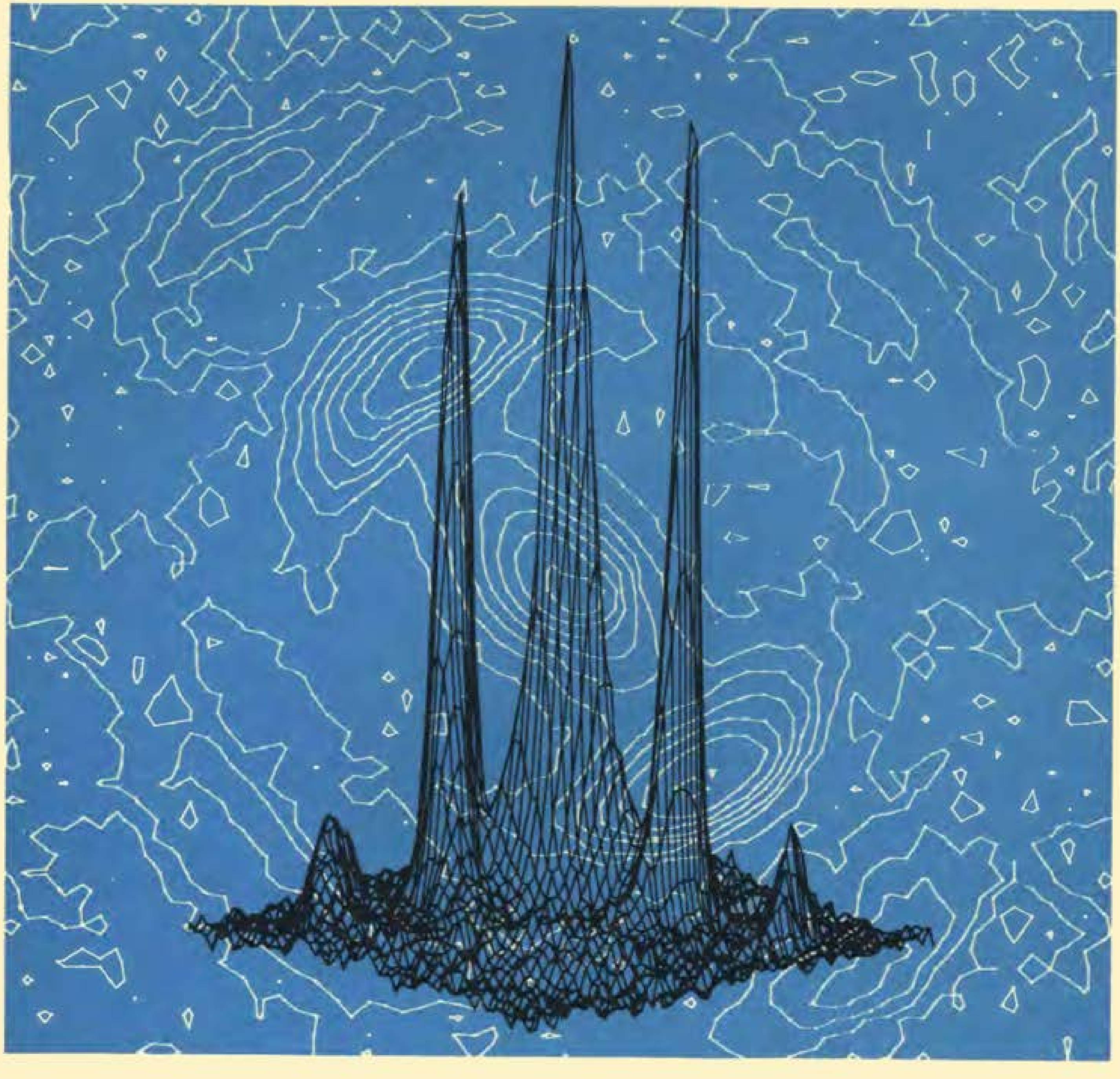
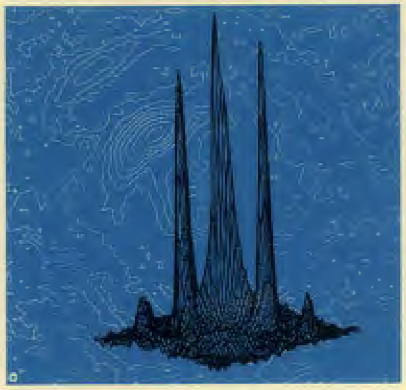
VOLUME 11 NUMBER 1

# REVIEW

OAK RIDGE NATIONAL LABORATORY WINTER 78





*COVER: The diffraction pattern from a specimen of* Halobacterium halobium, *2 mm diam × 200 μ thick, is depicted here by the small-angle x ray scattering spectrometer (SAXS) in two configurations: the iso-intensity contours, superimposed by a three-dimensional perspective. The software that enables the computer to delineate such pictures was developed by Tom Tucker. The SAXS is described in an article beginning on page 1.*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The *Review* is published quarterly and distributed to employees and others associated with the Oak Ridge National Laboratory. The editorial office is in Building 4500-North, Oak Ridge National Laboratory, P.O. Box X, Oak Ridge, Tennessee 37830. Telephone: (615) 483-8611, Extension 3-6900 (FTS 850-6900).


# REVIEW


**VOLUME 11 NUMBER 1 WINTER 1978**




## DEPARTMENTS




## OAK RIDGE NATIONAL LABORATORY

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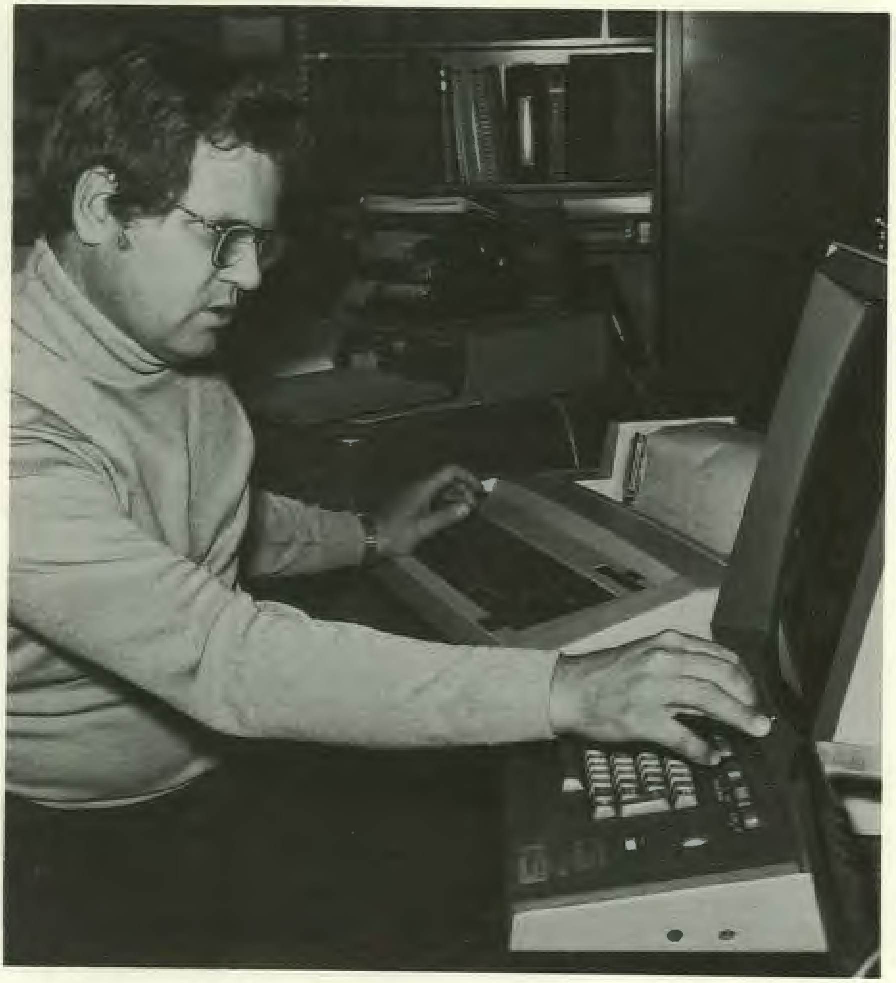


GARY WELCH

Bob Hendricks, with a doctorate in physical metallurgy from Cornell, has been a member of the Metals and Ceramics Division at ORNL since 1964. There, he has studied radiation damage and phase transformation problems using x-ray scattering techniques. The machine described here has won him the *Industrial Research Journal's* IR-100 award.

# A Novel Camera

## *Small-Angle X-ray Scattering*

By JEFF McKENNA

POLYETHYLENE—that twentieth century wonder plastic used for food wrapping, containers, kitchenware, and tubing—has, like most other polymers, a rather simple and well-understood structure. But what happens to that structure when the plastic is stretched has long been a difficult, troublesome determination for scientists. A recent advance at ORNL, however, may contribute significantly to the understanding of the mechanisms of plastic deformation of polymers.

Using the ORNL 10-meter small-angle x-ray scattering camera, one of this year's IR-100 award winners, researchers can now make a wide variety of structural measurements with unprecedented ease, speed, and accuracy. Other areas of research by this same technique range from the study of voids in irradiated reactor materials to the formation of minerals in teeth.

Small-angle x-ray scattering (SAXS) as a research tool is nothing new, having long been used to study microscopic levels of structure. When a beam of x rays strikes a material, the x-ray particles, called photons, may be scattered (deflected) when they pass close to an electron in the material. Detection of these scattered x rays thus reveals fluctuations in electron densities of the sample—such as the lamellae of partially crystalline polyethylene. Because the structural features of interest are often large (tens or thousands of angstroms; 1 Å = $10^{-10}$ m) compared to the wavelength of the x rays (e.g., 1.54 Å for many of the ORNL SAXS experiments), the scattering is observed at small angles.

Until recently, this seemingly straightforward technique was seriously constrained by very weak signals, which resulted because of the high collimation of the beam necessary to make measurements at small angles. Experiments thus had to be performed by collimating (lining up) the x rays by passing them through long slits, a method which produces good angular resolution in one direction, but poor resolution in the right-angle direction. This limitation (1) required relatively large specimens which were often difficult to prepare, (2) resulted in the possibility for significant multiple scattering, and (3) made nearly impossible the examination of specimens that showed anisotropic (having properties that differ according to the direction of measurement) scattering patterns. Stretched polyethylene, for example, is an anisotropic scatterer.

The ORNL 10-meter SAXS camera has four features that remove these impediments:

- A rotating anode x-ray source, which produces a significantly more powerful (higher flux) x-ray beam.
- Crystal monochromatization of the incident beam, which produces x rays of a single, known wavelength, depending on the anode material.
- Pinhole collimation (possible only with higher fluxes and/or a position-sensitive detector), which produces good angular resolution in all directions.
- An area detector, in this case the ORNL-developed a two-dimensional position-sensitive proportional counter which can simultaneously record many data points.

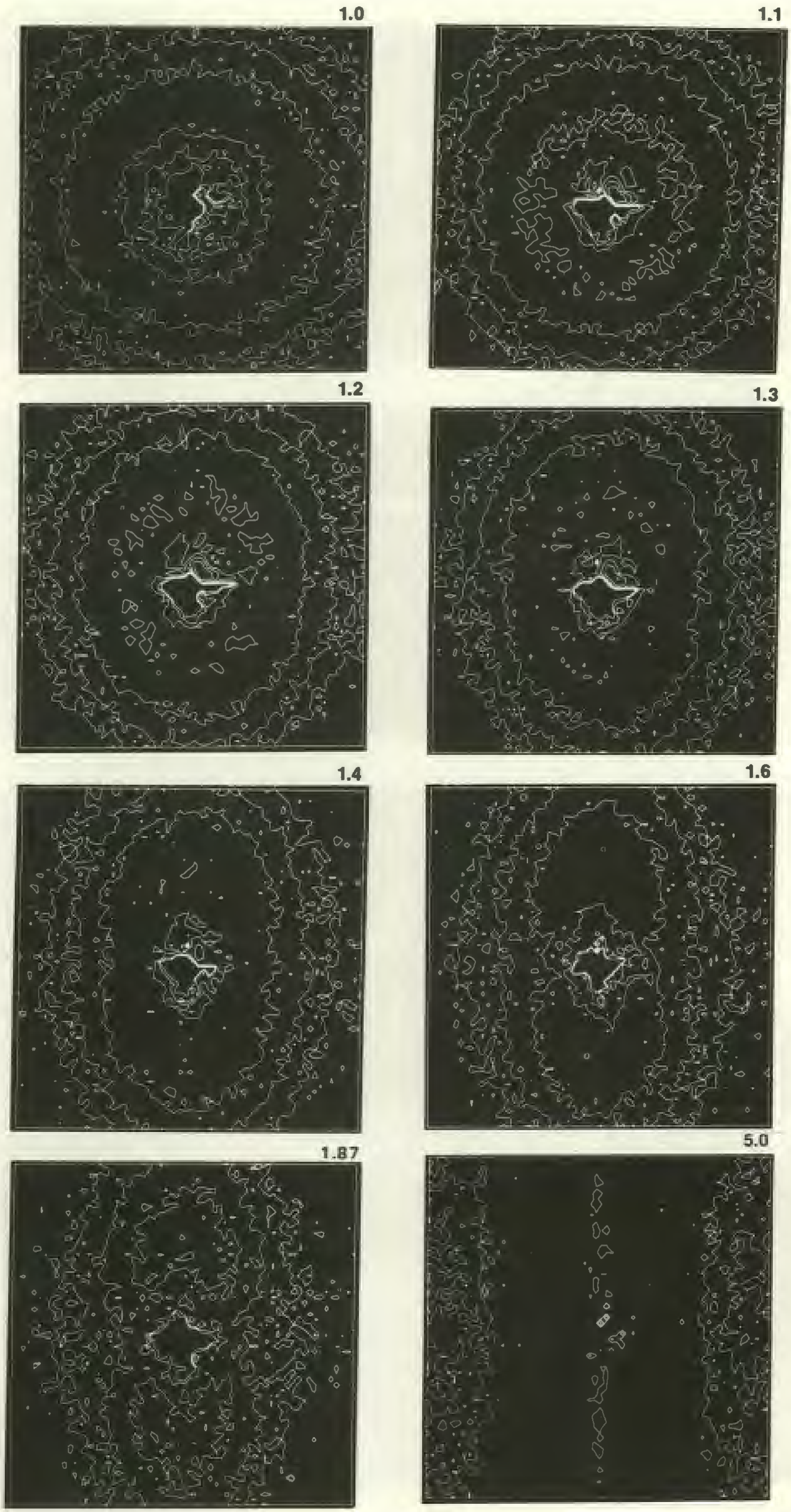
## A Radical Departure

"This camera is a radically different way of doing x-ray scattering experiments," said Bob Hendricks of the Metals and Ceramics Division, who developed the device. "The unique feature is the area detector—no other SAXS camera has one." Although the area detector was developed some years ago (in the late 1960s by Cas Borkowski and Manfred Kopp of the Instrument and Controls Division), its application to x-ray scattering has lagged because of its complex construction and the cost of the associated electronics and digital data acquisition system. What is unusual in the ORNL system is its unprecedented size. To achieve sufficient angular resolution, the camera is unusually long, with a maximum distance from the x-ray source to the detector of 10 m.

Because the sizes of the x-ray focal spot, the sample, and the resolution element of the detector are each about 1 × 1 mm, the camera was designed so that the focal spot-to-sample and sample-to-detector distances may each be varied up to 5 m to provide a system resolution in the range 0.5 to 4.0 mrad (higher to lower resolution). The detector simultaneously records scattered x rays at up to 4000 grid points over an active area of 200 × 200 mm. It performs the function of photographic film—with a spatial resolution of 1 mm—but is much more useful because it can digitize and encode the information in a matter of microseconds and transfer it to the memory of a minicomputer.

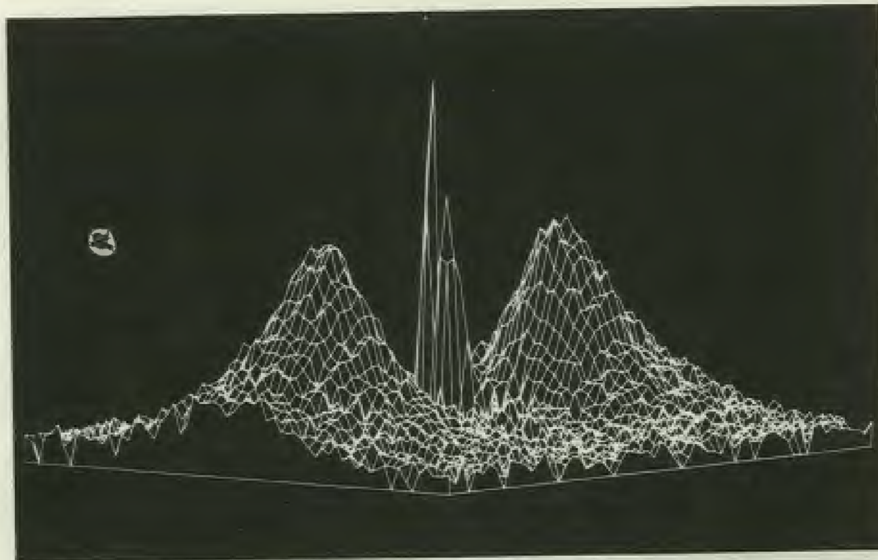
"With the old system," Hendricks said, "a detector would be set at one angular position, record the scattered intensity, move to another point, record it, and so on, one at a time. Now we're measuring all points at once, giving us an increase in counting speed of two to three orders of magnitude. This system is making possible experiments that simply couldn't be done previously."

