management of utility funds provided for the project through a second nonprofit group, the Breeder Reactor Corporation (BRC). Through BRC, more than 700 electric systems from the public, private, municipal, and cooperative sectors of the electric power industry have pledged over \$257 million toward construction of the CRBRP—the largest industry commitment ever made for a single energy research and development project. The entire project is estimated to cost about \$1.8 billion, including plant construction and investment, associated research and development, plus the operating costs through a five-year demonstration period. The balance of the funding is to be supplied by ERDA. Of this total estimated amount, \$1.2 billion represents actual plant investment costs, and \$600 million is associated with related R&D and operating expenses.

The Laboratory's LMFBR Program

Development work in support of the LMFBR concept began actively at the Laboratory in the mid-1960s with limited efforts in fuel cladding and structural materials development, shielding and cross-section studies, and fuel processing development. In FY 1966, the operating budget for the ORNL effort was about \$2 million. It went from a four-fold increase by 1968, when the Office of LMFBR Programs Coordinator was created, to an overall six-fold increase by 1971 when a formalized management structure was established for carrying out this multidivisional effort. The technology and safety support effort is now funded at about \$13 million, corresponding to about 160 professional and technical support man-years. The participating research divisions are

Diagram showing the areas of development pursued at ORNL in the LMFBR Program. The accompanying article will cover materials, high-temperature structural design, and advanced fuels; the remaining areas will be discussed in a subsequent article by Harms.



Instrumentation and Controls, Metals and Ceramics, Neutron Physics, and Reactor.

About one-half of the total effort is in the broad areas of materials and structural design, encompassing structural alloys to be used outside the reactor (25%), design methods and criteria (15%), and advanced fuels and control-rod materials (10%). Next in size are the program segments on physics at 25%, safety and core systems at 15%, and instrumentation and controls at 10%.

The RDT Standards task, which is generally applicable to all reactor concepts, is included because the current major emphasis is on the LMFBR concept. Management of this national effort is centered at ORNL under Russ Schmidt of the Engineering Division. Heavy interaction with CRBRP component design and procurement exists and will continue throughout the construction and preoperational stage.

Materials

The tasks listed for this program segment deal exclusively with structural materials used outside the reactor core itself, with emphasis on the primary and secondary heat-transport systems. They are all closely interrelated and interact strongly with the high-temperature structural design effort. Pete Patriarca of the Metals and Ceramics Division is program manager.

Chuck Brinkman, right, shows Jim Weir, M&C Division director, a readout of cyclic stress-strain plots obtained as part of the program to test LMFBR structural alloys for mechanical properties.

Steam Generator Materials. In the CRBRP steam generator, liquid sodium at around 500°C (930°F) will transfer its heat into low-alloy steel tubes containing water to make steam for driving the turbines that, in turn, generate the electricity. The consequences of leaks leading to significant sodium-water reactions could be very serious from the standpoint of plant performance and availability. Plant shutdowns for isolation and repair of regions affected by the corrosion and erosion associated with such reactions simply cannot be tolerated if a successful demonstration of the LMFBR concept is to be achieved. Through this task, the Laboratory has been assigned the primary responsibility for conducting a broad-based development program of materials evaluation, fabrication methods development, and nondestructive testing development for the CRBRP steam generators, as well as for more advanced concepts.

Gerry Slaughter is in charge of the work that covers corrosion, welding, mechanical properties, and nondestructive testing (primarily for flaws in welds). Jack DeVan and John Griess are determining corrosion allowances and water chemistry requirements under conditions prototypic of the CRBRP. They are trying to ascertain how thick the ferritic steel pipes in the steam generator system should be to sustain corrosion losses and still retain sufficient strength. There is a strong constraint on tube thickness, however, because designers desire as small a temperature gradient as possible between the sodium on one side of the tubes and the water on the other. To help control the amount of corrosion, the water (the Clinch River in the case of CRBRP) will be chemically purified and deaerated to remove harmful impurities. The corrosion program is aimed at determining the chemistry requirements for the water and sizing the purification equipment so that repair of minor leaks in the steam generator can be postponed until normal shutdowns for maintenance.

Artie Moorhead and Jim King are developing welding techniques for producing high-integrity, tube-to-tubesheet and dissimilar-metal transition pipe welds. A tubesheet is a thick metallic plate containing holes to which tubes for transporting water heated by sodium are welded. Dissimilar-metal transition pipe welds are required in the secondary heat transport system at the junctions between the ferritic steel pipes leading to and from the steam generators and the stainless steel pipes associated with the intermediate heat exchangers. The weld material must have properties intermediate between those of the two steels so that the welds can withstand the stresses introduced during both fabrication and operation without developing cracks leading to joint failure.

In a mechanical properties effort led by Chuck Brinkman, precise long- and short-term properties are determined for use in structural design. Bob McClung and colleagues are developing methods for vendors to use in nondestructive checks for flaws in tube-to-tubesheet welds during fabrication and for in-service inspection for possible flawed welds that could lead to leaks.

Mechanical Properties of Structural Materials. In addition to the work cited above for steam generator materials, the group headed by

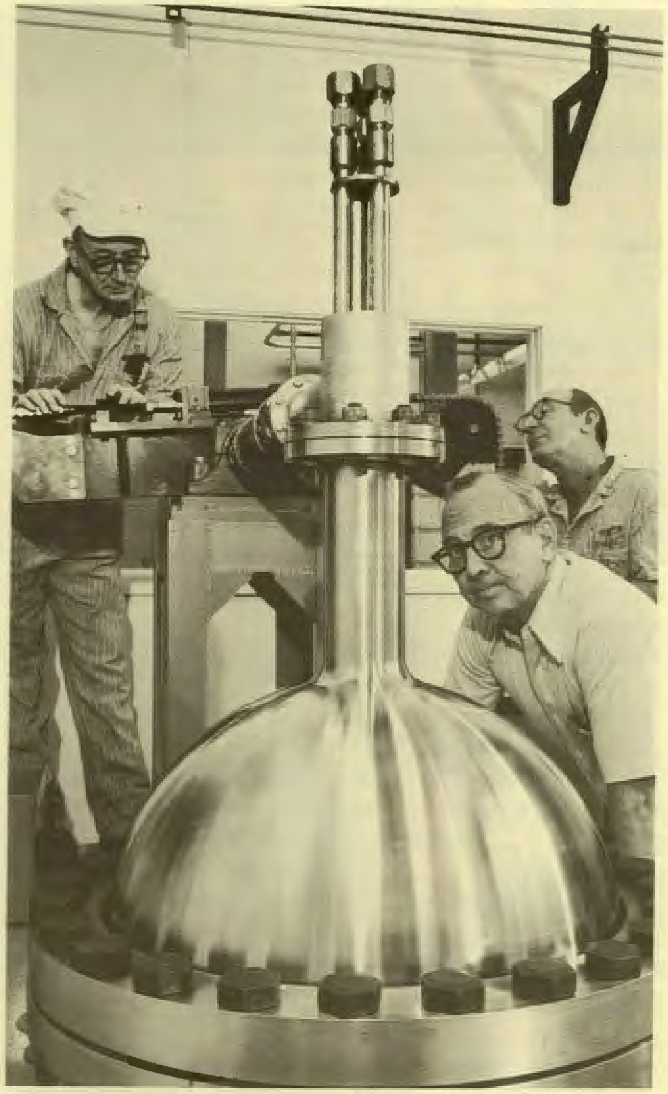
Pete Patriarca inserts a probe for introducing gamma-ray-producing isotopic pill into a tube to test for possible flaws in the joint between the tube and tubesheet. Bob McClung inspects this small section of tubesheet, a prototype of the intermediate heat exchanger of the CRBRP.

Brinkman is the principal source of evaluated high-temperature mechanical property data for CRBRP designers on the stainless steels to be used in the reactor vessel and sodium plumbing systems. This task also provides support for the structural design criteria and methods effort (described below), principally by assisting in the (a) generation of data leading to more precise mathematical descriptions of materials behavior under complex loading situations, including cyclic or alternating stresses (like those that occur during reactor startup and shutdown); (b) establishment of improved failure criteria (rules allowing one to predict with a reliable margin of safety when failure of the material is imminent); and (c) data generation and analysis for establishing realistic "design-allowable" stress levels, including allowances for the heat-to-heat variations in commercial alloys (the mechanical behavior of one batch or heat of stainless steel, for example, may vary significantly from that of a different batch).

Welding; Large Pipe and Fittings. These tasks under Gerry Slaughter represent the Laboratory's contribution to the CRBRP vessel and piping fabrication effort. Gerry's group has developed a stainless steel electrode containing controlled residual elements that produces unusually ductile weldments—that is, welded joints that stretch without breaking under stress at elevated temperatures. This type of electrode was used in actual fabrication of the FFTF reactor vessel. For the CRBRP, two additional commercial sources of this special type of electrode have been qualified, and an extension of the concept for use with other welding processes, including those required for piping, is being actively pursued. The automated pipe welding technique that was developed by this group, working with private industry, for the FFTF Project probably will be used in field construction of the CRBRP.

The CRBRP design calls for stainless steel piping 3 ft in diameter, and designs for commercial LMFBRs include piping as large as 4.5 ft in diameter. A state-of-the-art-and-technology study is now under way as part of this task to determine whether welded (as contrasted with seamless) pipe is to be recommended for these larger sizes. It is much less expensive to use welded pipe, but designers must be convinced that the mechanical behavior of the welded version is adequate. If the welded configuration is adopted, the expertise of this group will be employed in the development of a commercially adaptable process for producing welded pipe that will be compatible with the design methods and criteria used for seamless configurations.

Nondestructive Testing. Bob McClung and his staff have the responsibility for advancing the industrial nondestructive testing capability for LMFBR applications with emphasis on in-service examination, that is, evaluating the integrity of reactor components in the presence of sodium and in situations where there is limited accessibility. The effort encompasses the total base of nondestructive testing techniques, including radiography (a technique in which x rays detect welding flaws, for example), eddy currents (electrical currents, induced by magnetic fields to flow through metal, that become sidetracked by



Jim Corum, r., and Tom Hill examine a thermal-ratchetting test specimen consisting of a 2¼ Cr-1 Mo steel pipe welded to a type 316 stainless steel pipe. This specimen, which will be encapsulated in a furnace (part of which is hanging below the pipe), will be subjected to repeated thermal down-shocks [e.g., from 540°C (1000°F) to 370°C (700°F) at a rate of 17°C (30°F)/sec] in the Thermal Transient Test Facility. The strain gauges on the pipe will measure distortion of the specimen in response to the shock of the radically changing sodium temperatures. Data from such a test are expected to aid LMFBR designers, who must make sure that the reactor systems are built to accommodate changing sodium temperatures during reactor startup and shutdown.

Craftsmen B. E. Burdette, l., and W. A. Wilburn and engineer Malcolm Richardson, foreground, examine and adjust the nozzle-to-sphere test facility for the LMFBR program. This experimental facility will provide high temperatures and loadings to furnish realistic data for evaluating structural design methods for LMFBRs. The data also will enable the designers to assess the predictive capability of the computer programs used in designing system components.

cracks and thus cause perturbations picked up by monitoring devices), and ultrasonics (scanning metals for flaws by means of sound waves).

High-Temperature Structural Design

The objective of this task is to provide LMFBR component manufacturers with verified high-temperature structural design methods and criteria. Breeder reactor materials must be designed to withstand severe temperature transients, owing to the good heat transfer characteristics of the working fluid, sodium, as well as the high temperatures at which structural alloys creep (i.e., deform, or stretch permanently with the passage of time, under stresses that at lower temperatures would give rise only to recoverable elastic strains). Because of these temperature problems, the design methods and criteria for LMFBRs that are being developed under this task in the Reactor Division group headed by Jim Corum are far more complex than those already developed and used for light-water reactors. This group in the Reactor Division and Bob Swindeman in the M&C Division constitute the principal investigators. The results are used as a basis for industry-recognized codes and standards, improved component reliability and confidence levels, more economical and defensible design procedures, and an improved technological basis for licensing.

Examples of recent ORNL contributions that are affecting the CRBRP design process are inelastic (elastic–plastic and creep) analysis guidelines that are included in RDT standards and are necessary to implement ASME high-temperature code cases; computer programs and less expensive and less time-consuming simplified analytical procedures for industry use; improved simplified methods for evaluating ratchetting (continued growth or deformation under repetitive cyclic stress states) and creep-fatigue damage; and a basic set of high-temperature structural tests for verification of the analytical procedures.

Although progress in this important technological field has been rapid and effective over the past five years in a coordinated national effort led by experts at the Laboratory, much work remains to be done. If we are to obtain the necessary confidence and supporting evidence relative to the safety and long-term reliability of LMFBR systems (including the CRBRP) in the specified time frame, a substantial continuing effort is essential.

Advanced Fuels and Absorbers

The reference core design for the CRBR calls for uranium-plutonium oxide fuel, conventional (but slightly cold-worked) stainless steel for fuel cladding and core structurals, and boron carbide as neutron absorber material in the control rods (used for shutdown and for controlling reactor power levels). For the future commercial systems, improvements in or substitutes for these core components are highly desirable in the interest of enhanced breeding performance (higher breeding ratio and shorter doubling time) and reduced power costs. It is considered likely that some or all of these concepts, now under active development as part of Pete Patriarca's total fuels and materials program segment in the Metals and Ceramics Division, may be introduced in later core loadings of the CRBRP.