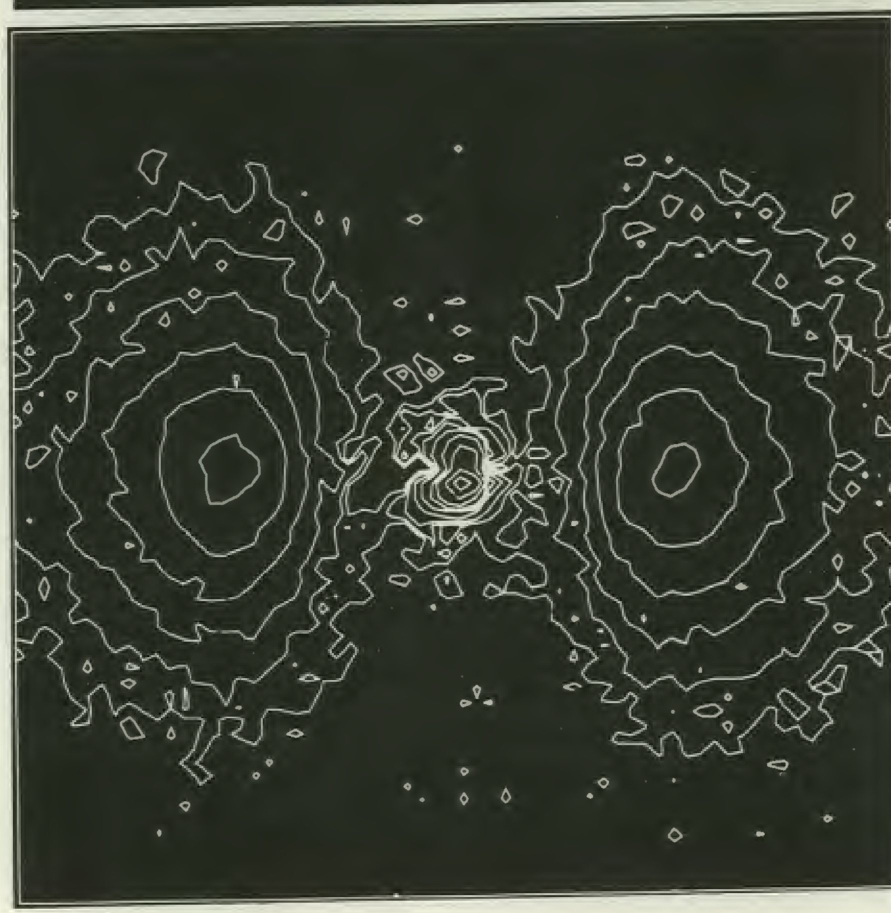
As an example, let's look again at polyethylene. Besides the study of structural changes from deformation, there is widespread interest in the kinetics of molecular motion during crystallization of polymers. Until recently, it has been very difficult to obtain dynamic structural information during




*Computer-generated, two-dimensional SAXS plots of low-density polyethylene at various stages of strain: elongation ratios are shown (stretch direction is horizontal).*

*Jeff McKenna, currently on leave of absence to complete a graduate degree at The University of Tennessee, is an editor in the Information Division.*





*Low-density polyethylene, plastically deformed to parallel lamellar morphology.*

crystallization because of the long times required to record a small-angle scattering pattern with traditional apparatus (about eight hours). For instance, researchers were forced to make measurements at low temperatures, where the kinetics of crystallization were slow compared to their data recording speed, or at faster kinetics and record data at only a few fixed angles, then attempt to infer the scattering curve from these data. With the ORNL 10-meter SAXS camera, however, scientists have been able to record a diffraction pattern of polyethylene in 30 seconds. A dramatic result is that eight measurements could be performed during the 400 seconds that elapsed between the start and completion of the crystallization process at 118°C; such measurements have been made at seven different crystallization temperatures.

## Impressive Software

The usefulness of the detector, regardless of how well it is designed and built, is limited by the on-line computer system that collects, manipulates, and displays the data recorded by the detector. According to Hendricks, "By far our single biggest effort was developing the computer software. Design and installation of the hardware was relatively simple; writing the programs to handle the data was a real undertaking." In the SAXS camera, the data are recorded in the memory of a minicomputer by a high-speed interface that uses a microprocessor to map the position of a scattered photon into an absolute minicomputer memory address. This interface allows the recording of over 100,000 events per second. The data recorded in the computer memory can be processed on-line by a variety of programs designed to enhance the user's interaction with the experiment.

"The combination of these two unique features—minicomputer memory (as opposed to external core memory) for data storage and a high-speed microprocessor—opens up a wide range of important dynamic experiments that are not possible with the area detectors in use at other laboratories," Hendricks said. "This is because with their systems, the external memories must be dumped to disk at the end of each time slice (which usually takes 0.1 to 1 s). With our system, up to eight 64 × 64 data arrays can be maintained in the minicomputer simultaneously, and the user can switch between them in 1 or 2 $\mu$s." Because of the great quantity of data recorded by the area detector, the camera's on-line graphical analysis capability is necessary to judge the quality of an experiment prior to detailed quantitative analysis. In cases where too much data are collected for on-line analysis, the codes have been duplicated to perform the analyses in batch mode (at one time with the same program) on the machines in ORNL's central computing facility.

## Versatile and Powerful

During its relatively short history of operation, the ORNL 10-meter SAXS camera has already demonstrated its versatility and power through application to a wide variety of both ORNL- and university-sponsored research problems, such as studies of inorganic material sciences, structural polymers (as discussed), and biophysical materials. Jar-Shyong Lin also of the Metals and Ceramics Division, is joining with Hendricks in this effort to make the SAXS camera an interdisciplinary research tool, as illustrated in the following examples.

A problem of continuing importance in the development of fission and fusion reactors is the adverse effect of neutron irradiation-induced swelling of structural components. Small-angle x-ray and neutron scattering techniques have been shown to be powerful tools for rapidly evaluating the size distribution and total volume fraction (swelling) of voids created by this irradiation in nickel, aluminum, and molybdenum. In all cases, void sizes and swelling determined by SAXS agree well with data obtained by electron microscopy. Preliminary results indicate that void concentrations of a few percent can be detected in specimens less than 1 $\mu$m thick.

In a wide variety of chemical processes, including hydrotreating and desulfurization in coal conversion technology and in the production of synthetic fuels, a cobalt-molybdate catalyst has proven useful to prompt the necessary reactions. To better understand the properties of this catalyst, its structure and surface properties were investigated and characterized by SAXS. Results on changes in the surface area, pore volume, and size distributions as specimens were heated to 1000°C compared favorably with two other methods of detection—gas adsorption-desorption and x-ray powder diffraction.

In a related area, an understanding of microporosity and mineral deposits in coal is essential to the development of coal gasification and liquefaction processes. SAXS was used to study samples from a high-volatile bituminous coal (Illinois No. 6). Micropores and fine minerals with sizes ranging between 50 and 1000 Å were observed and their size distribution determined; further results were obtained on the radius of gyration, surface area, and volume fraction.

Structural research on biophysical problems is also in progress. To understand the processes underlying the formation of teeth, the structural roles of various components in developing teeth are being studied. Of particular interest are the maturation of enamel and the process of apatite formation. Using SAXS, researchers observed changes in scattered intensity and increasing anisotropy of the scattering pattern as a function of tooth maturation. Calculations show a considerable distribution of particle sizes.

Other biophysical materials studies include the structure of duck tendon collagen fibrils; the structure and organization of nu bodies (globular chromatin subunits that contain a specific complex of proteins and DNA) within chromatin; light-induced structural changes in the purple membrane of *Halobacterium halobium,* a rod-shaped bacterium; and conformation changes in nucleic acids.

## SAXS Upgrade

"It is important to note that virtually all of the original design goals for the camera and detector have been achieved," Hendricks said. But despite the success of the current instrument, Hendricks is seeking to further increase its power and versatility, realizing that its performance must continue to improve to meet the needs of diverse and complex research problems. Toward that end, he has submitted a proposal to upgrade the camera.

The major component of the proposed upgrade is a more powerful x ray source which would increase the flux of the beam by a factor of 10. "The upgrade will allow us to do even faster experiments and thus a broader range of dynamic experiments, and also to do some experiments that cannot be done now because of the weak scattering signals as is the case with many biological specimens," Hendricks said. Additional proposed modifications to the area detector and signal processing electronics will increase the camera's sensitivity and decrease the dead-time between signal detection and computer encoding.

## A Neutron Addition?

Another proposal is in the works by Hendricks and Wally Koehler of the Solid State Division, which would make ORNL the finest small-angle scattering center in the world. They are seeking approval for the construction and operation of a national user-oriented small-angle neutron scattering (SANS) facility. According to Koehler and Hendricks, unlike the situation in Europe, where international SANS facilities exist, all existing American SANS facilities, including the two at ORNL, are dedicated to specific research programs and cannot adequately fill the needs of the large number of potential users in the university and industrial communities. The proposed device would be built at the High Flux Isotope Reactor, which would provide a continuous supply of thermal neutrons to the SANS facility. The instrument would be a "neutron analog" of the 10-meter SAXS camera and use an identical data acquisition system. It would use 4.75 Å neutrons, be 30 m long, and have fluxes competitive with those of the best European facilities.

The principles of neutron scattering are nearly identical to those of x-ray scattering, one difference being that the distribution of magnetic moments, as opposed to electron densities, are measured. According to Hendricks, the technique is complementary with SAXS. "It is now becoming clear," he said, "that in many areas of research, it is essential to perform consecutive neutron and x-ray experiments on samples selected from the same material. This is important, for example, in determining the structure of precipitates in ternary alloys (alloys of three elements) or in studying the differences of long-range fluctuations in magnetic moments and electron densities. By intercomparing results, you can obtain a lot of information you can get no other way.

"It would be ideal to have these two machines together at the same research establishment, but nowhere does this happy situation exist. We're optimistic, though, that the neutron facility will be built at ORNL." ■

**Letter to the editor:**

In my historical account of "Molten Salt Chemistry at ORNL," (ORNL *Review*, Fall 1977) acknowledgement of the contributions of Prof. Gleb Mamantov, University of Tennessee, was inadvertently omitted. In working concurrently in the ORNL Analytical Chemistry Division, where he is a consultant, Gleb played a significant role in developing electrochemical in-line methods for analyzing molten salts. I regret the omission and will appreciate your including this postscript to my article.

Stanley Cantor

# Take A Number.....

BY V. R. R. UPPULURI

## The Gossip Problem

Suppose we have three individuals Adam (A), Betty (B), and Charles (C), each with a different piece of information. There is one telephone over which two individuals can talk at a time, and during a call all the information is exchanged. It is clear that it takes three calls for *all* the three persons to obtain *all* the information. For instance, one call between A and B will let each have two pieces of information. Next a call between A and C (say) will let A and C have all the information. We need one more call to let B have all the information.

Similarly if we have four individuals, each with a different piece of information, and one telephone, it can be seen that we need a minimum of four telephone calls for *all* four persons to have all the information.

Now, one is tempted to use the principle of mathematical induction to find a solution to the general problem: Suppose we have $n$ individuals, each with a different piece of information, and a telephone. What is the minimum number ($a_n$) of phone calls necessary for *all* persons to obtain *all* the information? If we have $n + 1$ persons let us take an arbitrary individual first (call him A), and let there be a call between A and another individual in the group of $n$ persons. We know it takes $a_n$ calls for the $n$ persons to have all the information. Then one more call from any one of these $n$ persons to A will do the job. Thus, we have $a_{n+1} = 1 + a_n + 1 = a_n + 2$, which leads to the solution $a_n = 2n - 4$ for $n \geq 4$.

# A Laboratory in Flux

By ALBERT H. TEICH and W. HENRY LAMBRIGHT

INSTITUTIONS OFTEN OUTLIVE the purposes for which they were created, but the social and political consequences of disbanding them when their tasks seem less urgent tend to make them highly resistant to closure. To some observers, many of the large national laboratories created in the United States and other industrialized countries just after the Second World War appear today to be expensive monuments to yesterday's problems. In recent years, therefore, considerable attention has been given to the discovery of new tasks for certain large national laboratories—particularly those in the field of atomic energy.

In January 1975 the United States Atomic Energy Commission was disbanded and its staff, laboratories, and other facilities were transferred to the newly formed Energy Research and Development Administration. Currently, the former laboratories of the AEC are attempting to widen their scope to deal with problems outside the field of nuclear energy.

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*Excerpted from "Redirection of a Large National Laboratory," by Albert H. Teich and W. Henry Lambright, in* **Minerva,** *Vol. XIV, No. 4, Winter 1976-77, pp. 447-474. Reprinted with permission.*

In the early 70s, two political science professors, one on the faculty of the State University of New York at Binghamton, and the other from Syracuse University, were funded by the National Science Foundation to perform a study that would examine in detail the procedures by which large research institutions that had been established initially to answer a national need dealt with their viability when that need no longer existed. Of specific interest to them were the national laboratories set up during World War II. Al Teich and Harry Lambright, the authors of the study, chose ORNL as their prototype, and visited the Laboratory several times for this purpose in the summer of 1974. Director Herman Postma gave them free run of the archives, as well as unlimited access to staff members who had experienced ORNL's early moves toward redirection of its mission. The result was a report, published in 1975, entitled "Redeploying Big Science: A Study of Diversification at Oak Ridge National Laboratory." By then Teich had moved to The Institute for Public Policy Alternatives at SUNY Albany, and the report was published jointly by IPPA and the Science and Technology Policy Center at Syracuse Research Corporation. Teich is now on the faculty of George Washington University. The authors, Lambright on the left, are shown here at work in Teich's office.

It is still too early to tell how successful the redirection will be, but the prospects of the ERDA laboratories, as well as of other "big science" institutions, might be better understood if we examine what has happened when these large laboratories come to be operated by a number of sponsors rather than by one, as was the case previously.

In a very general way, national laboratories are controlled by officials at the higher levels of the administration. They are also, however, partially autonomous organizations with their own internally chosen scientific and technological tasks and their own purposes. The diversification of sponsorship, therefore, while affording a means for redirecting their research programs, also raises a variety of complex issues for policy and administration. These issues can be seen in the experience of Oak Ridge National Laboratory, a federally owned laboratory operated by a private contractor and now belonging to ERDA, which has succeeded the AEC. In 1960, virtually all the work done at ORNL was sponsored by the AEC in the field of nuclear energy; in 1974, approximately 15 percent of its annual budget of more than $100 million came from other agencies, and its range of efforts included research on problems as remote from nuclear energy as urban decentralization and the environmental aspects of cadmium.

## Conditions for Diversification

The diversification of sponsors began at ORNL in about 1960, primarily because the leadership of the laboratory decided to take action to keep the laboratory in existence in uncertain times. It was not part of any national strategy for the efficiency of its expenditures in research, nor was it the result of external demand for the services of the laboratory. It was largely a matter of the leadership of the laboratory striking out on its own to use its resources fruitfully and to assure the future existence of the laboratory.

From very early in its history, the staff of ORNL developed a strong *esprit de corps*. This was reinforced by the fact that ORNL had to compete against its stronger sister-institution, Argonne National Laboratory, for the resources to conduct research and development on reactors; and further by the fact that the contract to operate the laboratory was awarded, over the protests of many senior scientists, to an industrial firm, Union Carbide Corporation, rather than to a university. This experience caused the leadership of ORNL to be constantly concerned about the survival of the laboratory.

In this early period, Dr. Alvin M. Weinberg emerged as a powerful leader of the laboratory. He had come to ORNL in a relatively junior position near the end of the war. By 1948, he had become director of research. In that post, he took full charge of the laboratory's scientific program, and in 1955 he was appointed to the directorship of the laboratory. Dr. Weinberg, who has been a charismatic figure to many within the laboratory, became the strongest advocate of ORNL to the outside world.

ORNL's political connections and Dr. Weinberg's advocacy helped it to thrive and grow. It did not, however, acquire a prominent position in any of the major activities of the

AEC such as reactor development, physics research, or weapons production, and this placed it in a precarious situation in relation to the other laboratories of the AEC. Two of its major programs during the 1950s, the nuclear airplane and the aqueous homogeneous reactor, failed to meet expectations and were dropped. Only in radiation biology did ORNL achieve relative pre-eminence within AEC. In many ways, the biology division was the jewel in ORNL's crown, but it was characteristic of ORNL's situation that its most distinguished unit was not of primary interest to the AEC. ORNL's somewhat less favorable relations with the AEC meant that it had less to lose than its sister-establishments from transferring to new sponsorship.

Dr. Weinberg seems to have been viewed by the administrators of the AEC as especially independent—but a valuable asset to his laboratory and the Commission. With the apparent agreement of the AEC, the operating contractor, Union Carbide Corporation, exerted virtually no substantive control over the program of ORNL. With such an approximately free hand from both AEC and Union Carbide Corporation, ORNL was in a position, by and large, to set its own course.

## First Steps

Dr. Weinberg began to think about the diversification of sponsorship very early in his tenure as ORNL's director. His talk on the "Future Aims of Large-Scale Research," given in March 1955, touched on an idea which later he was to put into action:

> It is ... most unlikely that the problems big enough to challenge big laboratories will continue to lie in the areas of technology for which the big project laboratories were organized. This implies the necessity for flexibility in the organization of these institutions, or of the agencies of which they are a part, beyond what they now often seem to possess: the institutions must inevitably be prepared to move into areas outside their original interests if they are to attain immortality.

This idea was refined and expanded in Dr. Weinberg's subsequent speeches and writings. He was, moreover, in a position in which he could do more than talk about the subject—he could do something about it. And, by 1960, it was apparent that some kind of action was necessary.

In October 1960, Dr. Weinberg led the laboratory in the first act of diversification: the initiation of a series of "advanced technology seminars" at which senior members of the laboratory staff met to educate themselves on technical aspects of a variety of national problems. In these seminars, new tasks and new sponsors were investigated.

In the early 1960s, three new programs were established at Oak Ridge, each under the sponsorship of a different Federal agency. One of these, desalting, came directly from the advanced technology seminars—with the aid of Dr. Weinberg's PSAC connections [he was serving at the time on the President's Science Advisory Committee]. The other two, large-scale biology and civil defense, had been explored during the seminars, but did not derive directly from them. A fourth major program, in environmental research, was begun in the late 1960s, and a number of other efforts have followed it.

## Desalination

Dr. Weinberg's choice of this topic was influenced by his awareness of governmental interest in the supply of water and by the fact that ORNL had developed considerable expertise in such related areas as chemistry of solutions, separation processes, and corrosion through its work for AEC on plutonium separation. ORNL's pursuit of support was facilitated by Dr. Weinberg's contacts at the higher levels of government.

However, the staff of the Office of Saline Water, the tiny bureau of the Department of the Interior out of the limited budget of which the program had been supported, saw things differently. They had been largely disregarded in the original negotiations, and they saw the effort of ORNL as a bid by a large and politically powerful entity to take over the tasks of the OSW.

The financial support of OSW for the program of water research lasted from 1962 until 1974, gradually declining over the years. It eventually terminated as the combined result of the long-lasting strains between sponsor and research workers and reductions in OSW's budget for research.

Dr. Weinberg was also interested in the use of nuclear energy for desalination, particularly through large plants capable of producing fresh water cheaply enough for agricultural use ... In December 1962, less than a year after the water research program began, the laboratory proposed a study of the feasibility of a dual-purpose, power-reactor-desalting program to run for three years, to cost $4.5 million, and to be supported jointly by AEC and OSW ... the relations of OSW and ORNL in nuclear desalination were much more congenial than they had been in the program on water research, although conflicts over the degree of autonomy to be accorded the laboratory still existed.

There were, however, conflicts between ORNL and AEC. The nuclear desalination program drew its staff primarily from the reactor division of ORNL. Dr. Milton Shaw, who was head of the research and development on reactors at AEC during this period, viewed nuclear desalination as technologically unpromising and a diversion of scientists and engineers of ORNL who should have been working on the programs which he thought more important.

ORNL, meanwhile, through a study in the summer of 1967, began to examine the idea of using huge dual-purpose nuclear desalination plants as the cores of nuclear agro-industrial complexes or "nuplexes" in the arid zones of underdeveloped countries. Through the efforts of former President Eisenhower, the former chairman of the AEC (Admiral Lewis Strauss), and Senator Howard Baker of Tennessee, the United States Senate, late in 1967, passed a resolution calling for the construction of such plants in the Middle East, as a contribution to the maintenance of peace. ORNL received considerable publicity and a modest contract from the State Department to study the idea.

The laboratory was eventually successful in designing what is considered to be a practical large-scale nuclear desalting plant as well as a "nuplex"—although many scientists continued to be sceptical of the idea. A number of ORNL's technological accomplishments and designs were transferred to industry and are now commercially available. No one, however, was willing to invest the capital needed to build a full-scale installation for nuclear desalination. Without the support of politicians and public opinion, the program began to decline in the early 1970s and it had virtually disappeared by 1974.

## Large-Scale Biology

The ORNL biology division, led initially by Dr. Alexander Hollaender, has been from its earliest days one of the strongest units of the laboratory. By 1960 it had acquired a worldwide reputation, and Dr. Weinberg predicted that it would double in size during the 1960s. AEC, however, did not share this view, asserting in 1960 that biological research at ORNL would remain essentially level during the coming decade. The unwillingness or inability of AEC to support ORNL's aspirations in biology led the laboratory to embark on a campaign to diversify its sponsorship in that field at about the same time that it was carrying on its work in desalination. Dr. Hollaender, who ran the division rather independently, was the moving spirit in this activity.

A plausible sponsor for such work was the National Institute of Health, and the leaders of ORNL were acquainted with officials at NIH through their common professional interests. Recognizing the potential advantages of collaboration with NIH, the leaders of the division of biology and medicine at AEC encouraged the collaboration of NIH and ORNL, and did what they could to smooth the way.

In 1964, Dr. Weinberg announced that the National Cancer Institute and ORNL were drawing up a five-year plan for the expansion of ORNL's biological laboratories, and in 1965 predicted a tripling, by 1971, of the biological sciences at Oak Ridge. In essence, Drs. Weinberg and Shannon [Dr. James A. Shannon, director of NIH] were speaking of transforming part of ORNL into a "Bethesda South" to complement the main NIH laboratory complex in Bethesda, Maryland.

During these discussions, NIH suggested the possibility of establishing an educational institution to assist the development of ORNL as a major center in the life sciences. In response, ORNL worked out a cooperative arrangement with the University of Tennessee for a jointly conducted Graduate School of Biomedical Sciences. The school has been very successful, but the larger ambitions of ORNL were never realized.

The expansion of biology at ORNL was probably impeded mainly by the budgetary constriction of the late 1960s. In Dr. Endicott's [Kenneth Endicott, director of NCI] words, the NIH "honeymoon" with Congress ended. Congress was no longer willing to grant NIH "pie-in-the-sky increases." Naturally, NIH had to reassess its programs and found that its obligations to "Bethesda North"—and the rest of the scientific community—made it impossible to think of a "Bethesda South."

## Civil Defense

Research in civil defense was one of the areas Dr. Weinberg saw as appropriate for the diversification of support for ORNL—it was large, expensive, and "strongly in the national interest." It is likely, however, that not much would have happened in this area had it not been for the coincidence of Dr. Weinberg's interests and those of his old friend and colleague, Professor Eugene P. Wigner. Wigner, a Nobel Laureate who had been at ORNL during the war and had been research director before Dr. Weinberg, had a strong interest in civil defense.

A formal proposal [to AEC] recommended that ORNL establish an institute which would become the major agency for research and development of the Office of Civil Defense. Dr. Weinberg estimated that, by 1967, the proposed institute would employ more than 200 scientists in a wide variety of disciplines—including the social sciences—and would have an annual budget of about $4 million.

[The authors relate how an agreement was signed in 1964 between AEC and OCD for a research institute at ORNL on a far more modest budget than anticipated.]

To establish the "institute"—which because of its small scale took on more the character of a project—Professor Wigner went on leave from Princeton University and spent the academic year of 1964-65 at Oak Ridge. Although he returned to Princeton in the autumn of 1965, he has maintained his connections with ORNL, and he continues to spend about one week of each month at Oak Ridge to work on civil defense and give direction to the research there.

The elaborate plans developed by Professor Wigner and Dr. Weinberg in their original proposal were fulfilled only in small part. While the project has made a number of contributions to civil defense policy which Professor Wigner and others regard as extremely important, and while it has managed to survive for more than a decade, its staff has not exceeded 20 members and its total annual budget—from all sources—has never exceeded $1 million.

Although its original intention has not been realized, the civil defense project has broadened the range of its activities and has also been more or less successful in obtaining financial support from sources other than those of AEC and OCD. Support from other parts of the Department of Defense—outside OCD—was obtained for several studies. The concern with the defense of cities gave rise to an interest in urban decentralization, which gained the sponsorship of the Department of Housing and Urban Development; this support came to $500,000 by 1974 and led to the formation of a separate section within ORNL.

## Environment

Officials at AEC (by 1964) thought that a certain set of directive principles to guide "work for others" was needed. Issued in April, the directive principles excluded projects which would increase the size of the laboratory staff or require AEC to construct new buildings—as had been the case in biology.

The most important result of the directive principles was not to restrict diversification of sponsorship, but to legitimate and protect it, by—in the words of the official who issued them—"defining what ground was safe for them to walk on." With an AEC-sanctioned "hunting license" in black and white, entrepreneurship may have been somewhat more formalized for ORNL, but it was also safer. This formal acknowledgement of the right of ORNL to seek additional sponsors was especially important when congressional resistance to such actions developed within AEC and in the Joint Committee on Atomic Energy. This resistance occurred mainly when the laboratory attempted to take up environmental research, which had meanwhile attracted much attention and support.

The entry of ORNL into environmental research was stimulated by the JCAE. In 1967, Congress, led by Representative Holifield of the JCAE, modified Section 33 of the Atomic Energy Act, which deals with research for customers other than AEC, to authorize the laboratories of the AEC to conduct research not only if it was "appropriate to the development of atomic energy"—its original terms of reference— but also if it was in fields " relating to the protection of the public health and safety." Before the enactment of this legislation, Representative Holifield, in an address in 1966, had mentioned the potential role of the national laboratories in environmental research. Shortly thereafter, Oak Ridge—as well as the other laboratories of the AEC—received a request from the headquarters of AEC to consider the areas of environmental research to which it might contribute. This happened at a time when the tightening Federal budget for research and development and increasing emphasis by AEC on the fast breeder reactor—which was being developed at Argonne—seemed to press ORNL to look for new sources of funds if the laboratory was to be preserved.

Dr. Weinberg and his colleagues took the scheme [his new concept of a "national sociotechnical institute"] to Senator Howard Baker of Tennessee, a member of the Senate Subcommittee on Air and Water Pollution, and, at Sen. Baker's request, formed a committee at ORNL to prepare a report on it.

The staff of the Senate committee drew liberally on the report in preparing a bill, which was introduced in February 1970 and which called for the establishment of six national environmental laboratories.

Opposed by the White House, the national environmental laboratory bill did not receive congressional approval. Despite this, and the displeasure of the Joint Committee, ORNL was nonetheless able to initiate a large environmental research program in 1970 with the support of the National Science Foundation.

...It did not run wholly smoothly...a number of senior scientists at ORNL were critical of the quality of the work done on the environmental project. They feared that shoddy work by the environmental section would damage the reputation of the laboratory. At least two heads of division were reported to favor discontinuing the project on these grounds.

Among all of the undertakings with external sponsors, none produced as much internal stress in ORNL as the environmental research program. Even Dr. Weinberg, who had set the program in motion originally and had encouraged its champions along the way, began to have second thoughts on it by the autumn of 1970. His open scepticism encouraged others in the laboratory to express their doubts, and the environmental research program was soon challenged on many sides.

The laboratory was reorganized in 1974 and the descendants of the environmental program are now organizationally dispersed, so that nothing approximating a national environmental laboratory has taken shape at ORNL. Nonetheless, the program did produce many useful results and from the start devoted a considerable amount of attention to problems of policy in energy, particularly the conservation of energy. Thus ORNL acquired expert knowledge and skill in a field of direct interest to its new principal sponsor, the Energy Research and Development Administration. In the end, this may prove to be its most significant accomplishment.

## Diversification . . . and Recovery

Environmental research was the last program through which ORNL sought to widen the range of its sponsorship. As it began, the laboratory was entering the most difficult period it had seen since the early postwar days. There were a series of dismissals, with employment at the Laboratory declining from its high point of over 5,000 employees in 1968 to less than 3,600 in January 1974. Efforts to obtain funds were intense, but not coordinated as they had been before. Many of Dr. Weinberg's old allies in the scientific community were no longer in high office or, if still present, were becoming less influential. There were pronounced changes in AEC as a younger generation was appointed. Relationships between the laboratory and AEC became somewhat more remote, and Dr. Weinberg found that the residue of uneasiness from the last affair and his continuing disagreements with Dr. Milton Shaw, head of research and development on reactors in AEC, reduced his influence at the headquarters of AEC. Finally, Oak Ridge was affected by the diminished status of scientists in American public opinion.

Non-nuclear energy was emerging as an object of national policy. ORNL's major opportunity for research on energy other than nuclear energy lay in research in coal. The hydrogenation of coal had been explored at ORNL during the advanced technology seminars in the early 1960s, but scanty financial resources had kept this interest from developing further. In 1971, however, ORNL became active in research in coal through AEC's need to clean emissions from a power plant using coal which provided electricity for the separation of uranium . . . In 1974, AEC and OCR signed an agreement providing $800,000 from OCR and $400,000 from AEC for a program of research on coal. Within months, however, OCR and AEC were both absorbed into ERDA, and research on coal by ORNL was under a single sponsor once more.

With heightened political interest in research on energy, ORNL ceased to be in danger financially. Dr. Weinberg found, however, that his independence and his single-minded devotion to his laboratory were becoming increasing sources of tension within AEC. He resigned late in 1973 and Dr. Herman Postma was appointed his permanent successor in 1974. This marked the end of an era in organizational entrepreneurship for ORNL, but it was also the beginning of a new era offering substantial promise to the laboratory.

In a scientific and technological sense, ORNL made definite progress outside the field of nuclear energy with the aid of support by agencies other than the AEC. The diversification of sponsorship was also important in keeping the laboratory at work. Over the years 1960-74, some $136 million came to ORNL from agencies other than the AEC and, near the end of that period, more or less 15 percent of the operating budget of the laboratory was obtained from such sources. In view of the reductions in budget and staff of the late 1960s and early 1970s, this influx of external funds was indeed important. It may not have been large enough to offset the decline in funds from the AEC, but it did help to maintain the morale of the laboratory and permitted some growth and development during difficult times.

## lab anecdote

### Byington Freight Station

There never has been a freight yard for ORNL, although Y-12 and K-25 have theirs. During World War II, freight coming to the Lab on the L&N Railroad went to Byington, Tennessee, just east of Oak Ridge. In the analytical laboratory in Chicago where I worked, we received a mason jar of gravel from the "Byington Freight Area" for testing. Someone at the Lab was worried that there would be boron in the local dust that would be a neutron poison in the graphite to be used in the Graphite Reactor.

Several months later I reported for work at the Lab. The shuttle car from the employment office in Knoxville took me by way of the Beaver Ridge community and the Byington Freight Station where the driver picked up some freight invoices and some other papers. The station was the usual L&N green and white, and nearby were the company houses in the same colors.

Last month I drove past Byington on Highway 62. A railroad car on a side track was unloading lumber, but there was no longer a station or the railroad company houses. Instead, there's a traffic light. At the light, the business center of Karns, named for the nearby school, has given its name to the area, and only the road names carry on the old community names of Beaver Ridge and Byington.—*Herbert Pomerance*

# BOOKS

*"The Health Hazards of NOT Going Nuclear," by Petr Beckmann, The Golem Press, Boulder (1977). 182 pp. + Notes, Index, and Epilogue. Paper, $5.95; cloth, $10.95. Reviewed by David F. Cope.*

A SHORT STATEMENT on the last page of the book, under the heading, "About the Author," advises that Petr Beckmann was born in Prague, Czechoslovakia, where he obtained his Ph.D. and Dr.Sc. degrees. He worked for a research institute of the Czechoslovak Academy of Sciences until 1963, when he was invited to the University of Colorado and did not go behind the Iron Curtain again. He is the author of eight books and more than 60 scientific papers. Originally working in electromagnetics and probability theory, he became strongly interested in questions of energy and now publishes the monthly newsletter, "Access to Energy," in his spare time. Thus, Dr. Beckmann has good credentials as both a scientist and a writer.

The same statement from his book also notes that "he has no personal stake in nuclear power, owns no stocks of any corporation, nuclear or otherwise, and is not involved in any research projects funded by any corporation or the Federal government." Hence, he seems to have no conflict of interests which would dilute his sense of objectivity and fairness.

These statements about the author are important because his is a no-holds-barred attack on those who use half truths, distortions, items out of context, and falsehoods to misinform the public—and misinform it knowingly—on the dangers of nuclear energy. The author is righteously incensed and indignant about the lack of integrity by a certain class of nuclear opponents and the tactics being used by them to further their objectives, which are far more subtle than just to stop nuclear power. Consequently, he has undertaken a one-man crusade to cast the leaders of the movement in their true role by holding up their statements and actions to the light of truth, fact, and logic. He uses a broad sword rather than a scalpel, wandering through the field of controversy, attacking whenever he gets in the range of one of his favorite "pseudo scientific demagogues" (as he calls them). These include such well known activists as Barry Commoner, Henry Kendall, Linus Pauling, Hannes Alfven, Paul Ehrlich, Arthur Tamplin, David Comey, Donald Geesaman, John Gofman, Ernest Sternglass, George Wald, and all the well publicized names of those who constitute the self-appointed leadership of the anti-nuclear movement. He gives special attention to Lorna Salzmann, mid-Atlantic representative of the Friends of the Earth, but reserves his most biting sarcasm and criticism for Ralph Nader. In fact, the flavor of the book is caustically conveyed in the dedication: "To Ralph Nader and All Who Worship the Water He Walks On."

Neither does Dr. Beckmann spare the communications media—the daily press, television, periodicals, and scientific journals. He accuses the media of deliberately disseminating sensational and grossly distorted news in an attempt to inflame and influence the public against nuclear energy. He cites specific instances where unfavorable trivial incidents have been blown up and distorted; where significant news, favorable to nuclear power, has been ignored; and in general, the carrying on of a vicious, half-truth slander campaign to work the public into a state of hysteria not only against nuclear, but also against individuals and establishments who are not anti-nuclear, and who try to conduct any kind of a rational debate on the issues involved. He describes in some detail the case of an article, "The Nuclear Threat Inside America," written by a former *Look* publisher, Thomas R. Shepherd, for *Look*. Beckmann terms the article "a string of vicious half truths," along the lines of such a statement as, "Mr. X did not rape more than three women last week, at least in broad daylight." This article was found unacceptable by *Look* management, including the president of the *Look* Division of Cowles Communications, but the president was unable to stop its publication because the editors prevailed. Beckmann reports other cases, not associated with nuclear, in which *Look* knowingly published deliberately distorted articles.

The author shows no prejudice in identifying the members of the media who have been guilty of these practices. He lists the three leaders of the television industry: CBS, NBC, and ABC. He also notes that the anti-nuclear bias is not limited to the networks or the liberal press but includes, in addition to *The Washington Post* and the *New York Times,* such bulwarks of conservatism as *Business Week,* the *Wall Street Journal,* and the *Christian Science Monitor.* He gives special attention to the *Bulletin of Atomic Scientists,* which he classifies as a purely ideological-political publication attempting to masquerade as a scientific journal. *Science* also takes its licks, particularly the writings of Robert Gillette and Philip Boffey.

Throughout his book, Dr. Beckmann presents evidence in the form of facts and figures to show that nuclear power, while not perfectly safe, is much safer than fossil-fired power. He concludes that nuclear power is not only safe, but is environmentally and economically more acceptable than other forms of energy. He also believes that anti-nuclear groups know this to be true. "This being the case," he asks, "why should these advocates of a better deal for consumers, improved safety for the public, and a cleaner environment, oppose nuclear power? Dr. Beckmann analyzes this question in his final chapter. He concludes that to these people—masquerading as advocates of safety, as friends of the environment, and as consumer advocates—nuclear power is not the issue, it is the weapon. The real issue, he says, is an ideological-political one, and various people for various reasons are using the nuclear and other public issues that have a potential for sensationalism as tools to undermine and destroy the capitalistic, free-enterprise system—their ultimate objective. This chapter, which psychoanalyzes the motivations behind the anti-nuclear movement, is perhaps the weakest part of the book, but it raises enough smoke to lead one to want to see if there is a fire.

The book consists of a series of loosely-knit chapters, each (except the last) dealing with a particular aspect of the nuclear debate. This makes the book easy to read, and it enables the author to avoid the complications of becoming so deeply enmeshed in the intricacies of the nuclear issues that he gets bogged down in trying to present a complete and coherent argument on all issues. The subjects include many of the dominant issues confronting the public, but the author makes no attempt to cover the complete spectrum of issues in all their details, nor does he apologize for not doing so.

The book is hard-hitting, blunt, and biased; though the bias appears based on an objective analysis of the situation. It is a defense of nuclear energy, but this is almost secondary to the author's main target, "The Priests of The People's Lobby," and "The Citadels of Unelected Power," who he thinks are using the nuclear issue, as they have many other controversial matters, for more subtle and much more dangerous purposes.

Beckmann thinks that there are many groups with different objectives who form sort of loose coalitions to bring their collective force to bear on carefully selected targets. He also thinks that these groups have been surprisingly successful in scaring the public with a combination of distortions and falsehoods. Furthermore, he is not overly optimistic that in the end, reason will prevail, and he cites historical examples in support of his pessimism.

The book is refreshing, and presents a forceful argument for the side not usually defended by the communications media that serves most of the public. I recommend it to those who want to determine how well the adversary system works on primarily technical issues.

## Staff Quote:

*"It was generally agreed that the benefits, if any, of actinide partitioning and transmutation (of radioactive wastes) should be defined, but (nearly) all believe it is impossible to show conclusively at this time that there are none to be derived from this proposed disposal concept. I got the strong impression that no one believed partitioning should be a precondition to geologic or seabed disposal of fuel-cycle wastes, but that it very well may represent a desirable or even necessary future improvement over initial practices. It was generally recognized that some additional work must be done before a proper evaluation of this concept can be made or before any serious large-scale development of it is undertaken. Much of this work as now planned will extend over the next three to four years and will be centered in the United States, at Ispra (Italy), and to a lesser extent in France and Sweden."*—**Tex Blomeke,** *referring to a recent meeting in Vienna on "Environmental Evaluation and Hazard Assessment of the Separation of the Actinides from the High-Level Waste from Fuel Reprocessing."*

JIM RICHMOND

# One-Atom Detection

By CAROLYN KRAUSE

ON OCTOBER 11, 1976, a group of ORNL scientists observed an array of tiny green dots on the oscilloscope of a pulse-height multichannel analyzer. They became excited, for the signal they were seeing represented an electron stripped from a single atom of cesium by laser light. They had achieved the ultimate in analytical sensitivity—the detection of a single atom in the midst of billions of molecules and atoms of a different species. It was an accomplishment somewhat akin to finding a needle in the haystack in the dark.

As a result of this achievement, Sam Hurst, Munir Nayfeh, Marvin Payne, Bryan Wagner, and Jack Young received an IR-100 award this past September. And their work has been described in numerous publications, including *Laser Focus, Analytical Chemistry, Industrial Research,* and *Physics Today,* and by the American Chemical Society in its "Man and Molecules" radio feature.