Swelling-Resistant Core Alloys. There has naturally been great incentive to develop to a commercial level an alloy that is otherwise compatible with the core environment, but which has much greater resistance to swelling from the effects of fast neutrons and also has higher creep strength than the current reference stainless steel.

To this end, a research team headed by Everett Bloom in Jim Stiegler's group has identified through heavy-ion bombardment studies a modified version of the reference alloy that is five to ten times as resistant to radiation-induced swelling. Use of the modified alloy would allow for a tighter core design with a larger volume fraction of fuel relative to stainless steel and sodium and reduced frequency of fuel element loadings. This alloy will be tested under actual fast reactor conditions and may be used in a later core loading of the CRBRP. (It is described in detail on p. 33.)

Advanced Fuels Process Development. A team in Ralph Donnelly's group has just this year begun work on the synthesis and fabrication of advanced ceramic fuel compounds—such as mixed plutonium/uranium carbides, nitrides, or carbonitrides—based on methods that would be optimally economic and compatible with a practical fuel reprocessing system. These advanced fuels would be superior to mixed oxides in that they would permit increased breeding performance. This advantage stems from the fact that, for these advanced fuels, atoms of uranium and plutonium are packed together more tightly, thereby allowing more fissions per unit volume than can be safely done with mixed oxides. Another reason is that the advanced fuels have significantly greater thermal conductivity than the mixed oxides. High thermal conductivity is an important property because the fuel could melt if the heat inside is not conducted away fast enough.

This group also is charged with evaluating the environmental impacts associated with a fuel cycle based on advanced fuels. Washburn and Len Bennett headed a Laboratory effort that provided such an evaluation for oxide fuels that was used by ERDA in its environmental impact statement for the LMFBR program.

Europium Absorbers. Ralph Donnelly's team is developing and evaluating control-rod materials based on the element europium for use as possible replacements for the reference boron carbide concept in LMFBRs. A disadvantage of the boron carbide rods is that neutron absorption in the boron compounds results in the production of helium and tritium gas; the helium builds up pressure, which shortens rod life; and the radioactive tritium diffuses through the rod and may contaminate other parts of the reactor. The advantage of europium is that it produces no helium and creates less tritium than the boron carbide rods. Because neutron absorbers based on europium are expected to have a longer life due to a slower burnout rate and the absence of helium pressure buildup, they may be cost-effective relative to the conventional concept.

As part of the ORNL development task, experiments performed at the EBR-II have demonstrated that europium oxide pellets exhibited acceptable swelling behavior and physical integrity after an exposure of 6×10^{22} neutrons/cm^2 at 700°C (1300°F).

(Part II will discuss the role of physics, the safety and core systems, and instrumentation and controls.)

Awards and Appointments

At the Tennessee Professional Photographers Association Convention in July, **Don Dudenbostel** received a trophy for Best of Show and ribbons indicating two First Awards of Excellence and four Second Awards of Excellence. He and **J. B. Richmond** were awarded plaques as membership to the Court of Honor, and Richmond received ribbons for First and Second Awards of Excellence.

The American Nuclear Society has appointed **Melvin Tobias** to the position of Associate Editor of *Nuclear Science and Engineering*.

Robert F. Limburg was elected president of the Knoxville–Oak Ridge Chapter of the National Association of Accountants.

Awarded to **C. C. Coutant** by the Sport Fishing Institute, a commendation award for his review of requirements and effects of temperature for Centrarchid basses given as a principal address at the Bass Symposium presented by the Institute this year.

Jerry Braunstein has been elected vice-chairman of the 1977 Gordon Research Conference on Molten Salts. He will also co-chair the International Symposium on Molten Salts at the meeting of the Electrochemical Society in Washington next May.

John S. Wassom has been named to the Editorial Board of *Mutation Research*, international journal on mutagenesis, chromosome breakage, and related subjects.

James C. White was elected Secretary of the Analytical Chemistry Division of the International Union of Pure and Applied Chemistry for the period 1975–79. He is currently secretary of the IUPAC Analytical Chemistry Division's Commission V.7, Analytical Radiochemistry and Nuclear Materials.

Selected to be one of four scientists representing the United States at the International Atomic Energy Agency Advisory Group Meeting on Transactinium Isotope Nuclear Data in Karlsruhe this fall is **Subramanian Raman.** The appointment, made with the concurrence of the U.S. State Department and ERDA, entails Raman's giving two papers on the subject of actinide waste problems.

Industrial Research has selected **Yok Chen** and **Marvin M. Abraham** as recipients of a 1975 "IR-100 Award" for one of the 100 most significant new technical products of the year for their development of a technique for growing large, totally transparent crystals of magnesium oxide, calcium oxide, and strontium oxide.

Newly elected Fellows in the American Physical Society are **Eugene Eichler** and **Curt Bemis**. **Clifford A. Burchsted** has been elected a Fellow in the American Society of Mechanical Engineers. Elected Fellow of the American Society for Nondestructive Testing is **Billy E. Foster.**

A Tribute to Isotopes

Isotopes at ORNL Go Full Circle

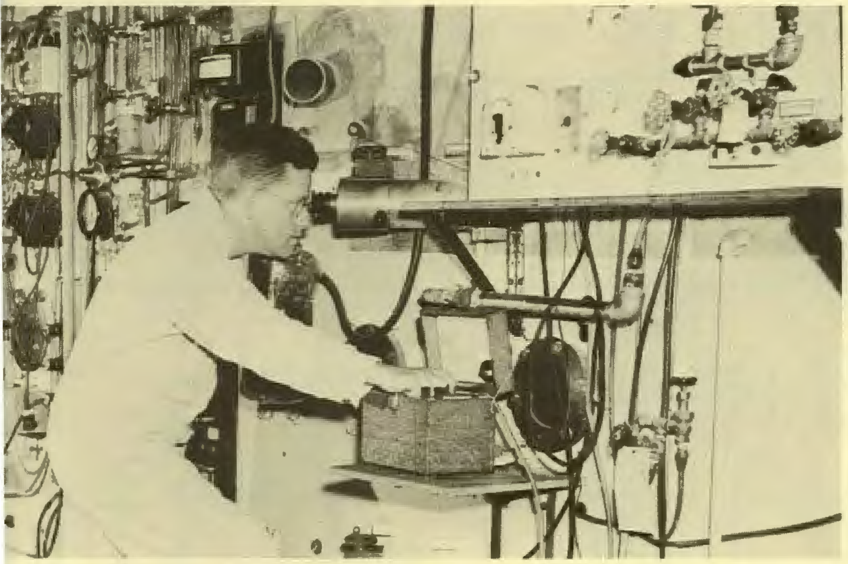
With the recent dissolution of the Isotopes Division and the assignment of its component parts to the Chemical Technology, Operations, and Solid State Divisions, an era has come to an end. Administratively, things are, to a considerable extent, back to where they were 30 years ago. Nevertheless, the impact of the isotope program through the years has been tremendous and will certainly continue to be of worldwide significance.

Since 1946, ORNL has been the world's chief supplier of electromagnetically enriched stable isotopes and, until the relatively recent takeover of many of the profitable radionuclides by private industry, was the world's prime source of radioisotopes. More than 200 kg of separated stable isotopes and 21 million Ci of radioisotopes have been processed at ORNL during the existence of the program.

The stable isotopes program was originally sponsored entirely by ERDA's Division of Physical Research to supply separated nuclides for nondestructive research uses. However, in the 1950s, a "sale-or-loan" policy was introduced which, on the one hand, established a research pool of stable isotopes and, on the other hand, made possible the sale of stable products for medical and other uses.

At the present time, the inventory of the stable isotopes research pool has a value of something like $25 million, with new loans averaging about $5 million worth per year. Stable isotope shipments in FY 1975 were nearly 3000, with a value of about $1.5 million. There have been nearly 230 thousand shipments of radioisotopes since inception of the distribution program—and without a single instance of radioactive effluent release!

More important than the number or amount of shipments, however, have been the unique contributions to the feasibility of otherwise impossible researches—not only here at ORNL but throughout the world—starting with the first shipments of radioactive C-14 and separated stable Cu-63 and Cu-65 in 1946. The stable isotopes have been the basis of hundreds of publications from ORNL, ranging all the way from assignments and disintegration schemes for numerous isotopes to the measurements of cross sections and yields, moments and spins, and isomeric levels. As an example of the importance of the enriched nuclides, Jack Harvey of the Neutron Physics Division indicates that the portion of their neutron cross-section program dealing with level spacings in neutron resonances would have been greatly curtailed (actually, limited to naturally abundant



Remote control and viewing equipment used in the separation of fission products from the Graphite Reactor's spent uranium. This 1946 photograph records some of the earliest radioisotope production work. The scientists are identified as, l. to r., George Parker, supervisor of fission product separations at Clinton Laboratories, Charles Coryell, Mr. Stack, and Gordon Hebert. This is pioneer laboratory work in fission product chemistry.

isotopes) were it not for the availability of highly enriched stable nuclides. In particular, in the region of the magic-number nuclides, where there are many isotopes per element, the separated targets are absolutely essential. The worldwide significance of our program is further illustrated by the fact that, for the past 10 years, more than 50% of the articles in *Nuclear Physics, Part A*, have involved separated stable isotope products from ORNL (in 1974 it was 66%).

The impact of radioisotopes has, perhaps, been greater outside ORNL than within the Laboratory. The most significant applications have been in the fields of biology and medicine. Carbon-14, I-131, P-32, S-35, Au-198, and Ca-47 are all familiar radionuclides. These, as well as many others, were pioneered at ORNL (and many of them, interestingly enough, have involved the use of enriched stable isotopes as targets for reactor or cyclotron productions).

The biological involvement with radioisotopes has run the gamut from the establishment of the mechanism of the process of photosynthesis to the assignment of the structure of DNA. As a matter of fact, Stan Carson of the Biology Division feels that a key historical event was the use of labeled phosphorus by ORNL scientists to discover "messenger" RNA in 1956—long before the full implication of its key role in DNA and protein synthesis was fully understood.

In medicine, diagnosis and therapy involve millions of applications of dozens of isotopes each year, with Tc-99m being considered as today's "universal isotope."

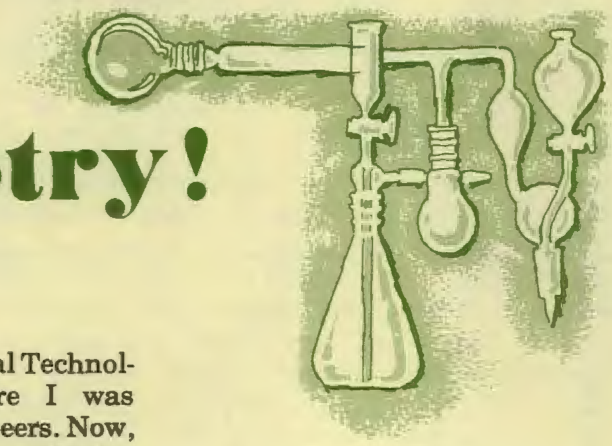
The use of fission products such as Cs-137 and Sr-90 for power generation and the use of numerous isotopes for industrial tracing and gauging are also of great importance.

Today, the major thrust of the electromagnetic separations program is to provide enriched targets for production of medical radioisotopes. The principal involvement of the radioisotopes program is to provide those radioisotopes not otherwise available from industry and to develop new and better isotopes for medical uses.

Bridging the gap between producer and user is the ORNL Target Fabrication Department, now a part of the Solid State Division. As reported in the *Review* of Summer 69, it has the capability of handling both stable and radioisotopes and converting them to usable targets for a wide variety of research needs.

ORNL's multifaceted contributions over the past 30 years to basic and applied research and to medical and industrial applications of isotopes have truly changed the world.—Phil Baker

Iran Thomas came to ORNL in 1967, the year he received his doctorate in chemistry from Vanderbilt University. After six years in the Chemical Technology Division, he spent a year on the staff of Associate Director Alex Zucker. In the fall of 1974, he was assigned to the position of chief of the physical and engineering section of the Chemistry Division. This upbeat account presents his views on the future of chemistry.



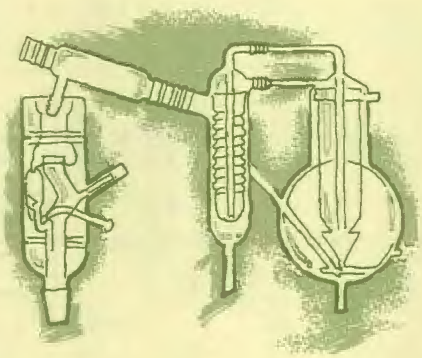
Buy Chemistry!

By IRAN L. THOMAS

After Lew Keller introduced me to the section that he had asked me to head, I gave a speech, as is usual on such occasions, which I began with the statement that the Laboratory's success would depend to a large extent on the success of the chemistry research program. As soon as I said this, I realized that I had just told a roomful of chemists that chemistry is important. The reason is that I have long been in the habit of telling people about the importance of chemistry. I was put to it when I was in the Chemical Technology Division where I was surrounded by engineers. Now, engineers have the irritating habit of proceeding to do what we chemists have told them could not be done—not always, but often enough for them to consider chemists, although useful, not to be taken too seriously. Later I worked with Alex Zucker, who is a physicist. The problem with physicists when it comes to chemistry is that most chemical problems involve more than two particles. But I have to give physicists their due because they often do reduce complicated problems to two bodies moving in harmonic potentials. In a way, these two disciplines describe the span of chemistry's domain. Chemistry is between and overlaps the elegant rigor of physics and the pragmatic demands of engineering.