The one-atom detection scheme has been applied to studying rates of chemical reactions, measuring density fluctuations of atoms, and detecting cesium as a fission fragment of californium-252. In addition, the technique holds promise for detecting rare events (such as fission isomers, quarks, and solar

Sam Hurst has the honor of having been the recipient of two IR-100 awards, which are given annually by *Industrial Research Journal* to developers of the top 100 industrial processes and instruments. His first one was granted in 1972 for his development of the Elograph, a data-processing instrument which unplots points from two-dimensional media. This spare-time project led to one of Hurst's entrepreneural ventures: the founding of Elographics, Inc., of which he is chairman of the board. His second IR-100 award was bestowed this past September for his work at ORNL in developing one-atom detection, a scheme using lasers, which are being employed increasingly as research tools at the Laboratory. (In the accompanying photo, the one-atom detection apparatus, which is described in the article, is being examined by its developers—from left, Hurst, Jack Young, and Munir Nayfeh.) Hurst, who holds a Ph.D. in physics from the University of Tennessee, came to ORNL in 1948 and served as section chief in radiation physics and dosimetry for the Health Physics Division until 1962. In 1956 he and Rufus Ritchie made the first of a series of visits by ORNL scientists to Japan to correlate ORNL test information with data developed by Japan's Atomic Bomb Casualty Commission on persons exposed to radiation during the Hiroshima and Nagasaki bombings. Since 1962 Hurst has held such positions at ORNL as section chief for radiation physics, leader of the atomic physics group in the Health Physics Division, and leader of the photophysics group in the new Health and Safety Research Division. After having taught physics as a visiting research professor at Florida State University and UT in the early 1960s, Hurst left ORNL in 1966 for a four-year stint as professor of physics at the University of Kentucky, from which he earned his M.S. in physics 30 years ago. When he returned to ORNL in 1970, Hurst—a native of Pineville, Kentucky and holder of 10 patents—became known in the Oak Ridge area as one of the founders of Scientists and Engineers for Appalachia, which sponsors an annual Inventors Fair as part of its effort to tap the scientific talent in Southern rural communities.

neutrino interactions) and for serving as an ultrasensitive analytical tool for detecting trace atoms of heavy metals, including those present in pollutants and those released by vaporization from concealed sources, such as ores and explosives.

"Our innovation here was to combine a proportional counter with laser beams to detect atoms," Hurst says. "Major analytical companies have expressed interest in this innovation, which could form the basis for developments of a new family of analytical instruments that would most likely be used in research laboratories."

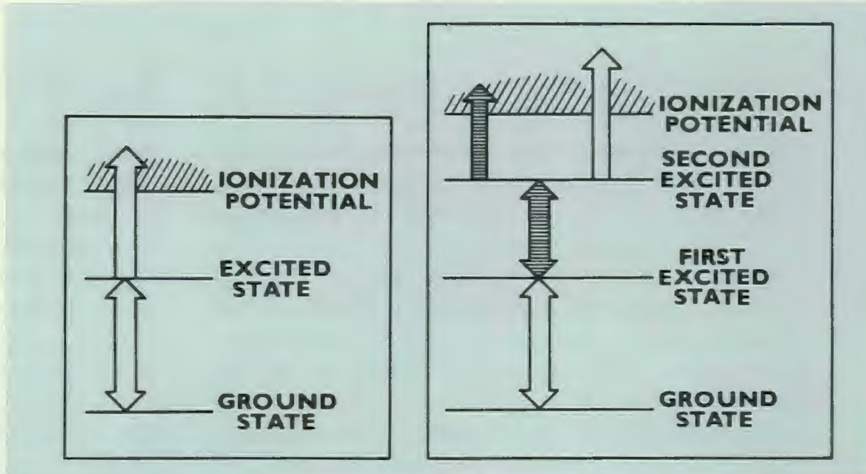
Essential to the one-atom detection scheme is the laser, a device which produces a powerful beam of light. Light from a laser has three important characteristics: (1) it has a high-intensity, well-collimated beam, having an extremely large flux of photons; (2) it can be made highly monochromatic (one color) so that all the photons emitted have approximately the same energy; and (3) it is coherent, or in phase.

## Selective Processes

Hurst and his colleagues use laser light of a preselected wavelength to excite atoms, causing an outer (valence) electron to jump to a new orbit farther from the nucleus. After excitation, another photon imparts energy to the outer electron freeing it from the atom, which then becomes an ion. As a consequence of the two-step process, in which one of the steps requires a photon energy in exact resonance with levels of a given atom, the process is extremely selective, i.e., only the atom of choice will be ionized. Furthermore, if the laser pulse contains a sufficiently large number of photons per unit of laser beam area, all of the atoms (of a given type) subjected to the beam are ionized. It is this saturation feature which makes possible absolute measurements of the number of excited states in a gas. It is also essential to the detection of single atoms.

Resonance Ionization Spectroscopy (RIS), the name given to this process, was conceived at ORNL in early

*An atom in its ground state is excited to a bound state when a photon is absorbed from a laser beam at a very well-controlled wavelength. Only if this resonance photoabsorption occurs will a second photon remove an electron from the atom. Work at ORNL showed that this resonance ionization process can be driven to saturation so that one electron can be removed from each of the selected atoms. By using two synchronously pulsed lasers, many more types of atoms can be subjected to the RIS process. The diagram to the right shows that the first excited state produced by the first laser is promoted to a second excited state by a second laser. Photons from either laser complete the photoionization process.*



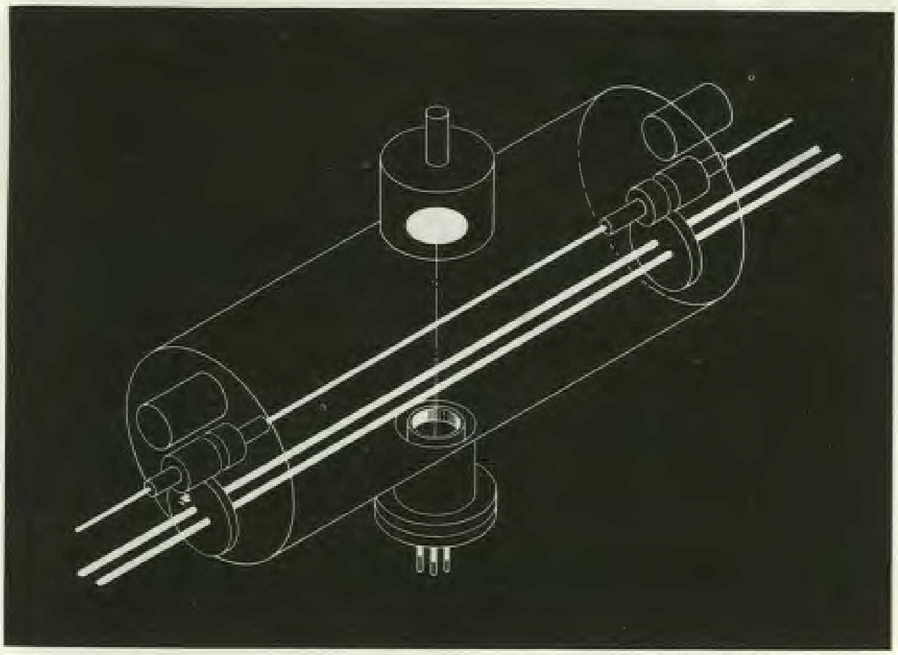

1974 and was first applied to a particle accelerator experiment in 1975 by Hurst, Payne, Nayfeh, Wagner, Young, John Judish, and Chung-hsuan Chen. This first experiment with RIS measured the absolute number of metastable states (a kind of excited state that lives for a long time) created in helium gas by a beam of fast protons.

Because cesium has an unusually low ionization potential (less than 4 eV), only two photons from one laser are required to strip away an outer electron. The first photon must be of the right frequency or energy to induce the valence electron to jump to a vacant orbit, and a second photon then removes that electron completely from the atom. (These characteristic frequencies make up what is called the optical absorption spectrum. Each characteristic spectrum, which is known in some detail for all the elements except some of the transuranics, is subtly influenced by the details of nuclear structure—that is, the effects of various numbers of protons and neutrons on the motions of the electrons.) Thus, cesium was the choice element for the first demonstration of one-atom detection.

The conversion of an atom to a positive ion and electron by laser light allows one-atom detection provided that the removed electron can be detected and counted. Hurst's group achieved electron detection and counting by pulsing an intense laser beam into a proportional counter which contained a few cesium atoms evaporated from a source below the counter. This particular counter, built by Dick Zedler of the Instrumentation and Controls Division, was specially designed by Hurst and Zedler to eliminate background noise and to provide special windows for laser beams and a port for sample introduction.

Hurst notes that in 1908 Sir Ernest Rutherford and Hans Geiger at England's Cavendish Laboratory established the basis of the first single-electron counters by employing collisions to magnify the number of electrons produced in a gas. Says Hurst: "One cannot avoid noting that if the laser had been available to Rutherford so that individual atoms could be selectively ionized, he most likely would have started the counting of individual atoms."

Using their specially-designed proportional counter, Hurst and his colleagues are able to detect a single atom of cesium amid $10^{19}$ atoms of argon and $10^{18}$ molecules of methane. Laser light of a preselected frequency that would be absorbed only by cesium is pulsed into the proportional counter. The gas in the counter, consisting of 90% argon and 10% methane, is essentially unaffected by the laser beam, but two photons absorbed in the single cesium atom strip away its valence electron, which drifts toward a wire with a positive potential. When an electron is attracted to within a distance of about 100 microns of a wire in a proportional counter, it gains enough energy from the intense electric field to produce additional electrons by collision with atoms and molecules. This process, known as gas amplification, can multiply electrons 10,000 times or more. The magnitude of gas amplification may easily be varied by changing the counter



*Single-atom detection is made possible by pulsing a laser beam through a gas proportional counter. A tunable dye laser is used to select atoms of a given type and to remove one electron from each of the selected atoms. Because a proportional counter can be used to detect one electron, a single atom in the laser beam can be detected. One-atom detection is comparatively simple, yet it is so selective that one atom in a volume containing more than 10 billion billion atoms of another type can be singled out and recorded. It also provides spatial definition and time resolution so that selective measurements can be made for a defined volume of space and at an arbitrary time—all at the ultimate limit of one-atom sensitivity. In this example a second laser beam is used to produce the atom by dissociating a molecule.*

voltage and other counter parameters. After electron amplification, pulses representing one initial electron can be displayed as a pulse-height distribution in a multichannel analyzer. Thus, the combination of a proportional counter with a laser, which can remove one electron from each atom, makes possible the detection of a single atom.

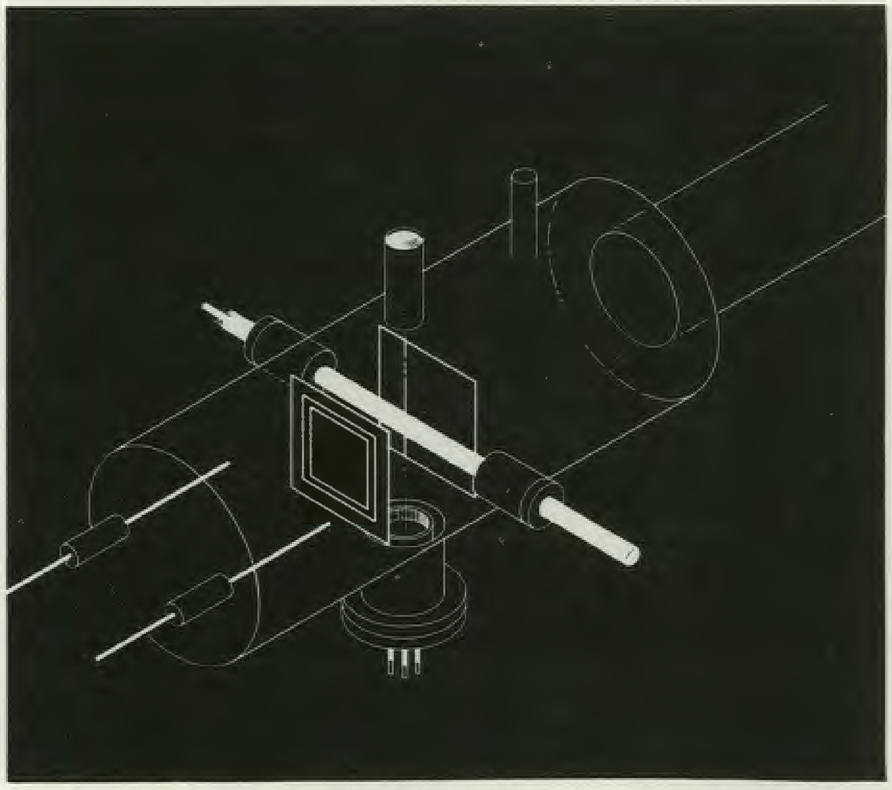
## Two-Laser Scheme

About half of the atoms in the periodic table can be converted to ions and electrons by three-photon absorption from two lasers. Since these elements, unlike cesium and rubidium, have a higher ionization potential (in the 10-eV range), two lasers emitting beams of two different wavelengths are required to achieve ionization. In the three-photon (three-step) process, the preselected atom is exposed to a photon of the proper frequency to promote the outer electron from the ground state to an excited state—that is, to induce it to leap into a vacant orbit farther from the nucleus. A second laser is required to provide a second photon of a different characteristic energy level to force the electron out into an even higher excited state. A third photon from either laser finally knocks the electron loose from the grip of the atom. Hurst says that the two-laser technique has been successfully used with lithium atoms and is being tried with atoms of aluminum.

The ORNL scheme has this limitation: it cannot detect half the atoms in the periodic table, including hydrogen, carbon, nitrogen, oxygen, fluorine, and chlorine. The reason: to detect these elements, a shorter-wavelength (far ultraviolet) laser is required to promote the transition of electrons to the excited state. One-atom detection of these elements may be possible following the development of far-UV lasers, a technology that Hurst believes is around the corner.

For their current research, Hurst and his colleagues use powerful, state-of-the-art lasers that emit photons whose frequency span is in the visible and ultraviolet region. The Chromatix linear flashlamp-pumped tunable dye laser is one such device. The UV light emitted from its xenon flashlamp is absorbed in a fluorescent dye. A special grating picks out photons of a desired frequency emerging from the fluorescent dye and diverts them through an output mirror in the form of a pulse with a duration of about 800 ns and a total output of about 2 mJ per pulse.

Hurst's group also uses several Phase-R coaxial flashlamp lasers, which provide higher energies per pulse (up to 1 J) and large beam diameters (up to 15 mm). In these lasers, a fluorescent dye stream flows directly through a xenon-filled coaxial flashlamp. In many experiments involving rare events, it is advantageous to use such lasers because of their large beam diameters.

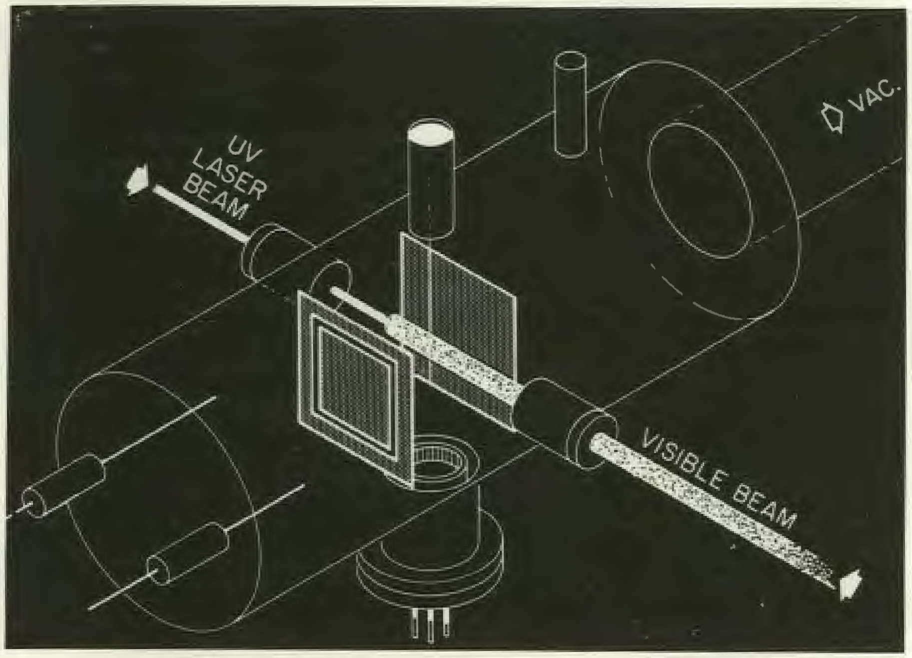


*Schematic of apparatus used to detect a single atom emitted from the nucleus of another atom. A signal generated in the surface-barrier detector indicates the occurrence of a single fission process. After the initial ionization has been swept with the collector plates, a laser pulse removes one electron from the single atom. The electron is drifted into a proportional counter and detected as a single event.*

## One-Atom Chemistry

The one-atom detection technique can be used to identify and count molecules and to study reaction kinetics, such as combustion processes and the rates of chemical reactions. It is more difficult to detect molecules than atoms because molecules have more energy levels; hence, lasers of good wavelength resolution would be required to promote valence electrons from the ground state through various transitions up to their ionization potential. To simplify detection, lasers can be used to dissociate molecules into atoms. For example, Hurst, Payne, Steve Allman, and Larry Grossman (University of Kentucky graduate student) have used one laser to dissociate cesium iodide into two atoms—cesium and iodine. Then they pulsed a second laser tuned to the cesium energy level, thus allowing them to detect and count the cesium atoms (and former CsI molecules) in the sample.

Oak Ridge scientists have used the one-atom detection technique to observe the diffusion of atoms and the rates of chemical reactions of atoms with molecules. Jack Young (Analytical Chemistry Division) and Steve Kramer (Health and Safety Research Division) are particularly interested in studying chemical kinetics using this technique. In one of their experiments, a laser was employed to dissociate traces of CsI in a mixture of argon and oxygen. A second pulsed laser was tuned to detect the cesium atoms. By repeating the pairs of pulses with various delay times between the two individual pulses, Young, Kramer, Payne, Hurst, and Grossman were able to observe the rate at which the cesium atoms disappeared—for instance, the rate at which they react with oxygen.




*Apparatus used to determine the absolute cross section for photodissociation of cesium iodide molecules and to study the reaction of liberated cesium atoms with other atoms or molecules. A pulsed ultraviolet laser beam liberates atoms in a small volume at $t = 0$, and a pulsed visible beam is used to detect atoms in a larger volume at time $t > 0$.*

Recently, Hurst, Nayfeh, and Young used resonance ionization spectroscopy to detect density fluctuations of free cesium atoms in a small volume. The shifts in the number of atoms present at a given time as a result of random movements have never been measured before, Hurst says, adding that density fluctuations previously could only be deduced from such phenomena as Brownian motion or the Rayleigh light-scattering model, which explains why the sky is blue.

## Rare Event Detection

Fruitful rare-event experiments may be possible with the help of selective photoionization. Hurst and his colleagues have already completed one successful experiment in which they used a laser to detect fission fragments from californium-252. Curt Bemis (Chemistry Division), Young, Kramer, and Hurst have observed neutral cesium atoms produced by the fission of an individual californium-252 nucleus. This was accomplished by pulsing a laser when a particle detector indicated that the Cf-252 sample was fissioning. It was found that neutral cesium atoms were injected into the laser beam as indicated by the observation that photons of a preselected frequency ionized the cesium atoms to the exclusion of the other fission products. The number of cesium atoms was determined by counting the removed electrons. The experiment showed that a certain number of cesium atoms borne in the spontaneous fission of Cf-252 change from highly charged ions to their neutral state after slowing down in the counter gas.

Kramer, Hurst, and Young have been working with Bemis to detect fission isomers produced in the Oak Ridge Isochronous Cyclotron. Specifically, they are searching for americium isomers—nuclear species that are highly deformed—yielded when uranium isotopes are bombarded with beams of lithium ions. To detect and study these isomers, they have to estimate the atomic energy levels of these nuclei, which are shifted because the atomic states are perturbed by the highly distorted nucleus. Then they plan to expose the isomers to a broad-band laser beam consisting of photons in the estimated frequency range. If atomic energy levels of americium isomers can be measured this way, then Bemis and his colleagues will be able to determine the extent to which the isomer nuclei are deformed.