This century could be called the Age of Chemistry. We are inundated internally and externally by products from chemical laboratories. Whether or not this can be considered a blessing may be questioned, but barring some great catastrophe, I expect that "Better Things for Better Living Through Chemistry," as the slogan of another chemical company goes, are here to stay and destined to increase. With regard to energy, there is no way around the fact that more than 90% of the energy produced today is chemical energy and that, for at least another generation, chemical energy will continue to dominate. Furthermore, there are very few energy conversion schemes that do not require chemistry.

We are still working on the chemical problems associated with fission reactors more than

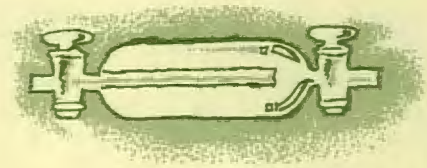


30 years after demonstration of feasibility. We are beginning to study the chemical problems of fusion reactors, and I expect that, 30 years after feasibility is demonstrated (whenever that happy event occurs), we will still be working on chemistry related to fusion. Ellison Taylor put it nicely when he pointed out that CTR can also stand for Chemistry To the Rescue. In spite of the many varied and difficult chemical problems associated with making nuclear energy practicable, I feel that ORNL is now facing much greater, more difficult, and broader problems in chemistry. We are now concerned with all kinds of energy conversion processes and, just as important and difficult, with a balance of energy sources. To produce just electricity, just gasoline, or just methane is not enough—we need all three and more.

The Chemistry Division has been evolving a research program, based on its strengths, dedicated to ensuring adequate energy supplies. We need two kinds of research, and following tradition, I will call these basic and applied. Out of the many definitions of these terms, I give you mine. By "basic" research, I mean that work that seeks to understand chemical behavior in terms of first principles. These first principles I take to be the behavior of electrons and nuclei subject to electromagnetic forces and the connection to the properties of bulk matter through statistical mechanics and thermodynamics or the converse. (For the sake of argument, I have not included the nuclear forces.) By "applied" research, I mean that work that seeks to understand chemical behavior to a suffi-

cient extent to exert control. To exert control, an understanding of the behavior in terms of first principles may be necessary, but often only empirical understanding is needed. Traditionally, basic and applied research in chemistry have been very close. Very often the same person will do both depending on serendipity, logic, or foresight. All our research is expected to be good, applied and basic alike.

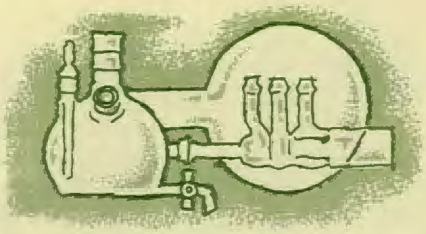
Chemists at ORNL realize that other laboratories have been working for many years in areas that are new to us (the ERDA Energy Research Center in Bartlesville, Oklahoma, for example, has been engaged in petroleum research since 1918) and that the new work we propose to do must reflect our



current knowledge and experience. Obviously, we cannot write reasonable proposals involving topics about which we are ignorant. However, it is true that the talents required for the development of nuclear energy cover most areas of chemistry. Moreover, because of the foresight of many people, the chemistry program at the Laboratory had already become diversified, and many among the staff were well into research on problems outside nuclear energy by the time energy became a national problem. We come to the challenge, then, with a good supply of talented people who are fully qualified to initiate research programs that, at first sight, might be thought to be outside their range of experience.

To determine the areas for redirection or expansion and to avoid duplication, many of us have been visiting ERDA, industrial, and academic laboratories. Our concern is to complement and extend the current research in those areas in which we have the experience and equipment that may be limited in the other laboratories. I should add that our colleagues at these laboratories have been helpful and encouraging.

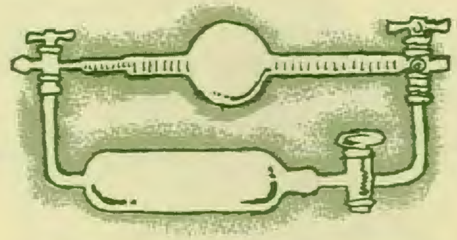
This process of finding where our skills can be contributed has answered the question, Why should the Chemistry Division of ORNL seek new areas of work when nuclear energy is still of great importance? For one thing, we have found that our experience with isotopically labelled organic compounds is of value in fossil-fuel-related research. For



another, our past experience with industrial waste treatment, desalination, and separations chemistry is closely related to certain enhanced oil recovery methods. Again, our long experience with high-temperature aqueous chemistry is clearly of value to the development of geothermal energy. Moreover, because of our experience with molten salts, we have the knowledge to study these as catalysts for the conversion of coal to fluid fuels. The list could cover several pages.

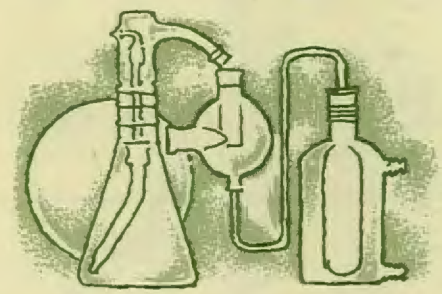
With all this redirection and expansion, two concerns preoccupy the ORNL chemistry staff and their sponsors. One is how basic research is to survive when a substantial portion of the division is to do applied research. The other is how applied research is going to survive in a division that traditionally has concentrated on basic research. This may sound facetious, but the questions are serious and not easily answered. We do not want a research program divided into two distinct and noninteracting parts; we must contribute both to meeting the short-term needs and to building the scientific base for the future.

The short-term work requires strict attention to immediate goals, with solutions to problems forthcoming in set time periods. Gone is the luxury of pursuing a line of inquiry as curiosity, or at times even logic, dictates. What has to be done is whatever is necessary to achieve a compromise goal—set partly by others—by means



that attempt to integrate technical merit with economic, social, and political factors. Generally, what is sought in applied research is not technical feasibility but optimization to achieve economic feasibility. For example, any chemist worth his salt could give you a technically feasible way to get gasoline from coal. If you add the conditions that you need millions of gallons a day and at a price comparable to current prices, about all he can do is give you a plan, conceived with the help of engineers, that would describe the research and the length of time needed to do the work with a given number of people. Such a plan can be made because the scientific principles are known. It is the complexity of the problem that makes it difficult.

Applied research may and usually does lead to basic knowledge and new technologies, but that is not its primary function. Hence, we cannot depend solely on this way of doing research to provide the scientific base for the future. What is lacking is not challenge or dedicated, intelligent people; it is time. Time to see through the complexity and



arrive at those experimentally verifiable generalizations that characterize and distinguish science from other human endeavors. Chemists recognize that many unsolved fundamental problems are directly related to energy. One example is photosynthesis. At 1500 kcal per person per day it takes about 0.4 quad per year to fuel 200 million people. This respectable amount of energy is an example of solar energy converted to chemical energy through a photochemical process. (Unfortunately, this energy is not very useful. Though it does keep us alive.) If we understood the process or discovered similar processes, we would have a solution to many of the problems of solar energy conversion. We do not understand photosynthesis, however, and many approaches to the solution will have to be taken before we do. Each approach is based on an idea or hypothesis that someone will pursue until it has been found to be true or false or to lead to redefinition of the problem because of an unexpected discovery. This last possibility is the one that precludes the close direction or management of basic research. The scientist must have the freedom to redefine his problem. It would have been silly and a colossal blunder if Ferdinand and Isabella had cancelled the exploration of the New World when they found that it had nothing to do with what the principal investigator had proposed.

We will strive in the Chemistry Division to have the freedom to pursue novel application or new knowledge, no matter whether these originate in a basic or in an applied program. At the same time, we cannot have complete freedom because science is no longer an activity of a few dedicated scholars or wealthy dilettantes. The enormous contributions of the few scientists of the past have made science a necessary and expensive component of our society; or, put another way, science has changed from hobby to job. Moreover, it has done so in just two or three generations. At ORNL, the job for chemists is to help prevent a dismal, energy-starved future. This job demands and deserves our best and need not—rather, *must* not—destroy the enchantment that I hope all of us have had with chemistry. Preventing disenchantment should not be too difficult because the problem is not narrowing, but broadening, the scope of our research.

Staff quote:

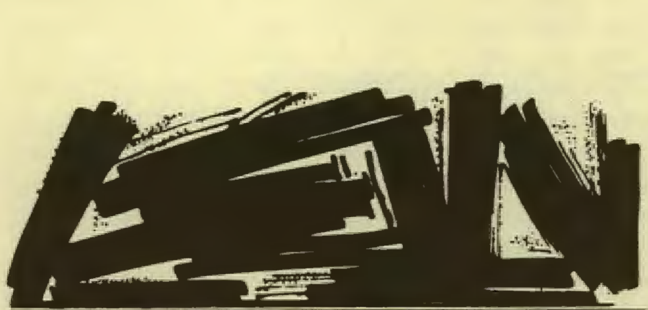
"....H. Brechna, Zurich, presented an invited paper on the biological effect of magnetic fields. This paper was particularly interesting, both because of the continuing concern with environmental hazards and because of the vast increases in size and field projected for superconducting magnets of the future.

In addition to summarizing recent work, Brechna reviewed early work such as that of Tasla who exposed 12 men by having them sit for days at a time with their upper torsos inside two large solenoids. No effect was observed. The attempts to use magnets for healing purposes were also presented. Slides based on 18th Century engravings of Mesmer's magnetic boxes made a big hit with the audience. Lest the Americans should sneer at the gullible Europeans, we were reminded that both George Washington and John Marshall used Perkins' magnetic tractors to treat their headaches.

In a more serious vein, we were told that literature on the subject is voluminous, covering more than 6000 references. All types of cells, tissues, and even macromolecules have been tested in high magnetic fields. Mice, algae, and astronauts have been tested in low fields.

No influence was observed on the astronauts' body temperature, pulse, EKG, EEG, blood pressure, and memory. However, the ability to distinguish between the reproduction time of intervals (flicker fusion frequency) was somewhat reduced after 3 or 4 days of exposure. This investigation, which was done for the U.S. NASA, should be reviewed by competent people with industrial hygiene responsibility....

After listening to Brechna's talk and giving the whole question serious thought, I would like to recommend against any substantial funding of an experimental program in this area until the literature has been carefully examined. It seems clear to me that, if there is any pronounced effect or hazard, we would already know about it. Furthermore, the mechanical hazards of large magnets such as flying wrenches and bending roof beams and the nuisance problems associated with instrumentation will doubtless keep most workers out of high field regions most of the time. I believe that existing experience and common sense will serve as excellent guides."—**Roger Derby**, *commenting on a meeting on Magnet Technology held in Rome this year.*



BOOKS

By Alex Zucker

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"The Brain Bank of America"

Philip Boffey. 312 pp. McGraw-Hill, 1975. $10.95.

The Academy is in the barrel! Whether you enjoy the scene depends on whether you subscribe to the Boffey-Nader world view: There are two forces abroad—the forces of darkness and the forces of light—that are locked in a perpetual Zoroastrian conflict over every aspect of our lives. Boffey supplies the lineups of the competing teams. For darkness: industry, government (especially the Federal executive bureaucracy), farmers, the rich, the safe, and the successful. For light: public interest law firms, some foundations, and some environmental groups.

When viewed from this vantage, the Brain Bank of America—Boffey's name for the conglomerate that includes the National Academy of Sciences, the National Academv of Engineering, the Institutes of Medicine, and the National Research Council—becomes a pawn to be wrested away from the bad guys and obverted by the good guys for their own purposes. In his concluding chapter, he outlines a new structure for the Academy to be a forum for adversary proceedings on science-related issues of national significance. The mission of the Academy, in Boffey's version, is not to advise the government but to protect the public good.

There are two problems with this. First, the Academy was chartered by Congress for quite another purpose: "Whenever called upon by any department of the Government, [the Academy will] investigate, examine ... and report upon any subject of science." Second, I question the a priori sanctification of any organization that represents itself as the anointed advocate of the people, and that includes the Center for Study of Responsive Law, for which Boffey works. Who determines what good is? And what are the checks and balances imposed on its protectors? History overflows with tyranny justified in the name of public good.

Boffey is an experienced reporter. The Academy was his beat for several years and he describes its structures and operation with verve. Almost immediately Boffey attacks: The Academy—a happier term than Brain Bank—is a self-perpetuating elitist institution. "How accomplished are the Academy members? Are they really the best in American science?" asks Boffey. And he answers: "While they are unquestionably good, they are not necessarily the most outstanding in terms of scientific originality." He notes also that more than 90% have been trained in twenty universities, more than 70% in just ten. But when we reflect that most academicians received their highest degrees before 1950, this distribution does not seem so outrageous. It is a fact that quality attracts quality.

Boffey quickly shifts his sights to where the action is—the National Research Council (NRC), the part of the Academy that advises the government on all manner of things from acoustics to zoology, through several hundred committees. He describes the advisory process—how government agencies seek advice, how committees are formed to respond, how the committees deliberate, and finally how a report is prepared, reviewed within the Academy, submitted to the agency, which may or may not take the advice. The book does not do justice to the volume of work: The NRC produces approximately 400 reports a year; they vary in importance, quality, length, and value, but taken together they represent a significant flow of ideas from the scientific community to the government.