Another possible rare-event experiment could be the detection of quarked atoms. A quark, so named by American physicist Murray Gell-Mann, is a hypothetical particle that carries a fractional charge and is held to be a constituent of known elementary particles. Theorists say that one type of quark possesses one-third of an electron's charge. If quarks exist, it is believed that they would be attached to the nuclei of atoms.

Solar neutrino interactions are another kind of rare event for which one-atom detection might prove useful. These neutrinos are neutral elementary particles with zero rest mass that interact weakly with matter after being created in the process of particle decay in the sun. Even though the probability of interaction is small, some neutrinos do interact—with thallium, for instance, to produce a few atoms of lead-208. Hence, scientists at Argonne National Laboratory have proposed a search for solar neutrinos by inspecting thallium ore for possible isotopes of lead atoms. The flux of neutrinos from the sun provides information, not obtainable in any other way, about the interior of a star.

## Analytical Uses

Hurst and Young have been studying the analytical applications of one-atom detection by laser light. Since this innovation offers extremely sensitive detection, identification, and quantification of gaseous molecules and trace heavy metals in air samples, it might prove useful for measuring trace pollutants. Candidates for metallic pollutant detection might include arsenic, cadmium, mercury, and selenium. However, molecular pollutants like hydrocarbons and nitrous oxides cannot be detected by the ORNL technique.

Mention has been made in the news media about possible prospecting and security applications for one-atom detection. Concerning prospecting uses, Hurst injects this note of caution: one-atom detection cannot be used for many ores, such as gold, because the vapor pressure of these metals is so low that very few atoms would escape to the air. However, Hurst does not rule out the possibility that the ORNL technique might aid in the low-level detection of vaporized atoms and molecules that could indicate the proximity of terrorist bombs and explosives.

## History

Hurst, a physicist in the Health and Safety Research Division (along with Payne, Wagner, Kramer, Judish, and Chen), has long been interested in the interaction of radiation—particularly charged particles—with matter. It is this interest and his work in energy pathways research (begun in 1966) which spawned the development of the concept of resonance ionization spectroscopy in January 1974. The idea of one-atom detection followed in less than two weeks. Resonance ionization spectroscopy was first demonstrated experimentally in March 1975, but the demonstration of one-atom detection took another 18 months. Coincidentally, a patent on one-atom detection was issued to Hurst, Payne, and Wagner in October 1976, nearly coinciding with the conclusive experimental demonstration of this scheme by Hurst, Nayfeh, and Young.

Among the questions that Hurst and his colleagues tried to tackle in their research were these: When radiation interacts with matter, what fraction of the atoms are promoted to higher energy levels and how many electrons are formed? To ascertain the nature of the excited states and the fate of electrons, Hurst and his colleagues used beams of charged particles from the Van de Graaff accelerator in ORNL's High Voltage Accelerator Laboratory to excite atoms of helium and other noble gases. A standard technique had been fluorescence spectroscopy, which involves detecting light emitted when electrons fall back to their original orbits. The new method, that is, resonance ionization spectroscopy, uses beams of photons to study excited states by photoionization. The decision to develop the new technique required the acquisition of several lasers, which the photophysics group continues to use in research at the High Voltage Lab.

What is the lesson in all this? According to Hurst, the practical one-atom detection technique stems from a long-term basic research effort. "Exciting applications emerge from programs of basic research," he says. "To paraphrase Ernst Mach, you cannot use knowledge that you do not have." ∎

# Information Meeting Highlights

### Fusion Energy, July 19-20

Technical successes by ORNL's Fusion Energy Division in 1976-77 have improved the outlook for the national effort to harness thermonuclear reactions to produce electricity. Here are some highlights, as reported at the Division's annual information meeting held last July.

According to Bill Morgan, 1976 was "the most productive year in the 20-year history of plasma technology." He was referring especially to the successful production and use of neutral beams (accelerated hydrogen ions which regain their electrons just before colliding with plasma particles) to heat up hydrogen plasmas to such record levels as 20 million °C—half of the required ignition temperature for a fusion reaction. Another first was the achievement of an ion temperature that exceeded the electron temperature. ORNL researchers have also demonstrated that neutral beam injectors can be scaled up. Hence, the group that developed neutral beams capable of injecting 350 kW of energy into the ORMAK plasma has built four neutral beam systems that will inject 3 MW into a plasma, raising its temperature to 50 million °C. These injectors were installed in 1977 at the Princeton Large Torus (PLT). The Fusion Energy Division has also completed a test stand that will be used for beam development for the Tokamak Fusion Test Reactor, Princeton's fusion break-even experiment scheduled to go into operation in 1982.

Don Steiner and his colleagues have developed a conceptual reactor design which suggests that tokamak power systems can be economical without being monstrously large (both in electrical output and in physical size), that their capital costs do not have to exceed those for other advanced energy systems such as liquid metal fast breeder reactors and solar electric plants, and that their reliability will be acceptable to utilities. In this design, power output per unit would range from 500-1000 MW(e). This compares to the earlier 2000-MW(e) designs, which reflected the assumption that tokamak power densities were inherently low and that utilities of the future would require mammoth power plants.

Thanks to studies conducted by John Clarke and others in 1976, it appears that higher power densities can be achieved, allowing a reduction in the size of fusion reactors without sacrificing efficiency. The attainment of higher power densities seems feasible because of certain developments and improvements in which ORNL played a major role. In addition to neutral beam heating, ORNL researchers have developed radiation-resistant materials which could extend the wall lifetime (the wall is subjected to bombardment by highly energetic neutrons from the plasma), have identified molten-salt coolants that would effectively carry away heat deposited in the lithium-bearing blanket, and have evolved an improved engineering design of the blanket (which would be used for breeding tritium, a fusion fuel in reaction with deuterium).

Studies at ORNL and elsewhere have also shown that efficient use of the magnetic fields and effective shaping of the plasma will result in higher beta stability of the plasma. Beta, defined as the ratio of plasma pressure to magnetic pressure, refers to the ability of the magnets to resist the plasma's tendency to expand.

Experiments on the ELMO Bumpy Torus (EBT), an invention of Ray Dandl which combines magnetic mirror principles with a closed toroidal magnetic field, have shown close to classical confinement and good stability of the plasma. EBT differs from ORMAK and other experimental tokamaks in that it is asymetrical, offers the possibility of steady-state operation, and has its plasma heated by microwave radiation. The rapid development of this plasma confinement concept makes it one of the leading alternatives to the tokamak as a toroidal fusion reactor concept.—C.K.

## Information Meeting Highlights (cont'd)

Princeton had a troublesome torus
It seems their confinement was porous
So they bought Oak Ridge beams
And they hired Oak Ridge teams
And they said, "Won't you please fix it for us?"
*—Martha Ketelle and John Clarke*

### Chemistry, Sept. 7-9

Several basic research projects reported on at the Chemistry Division's annual information meeting this past September show promise in providing essential information that could lead to more economic processes for making fuel from coal, removing presently unrecoverable oil, extracting more energy from geothermal sources, and producing energy electrochemically.

Vernon Raaen has found a potentially more useful method for ranking coal with respect to its suitability for solvent refining and other liquefaction processes. Customarily, coal is ranked for this purpose on the basis of its carbon or oxygen and sulfur content along with other criteria. Raaen's method is to rank coal according to how much hydrogen it yields to an acceptor, benzophenone, under conditions typical of the solvent-refining process. In a recent study, Raaen obtained results which indicate that vitrinite from Illinois #6 coal, vitrinite from low- and mid-Volatile Pocahontas coal, and the lower-ranked western coal, Wyodak, were much more efficient hydrogen donors than tetralin, the hydrogen donor commonly used in the bench-scale processing of coal.

In research related to development elsewhere of a process to make gasoline directly from coal using molten salts, Pete Smith and Art Dworkin may have opened up a new field in organic chemistry with their discovery that, under mild conditions, anthracene molecules in solution in molten antimony trichloride are spontaneously hydrogenated by other anthracene molecules, which lose hydrogen in the process. The hydrogenation of anthracene is a type of reaction related to an important step in the manufacture of gasoline from coal.

Because only a third of the petroleum in oil fields can be recovered by conventional methods, interest has been revived in making more economic one current process of enhancing oil recovery so as to increase the nation's supply of liquid fuels. The "micellar flood" process under study at ORNL involves treating the oil-bearing formation with a surfactant solution (usually a detergent dissolved in water to reduce the surface tension of the residual oil enough to free it from porous rock) followed by a polymer solution to assure that the oil will flow from the formation in a solid front rather than "finger" out in different directions during flooding. Patience C. Ho and Kurt Kraus have been studying benzene sulfonates containing only short side chains that could serve as a model surfactant that would significantly increase the solubility of the oil in the water injected into the formation. They found that adding an aqueous solution of short side chain benzene sulfonates to a mixture of butanol and hydrocarbon is particularly effective in enhancing the solubility of hydrocarbons in water.

Alicia Compere, Bill Griffith, and Jim Hall have been examining the question of how to produce more cheaply the polymers needed to control the movement of residual oil. Desirable chemicals such as polysaccharides can be produced microbiologically by feeding glucose to a specific organism. In their search for a less expensive nutrient, they have had some success, at bench-scale levels, in inducing polymer-synthesizing organisms to feed on agricultural solid wastes. Work continues on finding ways to remove undesirable constituents from these wastes so that the organisms will better tolerate the substance and yield desirable amounts of chemicals.

Hot brines from below ground offer an important energy source, but geothermal energy developers have to cope with problems in handling brines, which can corrode pipes and deposit in heat exchangers. Silicates in brines can also clog up geothermal formations following reinjection to dispose of exhausted brines and to prevent subsidence of the formations. To better understand the properties of silicates in brines, Dick Busey has obtained data on ionization behavior of silicic acid and polysilicate formation in aqueous sodium chloride solutions at temperatures up to 300°C. Ionization of silicic acid [$Si(OH)_4$], which retains a negative charge upon the removal of a hydrogen ion, was found to occur under certain experimental conditions (such as changes in temperature, acidity, and concentration in salt) which may be encountered in geothermal brines. Busey has found that (1) at the lowest concentration of silica in salt solutions, only mononuclear species occur over wide temperature and pH ranges; (2) at higher concentrations of silica in salt solutions, small polysilicates which equilibrate rapidly occur; and (3) polysilicate formation decreases with increasing temperatures. Busey's data can be used as a basis for calculations of the solubility of silicates as a function of the acid content of geothermal brines.

Concentrated geothermal brines (30% solids) consist of such salts as sodium chloride, potassium chloride, calcium chloride, and magnesium chloride. Since no thermodynamic data had been available for single and mixed electrolyte (dissolved salt) solutions in a temperature range typical of geothermal brines, Howard Holmes, Charlie Baes, and Bob Mesmer recently reactivated ORNL's high-temperature isopiestic (equal pressure) facility to obtain the needed data. In this method, dishes of various salts are exposed to a limited supply of water vapor in a thermostated vessel until all solutions have the same vapor pressure (of water). This is determined by weighing the dishes on a sensitive electrobalance. Comparisons of the concentration of the various solutions to the sodium chloride solution present as a reference standard permits the calculation of the osmotic coefficient (a measure of the water vapor pressure) and less directly, the activity coefficient (a measure of the chemical reactivity) of the salt. The activity coefficients of KCl, $MgCl_2$, and $CaCl_2$ were found to decrease with increasing temperature in the range 110° to 200°C and become less dependent on concentration.

Work is proceeding at Argonne National Laboratory on developing lithium-sulfur batteries that could offer an efficient way to propel automobiles. At ORNL a basic research effort is under way to study molten salt mixtures including those that are likely to be used as electrolytes in batteries, fuel cells, and other high-temperature electrochemical devices. In a lithium-sulfur battery, lithium ions are formed at one electrode in a molten salt mixture of lithium chloride and potassium chloride and react with sulfide ions formed at the opposite electrode. Electrons from the lithium and sulfur electrodes cannot pass through the molten salt mixture and hence move externally in an electrical circuit, while current is carried through the salt by the migration of lithium and potassium ions.

To make such a battery operate efficiently for a suitable length of time, researchers must find ways to maintain optimum electrolyte composition and to circumvent the problem of ions precipitating out; this problem may be caused by an undesirable nonuniformity in the molten salt mixture resulting from the ionic flows. Catherine Vallet and Jerry Braunstein have developed a theoretical model that predicts what the composition gradients would be under different conditions for analogous molten salt mixtures of silver nitrate and potassium nitrate; then, with Dale Heatherly, they tested the model experimentally. Their model could be useful in understanding how to improve ion flow and to minimize nonuniformity in molten salt batteries by adjusting composition, temperature, and other conditions.—C.K.

# Hard Paths and Soft Paths

## A Dialogue

*By HELEN BRAUNSTEIN and R. D. ROOP*

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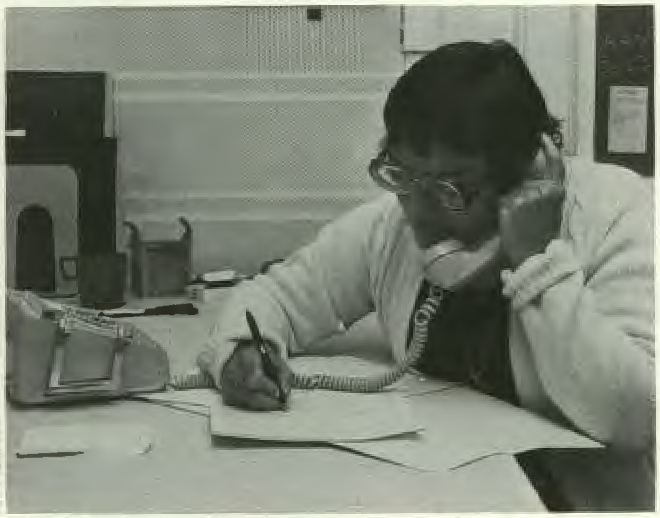
*In October of last year, a young man named Amory B. Lovins, who identifies himself as the American representative to England for Friends of the Earth, spoke at the Institute for Energy Analysis in a symposium on "Future Strategies of Energy Development." In the same month,* Foreign Affairs *published his article "Energy Strategy: The Road Not Taken?" In both of these presentations, Lovins proposed a strategy, called the "soft path" to long-term energy use, that has received much attention and may even have left its mark on President Carter's National Energy Plan. His approach virtually abandons our present "high technology" and turns instead to so-called "soft" energy paths that employ conservation and decentralized, diverse technologies that rely entirely on renewable energy sources. It includes the complete phase-out of nuclear power by 2025 A.D. Needless to say, this plan has initiated dialogues in many places, with varying degrees of intensity. In answer to the* Foreign Affairs *article, Charles Yulish published a series of critical essays, "Soft* vs *Hard Paths," whereas in May, Friends of the Earth and Ballinger Publishing Company released Lovins's book, "Soft Energy Paths: Toward a Durable Peace." In his book, Lovins articulates many of the philosophical and ethical assumptions underlying several of the prominent countercurrent movements, including the "appropriate technology" movement, the environmentalists, the anti-nuclear forces, and those concerned with armaments and the Third World. His challenge is to the decision-makers with questions about electrification, the scale of energy production systems, lifestyles, and the quality and quantity of energy required for our end-use needs. Last spring, Lovins spoke at a conference, sponsored by* Energy Daily, *at Georgetown University on "Technology in Crisis: An Examination of the Hard and Soft Paths in Energy." Helen Braunstein, a chemist on the Fossil Energy Environmental Project in the Energy Division, attended the conference. In the dialogue that follows, she and Dick Roop, of the ecological and analyses program in the Environmental Sciences Division, kick around the pros and cons of Lovins's unorthodox proposal. (Helen and Dick work together on environmental assessment of energy systems.)*

**Dick:** He was brilliant! Lovins was putting out a very unorthodox view on energy supply, but he carried it off well. He was talking at a hearing sponsored by the Council on Environmental Quality to review ERDA's programs on energy and environment. He's young, probably under 30. But he has a global perspective, trying to relate U.S. energy policy to world development and control of nuclear proliferation. Very quick-witted, and a tireless debater. I saw him as just what was needed, an articulate spokesman for some new and important views. Very idealistic and very energetic. Lots of facts and figures and enough drive to make people really think seriously about energy alternatives.

**Helen:** That's odd—I got an entirely different impression. I heard Amory speak to about 100 highly involved listeners, mostly from the electric and nuclear power industries, at a one-day symposium in Washington on "Technology in Crisis." He came across to me as a limp, arrogant, annoyed little man; one who resented having to defend as obvious a truth as the energy gospel which now has come to be associated with his name. His paternalistic



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attitude was disquieting. Knowing his audience consisted of key people in energy production, he assured us that we'd get used to his way, and that, like bitter medicine, it would ultimately be good for us, and that once widely disseminated, the message's acceptance was almost inevitable. Therefore, we should abandon our past ways, take up the cause and use our resourcefulness and ability to find a piece of the action in his new order.

**Dick:** The most important thing Lovins is saying is "Let's redefine the energy problem." Energy supply is a complicated problem; social as well as technological. As we plan our energy future, we need to include humanistic social goals and more modest lifestyles. Above all we need to recognize that our greatest threat is nuclear war, so we need energy technologies that avoid nuclear proliferation; technologies suitable for world development, and technologies that will conserve our rapidly diminishing resources and preserve our environment.

Lovins believes that our projections of future energy demands are grossly inflated. If we have the right kind of energy, we won't need so much of it. He's saying that we should do our energy planning by setting some goals for where we want to be in 50 years rather than just extrapolate, based on our past. Lovins lays out two alternative energy scenarios for the next 50 years. He calls these the hard path and the soft path. The hard path is essentially an extrapolation of our past energy policies, which have relied on rapid expansion of centralized high technologies. Fossil fuels and nuclear fission are the mainstays of this scenario. The hard path implies massive electrification and exhausts our energy reserves. Lovins contends that the hard path will fail because of its high costs, both economic and environmental.

On the other hand is the soft path, which Lovins advocates. He uses the word "soft" to connote technologies which would be, in his words, "flexible, resilient, sustainable, and benign." Fossil fuels would provide an interim energy supply while we are putting soft technologies in place and phasing out nuclear power.

The soft energy path would involve both energy conservation and improved efficiency of energy use. Lovins says we can maintain a high standard of living even on a reduced energy budget. The key is to design soft technologies that provide energy matched to end-use needs. Lovins argues that much of our current energy use goes into heating where the change in temperature we want is only 10 to 30 degrees C, and we should use solar energy to do this low-grade heating. Fossil fuels and electricity are very high-quality forms of energy which should be reserved for special tasks.

Lovins opposes increased electrification for several reasons. First, electric power systems are thermodynamically inefficient. When we convert fossil fuels to electricity, we lose two thirds of the energy to wasted heat. We lose additional energy when we transmit electricity along power lines, especially if distances are great.

Second, there are very large costs associated with distribution of electricity. For delivering electricity to smaller customers, almost 70% of the cost is in the distribution systems. Third, systems for generating electricity are too large in scale. This results in decreased reliability of generating units and longer lead times for deployment. Finally, Lovins argues that electricity is not needed in large quantities. He calculates that only 8% of our current energy end-use actually *requires* electricity. Of the total amount of energy *delivered to the point of end-use*, 4% runs industrial electric motors, and another 4% provides the power necessary for *all* lighting, electronics, telecommunications, electrometallurgy, electrochemistry, arc welding, railways, and electric motors in households. Another 5% of our total end-use energy is electricity for low temperature heating and cooling, and Lovins feels this use of electricity could be eliminated by using soft technologies. Thus, Lovins argues that virtually no additional generating capacity is needed.

**Helen:** Lovins's plan sounds so reasonable, but in examining his overall view, it becomes apparent that his scheme is predicated primarily on negation; negation of our present

sociopolitical structure, negation of our existing economic system, and negation of our currently functioning technological arrangement, especially electric power production. His objections to electrification are secondary to his prime objective: to establish a sociological utopia and to force the implementation of his utopia by controlling the total amount, the availability, and the sources of energy. As Lovins sees it, the benefit will be eternal peace through the absence of nuclear material, environmental blessing through the absence of fossil fuels, and brotherly love through the absence of tension produced by centralized power production. Lovins suffers the ills of all utopian dreamers—more wishful thinking than workability. Utopias depend on the willingness of man to forego individual needs and desires for another good, often an intangible benefit. In Lovins's case, man's "willingness" will be induced by high prices, legislation, and persuasion.

Lovins's thesis has received unwarranted attention by capitalizing on the public's insatiable appetite for bad news, real or otherwise. He threatens danger and disaster, especially nuclear disaster. We must no longer proceed along the presently traveled energy pathway, regardless of how well this pathway has served us in the past. Although he has sound arguments for promoting energy conservation and eliminating electric resistance heating for homes, he packages his soft technology pathway in an all-or-nothing deal. In Lovins's view, the two pathways are incontrovertibly mutually exclusive. Thus we must take steps to phase out the high technology and usher in the soft immediately, to: one, correct institutional barriers (bring construction of centralized power plants to a screeching halt); two, remove subsidies to fuel and power industries; and three, raise energy prices to what energy will cost in the era of soft technology—for example, thirty dollars per barrel of oil versus the present ten to eleven dollars per barrel.

**Dick:** Helen, you say that Lovins is scaring the public with threats of disaster? Nuclear terrorism and nuclear war are terribly real threats, no matter how much we try to push them out of our minds. The hard technologies may have served us well up to now, but how long can it go on? We're running out of oil, we've virtually exhausted our clean energy supplies, and now we have to take a hard look at the cost of continuing this way, especially at increasing prices. To use the fossil fuels we have left, we'll either have to pay very high prices, or we'll have to accept terrible environmental degradation, perhaps even climatic change. Aside from powering ships, nuclear power so far has only produced electricity, and that's not the form of energy we need most. Furthermore, relying on nuclear power requires breeding the fuel, and breeding is not a proven technology by any means. We don't know yet what it will cost to complete the nuclear fuel cycle. In a plutonium economy it may prove very costly to protect workers, to protect the environment, and to maintain adequate security. I think Lovins has a strong argument when he says that much of the energy we need can come from the sun.

**Helen:** Dick, at some point we'll have to examine the hard truth about our energy future and not depend on wishful thinking or reach for as-yet-uninvented miracles of soft science or soft technology. Since Lovins's pathway depends heavily on small-scale solar, wind, and fluidized-bed technologies, let's examine these for individual home energy supplies. Engineers experienced in practical home heating feel that at best solar panels can supply no more than about one half of a year's household heating needs. This means a conventional heating system will also need to be installed, to take care of needs at other times such as during the coldest part of the winter. Solar heating systems currently sell for from $7,000 to $10,000, the largest portion of the cost going to installation charges which are not expected to decrease for the individual homeowner even if the use of solar panels becomes widespread. A similar capital outlay would be necessary for a home windmill for electricity production and also for a fluidized-bed home coal burner. An economic assessment by the Council for Energy Independence shows first that the cost of natural gas and electricity would need to treble before solar panels and windmills become barely economical in terms of the homeowner's heating and electrical costs, and secondly, that the total U.S. capital investment for 40 million homes and 24 million apartments would be $364 billion for solar panels and $520 billion for windmills, a total of $884 billion. If we invest the $364 billion in coal gasification plants producing synthetic natural gas and the $520 billion in electric power plants, the problem of a gas shortage would disappear rapidly and we would double our electric generating capacity.

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Thus, for the homeowner, there would be a decided economic advantage both in terms of investment and final cost to continue buying heat and electricity from a centralized high technology source. Lovins realizes this. To counter this economic disadvantage of soft technologies, he would artificially increase the price of energy to fall in line with that of soft technologies—for example, to treble the price of gas and oil immediately. Unfortunately, Lovins suffers from myopia. He grew up in the midst of comfort and plenty and he perceives the householders of this country installing solar collectors, insulating their houses, buying windmills, and inculcating their children with a healthy frugal attitude toward energy use. He misses the plight and right of the subsistence-level poor and elderly; the vulnerable of our society, who are without means for meeting an increase in energy cost and who also have little to gain from the intangible sociological and aesthetic benefits of a soft path. Soft technology is undoubtedly for the affluent.

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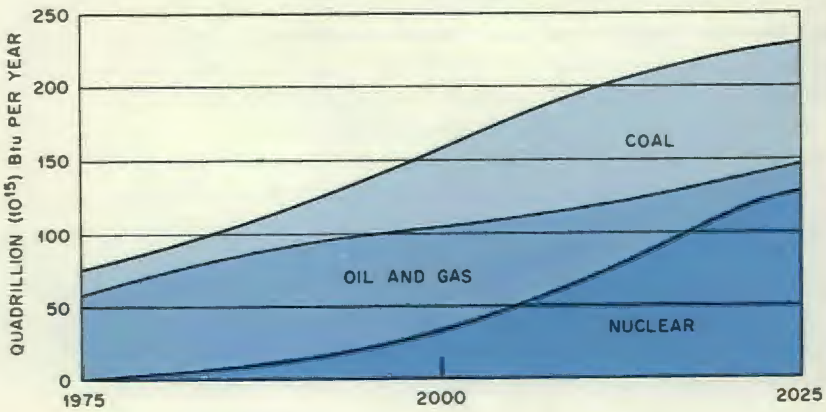
Lovins projects this as the hard path toward energy use in the next 50 years. It is essentially an extrapolation of our past energy policies, and relies on rapid expansion of centralized high technologies to increase supplies of energy (especially electricity) at the rate of about 3.5% per year.



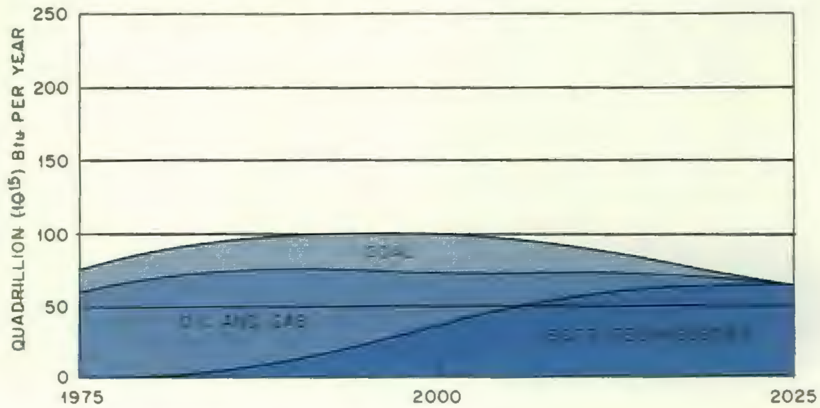

**Dick:** The poor and elderly will suffer from rising energy costs regardless of whether we use hard or soft technologies. These are problems of income distribution which must be addressed in any case. To gain political acceptance, any policy which artificially raises energy prices must also include equitable redistribution of income. I agree that solar systems involve high front-end costs. So do power plants. But solar systems pay for themselves in 10 to 20 years. In order to finance the high initial costs, Lovins recommends that government and financial institutions make capital available to homeowners, small business, and industry.

Let's not forget about inequities created by centralized energy production. When we site large-scale central power stations in rural areas to serve distant load centers, local communities suffer impacts in terms of pollution, land-use, housing, municipal services, and sociopolitical stresses, whereas the distant recipients of energy receive only the benefits. With localized soft technology, the benefits and impacts are more equitably distributed.

The best part about the soft energy path is that everybody can get into the act. We can have literally millions of people developing the technology, perhaps more creatively than our present bureaucratic development schemes. The components for soft technologies are small, familiar, and they could be mass-produced at low cost. We can develop soft technologies very quickly over the next few years, and in the meantime concentrate on two other very important tasks: improving efficiency of energy use and energy conservation.

**Helen:** Few people can argue against conservation. A well insulated house is a joy forever. But how does Lovins intend to implement energy conservation? He is surely aware of the necessity for and the difficulty of creating a "conservation ethic" in order to effect a successful conservation program. Social science research by the Northwest Energy Policy Project indicates that, of the strategies tested for altering people's actions in order to promote conservation, the least effective were informational and persuasion programs (convincing people of the seriousness of the problem). More effective were pricing and inducement programs (raising the price of energy and offering rewards for adopting conservation practices). But the most effective programs were regulation and guidance (establishing laws and exercising power). What this says, and Lovins appears to concur, is that conservation will have to be coerced by legislation and high prices, adding another hardship to the burden

Lovins advocates instead this projection, in which energy users would shift to smaller scale technologies that rely on renewable resources: solar heating, windmills, firewood, etc. Note the complete phase-out of nuclear by 2025.




of the poor who are now and have always conserved to the limit of their ability. Conservation apparently is also for the affluent.

A more subtle effect of the conservation ethic involves a possible psychological result of enforced frugality. The technical and economic dominance of the U.S. is certainly at least partially due to the free application of human resourcefulness, creativity, and invention. These require experimentation, and experimentation by its intrinsic exploratory nature is wasteful. Frugality stifles experimentation. Without experimentation inventiveness dies; without invention we stagnate. If we stagnate, we enter a new Dark Age. This is a possible real outcome of Lovins's no-growth thesis.

**Dick:** Negative energy growth does *not* necessarily mean negative economic growth. Furthermore, per capita energy consumption can't increase forever. On a per capita basis, Americans consume three times as much energy as the French and four times as much as New Zealanders. The waste in our energy system is a global rip-off! I suspect we could endure quite a bit of frugality without plunging into a Dark Age. *Necessity* is the mother of invention, not affluence.

Lovins concedes that there are large problems on both the soft and the hard paths, but he simply feels that the problems on the soft path are preferable. On the hard path Lovins sees overcentralized control of society and excessive concentration of economic and political power with those who control our energy supply. The hard path, he argues, "nurtures—even requires—elitist technocracy whose exercise erodes the legitimacy of democratic government." Lovins believes that soft technologies are more participatory and less coercive. "In a nuclear society, nobody can opt out of nuclear risk . . . but in a soft path, people can choose their own risk-benefit balances and energy systems to match their own degree of caution and involvement. The stakes are smaller, the choices wider, and mistakes more forgiving."

Perhaps the foundation of Lovins's entire thesis is that rejection of hard technologies and full embracing of soft technologies will greatly enhance the prospects of world peace. If soft technologies can meet the needs of developing countries, we could avoid further worldwide export of nuclear technology. Lovins believes this would greatly reduce the risk of nuclear weapons proliferation. Clearly there are many ways for a country to obtain nuclear weapons,

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but Lovins contends that nuclear power is the main driving force behind proliferation. Lovins sees soft technologies as well-suited to world development, especially in tropical areas where solar income is greatest. Soft technologies are also well matched to the resources of developing countries. These countries are not rich in minerals or fossil fuels needed for hard technologies, but they could exploit soft technologies using their abundant supplies of labor. As Lovins sees it, a choice by the U.S. to pursue a soft path will improve the prospects of peace for centuries to come.

**Helen:** All utopian dreams call for brotherly love and world peace. But what, in fact, is peace? It is the antithesis of war. War results from a breakdown of international politics, not centralized energy production. War results from the deployment of weapons, not the type of energy we use. Does Lovins really expect the U.S. to discard our existing weapons potential? Does he really think we need commercial reactors to produce nuclear weapons? We had the bomb long before we ever had a nuclear power plant. Clearly, shutting down power plants will not get rid of bombs. Not in any country.

But it can make other countries angry. If we phase out high technology, we deny cheap, abundant energy to the rest of the world, especially the Third World; those who are seriously deprived.

Few can deny that cheap energy—and electrification in particular—is the basis of modern society. In this context, Dr. and Mrs. Meinel note, "The harnessing of energy and inventions, and the enactment of laws to control their exploitation, opened the way to freedom and dignity for man." So, in my own mind I wonder why there is a movement suddenly to eradicate this freedom and dignity?

Professor Maxey of the University of Detroit has carefully explored the ethical and political dimensions of our energy debate by elucidating its historical origin and the present cultural environment nurturing it. Our awareness of the interrelation of technology, the environment, and human values derives from early philosophical notions that ". . . Nature is in itself or by derivation from a deity, SACRED—implying that it is not only 'unspoiled' or 'pure' in its pristine, wilderness conditions, but also endowed with certain inalienable rights which for man to 'violate' or transgress would be immoral. Human needs, consequently, should be met only with small, soft, gentle, appropriate technology." Unlike nature, man, especially technological man, is thought to be imbued with selfish greed and its resultant reckless, malicious tendency to destroy. This must be overcome, for there is one and only one fragile Earth, and we are its stewards.

Maxey isolates several outspoken social groups that subscribe to these views: those older and established, who express a nostalgic wish to return to the simpler life of low energy use of a hundred years ago (they have been seduced by high technology, are economically secure, and are in pursuit of the more aesthetic elements of life, such as ego fulfillment); those younger, who are part of the generation reared virtually free of material needs, who claim that our planet has been befouled by profit-seeking corporate industrialism (they feel the need to do something to improve the world—to have made a difference for having lived); and those consumer advocates who have become so comfortable they are now able to enjoy the luxury of worrying about the more subtle global problems: fluorocarbons and the ozone layer, carbon dioxide and the climate, the possible disappearance of one species of snail darter, etc. This is not to imply that these are not real problems to be seriously addressed and solved. Rather, it is to place in perspective some of the motivating forces pushing for a soft technology. It is worth noting that those described by Dr. Maxey as subscribing to Lovins's theology turn out to be a powerful, comfortable middle class.

What about the others—those in our own country who still labor to achieve the full benefit of high technology and those abroad who would gladly trade places with our disenchanted elite middle class? Our choices, made in response either to fear of catastrophe or in righteous indignation to the invasion of Nature's privacy, affect all the world's people. In Maxey's view, the basic needs of the world call for more energy, not less; more high technology, not less; and more statesmanship and political imagination, not misplaced religious piety. And this demands that we increase our commitment to the nuclear option, especially the breeder. ". . . freezing growth and going local is one of the surest ways to guarantee a global catastrophe. If international inequalities continue, the hope and optimism about the future in poor nations will force them to demand immediate relief, even at the price of a suicidal war." Unlike our overstuffed middle class, the poor of the world are not enchanted by thoughts of self-denial.

We are a rich and powerful nation with the technological and political means for developing true cooperation and interdependence among nations. Like Maxey, I am convinced that a world without war is a politically meaningful goal and that this goal will be achieved only when all nations enjoy the quality of life we now know to be associated with cheap abundant energy—that kind of energy that results from increased application of science and high technology.

*Editor's note: Readers' comments on this issue are invited.*

JON THOMPSON

**Suggested reading on the subject of the Lovins concept of soft technology:**

Edison Electric Institute. "Soft *vs* Hard Paths: A Series of Critical Essays on Amory Lovins's 'Energy Strategy: The Road Not Taken?'" *Electric Perspectives,* no. 77/3, 1977. (This volume contains condensed version of essays found in the volume edited by Charles Yulish, cited below).

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Maxey, Margaret N. "Nuclear Energy Technology: A Case Study in Ethical Priorities." Paper presented to Technology in Crisis Symposium, Georgetown University, Washington, D.C., June 11, 1977.

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Olsen, Marvin E. and Jill A. Goodnight. *Social Aspects of Energy Conservation, Northwest Energy Policy Project.* NTIS no. PB 266 029, 1977.

Schumacher, E. F. *Small is Beautiful: Economics as if People Mattered.* Harper and Row, N.Y., 305 pp.

Yulish, Charles B., ed. *Soft vs Hard Energy Paths: 10 Critical Essays on Amory Lovins's "Energy Strategy: The Road Not Taken?"* Charles Yulish Associated, Inc. N.Y., 1977

This volume contains the following articles:

Bruce Adkins, "Misdirections in Energy Strategy"

Peter J. Brennan, "The Soft Path, The Yellow Brick Road and Pie in the Sky "

Sheldon H. Butt, "A Solar View of the Soft Path "

Dr. Ian A. Forbes, "Energy Strategy: A time for Realism"

Daniel W. Kane, "Comments on Article by Amory B. Lovins"

Dr. Ralph Lapp, summary of "A Critique of Amory Lovins's Article"

Dr. Aden Meinel and Marjorie Meinel, "'Soft' Energy Paths — Reality and Illusion"

Drs. George W. Pickering and Margaret N. Maxey, "The Road Not Taken — and Wisely So: A Path too Soft to Travel"

J. A. L. Robertson, "The Plain Man's Guide to Amory Lovins"

Dr. Arnold E. Safer, "A Critical Review of 'Energy Strategy: The Road Not Taken?'" ∎

GARY WELCH

*Pam Mellor, Dick Gammage, and Tom Gesell wire the dosimeters to the pegboards.*

# Comparing the World's Dosimeters

By BARBARA LYON

INTEREST IN THE AMOUNT of radiation in the environment, both natural and man made, began with the emergence of the Nuclear Age in 1946, and has mounted as fast as it has spread ever since. The methods of measuring this radiation include the varying designs of the so-called "passive" dosimeter, the commonest type being a solid state thermoluminescent device (TLD), but also include detectors that use film as well as those in the experimental stage, such as the thermally stimulated exoelectron dosimeters. In fact, nearly every laboratory or institution makes its own unique design with one or more of about six different thermoluminescent phosphors that are in general use. This has given rise to the speculation that the differences in dosimeters may also produce differences in accuracy.

Accordingly, a pilot study was performed in 1973 at DOSAR, the Health Physics Research Reactor Site at ORNL, in which five laboratories participated with their own detectors. The results bore out the original apprehensions, as the five dosimeters produced an unacceptable variation in their readings. In short, they did not perform within their assumed accuracy limits.

A discussion of this study and the overall problems of environmental measurements during an AEC workshop on environmental radiation in 1974 led to the formation of an ad hoc committee for the purpose of carrying out more systematic and comprehensive studies of dosimeters suitable for measuring x-ray and gamma-ray activity in the environment. On this committee was Klaus Becker, at that time a member of the ORNL Health Physics Division staff, and now with the German Nuclear Standards Council in Berlin. The other members were Gail de Planque, of the AEC Health and Safety Laboratory (HASL), and Tom Gesell, of the University of Texas School of Public Health at Houston.

The subsequent study in 1974, termed the First International Intercomparison of Environmental Dosimeters, was held in Houston during the summer months when hot and humid conditions prevailed. Forty-one laboratories in eleven countries submitted 56 sets of dosimeters for testing under both field and laboratory conditions. The study and its results were reported at the annual meeting of the Health Physics Society and published in its journal, *Health Physics*.