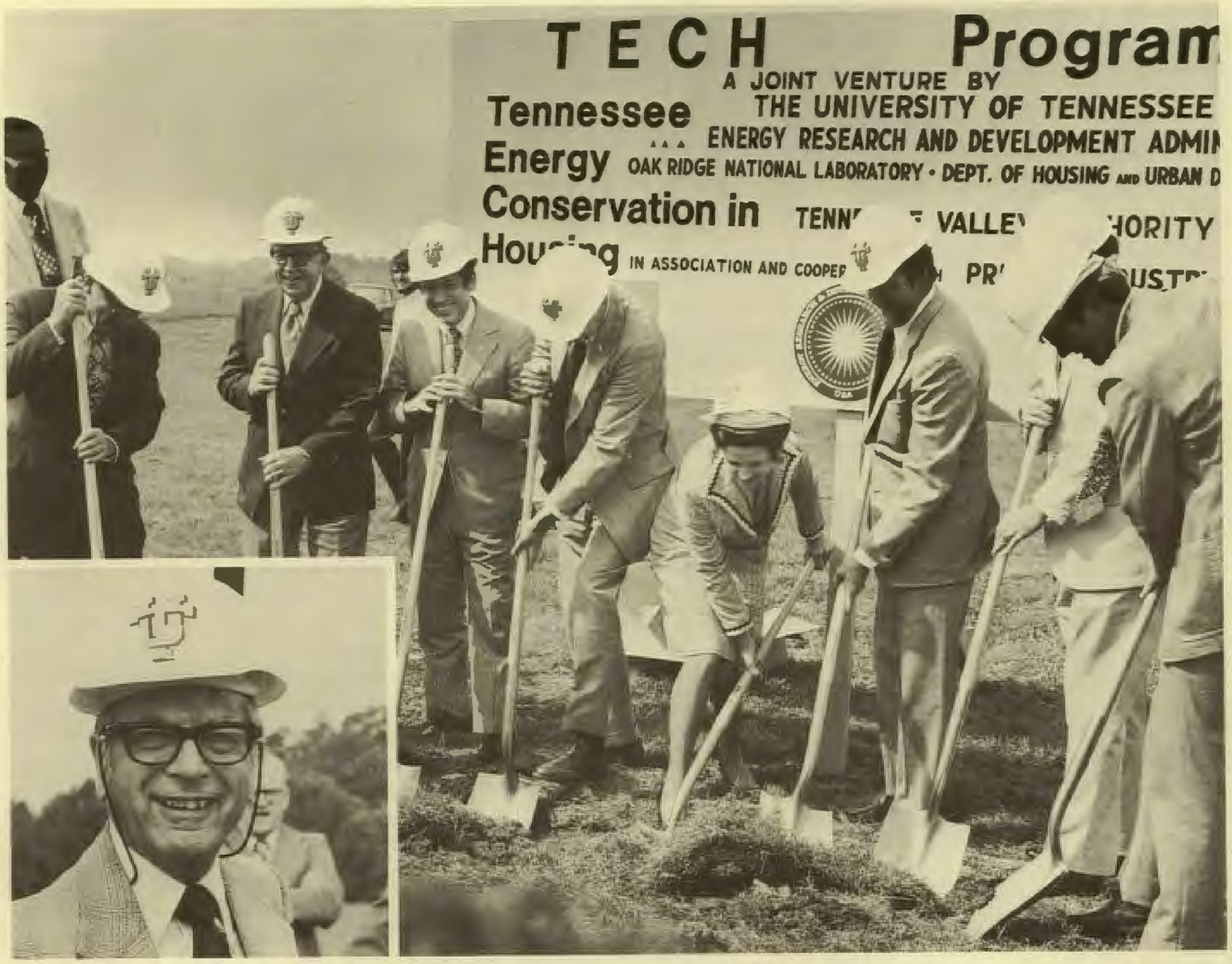
All sorts of things are wrong with the NRC, says Boffey. He zeroes in on a vulnerable point: conflict of interest of committee members that purportedly distorts the deliberations and recommendations of committees. Here his world view comes in—Boffey cannot conceive of an industrial scientist who would not distort facts to protect his employer or of an academic scientist who receives government funds who would present data that embarrass that government. Nearly 9000 scientists currently serve on NRC committees; to accuse them of wholesale whoredom seems not to bother the author.

The dilemma is nevertheless real. If a committee consists of experts in a field, they are bound to have preconceived biases, sometimes connected with their occupation, sometimes purely scientific. The alternative is to assemble a committee of people who know nothing about the subject but who are unbiased. The recent practice of the Academy is to require committee members to submit a statement of potential bias and to constitute committees so as to balance the biases. Boffey applauds this move, but is not sanguine about how well it will work in practice.

There is a curious kind of uncriticality in Boffey's search for bias. He cites committee memberships just brimming with people who have apparent reasons to be biased, but he rarely examines whether the reports they wrote are scientifically unsound. When he does so, his cause stumbles. For example, the committee that reported on the biological effects of fluorides in 1971 "was composed entirely of scientists from universities and research laboratories that were seemingly independent of industry's influence. But ... four of these scientists, who had written most of the report, had close ties with the aluminum industry, which is a major emitter of fluorides." The result: "The report ... proposed tolerance thresholds which were somewhat more lenient than standards proposed by the Center for Science in the Public Interest." Boffey neglects to say that the thresholds were those of the American Conference of Government and Industrial Hygienists, that the committee did not propose or endorse them, that in fact the committee's task was to present scientific evidence on the effect of fluorides (which proved invaluable to standard-makers), that it set no standards, and that its only recommendations had to do with future research that seemed important and necessary. When fully examined, the story does not fit the world view of unrelieved venality and corruption in the camp of the forces of darkness.

Boffey is great in describing the mechanics of the NRC; he can track down hidden allegiances of committee members, but he fails to understand what happens when a committee meets. Science imposes limits on bias, and in the absence of willful evildoing, of which Boffey never accuses the Academy, the advice proffered by the NRC will usually be sound and factual. No institution is without its sins, and Boffey exposes a number of the Academy's. After he is all through with the biases in the Food Protection Committee, the checkered history of advice on radioactive waste disposal and on pesticides, the absence of NRC militancy in the SST controversy, the obscurantism of the Airborne Lead report, this reader concludes that even in these cases the Academy did not do too badly. Reports were sometimes suppressed by the agencies, but that is hardly the Academy's fault (to get out of that one, the Academy now reserves the right to publish all reports); some stands that were taken seem less than heroic in retrospect, and some were just not very smart. Other reports, however, were farsighted, useful, timely, and courageous. Boffey does not dwell on the good aspects; apparently, it is not his intention to present a balanced view of the Academy. And that is a shame. There are many good things about the Academy. It is, after all, a place where some of the brightest and most thoughtful men and women strive mightily to improve matters that in the long run affect each of us. They work hard, receiving no pay and but scant honor, they shoulder their burden of bias, and in the main they succeed.

In the spirit of the NRC, it is appropriate for me to state my bias. I have worked for many years for the AEC as a nuclear physicist, and hence owe allegiance to the government that has supported my research. For two years I was on the staff of the NAS-NAE Environmental Studies Board, which, by the way, gets good marks from Boffey. I have also served on several NRC Committees. Am I biased? Of course, but far less than Boffey.



The Ice Bin Cometh

By CAROLYN KRAUSE

One day in August 1974 a man from Maryland stopped in to discuss an energy-saving idea with anyone interested at the Central Employment Office of Union Carbide's Nuclear Division in Oak Ridge. The man he met at Central Employment suggested that he present his idea to Sam Beall, then director of the newly created Energy Division at ORNL. Beall could not be reached that day, but on the next day the man from Maryland, Harry C. Fischer, arranged an appointment with Beall.

Fischer, then a retired engineer and inventor, had been vacationing at Watts Bar Lake when he decided to see if there was anyone at one of the

When Robert C. Seamans, Jr., ERDA administrator, toured ORNL facilities last April, he was particularly impressed by a research project known as the Annual Cycle Energy System (ACES), whose principal developer is Harry C. Fischer. Fischer, now an ORNL consultant, is an inventor with more than 50 U.S. and foreign patents in the heating, refrigeration, and air conditioning field. A Michigan native with two B.S. degrees in chemical and metallurgical engineering from the University of Michigan, Fischer has held a number of positions in private industry. His first jobs were with Chrysler Corporation and Mechanical Heat and Cold Company in Detroit. Then he served as project engineer with Temprite Products of Detroit; chief engineer for Ebco Manufacturing Company of Columbus, Ohio; and manager of product engineering with the General Electric Heat Pump Department in Bloomfield, New Jersey. Later he became vice president in charge of R&D with Stillman Manufacturing Company of New York City. In 1963 he moved to Royal Oak, Maryland, and formed Fischer Associates, a consulting firm in the area of heating, air conditioning, and refrigeration equipment design, whose clients include Union Carbide Corporation.

Ground was broken last September on Alcoa Highway for two experimental houses, one of which was a model of Harry Fischer's cyclically cooled and heated construction. At the groundbreaking ceremony were a number of notables, of which are shown here, l. to r., UT President E. J. Boling, TVA Board of Directors Chairman A. J. Wagner, Senator Howard Baker, ERDA Administrator R. C. Seamans, Congresswoman Marilyn Lloyd, Senator Bill Brock, and ORNL Director Herman Postma. Fischer, inset, watches as his energy-conserving idea comes to fruition. (Group photo by Frank Hoffman; Fischer portrait by Linda Pearlstein.)

local Atomic Energy Commission plants who might want to hear his scheme for heating and cooling homes and commercial buildings more efficiently. After his proposal for funding development of the concept was turned down by the National Science Foundation, Fischer sought the advice of his Talbot County neighbor, Rogers C. B. Morton, Secretary of the Interior at the time and now President Ford's chief energy coordinator and Secretary of Commerce. Morton said that the Interior Department had no funds to support work on Fischer's idea, but he recommended that Fischer talk to the AEC.

So in August 1974 Fischer sat down in Beall's office and told him of what has become known as the Annual Cycle Energy System (ACES) concept. The scheme, Fischer told Beall, involves using a heat pump to extract heat from a large, insulated tank of water (instead of air) to provide warm air for wintertime heating of buildings and to make domestic hot water all year around. As the heat is withdrawn from the tank, the water gradually turns to ice. An alcohol-water solution circulating in tubes in the ice bin during the summertime would be chilled by the ice to provide air conditioning at a negligible cost. The system, Fischer told Beall, promises to cut the homeowner's energy bill at least in half. The reasons are that air conditioning costs are minimal (the ice essentially replaces the power-hungry compressor), and the one-directional heat pump operates more efficiently because heat is so much easier to extract from an insulated tank of water than from cold air.

Fischer's concept is not really new, as he is quick to admit. The idea of using a refrigerator as a heat pump to heat houses was first suggested by Lord Kelvin (William Thompson) in a paper presented before the Royal Society in 1852. The paper, entitled "On the Economy of Heating and Cooling of Buildings by Means of Currents of Air," was published in the December 1852 issue of the *Glasgow Philosophical Society Proceedings*. Interest in using a refrigerator for a heat pump was revived in the late 1920s, and in 1932 a paper on "Application of Refrigeration to Heating and Cooling of Homes" was published by three General Electric Company engineers. One of the engineers, Frank H. Faust, was a colleague of Fischer's when they both worked at General Electric in the 1950s. The 1932 paper that Faust coauthored alluded in a footnote to the possibility of heating a house from an ice bin:

> It has been suggested that the latent heat of the water be extracted by freezing it. In Washington (D.C.) the amount of ice formed during the winter in heating a 14,000-ft^3, well-insulated house would be 210 tons, or 7800 ft^3, which would make a pile about half the size of the house.

(Fischer notes that, with present insulation, such an ice pile would amount to only 3500 ft^3.)

While Faust et al. mentioned the possibility of extracting heat by freezing water, Fischer's contribution in the mid-1950s was the idea of keeping the ice formed at the end of the heating season and using it for space cooling.

"Due to the cost of the ice bin and the low cost of energy at the time, it was not economically feasible," Fischer says. "But at the time I said that energy won't be cheap all that long, and it didn't turn out to be.

"I kept a folder on the (ice bin) project. It dates back to the days when I was in a professional management course at General Electric. When the energy crisis occurred, especially when the Arab oil embargo came along in December 1973, I realized it was time to dust this folder off."

Beall, impressed by Fischer's scheme, asked him to discuss the ACES idea with Eugene Hise, John Moyers, and Garland Samuels on the next day. They heard him out and asked him to return the next week and work on the application of ACES to a live model of Modular Integrated Utility System (MIUS). After a week's effort, Fischer, Hise, and Moyers met with Beall and reported that the ACES idea stood the test of analysis. Beall offered Fischer a part-time consultant job. Fischer came out of retirement, moved with his wife Helen to Oak Ridge, and began work September 4 in Building 9102 at the Y-12 Plant, where the MIUS Project was under way.

During that fall, Fischer headed a preliminary feasibility study, including a detailed calculation of the energy that could be saved by using ACES for an existing apartment complex in the Washington area. The 406 apartments, located in 68 different buildings, are heated and air-conditioned from a central boiler plant fired with natural gas. Fischer and his colleagues were able to obtain actual 12-month usage records on the complex and analyze how an ACES would have functioned during that same 12-month period. They found that use of ACES for the gas-fired apartments could possibly provide an energy saving of 71%.

At Thanksgiving last year, Fischer returned briefly to the home he still owns near Chesapeake Bay where he saw Morton. Fischer showed him a copy of the ACES study he did on the Washington apartments and told him of prospects for Federal money to support a program of assembling and installing test equipment.

"I have a memory like an elephant," Morton said. "Harry, how long after you get the money are you going to have something to show for it, like a working model?"

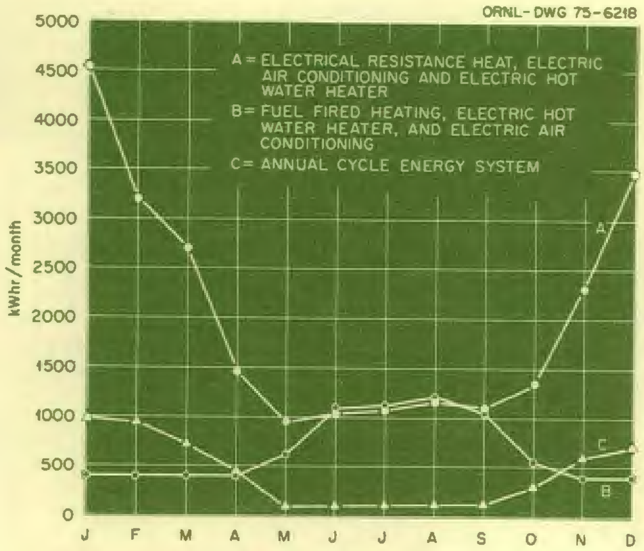
"Ninety days after we get the money committed, we'll have something running," Fischer said.

"Okay, I'll remember that," Morton said.

On December 20, 1974, Fischer and his colleagues received a grant of $101,000 from the U.S. Department of Housing and Urban Development (HUD) for the ACES project. On February 20, just two months after the grant money was committed, the first test ACES system was built and operating. A month later, Westinghouse Electric Corporation independently built their own ACES system (Fischer had suggested to Westinghouse officials at an October 15, 1974, meeting that they build their own ACES system for their domestic engineering center at HOMELAB near Pittsburgh).

"We have done most of the experimental work," Fischer says. "We have confirmed our calculations. We are in the process now of writing out the design specifications for the system and trying to get the system commercial by 1976."

Before ACES can be acceptable to the commercial sector, it must be successfully demonstrated in a model house. A demonstration ACES house is now being completed on Alcoa Highway between Knoxville and the McGhee-Tyson Airport. The ORNL house, funded by ERDA, HUD, and the Federal Energy Administration, is being built alongside a solar energy demonstration house sponsored by the University of Tennessee and the Tennessee Valley Authority. The two houses were designed by the same architects; they have the same floor plans. The roof lines, however, are different because the two houses will be making use of the sun's rays in different ways. In a sense, the UT-TVA house and the ORNL house will be competing with each other because data will be obtained on how energy-efficient each house is.



Annual electrical use pattern for an 1800-ft² house with three different HVAC systems.

The arrangement for building an ACES house alongside the UT-TVA solar house came about last January when Fischer and Hise happened to see John H. Gibbons, director of UT's Environment Center, at the airport. They discussed the ACES idea with Gibbons, who became so interested that he suggested that a second house with the same floor plan as the solar house be proposed.

If both heating and cooling of the ORNL demonstration house prove economically feasible, then the next step, according to Fischer, will be to persuade the commercial sector to manufacture and install ACES in new construction projects and to retrofit current buildings.

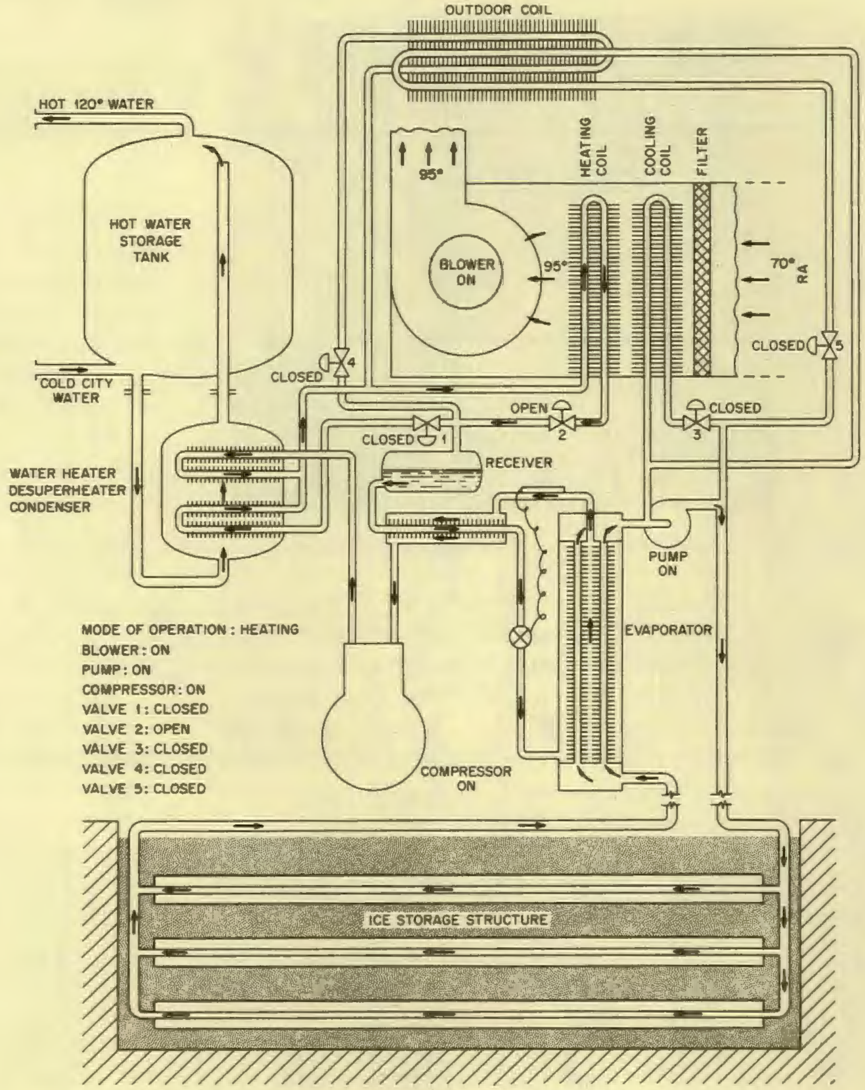
Fischer believes there are at least a dozen companies that would be interested in manufacturing and installing special ACES equipment. He notes that one firm makes a modular manure tank that could be used as an ice bin for big systems like a complex of 100 apartment units. Another company makes a steel tank that could serve as an ice bin. Fischer says that the ACES idea is not patentable, but he believes that manufacturers may develop patentable features in ACES hardware as time goes on.

"I see our role as pulling it all together," Fischer says. "It's a teaching job. We've got to have these workshops and teach consulting engineers, architects, mortgage bankers, and utility commissioners that there is an answer to the problem. Fortunately, it's an answer where everybody wins."

Fischer, who is as much a salesman as a developer of the ACES concept, says, "It has something for everybody. The utilities should be interested in it because it is inherently a load management system, since the compressor does not operate on their peak hours. The homeowner wins because he saves 60 to 75% of his energy costs. As for the manufacturers of equipment and firms doing installation and retrofit, ACES can contribute up to 55,000 new jobs a year as it spreads across the country. The Government wins because of the reduced need for oil imports. The money market will win because we don't have to build so many new power plants on such a tight schedule. Even the environmentalists win because fewer power plants mean fewer smoke-producing chimneys."

Right now there is little demand for this method of heating and cooling houses and office buildings, partly because the concept is not widely known. Moreover, once people do become familiar with the system, there is the question of whether they are willing to pay the first cost of buying and having installed a huge ice bin that can range in cost from \$800 to \$1600. Fischer believes the ice bin concept will become more and more attractive as the cost of electric power continues to rise. He cites predictions that the cost of electricity will quadruple in the next 20 years. That would mean, for example, that people living in Washington, D.C., who now pay 4¢/kWhr will probably be more interested in a system like ACES as the price of power approaches 16¢/kWhr. The capital cost of an ice bin suddenly becomes justified if the system offers a 60 to 75% reduction in one's electric power bill over the succeeding years.

Fischer and his colleagues are now trying to optimize ACES for different-sized homes owned by families earning various incomes and paying varying electric rates in different climatic regions. However, if electric costs are going to soar by as much as a factor of four in the next 20 years, then Fischer reaffirms the economy of buying a full-size bin on the order of 2400 ft³ at a cost of \$1600. Such a large bin could effect an electrical cost savings of 75%, whereas a 500-ft³ bin might save only 60%. Retrofitting an old house with the large bin might cost \$2500, but the capital cost should prove worth it because of lower operating (fuel) costs in



Flow chart showing how the Annual Cycle Energy System works.

subsequent years, according to Fischer. Ice bins for new housing construction could be installed under the house or garage or patio. For apartment complexes, the bins could be put under parking lots or tennis courts. For retrofitting old houses, the ice tanks could be located under the back or front yard.

In the case of the ORNL demonstration house on Alcoa Highway, a 2900-ft^3 bin has been built under the house. In a normal year this size of bin will hold all ice necessary for summer air conditioning and can supply all the heat for the house. In more northern areas the amount of heat required is several times the amount of cooling required. In more southern areas the cooling requirements will deplete the ice supply before the summer is over. ACES is now economical within a latitude of 30° and 44° north.

To overcome the inherent problems of weather imbalance from year to year, the ORNL demonstration house is equipped with a solar/convector, which is an external venetian-blind-like area located on a vertical south-facing part of the roof structure. The elements of this solar/convector are 3-in.-wide aluminum extrusions, with a tube in the center of each one through which an alcohol—water solution is circulated in the wintertime when the sun shines and heat can be obtained. This panel will be used if the ice bin is in danger of freezing solid before the heating season is finished. Conversely, this solar/convector will be used in the summertime if the ice supply is depleted before the last of the hot weather. In that event, the compressor would come on at night after the peak utility hours and make more ice for the next day. The heat that the system has to dissipate will be convected to the night air and radiated to the night sky.

The solar/convector elements can be painted any color (except white) to blend in with the decor of the house. If necessary, the panels can be built instead into a solar/convector fence.

In the ORNL demonstration house, a heat pump will withdraw heat from water in the below-ground storage tank to provide space and domestic water heating. In conventional systems, heat pumps extract heat from air for heating buildings in the winter, which is the time when there is the least amount of heat available in the air. The heat pump accomplishes its task by using a heat-transfer medium (Freon) to pick up the outside heat. The medium is kept at a low pressure so that it can evaporate with the low-temperature heat it absorbs. The vapor is then moved through the compressor where it is placed under high pressure, causing it to condense and therefore give off heat. This resultant high-temperature heat is used for space and water heating. The main components of the heat pump—compressor, condenser, and evaporator—are powered by electricity. Hence, engineers look at the efficiency of heat pumps in terms of "coefficient of performance"—the ratio of energy coming out of the system (heat) to energy put into the system (electricity). In air-to-air heat pumps, the coefficient of performance (COP) is approximately 1.6 to 2.0 (for every Btu of electricity used, about 2 Btu of heat are supplied to the heating system). Fischer has calculated that with optimized Annual Cycle Energy Systems, heat pumps should be able to obtain a heating COP of 3.5 to 3.9. This is partly because an ACES heat pump can operate at a narrower temperature range than an air-to-air heat pump because there is more latent heat in an insulated tank of water than in the air. Hence, the water heat pump does not have to use as much energy as the air-to-air heat pump to "lift" the level of heat absorbed to the level of high-temperature heat required for heating buildings (25 to 100°). The seasonal COP of the Annual Cycle Energy System can be as high as 5.0 because both the cooling and heating outputs of the heat pump are used with the compressor operating only in the wintertime.

An inherent advantage of water as a source of energy is that it requires 144 Btu of heat to turn a pound of ice into a pound of water at a given temperature. Conversely, a pound of water yields 144 Btu as it is converted to a pound of ice. The heat removed is the "heat of fusion." In conventional air conditioning systems, a refrigerant like Freon removes heat from buildings to cool them. As a result, the refrigerant is evaporated and must be compressed again to cool the vapor into a liquid that can be recycled through the system. Most of the electricity used in these conventional air conditioning systems is consumed by the compressor. In the ACES concept, the coolant is an alcohol-water solution, which is chilled in tubes in the ice storage bin and then circulated through the building to keep it cool. The ice gradually melts during the cooling season as it absorbs natural summertime heat, but as long as there is any ice in the system, the compressor is not running up the electric bills.

While awaiting the completion of the ACES demonstration house this year, Fischer and his colleagues have been doing computer studies on the effects of using Annual Cycle Energy Systems for residential and commercial buildings in the eastern corridor between Boston and Washington. He feels that this section of the United States could benefit significantly from ACES because it has higher electrical rates, more pollution, and more population density than most parts of the country.

Fischer believes that the first large-scale application of ACES could take place soon if the U.S. Department of Defense (DOD) decides to have its military townhouses at Bolling Air Force Base in Washington retrofitted with ice-bin systems. Because these military houses have electrical resistance heating, DOD could save the taxpayer money by retrofitting them with ACES to make them more energy-efficient. Fischer and his colleagues are now conducting a study for the Deputy Assistant Secretary of Defense on the benefits and costs of retrofitting military housing with ACES. It is possible that DOD may be the first agency of the Federal government to demonstrate to the commercial sector and public on a large scale that ACES can indeed be an ace in the hole in the age of the energy crunch.