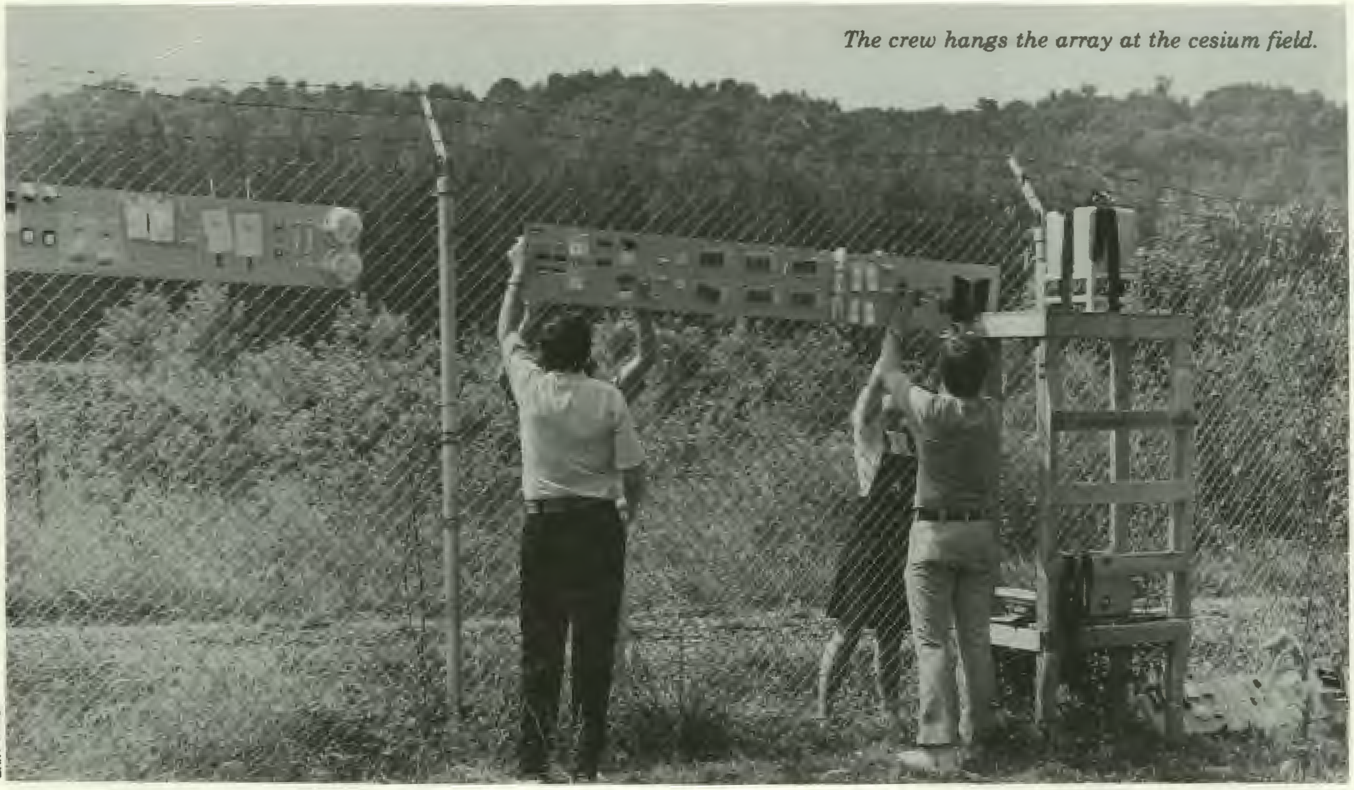
The interest that this report generated led to a demand for a second such study, which was performed during the harsh winter months of 1976 in upstate New York, with HASL the host laboratory. This time 85 participants from 26 countries submitted 133 sets of dosimeters.

These first two international intercomparisons were carried out in low-level, natural background radiation fields with the radiation incidence on the dosimeters from all directions. The object of many determinations of environmentally occurring radiation, however, is to

GARY WELCH

*Some of the variety can be seen in the first three boards ready to be hung. Mellor, Gammage, and Gesell, from left.*

measure increments to this naturally occurring background caused by the release of man-made radionuclides from, for example, nuclear power plants. While the objective of the first two intercomparisons was to test performance under harsh summer and winter conditions in naturally occurring radiation fields, the third study had as its objective performance evaluation in an artificially elevated gamma radiation field in which the radiation intensity was coming principally from one direction.



GARY WELCH

*The crew hangs the array at the cesium field.*

As these unique studies become more widely known, the response to them grows, and so, when the Third International Intercomparison of Environmental Dosimeters was held this year at ORNL, 109 participants from 26 countries sent in 163 sets of dosimeters, all of different design. Consideration is being given now to establishing this event as a periodic service, to be held at least one more time at ORNL, where the facilities, equipment, and personnel are now geared to repeat last summer's study. Taking Becker's place on the committee this year was Dick Gammage, of the Assessment and Technology department of what is now the Health and Safety Research Division.

The results of the first two studies revealed as large a variation as in the pilot study, but also showed that the most reliable of the devices were the thermoluminescent dosimeters, made with phosphors. Handled correctly, they had less standard deviation in their results than the film-based devices, and, indeed, the studies reaffirmed the previously held conjecture that film cannot be used for environmental monitoring. Certain differences among the different types of phosphors used showed up, but when these idiosyncrasies were taken into account, the TLDs performed well. The results of the 1977 study will appear in a paper to be given by de Planque, Gesell and Gammage at the June meeting of the Health Physics Society.

## The Study Format

In early March of this year, following a successful pilot run held at ORNL by the committee members in December, an invitation to participate in the summer study went out over de Planque's name to approximately 118 institutions, public and private, who were involved in the design and operation of passive dosimeters. Of the 92% response, six sets came in from Iron Curtain countries, 13 from the Orient, and five from the Southern Hemisphere. As instructed, the participants responded by sending six dosimeters of each design to be tested to Gammage at ORNL: two for the field, two for the laboratory, and two controls to be kept in a shield. The shield used at Oak Ridge was the Laboratory's Whole Body Counter, in Building 2008, which was built with the express purpose of excluding the maximum amount of the ambient radiation. As the dosimeters came in, they were stored behind this shield until the official day of testing.

*Gesell and Gammage view the disks from which the dosimeters, attached on the underside edges, will receive the beta radiation at the burial site.*

JON THOMPSON

*Pam Mellor affixes the dosimeters for the beta radiation test.*

As co-investigator in the study, Gesell came to Oak Ridge for the summer. Technician Danny Christian was part of the team, as was Pam Mellor, a Kenyon College student, who was at the Laboratory for the summer under the Great Lakes Colleges Association program.

On July 13, Gammage and his crew, working quickly, attached all 163 "field" sets of two to long strips of pegboard and hung them, two meters above the ground on a fence close to a penned area which, several years ago, had been seeded with cesium-137 to simulate radioactive fallout. Preliminary tests the previous winter had established that the exposure rate was uniform along the entire length of the fence from which the dosimeters were to be hung. From HASL, de Planque sent a calibrated, high-pressure argon ion chamber, which operated continuously at the field site, recording the radiation exposure rate. The quality or energy spectrum of the radiation field was also measured with an ORNL GeLi (germanium-lithium) detector.

The "laboratory" sets of two were kept behind the shield with the controls until August 3, when they were moved, in four batches, to a calibration facility established temporarily in the High Voltage Accelerator Laboratory and then exposed to a known-but-unrevealed amount of radiation from an NBS-calibrated cobalt-60 source for 18 hours. On August 15, all the dosimeters were packed up and returned to their owners in a veritable marathon of industry by all the ORNL members involved, who worked without stopping until the job was done, a mailing of 978 dosimeters in all. At this point, time was an important factor, and the recipients of the dosimeters were instructed to waste no time taking the necessary readings upon their arrival. It was important to minimize the chances of extraneous amount of radiation accumulating, either intentionally or in transit, over those already received.

## Additional Testing

In addition to the dosimetry tests, two more were offered to select participants: About six members of the group, of known expertise in radiation measurement, were invited to participate in a small-scale field test designed to measure beta exposure in the presence of gamma emitters. The

GARY WELCH

*In the laboratory test, one-third of the dosimeter sets are in place for the measured exposure. Danny Christian places the cobalt-60 source for its 18-hour job.*

second small-scale test was to determine the effect of dosimeter package design on internal temperature excursions when the instruments were submitted to 24-hour outdoor exposure. The higher the temperature gets inside the package, the more susceptible the detector is to "thermal fading," in which the latent thermoluminescence signal partially leaks away with a corresponding loss of accuracy in the subsequently measured radiation exposure.

For the first test, participants were asked to send three identical dosimeters, which would be taped to the underside of styrofoam disks located at three distances from the ground at a burial site that is known to have a high ratio of beta to gamma radiation. Its goal was to test the effectiveness of different kinds of phosphors and different densities and thicknesses of absorbers in order to assist in the future design of monitors for beta-emitting effluents.

For the second test, participants were asked to send one empty dosimeter package, into which a thermocouple would be placed before deployment in the field. The results of such a test would aid substantially in the subsequent packaging design for environmental dosimeters.

## Advantages to ORNL

There is no doubt that these studies perform a service of inestimable value to those who submit their dosimeters for intercomparison. However, the advantage is not all one-sided. Gammage sees this as an opportunity to examine a wide variety of solid state dosimetry designs, and to gain as well useful information about their effectiveness for monitoring in different situations under varying extremes of climatic conditions. As a researcher in solid state dosimetry, he deems it essential to know the task effectiveness of a particular type of dosimetry system. He is at the same time concerned with being able to optimize the package design. Lessons learned will benefit ORNL's own applied environmental radiation monitoring services, headed by Tommy Oakes of the environmental surveillance and evaluation section of the Industrial Safety and Applied Health Physics Division.

With the results from the beta-field exposure, he envisages a growing interest in a possible large-scale intercomparison study in the future that will use a mixed beta–gamma field of radiation. Until now the concern has been limited to penetration photon radiation fields alone.

# Fuel from Accelerators

## *An Alternative to Breeder Reactors?*

By LORRAINE ABBOTT


JIM RICHMOND

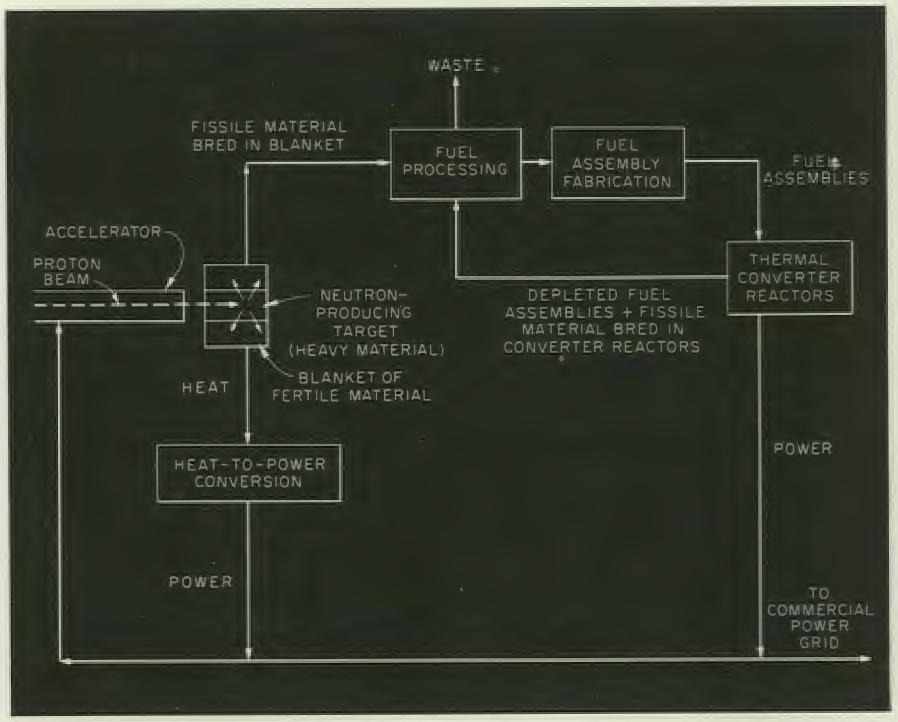
The idea of using particle accelerators to breed fissionable materials is not new. The first minute quantities of plutonium-239 were produced with the cyclotron at Berkeley, California in 1940 when Glenn Seaborg and his associates bombarded uranium-238 with deuterons (heavy hydrogen particles). During World War II small amounts of the isotope continued to be produced at that facility for the Manhattan Project, although most of the $^{239}$Pu needed for weapons fabrication was obtained by exposing uranium to the neutron fluxes inside graphite-moderated reactors constructed near Richland, Washington. After the war the Atomic Energy Commission considered the use of linear accelerators for weapons material production to the extent that a test model for a huge accelerator proposed by E. O. Lawrence was constructed at Livermore, California. The plan was to direct 500-MeV deuterons onto a primary target of beryllium surrounded by a secondary target of $^{238}$U. Neutrons ejected from the beryllium would be absorbed by the $^{238}$U to transmute it into $^{239}$Pu. But the Livermore project was cancelled in 1952 when the AEC decided instead to build additional materials-production reactors; this time, heavy-water reactors at Savannah River, South Carolina.

Coincident with the cancellation of the Livermore project, In its search for energy sources, the United States has revived interest in an old idea—producing fissile fuel with high-energy particle accelerators. The Laboratory's interest has gone even further. An ORNL study team led by Fred Mynatt last year studied the feasibility of a power system consisting of an accelerator "breeder" and thermal converter reactors in which all components of the system produce both fuel and power. Results of the study were published in detail in Report ORNL/TM-5750 and are summarized in the accompanying article. Other members of the study team were R. G. Alsmiller, Jr., Joe Barish, and Tony Gabriel, who performed target and blanket physics calculations; Dave Bartine, Tom Burns, and Ed Tomlinson, who performed the nuclear engineering analyses; John Martin and Mike Saltmarsh, who evaluated accelerator design possibilities; Ed Bettis and Dick Engel, who handled the heat transfer and mechanical designs of the system; and Jim Horak, who participated in the area of materials technology. Fred Mynatt, who was, at the time this study was made, section head of the Nuclear Engineering Analysis Group of the Neutron Physics Division, received his BS, MS, and PhD degrees in nuclear engineering from the University of Tennessee. He had worked with the Neutron Physics Division since he came to ORNL in 1965, originally as a member of what is now the Computer Sciences Division and since 1969 as an NPD staff member. He has specialized in radiation shielding, reactor physics, and radiation effects of nuclear weapons, and has led numerous projects associated with space nuclear power, Defense Nuclear Agency tasks, and civilian reactor technology. He has recently been named director of the newly formed Reactor Safety Research Program. Lorraine Abbott, also in the Neutron Physics Division, is a chemistry major turned technical journalist. She has been at ORNL since graduating from Maryville College in 1948. During this time she has edited several radiation shielding handbooks and authored numerous technical reports and project reviews in the field of reactor and weapons shielding.

W. B. Lewis of Canada reflected on the possibilities of using accelerators to generate even more intense neutron sources than the source proposed by Lawrence. He suggested that if heavy metal targets were bombarded by deuterons or protons of much higher energies, the spallation processes, together with particles that would subsequently "evaporate" from the heavy nuclei, would result in the production of a large number of neutrons for each incident particle. The fact that the United States did not explore this technique as a means for extending the fuel supply for reactors was no doubt greatly influenced by the successful operation in 1951 of the world's first experimental breeder reactor in Idaho (the EBR-1), which, as it happened, was also the world's first reactor to generate electrical power (except, of course, for the unauthorized "proof-of-principle" light-bulb experiment carried out at our own Graphite Reactor in 1945). Significantly, the EBR-1, unlike the weapons program reactors, operated on fast neutrons, it already having been established that reactors operating with lower average neutron energies would be inefficient for producing excess fissile materials in large quantities.

## ORNL Aids Canada

The Canadian interest in accelerator neutron sources persisted, however, and a decade later the AECL (Atomic Energy of Canada Limited) enlisted the aid of the United States in determining the neutron yields that could be expected from the interactions proposed by Lewis. An experiment at the Brookhaven Cosmotron was designed, and ORNL's Bill Gibson, Alex Zucker, and Ed Gross joined AECL staff in making the measurements. Several targets were bombarded with protons having energies up to approximately 2 GeV, and neutron yields on the order of 20 to 50 per incident proton were observed. About that time Wayne Coleman and R. G. Alsmiller, Jr., of ORNL were developing a computer code which could utilize particle-production cross sections calculated by




*Power-producing system linking an accelerator breeder with thermal converter reactors.*

ORNL's Hugo Bertini to predict the interaction and transport of particles having energies as high as 2 GeV. To test the method, they applied it to an analysis of the AECL-ORNL data: the calculations agreed with the experimental results. With these high neutron yields, the conclusion was that, in principle at least, it would be possible to produce neutron sources with accelerators that could rival reactors.

Armed with this knowledge, the Canadians visualized using accelerator-produced neutron sources for various areas of fundamental research, with the ultimate purpose to build accelerator breeders to convert large quantities of $^{238}$U into $^{239}$Pu, or alternatively, to convert $^{232}$Th into $^{233}$U. In this way fissile fuel could be produced for subsequent use in their CANDU reactors without previous stockpiles of $^{235}$U or $^{239}$Pu being required. Moreover, it appeared possible that such facilities could be designed to generate power directly. Pursuing this logic, the AECL in 1966 proposed a design for an Intense Neutron Generator (ING) in which 1-GeV protons would be delivered in a continuous 65-mA current to a primary target consisting of a bismuth-lead eutectic. The accelerator itself was patterned after the Los Alamos Meson Physics Facility (LAMPF), an 800 MeV proton linear accelerator. While construction of the ING facility has not yet been realized by Canada, the concept is still supported by AECL and it has captured the interest of other countries, including, belatedly, the United States.

The recent interest of the United States in the accelerator breeder has been prompted by our country's reexamination of its overall fission power technology, which in turn has been greatly influenced by concerns regarding the implementation of the Liquid Metal Fast Breeder Reactor (LMFBR). It was against this background that ORNL last year appointed a group under the leadership of Fred Mynatt to perform a preliminary study of the technical and economic feasibility of a nuclear power system based on the "symbiotic" operation of an accelerator breeder and thermal "converter" reactors, which produce fuel at a rate slower than they consume fuel. By thus precluding the use of fast breeder reactors, the probability of the highly publicized HCDAs (hypothetical core disruptive accidents) would be greatly diminished.

## Advantages of $^{233}$U

Although the ORNL team was chartered to study the possibilities of an accelerator breeder producing either $^{239}$Pu or $^{233}$U, it seemed clear from the outset that $^{233}$U was the more attractive isotope, not only because of the objections to $^{239}$Pu per se, but also because $^{233}$U is a more efficient and effective fuel for thermal reactors than $^{239}$Pu. Furthermore, a fission power technology based only on $^{233}$U would have several advantages, one being that the hazard of radioactive actinide wastes produced by a fuel cycle including only $^{232}$Th and $^{233}$U would be reduced by factors as large as a million when compared with the hazard associated with the $^{235}U$-$^{238}U$ cycle. More importantly, the problem of nuclear weapon proliferation could be reduced if the United States converted to a $^{233}U$ reactor fuel denatured with $^{238}U$, which would render the fuel unsuitable for direct weapon fabrication, although the reintroduction of $^{238}U$ into the fuel cycle would also result in plutonium production and bring back the actinide waste problem.