This article will introduce the Review's *new staff member, Carolyn Krause, B.A., M.A.T., M.S.J., former science writer for the Pittsburgh* Press *and the* Oak Ridger, *whose thesis, a 350-page "History of Science Writing in the United States," has been cited by the trade press as a definitive work.*

ANFLOW Bio-conversion

R&D *Achievement* at ORNL

Using cylindrical columns to pack in millions of one-celled organisms that feed on liquid wastes in an oxygen-free environment, two ORNL researchers have developed a system for efficiently converting some industrial pollutants into useful products—mainly, organic chemicals and fuels. For three years, Bill Griffith and Alicia Compere have been testing several ANFLOW units, as they call the "anaerobic upflow packed-bed biological reactors" they have developed. The AN-

Bill Griffith draws a sample while Alicia Compere checks a sample tap on one of the columns in the small ANFLOW pilot plant at Oak Ridge's East End Sewage Treatment Plant. The two researchers are testing the capability of the ANFLOW system to treat sewage and produce methane simultaneously.

FLOW system, if commercialized on a large scale, offers more efficient and economical treatment of urban sewage and liquid industrial wastes than most conventional systems provide. In addition, Bill and Alicia say, the ANFLOW system has the potential of producing from sewage a fuel gas containing methane and of recovering from organic industrial wastes even more valuable chemicals that could substitute for derivatives from increasingly expensive imported petroleum.

For example, industrial ethanol, currently derived from petroleum, could be competitively produced now by the fermentation of vegetable and fruit canning wastes in an ANFLOW system. ANFLOW could also yield lactic acid from the fermentation of dairy wastes such as whey or a variety of industrial wastes; lactic acid can be used for making cheese, sour cream, and buttermilk or for producing acrylic acid, a potentially valuable export that is a monomer for acrylic plastics. Industrial chemicals like butane and butanediol can be obtained by fermentation of starch wastes. Hence, ANFLOW offers such dividends as production of chemical resources and energy sources as well as the potential to help the U.S. balance of payments by obviating the need to import so much petroleum for producing industrial chemicals.

A major benefit of ANFLOW appears to be pollution abatement. Bill and Alicia say that ANFLOW as a potential sewage treatment system has these advantages over conventional secondary sewage treatment plants:

- ANFLOW treats both suspended and dissolved organic matter passing through the system, not just organic matter that has settled out as in a sewage pond;
- It uses anaerobic bacteria and protozoa rather than aerobic (requiring the presence of oxygen) microorganisms commonly found in sewage treatment plants. Because anaerobic organisms do not need air for survival, ANFLOW treatment systems do not require the costly, energy-consuming aerators generally used in conventional sewage systems.
- Anaerobic microorganisms grow more slowly than aerobic organisms; hence, they produce less dead cell mass, or sludge. As a result, less manpower is required for handling and disposing of sludge for an ANFLOW system.
- ANFLOW, a closed system unlike sewage treatment ponds, poses a lesser public health hazard.
- ANFLOW can produce methane more efficiently than

conventional sewage systems.

To test their claims concerning the advantages of ANFLOW for sewage treatment, Bill and Alicia hope to obtain funds from ERDA and industry to build an ANFLOW pilot plant at Oak Ridge's East End Sewage Treatment Plant. The pilot plant, which would be a column 15 ft high and 5 ft in diameter, would demonstrate the treatment of sewage and production of methane. ANFLOW, according to Bill and Alicia, has the potential of yielding about three times as much methane as the Oak Ridge facility now produces.

In the bench-scale ANFLOW system, liquid organic wastes are pumped into the bottom and up through vertical columns as high as 6 ft and ranging in diameter from 2 to 8 in. (An actual ANFLOW sewage treatment system could be adapted to gravity flow to save energy and operational money.) The liquid wastes flow up past packing materials to which myriads of anaerobic microorganisms are attached with the aid of specially developed coatings such as gelatin cross-linked with glutaraldehyde, ethylchloroformate, or formaldehyde. Microorganisms are introduced into the column by flooding it with a combination of paunch manure from slaughterhouses and sewage sludge from waste treatment plants. The packing used comes in a variety of shapes—rings, saddles, short pipes—and can be made of a number of different materials such as ceramics, stoneware, plastic, or aluminum. Packing materials are designed so as to facilitate flow of the wastes and permit maximum surface contact between the organisms and wastes. Some organisms exist in the free space in the packing, whereas others form layers as thick as several millimeters on the packing material itself. The organisms survive and reproduce by consuming the wastes, which they transform into useful products. Bill and Alicia measure the rate at which the wastes are degraded in the columns by observing the samples they draw from a series of taps placed a foot apart from the bottom to the top.

Staff quote:

"In a large country, where there are many research institutions, many knowledgeable and capable colleagues, many active collaborators, it is relatively easy to maintain enthusiasm. We can travel around the United States and attend several meetings a year at which we can talk to any number of collaborators, competitors, and others involved in our own research areas. I think many of us take all this for granted. It is quite another matter to conduct, more or less alone, a research project in a country like Finland, where one may receive the journals six months after they are published in the United States, where one may only a few times in his research career have the opportunity to talk to leaders in the field whether they be from the United States, United Kingdom, Japan, or wherever. Science belongs to the world. Maybe we ought to think about more ways to see that the world, all of it, feels like it belongs to the community of science."—**James D. Regan,** *after attending a meeting at Turku University in Helsinki."*

Gray Henderson and Dale Huff share an expertise in hydrologic transport of trace elements. Both 1968 Ph.D.s, Henderson from Cornell and Huff from Stanford, they are relative newcomers to ORNL. Here (Huff in the foreground) they are measuring water flow at one of the streams in Walker Branch Watershed, the importance of which they have lined out in the accompanying article.

The Watershed Contribution

By GRAY HENDERSON and DALE HUFF

Walker Branch Watershed, a 97.5-hectare (250-acre) forested tract on the Oak Ridge Reservation, is one of the most valuable tools for ORNL ecologists studying interactions among air, water, land, plants, and animals. An experimental area dotted with instruments and gauges, it is as much admired for its natural beauty as for its potential in providing useful data. Walker Branch, formed by the confluence of East and West Forks on the south slopes of Chestnut Ridge, is a tributary of the Clinch River, which drains now into Melton Hill Lake. Data from experimental studies of Walker Branch Watershed advance our quantitative understanding of forested ecosystems and can be used to guide the processes of decision-making in such controversial areas as power plant siting and land use. The National Environmental Policy Act (NEPA) of 1969, translated into operational goals for Federal agencies like ERDA, demands extensive field research into what energy development does, or may do, to the quality of the environment. The purpose of this article is to illustrate the importance of watershed research to total environmental studies, particularly those that are crucial to regional assessment of energy-related impacts.

Public awareness of problems related to the nation's water resources first dawned about the turn of the century. Introduction of the Hapless Newlands Bill in 1908, providing for integrated water resources planning and the 1911 passage of the Weeks Act, authorizing purchase of certain eastern national forests for watershed protection, initiated an established public policy of water resources research. Early studies addressed streamflow regulation and the moderating influences of forests on runoff. During the 1930s a number of experimental watersheds were established to evaluate the effects of land use and

vegetation patterns on water yield (total runoff from drainage area), flow rates, and erosion. Through the years, 18 different government agencies have actively conducted or supported watershed research.

Currently, much of ERDA's ecological research must be focused on energy-related problems. For example, the effects of airborne pollutants on productivity of vegetation and the concentrations of contaminants in food chains and in water draining into the nation's waterways stand out as important considerations. Experimental watersheds constitute ideal laboratories for assessing atmospheric pollution and its effect on soil and water. We also need to measure how water quality is affected by movement of agricultural chemicals and by newly developing or rapidly changing land use patterns. Mathematical models of the relationships between water quality and streamflow are also needed. All these needs can be met through properly instrumented, well-conducted studies of small watersheds, often with drainage basins of less than 20 km^2.

Watershed Research

Watershed research provides important information about air, water, and biomass which is otherwise hard to obtain. Such information includes (1) analysis of both natural and altered landscapes in terms of their *material balance*, (2) characterization of *transport mechanisms*, (3) characterization of interactions between *terrestrial and aquatic ecosystems*, (4) description of mathematical *simulation models* and their validation, and (5) discussion of the way in which watersheds serve as fundamental components of *regional assessment studies*.

A simple approach to the study of environmental transport of water and materials is through use of an input–output budget. Measured inputs are compared with measured outputs to determine the overall net behavior of water and chemical elements in the landscape. Experimental watersheds are the only areas in which these balances can be quantified, effectively integrating the interactions among atmosphere, vegetation, fauna, microorganisms, soil, and bedrock which influence water yield and element release.

Some universally accepted generalizations have emerged from water-balanced studies. First, reduction of forest cover increases water yield, and conversely, establishment of forest cover on sparsely vegetated land decreases water yield. Research has also shown that water yield varies among watersheds because of differences in direction and magnitude of slope, soil depth, land use and vegetation cover, and precipitation, among other factors. For example, at the Coweeta Hydrologic Laboratory in North Carolina, Philip Johnson, now director of ORAU, and Wayne Swank, of the USDA-Forest Service, found significant differences in water yield among four watersheds with different vegetation types. A grass–shrub-covered watershed and a seven-year-old hardwood coppice watershed yielded more water than one vegetated with mature hardwoods. A watershed covered with 13-year-old pine trees yielded less water than any of the other three. This kind of information is essential for estimating and evaluating the effects of forest management on our water resources, helping foresters to determine which vegetation can be cut safely and which should be retained or established, depending on the desired quality and quantity of water runoff.

Experimental watershed research has contributed to fundamental advances in scientific hydrology, including the variable source area concept. A hydrologic source area is a part of a watershed that yields much more runoff water per unit area than the watershed as a whole. Source areas expand or contract depending upon soil moisture conditions, hence the adjective "variable." During major storms, variable source areas appear to yield nearly all the storm flow, and

there is reason to suspect that further research will reveal that they are extremely important in determining element losses from watersheds.

Research on Walker Branch Experimental Watershed has contributed to our understanding of nutrient and trace-element transport, accumulation, and cycling in a forested landscape. For example, Henderson and Frank Harris have constructed a detailed nitrogen budget for the watershed and have compared it with three other watersheds in the United States. Nitrogen inputs from the atmosphere average 13 kg/hectare (ha) on Walker Branch, and streamflow outputs amount to 3 kg/ha. The 10 kg/ha differential is primarily accumulating in the watershed vegetation. At least 124 kg nitrogen/ha is circulated (cycled) annually within the watershed by various mechanisms, and because only 3kg/ha is lost in streamflow, it is apparent that this forested landscape effectively retains this critical nutrient. The other three forested watersheds are also accumulating nitrogen, but in different magnitudes depending on vegetation, climate, and the quantity and form of atmospheric inputs.

Robert Van Hook, Harris, and Henderson have done more recent work on some trace element distributions and cycling on Walker Branch. They found that zinc, lead, and cadmium tend to accumulate in small roots and soil organic layers. By comparing the outputs of these elements with the total quantities in the watershed, they also calculated turnover times for these elements. These times varied from 50 years for cadmium to 4700 years for lead and give a relative measure of how long it may take a landscape to recover from accelerated inputs of these materials.

Walker Branch research is supplying information on element discharge during periods of high streamflow that most watershed studies are not able to supply because they do not have appropriate sampling facilities. In studying elemental transport of particulate and dissolved material in a stream channel, the controlling factors are direct input by precipitation and indirect inputs from surface water runoff, soil water, and groundwater. A hydrologically calibrated watershed provides both a framework within which each component can be studied in detail and a final integrated result of the operating processes.

Sediment transport depends largely on the quantity and timing of water yield. Organic and inorganic materials are eroded from variable source areas and scoured from the stream channel. We need detailed knowledge of the hydrologic response and associated material loads to quantify this episodic, and sometimes catastrophic, rush of storm waters into downstream aquatic systems. It is also important to compare the effects of such flooding with those of the more continuous baseflow (i.e., that water in the saturated zone of the soil where soil leaching and bedrock chemical equilibria regulate the discharge of elements). For example, calcium and magnesium concentrations in streamflow are predominantly controlled by weathering rates of the bedrock dolomite. Potassium concentrations, on the other hand, are related to interactions of both soil and vegetation with the water cycle, which is a seasonally variable relationship. In response to increased streamflow, potassium concentration changes very little during spring and summer and appears to be largely controlled by soil chemical equilibria. However, during autumn and early winter, leaching from senescing foliage and fresh leaf litter puts higher potassium concentrations into the streams. Nitrogen concentrations in both dissolved and particulate

form are low for most of the year and increase only during storms. The measured increase in dissolved sulfur concentrations during stormflow, while not yet fully understood, is of considerable current interest because of high sulfur releases from coal combustion.

Changes in concentrations during high-flow periods help us to understand how different elements are exported from the watershed. When combined with water discharge measurements, they also help us evaluate the effects of catastrophic loading by storms on lakes and reservoirs and compare them with the loading from baseflow.

Research watersheds are ideally suited to studies of the response of aquatic systems to their terrestrial environs. Because many stream systems are dependent on the terrestrial system for their energy and nutrient base, studies of element cycling in the terrestrial system contribute to our understanding of this relationship.

In addition to such interaction studies, measurements of element discharge are valuable to water quality research on the downstream lakes and reservoirs. Land has a critical ability to accumulate or discharge the pollutants that are deposited on it. It is important to determine not only the extent of retention, but also the physical, chemical, and biological processes within the terrestrial system that determine the form in which these pollutants are carried.

Mathematical simulation models help to predict hydrologic and element yields from landscapes. The process of model building is iterative and depends upon watershed research that supplies data and understanding for construction as well as validation. Modeling and simulation results, in turn, identify critical parameters or processes that bear further study. Although predictive ecosystem model development is still in its infancy, a tremendous potential exists for model application in a research setting, especially for characterizing water movement.

We are using water and element discharge data from the entire Walker Branch Watershed,

and data from complementary plot studies together with mathematical simulation models increase our understanding of the details of material transport. For example, PROSPER, a model of soil-plant-atmosphere water relations, has been used together with watershed data to develop continuous estimates of throughfall—the amount of rainfall passing through the canopy of tree branches to the forest floor—and the content and rates of movement of water in the soil profile in the basin. These estimates are, in turn, used to predict the transport and distribution of elements throughout the study area and to suggest specific detailed field studies. The successful development and validation of models such as PROSPER have great application for research in regional analysis and assessment of energy technologies, especially in connection with evaluating the fate of materials released to the environment during energy production.

Role in Regional Assessment

No single experimental watershed is truly representative of a large region. However, it is common engineering practice to extrapolate results from one watershed to a similar, ungaged basin in the same region. Thus, by assembling results from several watersheds, we can estimate the regional response to the introduction of a manmade change. Although sufficient data could conceivably exist to make estimates for purely hydrologic variables, data are not yet available for regional evaluations of human- or energy-generated pollutant transport.

In evaluating a site for an energy-related facility such as a nuclear power station or a coal-fired steam plant, one first screens out sites that lack such properties as adequate water quantity or quality. This screening can be done by fairly simple empirical extrapolation methods from existing watershed data. However, once the candidate locations are identified, detailed assessments of both short- and long-term consequences of development of the site are

necessary. Mechanistic simulation models are valuable here, provided there are enough data to justify their use. Thus, basic watershed studies enhance the predictive capability of such models. At the same time, they provide useful empirical data relating land use to the quantity and quality of runoff water.

Experimental watershed research has already provided documentation of the effects of various land use practices on water quality. Bormann, Likens, and their coworkers showed that forest denudation (i.e., clearcutting with elimination of all vegetation) at the Hubbard Brook Experimental Forest in New Hampshire affected the water quality by markedly increasing both concentrations and total yields of nitrate, calcium, magnesium, potassium, and sodium. Although the Hubbard Brook experiment should not be interpreted as a conventional harvesting operation, it did yield valuable information on the influences of forest cover and decomposition on nutrient discharge. Recently, two watershed studies on the Fernow Experimental Forest in West Virginia documented water quality changes due to carefully conducted conventional clearcutting and forest fertilization. The clearcutting resulted in slightly elevated nitrate and phosphate concentrations in streamflow, whereas cation concentrations remained unchanged. Fertilization with urea caused a tenfold increase in nitrogen discharge and an accelerated loss of some cations. Nitrate concentrations in streamflow were shown to increase markedly during summer storms, a

finding significant both in terms of loss from the terrestrial system and of nutrient loading of downstream aquatic systems.

The effect of land use on stormwater runoff quality and element cycling has been recently reported by Ralph Turner, now a member of the Environmental Sciences Division. Two Florida watersheds, differing in land use (one a semiforested agricultural watershed and the other residential/commercial/urban) but otherwise comparable, were studied for the effect of land use on nutrient and sediment discharge. The differences observed resulted in the realization that techniques for management of stormwater quality are urgently needed to prevent undesirable changes in downstream ecosystems as a result of hydrochemical changes in runoff from urban watersheds.

Studies on watersheds such as Walker Branch have allowed us to quantitatively relate many ecosystem processes to element transport and accumulation. Such research has thus given us a basis for assessing some of the impacts of various land uses and pollutant discharges on forested ecosystems. However, new environmental problems arise as advanced energy technologies develop. As ERDA and ORNL ecologists continue to respond to these problems, we think watershed research will also make important contributions to the understanding necessary for their solution.

Take A Number.....

BY V. R. R. UPPULURI

A SEARCH FOR PATTERNS

Take the three-digit number 182. Find the sum of its first two digits, 1 + 8 = 9. Multiply this sum by 11 to get 9 × 11 = 99. Add this result to the original number to get 99 + 182 = 281. Note that by this procedure we inverted 182 to obtain 281. If we start with 819 and apply this procedure (819 → 8 + 1 = 9 → 9 × 11 = 99 → 99 + 819 = 918), we obtain the inverted number 918. One can show that **182**, **273**, **364**, **455**, **546**, **637**, **728**, **819** are the only three-digit numbers for which the above procedure yields the respective inverted numbers.

Take the three-digit number 729. Find the sum of all its digits this time, 7 + 2 + 9 = 18. Multiply this sum by 11 to get 18 × 11 = 198. Add this result to the original number and get 198 + 729 = 927. Note that by this *new* procedure we inverted 729 to obtain 927. If we start with 162 and apply the above procedure (162   1 + 6 + 2 = 9 → 9 × 11 = 99 → 99 + 162 = 261), we get the inverted number 261. One can show that **162**, **243**, **324**, **405**, **486**, **567**, **648**, and **729** are the only three-digit numbers for which the above procedure yields the respective inverted numbers.

By now, some readers might have perceived a pattern. In the first paragraph, the number represented by the first two digits is equal to *nine* times the last digit (e.g., in **364**, 36 = 9 × **4**); in the second paragraph, the number represented by the first two digits is equal to *eight* times the last digit (e.g., in **405**, 40 = 8 × **5**,). One would expect such an interesting property to hold for three-digit numbers where the number represented by the first two digits is equal to *seven* times the last digit (e.g., for **142**, 14 = 7 × **2**). It is true that **142**, **213**, **284**, **355**, **426**, **497**, **568**, **639**, exhibit a similarly interesting property. For example, if we wish to invert **284**, we need to add to it 11 × (2 + 8 + **4**) + 11 × **4** = 198, and so on.

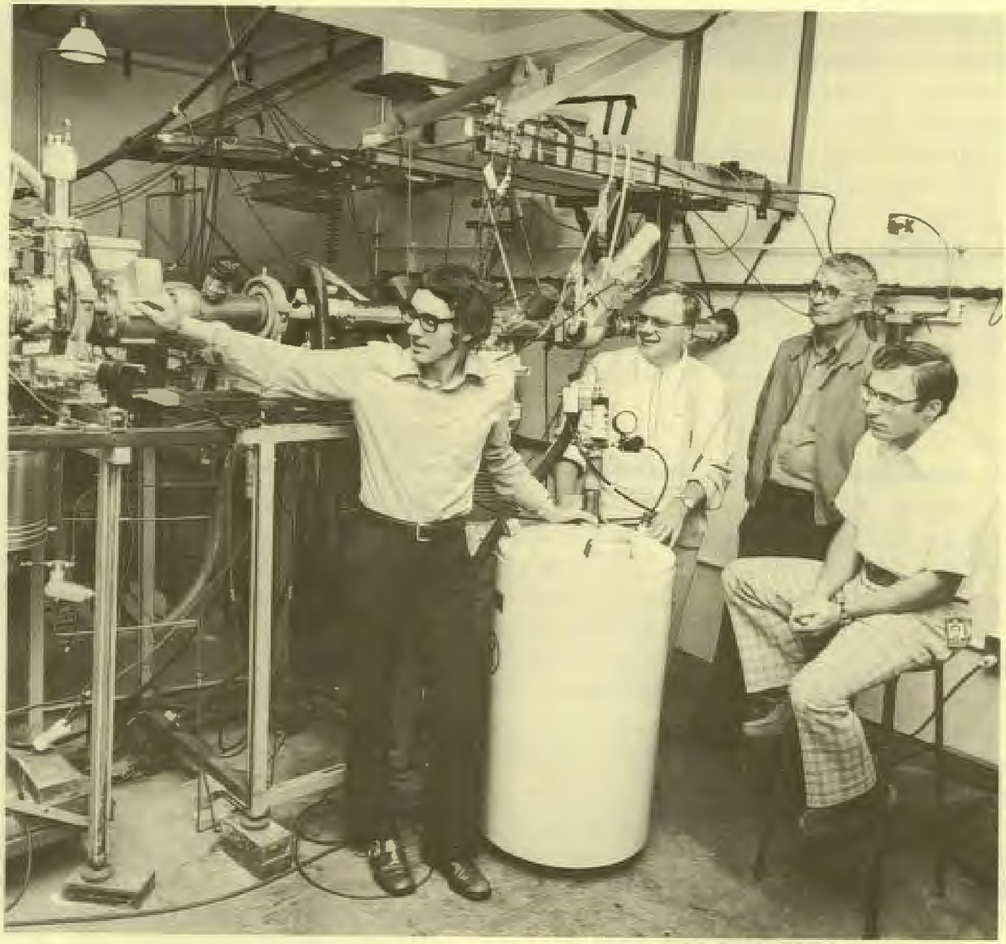
If we are working with *six*, the only three-digit numbers will be **122**, **183**, **244**, **305**, **366**, **427**, **488**, and **549**. If we wish to invert **488**, we need to add to it 11 × (4 + 8 + **8**) + 11 × 2 × **8** = 396, etc.

If we are working with *five*, the only three-digit numbers will be **102**, **153**, **204**, **255**, **306**, **357**, **408**, and **459**. If we wish to invert **255**, we need to add to it 11 ×(2 + 5 + **5**) + 11 × 3 × **5** = 297, etc.

If we are working with *four*, the only three-digit numbers will be **123**, **164**, **205**, **246**, **287**, **328**, and **369**. If we wish to invert **287**, we need to add to it 11 × (2 + 8 + **7**) + 11 × 4 × **7** = 495, etc.

If we are working with *three*, the only three-digit numbers will be **124**, **155**, **186**, **217**, **248**, and **279**. If we wish to invert **124**, we need to add to it 11 × (1 + 2 + **4**) + 11 × 5 × **4** = 297, etc.

If we are working with *two*, the only three-digit numbers will be **105**, **126**, **147**, **168**, and **189**. If we wish to invert **147**, we need to add to it 11 × (1 + 4 + **7**) + 11 × 6 × **7** = 594, etc.



This is the team that developed the low-swelling stainless steel. Gathered in front of the ion beam tube of the Van de Graaff are, l. to r., Arthur Rowcliffe, Jim Stiegler, Jim Leitnaker, and Everett Bloom.

Metallurgy's Double Play: Making Two Improved Alloys

ORNL has developed and tested two improved metallic alloys that already are being recognized as significant contributions to the nation's fast breeder reactor and space exploration programs. Both materials—a special alloy of stainless steel and an alloy of iridium—were developed primarily by the Metals and Ceramics (M&C) Division, but assistance in the development and testing of the metals was provided by other Laboratory divisions. These achievements are outstanding results of multidisciplinary and multidivisional efforts.

Low-Swelling Stainless Steel

Nine years ago in England, the discovery was made that bombardment of conventional reactor materials with intense, high-energy neutrons such as would occur in the cores of liquid-metal fast breeder reactors (LMFBRs) can, under certain conditions, cause the metals to swell. The phenomenon is ascribed to the displacement of the metallic atoms from their lattice positions by the neutrons. Each atom is believed to be displaced one thousand times as often in LMFBRs as in conventional light-water reactors over the 30-year lifetime of reactor components as a result of neutron irradiation. At operating temperature, the atoms are sufficiently mobile to allow the dislodged atoms to collect, forming new planes of atoms, while the vacated sites accumulate into voids (empty spaces). The material then increases in volume and decreases in density. ORNL researchers have been able to measure the swelling in several ways, including the laborious counting of atom platelets and voids seen with an electron microscope and the ancient Archimedes technique.

The swelling behavior of reactor materials exposed to high neutron fluxes must be considered by designers of such LMFBR facilities as ERDA's Fast Flux Test Facility (a test reactor for breeder fuels and components) and the Clinch River Breeder Reactor Plant (the nation's first breeder demonstration power plant), which is to be built in Oak Ridge. For LMFBR designers, this swelling must be accommodated by leaving enough space for the bowing or warping of the fuel cladding and duct (hexagonal can containing fuel rods) so as not to restrict the flow of the liquid sodium coolant that carries away the heat for producing steam to generate electricity. The greater the space that must be left in the design, the lower the breeding ratio. That is, neutrons from fissioning nuclear fuel are less efficiently captured by the uranium-238 in the blanket. As a result, less plutonium-239 is bred per fissioning atom than would be possible if swelling of the structural materials is minimal. Plutonium is an essential product of LMFBRs because it is expected to supplement declining uranium resources as a nuclear fuel.

Researchers at ORNL and Argonne National Laboratory have calculated that the economic benefits of a low-swelling alloy could be as much as \$10 to \$20 billion for a fully developed breeder economy with 200 LMFBRs operating over a 30-year lifetime. Use of a low-swelling alloy would mean that more plutonium could be bred per fissioning atom, that the frequency of fuel loadings to achieve maximum burnup of fuel could be reduced, and that the breeder reactor could operate at higher power levels.