Regardless of whether the fuel to be bred is $^{239}Pu$ or $^{233}U$, however, the operation of accelerator breeders could result in a substantially smaller insult to the environment from mining than the operation of $^{235}U$-fueled reactors. Existing supplies of depleted $^{238}U$ would be sufficient as the fertile material for $^{239}Pu$ production, and adequate amounts of thorium ore, which can be fully utilized for $^{233}U$ production, could be mined with much less destruction to the environment than is possible in mining the much larger quantities of uranium ores required for $^{235}U$ extraction. This is particularly true as the known deposits of high-grade uranium ores dwindle.

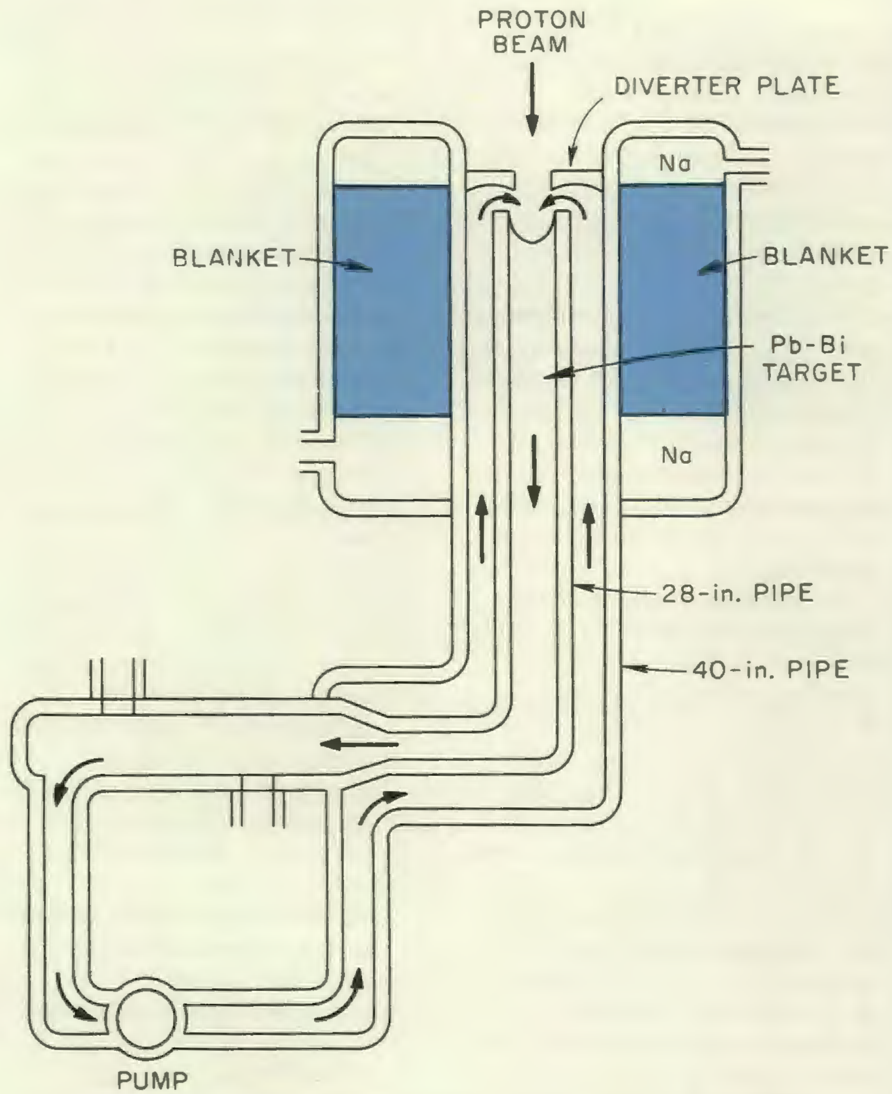
With the ING machine adopted as a reference, the ORNL team selected a continuous beam current of 300 mA as a basis for their study. This would deliver $2 \times 10^{18}$ 1-GeV protons/sec to the target, which, when combined with a neutron production rate of 20 to 50 per proton would yield 6 to 15 moles of neutrons per day. Mike Saltmarsh and John Martin were given the responsibility for evaluating the accelerator subsystem of the accelerator breeder. Their investigations indicated that the beam current is attainable, although considerable additional development over current accelerator designs will be necessary. The single most important factor influencing the overall accelerator efficiency is the efficiency of the system devised for converting alternating current power to radio frequency power for the high-frequency coupled-cavity stages of the accelerator. The major problems for the accelerator are beam control, heating, and radiation damage, the need for reliable high-current injection, and heating and damage of the window separating the accelerator and target zones.

In the reference design the lead target would be surrounded by a blanket of $^{238}U$ or $^{232}Th$. Most of the neutrons from the target would be absorbed in the blanket to produce $^{239}Pu$ or $^{233}U$ but because of their initial high energies they would also produce fast fissions in the $^{238}U$ or $^{232}Th$, thereby leading to neutron multiplication in the blanket. The multiplication would increase as the inventory of bred fuel increased and subsequently fissioned. Thus the blanket would become a subcritical reactor, with the neutrons from the fissions contributing to the buildup of $^{239}Pu$ or $^{233}U$ in situ. Under ideal conditions, as much as 7 kg of $^{239}Pu$ could be produced per day, even allowing for the loss due to the $^{239}Pu$ fissions. Somewhat less $^{233}U$ would be produced with a thorium blanket, since the fast fission effect in thorium would be significantly lower than in $^{238}U$.

## Energy Return Questions

The energy return from this type of fuel production is, of course, of utmost importance. The upgraded accelerator is estimated to have a total power requirement of approximately 660 MW, which is comparable to the total output of some currently operating power reactors. Clearly, the energy worth of the accelerator-bred fuel must exceed this amount for it to be a viable option. It is hoped that this condition can be met not only by producing reactor fuel but also by converting some of the heat produced by the proton–target interactions and blanket fission events into power that can be fed back into the system. The heat transfer and mechanical systems and other engineering aspects of the study, which must rely heavily on reactor engineering technology, were handled by Ed Bettis and Dick Engel, with Jim Horak participating in the area of materials technology.

The efficient design of a heat-to-power system requires that the generation of power in the blanket be at a nearly constant rate, so that such large components as heat exchangers, turbogenerators, and cooling towers, which always represent a large fraction of the capital investment of a plant, need not be overdesigned to ac-




*Design concept for accelerator breeder utilizing a Pb-Bi target in a sodium-cooled CRBR-type blanket.*

commodate peak levels. With the buildup of fissile material in the blanket and the concomitant increase in the heat generation rate, the power generation rate in an accelerator breeder plant can only increase. A constant power could be approached if neutron-absorbing poisons were introduced in the blanket as control rods are introduced into reactor cores or if the accelerator beam power were reduced as the fissile material builds up. But both these measures would be self-defeating since they would result in a decrease in the amount of fissile fuel produced. An alternative is to remove fuel from the blanket on a schedule designed to control the power level, and at the same time maintain an adequate inventory of fissile material in the blanket to keep the plant power output at its rated level. Another aspect of this problem is that the heat generation rate should be constant throughout the blanket, not only to facilitate the maintenance of a relatively constant total output but also to minimize the radiation damage to structural components by localized peak neutron fluxes and to simplify the design of the coolant system. Thus, in addition to removing fuel from the blanket on a scheduled basis, fuel must also be redistributed within the blanket with compensating amounts placed in strategic locations. Obviously, the development of a sophisticated fuel management system will be essential and, to a large degree, will dictate the mode of operation of the accelerator breeder.

## Analysis of a Concept

Recognizing all these constraints, the ORNL study group studied several target-blanket concepts, but the only concept for which enough data existed for an in-depth study was one that utilized the ING liquid lead and bismuth target and a blanket and coolant system similar to that planned for the Clinch

River Breeder Reactor (CRBR).

A nuclear analysis of the target and blanket was performed with powerful and highly sophisticated computer codes that essentially simulate the real situation. The most rigorous codes available are the so-called "Monte Carlo" codes with which the geometry and composition of a system can be described in three-dimensional detail and the pathways of individual particles can be followed throughout a system. However, because of the time requirements, Monte Carlo calculations are inappropriate for design scoping calculations. Instead, design calculations are performed with "discrete ordinates" codes, which are limited to geometries described in one or two dimensions but which yield detailed results for all regions of the system in much shorter times.

In this study a Monte Carlo analysis of the physics of the target and a simplified configuration of the blanket was carried out by R. G. Alsmiller, Jr., Joe Barish, and Tony Gabriel with the High Energy Transport Code (HETC), an advanced version of the code that was earlier used by Coleman and Alsmiller to analyze the ORNL-AECL experiment at the Brookhaven Cosmotron, and the MORSE code, a well-known ORNL code developed for the lower particle energies encountered in reactor and weapons shield analyses. For this first concept they found that 25 neutrons would be produced for each incident proton and that the total neutron leakage from the target would be 5 x $10^{19}$ neutrons/s. The resulting neutron fluxes within the blanket were used as a standard for normalizing the nuclear design calculations.

The design calculations were performed by Dave Bartine and Tom Burns with the one-dimensional discrete ordinates code ANISN and neutron and gamma-ray interaction cross-section sets developed for similar analyses in the LMFBR program. For these calculations, which were in progress before the Monte Carlo results were available, an approximate energy spectrum for the neutrons leaking from the target was assumed, and the system geometry was described as an infinitely long cylinder. The numerous calculations covered a range of $^{239}$Pu enrichments in the blanket, as the fuel was constantly being shuffled to keep the enrichment uniform. The results showed that at zero initial enrichment, $^{239}$Pu would be produced in the blanket at a rate of 2.4 kg/day and that the peak production rate would be 2.6 kg/day at an average enrichment of 2%. At higher enrichments, the net production would decrease due to the increased probability that the $^{239}$Pu would fission. At the 2% average enrichment the blanket power production would be 640 MW(t), which when combined with a target output of 186 MW(t) gives a total system output of 826 MW(t). This corresponds to an electrical output of 290 MW, which is somewhat less than one-half the 600-MW power requirement for plant operation.

## Fuel Management Scheme

In order to keep the enrichment and power level reasonably constant, a fuel management scheme was devised in which 18 of the 216 fuel assemblies in the blanket would be replaced every 17 full-power days and the remaining assemblies would be shuffled to flatten the power distribution. A given assembly would reside in the blanket 200 days and would contain 2.4 kg of $^{239}$Pu when removed.

Even with the fuel management, however, the neutron fluxes generated in the target and blanket, especially in the inner regions of the blanket, were found to be sufficiently high to cause serious radiation damage problems. As a result, the mechanical design would have to allow for periodic replacement of at least the upper portion of the 28-in. central pipe, as well as the walls of the blanket assembly. The fuel assemblies would also have limited lifetimes. However, the limits of all these components would depend on the requirements placed on the structural materials.

The nuclear analysis also considered possible accidents with an accelerator breeder type plant. Although the plant will not be subject to energetic accidents such as might be postulated for an LMFBR plant, the problems associated with a possible loss of coolant remain. The ORIGEN code, another ORNL calculational tool, was utilized by Ed Tomlinson to predict the maximum fission-product decay heat that would be generated in the 2%-enriched CRBR-type blanket instantaneously following a loss of coolant. The heat produced was equivalent to 44 MW(t), an amount that could be removed by natural convection and with an auxiliary heat exchanger. However, if as a result of a catastrophe the blanket were even to melt, the fuel would still remain subcritical.

### Feasibility of Concept

As has been pointed out above, this detailed analysis for a CRBR-type $^{239}$Pu-producing blanket rather than for the preferred $^{233}$U-producing blanket was prompted by the availability at ORNL of an LMFBR analysis technology. However, on the basis of these results, it was estimated that with the same target–blanket geometry, a maximum of 1.8 kg of $^{233}$U could be produced per day in a thorium blanket. This is somewhat lower than the $^{239}$Pu production, but the fact that the thermal reactor power production potential of $^{233}$U is higher than that for $^{239}$Pu must be taken into consideration when comparing the two fuels.

Beyond the issues of technical and engineering feasibility, there lies the question of whether fissile fuel produced with an accelerator breeder would be economically competitive with other means of production. Since the accelerator breeder does not require fuel reserves, the cost for the fuel produced is based primarily on the capital costs of the machine plus the cost of any power that has to be purchased to operate it. Because of the limited study by the ORNL team, any dollar estimates given are highly uncertain; however, the information to date indicates that the fuel produced would cost on the order of $100 per gram. This is competitive with the costs of uranium extracted from low-grade ores such as Chattanooga shale, and, as pointed out earlier, damage to the environment due to thorium mining will be substantially less than that due to uranium mining because of the much smaller quantities of ore required for comparable yields of fissile material. Therefore, this concept assures a long-term fissile uranium supply without extensive disruption of land.

Probably a more important economic aspect is the relative insensitivity of the cost of fission power to the fuel cost, together with the advantages gained from a symbiotic system consisting of an accelerator breeder and converter reactors operating on a $^{233}$U-Th cycle. In such a system all components (i.e., the accelerator and each reactor) will be producing both power and $^{233}$U fuel while utilizing only thorium ore as the feed material. With this system, the cost of producing the power is estimated to be about 35 mills/kWh. While this is higher than the cost of 20 mills/kWh for power from currently operating light water reactors, it is essentially equal to the cost of 31 mills/kWh projected for reactors now contracted for construction.

Can such a system then be considered a feasible alternative to the fast-breeder reactor? At this point it has to be stated that the plutonium fast breeder reactor appears to be more economical than the accelerator system. However, it is the opinion of members of the ORNL study team that the accelerator breeder should be viewed seriously as a backup for the fast breeder or, if necessary, as an alternative. In either case, the concept warrants and is receiving further study. In addition to the ING target and CRBR blanket design, in its preliminary study the team has already considered designs based on the fuel and coolant systems of the Gas Cooled Fast Breeder Reactor and a molten salt reactor. In both cases the target and fertile material were combined and the proton beam was spread over the surface. This arrangement seems to be required to eliminate or minimize steep flux gradients in the blanket and also to eliminate the necessity for fixed structural components between the target and blanket where they are highly susceptible to radiation damage. Other characertistics required for an optimum design are a high average neutron energy in the blanket to increase breeding, and an effective and efficient fuel management scheme. The study team is seeking designs with the best combination of these characteristics and is currently focusing attention on a concept of metallic Pu-U-Th fuel cooled with sodium. When these studies are completed, and when the status of the LMFBR and other alternative power sources is clarified, the relative merits of the proposed symbiotic system can be more accurately determined. ■

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# Awards and Appointments

**Alfred C. Butler** has been registered by the National Registry of Radiation Protection Technologists. He is the first Nuclear Division employee and one of only 40 in the United State to be so recognized by the Registry, which was established by the American Health Physics Society in 1976.

**Jack Cunningham** was appointed associate editor of the American Society of Metals/American Nuclear Society Nuclear Engineering Materials Handbook Program.

**Ellison Taylor** was selected to receive the Samuel Lind Lecture Award for 1977. The honor is bestowed annually by the East Tennessee section of the American Chemical Society upon an American chemist of distinction. His two lectures were on the subject of "Some Simple-Minded Ways to Study Chemical Reactions."

**O. B. Morgan** has been appointed director of the Fusion Energy Division, replacing John Clarke, who was named deputy director of Division of Magnetic Fusion Energy at the U.S. Department of Energy. **Lee Berry** has been appointed director of ORNL's new Fusion Program, which embraces all the Laboratory's fusion energy activities.

Newly appointed director of the Engineering Technology Division is **Herbert E. Trammell,** formerly director of the Gaseous Diffusion Development Program at ORGDP. He will replace Gordon Fee, who has left the Laboratory to serve as manager of the Gas Centrifuge Project in Oak Ridge.

**Tom Wilbanks** has been appointed a senior planner for social sciences in the Energy Division. He will assist in developing social science capabilities and in integrating these with other energy research programs at the Laboratory.

**Enzo Ricci** and **Dick Hahn** were selected to receive the American Nuclear Society's Radiation Industry Award for 1977 at the ANS national meeting in San Francisco this past November. Hahn has been elected to a three-year term as secretary of the Division of Nuclear Chemistry and Technology of the American Chemical Society.

**Irving Spiewak** has been appointed manager of the new Nuclear Energy Assessments Program.

**Fred Mynatt** has been named director of the newly formed Reactor Safety Program.

**Edward G. Struxness** has been awarded an honorary doctor of science degree by Luther College in Decorah, Iowa.

**Dr. A. Seaton Garrett** is the new director of the Health Division, replacing Dr. T. A. Lincoln, who has joined the Union Carbide Corporation staff as associate medical director.

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**D. J. Horen** was elected fellow of the American Physical Society.

**W. J. Lackey, David P. Stinton,** and **John D. Sease**'s paper entitled "Improved Gas Distributor for Coating HTGR Fuel Particles" was selected as the best paper by the American Nuclear Society's Fuel Cycle Division. The ANS Division of Remote Systems Technology conferred its best paper award on **John Bigelow, Joe Knauer,** and **L. C. Williams** for their paper entitled "Equipment and Techniques for Remote Fabrication and Calibration of Physically Small High-Intensity $^{252}$Cf Neutron Sources."

**Robert J. Gray** was elected president of the International Metallographic Society for 1977-79. ORNL winners in the Society's annual metallographic exhibit in Houston were: **Vinod K. Sikka, Elmer H. Lee, C. W. Houk,** and **T. J. Henson,** first place in the Optical Microscopy Class on Iron, Stainless Steel, Nickel Petrographic, Ceramographic and Cermet Materials for their exhibit entitled "Effect of Rare Earth Migration in an Irradiated $UC_2$ Gas-Cooled Reactor Fuel Particle"; **Ray W. Carpenter, Edward Kenik,** and **James Bentley,** second place in the Electron Microscopy-Analytical Class for their exhibit on "Phase Stability and Void Nucleation During Irradiation." Henson, Shrader, Tiegs, and George C. Wei also won awards for their exhibits at the American Ceramic Society's recent annual meeting in Chicago. Henson and Tiegs's entry on "Irradiation Performance of Gas-Cooled Reactor and Nickel Alloys for their exhibit entitled "Small Niobium Additions Show Significant Improvement in Intergranular Corrosion Resistance of Type 304 Stainless Steel"; **Terry N. Tiegs** and **Larry Shrader,** first place in the Optical Microscopy Class on Particles Made From Weak-Acid Resins" won the first place award in the Scanning Electron Micrograph (Natural Surface) category. Shrader and Tiegs teamed up to win the second place award in the Optical Micrograph (reflected) category with their exhibit on "Effect of Rare Earth Migration in an Irradiated $UC_2$ Gas-Cooled Reactor Fuel Particle," and the Wei and Henson exhibit on "Vanadium Impurity in Residual Oil Combustion Products Attacks High-Duty Fireclay Refractories" won second place in the Scanning Electron Micrographs (Natural Surfaces) category.

At the close of this year, **Floyd L. Culler, Jr.** will leave his post as deputy director of ORNL to join the management of the Electric Power Research Institute, becoming its president in the spring. The man who, in his brief tenure as acting director of the Laboratory during its severest vicissitudes, managed to retain the loyalty and affection of its entire staff notwithstanding, is leaving an institution that he helped to build in the 30 years he devoted to it. Every Laboratory employee will be affected by his departure.