ORNL materials researchers this year have identified, through heavy-ion bombardment studies, a modified version of the reference alloy of stainless steel that is five to ten times as resistant to radiation-induced swelling. A research team headed by Everett Bloom in Jim Stiegler's group in the M&C Division discovered that an alloy of type 316 stainless steel to which silicon and titanium were added in a controlled manner swelled by less than 10% of its original volume, compared with 30 to 70% swelling observed in the conventional alloy irradiated under the same conditions. In the past, the only way to test various alloys for radiation damage in a fast breeder environment was to place them in the core of ERB-II, the experimental breeder reactor operated for ERDA by Argonne National Laboratory in Idaho. However, heavy-ion accelerators can simulate reactor radiation damage in much shorter time spans. Therefore, the M&C Division, in collaboration with the Physics Division, equipped the 5.5-MV Van de Graaff accelerator in Building 5500 so that it could bombard modified stainless steel with nickel ions. This type of charged projectile was chosen because it would not disturb significantly the composition of the target (stainless steel is 10 to 12% nickel). Solid State Division members calculated that 6 hr of irradiation of one of these alloys with a beam of ionized nickel atoms would simulate the radiation damage that would be inflicted on the same alloy by neutrons from six years of EBR-II (operating full time at peak power).

In 1973, Bloom, Stiegler, and Jim Leitnaker showed that the presence of certain metallic impurities in stainless steel, particularly silicon, suppressed the onset of void formation and the resultant swelling during neutron exposure. They theorized that an alloy with an increased silicon content would swell significantly less. Controlled additions of titanium were included because earlier work by Jim Weir and Bill Martin had shown that this element suppressed radiation embrittlement in stainless steel. The expectations were confirmed by using the Van de Graaff to test several batches of stainless steel alloys doped with silicon and titanium.

The ORNL Materials Radiation Facility was developed for heavy-ion bombardment of stainless steel alloys by personnel in both divisions. The ion source was developed by the same group in the Physics Division that was responsible for designing a unique beam-focusing lens unit, which was a key element in making the experiment successful. Mike Saltmarsh of the Physics Division directed and coordinated design and operation of the accelerator. An M&C Division group led by Nick Packan and Ed Kenik was responsible for the design, construction, and use of the irradiation chamber. Bloom and Arthur

Rowcliffe have interpreted the results and designed additional experiments to confirm the alloy performance.

The special stainless steel alloy developed at ORNL will be further tested in the breeder reactor environment of EBR-II to determine whether it is as low-swelling a material as experiments at Oak Ridge indicate. Because of the time required to test this alloy further, it will not be used for the Fast Flux Test Facility (scheduled to be completed in 1978) or initially in the Clinch River Breeder Reactor (scheduled to go into operation by 1983, but it is proposed for a CRBR replacement core.

The special alloy probably will be manufactured commercially for additional testing by ERDA facilities. ERDA's Hanford Engineering Development Laboratory has been assigned the task of testing the new alloy for other properties, such as ductility, that have an effect on design. The ORNL alloy is expected to pass the tests because it is essentially within the specification of type 316 stainless steel and because the principal effect of the titanium is to improve the ductility.

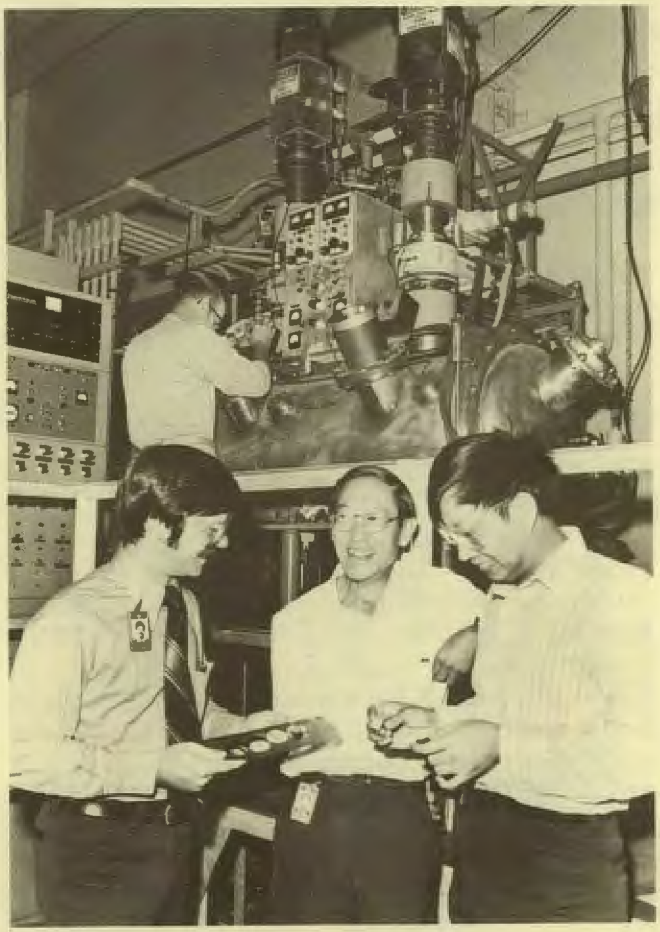
Tougher Iridium

By careful control of trace additions of certain alloying elements to iridium, ORNL materials researchers have developed an improved alloy, thus enhancing the safety and reliability of nuclear-powered thermoelectric generators used for earth satellites and deep-space probes. The M&C Division currently produces the special iridium alloy for use as cladding in NASA's Mariner Jupiter-Saturn spacecraft scheduled for launch in 1977. The cladding will contain plutonium-238 oxide fuel in golfball-sized spheres that serve as a heat source. A semiconductor thermocouple system heated by the radioisotope source supplies electricity to the experiments and communication equipment on the space probe. ERDA is in charge of developing the Multi-Hundred Watt (MHW) generator and its heat source, which will consist of 24 nuclear fuel spheres, each producing 100 W(t).

Because of the remote possibility that a spacecraft may abort or accidentally plummet back into the earth's atmosphere, where it would undergo the searing heat of reentry, ERDA has spelled out certain requirements for the cladding to ensure that the hazardous radioactive fuel does not escape into the environment during reentry or after striking the earth's surface. The cladding, according to ERDA's specifications, must be able to withstand high temperatures (exceeding 1800°C), resist reaction with oxygen in air and seawater at high temperatures, and endure forces of impact generated at speeds up to 300 fps while at 1400°C. Iridium, a precious metal costing $22/g (twice as expensive as platinum), was selected to contain the nuclear fuel because of its high melting point (about 2450°C), its excellent resistance to oxidation at elevated temperatures, and its good fracture toughness. It is also compatible with $^{238}PuO_2$ and the ablating material surrounding the iridium cladding. (The material, graphite, would burn off during reentry, thus preventing the heat source from getting hotter than the melting point of iridium.)

Although iridium has many favorable properties, tests have indicated that the element could become brittle and crack under impact in maximum credible accident situations. ORNL materials engineers, principally Hank Inouye and Chien Liu, traced the variability to impurities in the iridium. The identities and quantities of the impurities in the iridium were determined by a spark-source mass spectrometric method developed and applied by Joel Carter of the Analytical Chemistry Division. But purification was not the complete answer; pure iridium is too weak and brittle. Carefully controlled additions of trace amounts of certain elements increased the overall strength and ductility of iridium. These elements—thorium, nickel, iron, aluminum, and rhodium—are sometimes present in iridium powder obtained by ORNL from Government stockpiles or are introduced during commercial processing of sheet material.

Spectroscopic analysis showed that the stockpile iridium, which could be expected to crack under maximum impact conditions, had either excessive or inadequate levels of impurities. These impurities were concentrated in the grain boundaries, the regions between neighboring metallic crystals. ORNL materials researchers later discovered, after preparing and testing ingots of five alloys with different amounts and combinations of impurities, that adding just the right levels of impurities (or "dopants") imparted to iridium the extra ductility to withstand impact forces in maximum credible accident situations. ORNL researchers tested the strength of the alloys with different modified compositions by using a gas-powered impact gun previously operated by the former Isotopes Division. As modified by the



Tony Schaffhauser, left, examines a rolled sheet of iridium from which disks have been cut out, while Hank Inouye looks on. Chien Liu, right, inspects a small sample of iridium. At back, Glynn Angel makes an adjustment on the electron beam melting machine.

M&C researchers, the gun fires a bullet into an impact plate connected at both ends to tensile specimens of doped iridium. One alloy of iridium, strained by test forces simulating those of "worst case" impacts, did not crack in the gun experiment. The same alloy, designated DOP-4, showed strong resistance to impact in a high-velocity punch test conducted by ERDA's Los Alamos Scientific Laboratory and in full-scale impact tests ordered by ERDA's Space Nuclear Systems Program. The latter tests, carried out by GE-Valley Forge (ERDA's prime contractor for the MHW heat source), involved firing three capsules containing DOP-4 iridium cladding and thorium oxide as a simulant fuel at speeds exceeding 300 fps against a block of granite at high temperatures. Success was complete.

The M&C Division has developed other techniques for producing iridium for space vehicle applications. Three years ago, when commercial vendors were unable to provide hardware of the required quality, AEC's Space Nuclear Systems asked ORNL to develop an improved production process and to produce iridium disks on a tight schedule. The disks, according to the plan, were to be sent to AEC's Mound Laboratory, where they were to be shaped into hemispheres, loaded with fuel, and welded together. The spheres were then to be mounted into the U.S. Department of Defense's Lincoln Experimental Satellites (LES-8 and LES-9), scheduled for launch later this year. The ORNL crash program was a success—the 500 iridium disks required for LES heat sources were produced on time by the Laboratory.

The production process developed by the M&C Division consists of these steps:

1. The alloying elements are blended with pure iridium and pressed into compacts. At this point 0.3% tungsten is intentionally added to override the effect of varying amounts of refractory metal impurities, which had been found to affect the recrystallization of the metal during rolling and annealing, making it difficult to produce a consistent fabricable material.

2. The compacts are melted by electron beam to boil off the residual impurities (all but very refractory metals are more volatile than iridium) and cast into ingots.

3. The ingots are reduced to sheet by hot rolling in molybdenum frames.

ORNL's Plant and Equipment Division added to the M&C Division's contributions by developing machining techniques of blanking and grinding to cut out disks of the desired size from the iridium sheets.

Following the alloy development, Tony Schaffhauser and colleagues developed and executed the fabrication process under the overall coordination of Ralph Donnelly. ERDA recently extended special recognition of the ORNL effort by sending letters of commendation to Inouye, Schaffhauser, and Liu.—C. K.

Lab anecdote

Pile of Pebbles

The several times in the last few months that I have heard mention of the Daniels pebble pile prompted me to look up his first use of the name.

To the physicist a nuclear reactor is a medium to control the diffusion of neutrons. To the engineer a nuclear reactor is a big heat exchanger that transfers fission heat to air in the old Clinton pile, to water in most subsequent reactors, or to sodium or helium in a few others. Farrington Daniels (known to several generations of chemistry students as half of Getman and Daniels) was a chemist with a predisposition for the heat transfer side. Before he went to the University of Wisconsin as professor of chemistry, he worked for a year in the fixed-nitrogen research lab of the Department of Agriculture. Twenty years later he used a bed of magnesia pebbles in a recuperative furnace to fix nitrogen with oxygen. The patent notice has the phrase, "pebble bed," in the first line, but then grows increasingly cryptic.

In 1944 Daniels joined the Manhattan Project's Metallurgical Laboratory in Chicago and, shortly thereafter, proposed that his pebble bed be adapted to a high-temperature nuclear power reactor. The pebbles would be a refractory uranium compound, the oxide or carbide or nitride, without jackets that impede heat flow. The circulating helium would be treated to remove the radioactive dust. Neutron moderation would be provided by beryllium oxide.

The Clinton Laboratory under the operation of Monsanto Chemical Company put a lot of effort into the development of the nuclear pebble pile, and Daniels was a frequent visitor. This was during the same time as the old Training School in 1946 and 1947 and the same time as the design of the

Materials Test Reactor (MTR) that was later built at Arco, Idaho. (Incidentally, one of the low-cost bets that Alvin Weinberg lost was for his belief that ground would be broken for the MTR before 1948 and in Oak Ridge.) The Daniels pebble pile had very little hardware to show for all the developmental effort. The hollow beryllium oxide prisms shown here were made by the Bureau of Mines in Norris and belong now to a private collection; the black surface comes from a graphite mold. A more important bequest of the Daniels pile group at Oak Ridge was the nucleus of trained engineers for the naval reactor project at Bettis Field and the breeder reactor at Argonne, from which came the first two power reactors in the United States.—Herbert Pomerance

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On September 12 ground was broken for the Environmental Sciences Laboratory. Among the dignitaries present for the ceremony was the brother of Dan Nelson, whose untimely death prevented his witnessing the realization of the building that owes a great deal of its design to him. Director Herman Postma, l., converses with Samuel Nelson, who is holding a duplicate of the gold embossed plaque, r., that will hang in the new laboratory. The auditorium of the building will be designated The Daniel J. Nelson Memorial Auditorium.

ENVIRONMENTAL SCIENCES LABORATORY

in Memory of

DANIEL J. NELSON

1925–1975

Assistant Director
Environmental Sciences Division

Ecologist — Scientist — Enthusiast

His unswerving dedication to Ecology, his ability as a scientist, and his unselfish contributions to the goals and achievements of this Division helped to convert the vision of an environmental research facility into reality.