REVIEW

OAK RIDGE NATIONAL LABORATORY · WINTER 75

State of the Laboratory-1974

THE COVER: Rosy is the future for Oak Ridge National Laboratory, being, as it is, in the right place, at the right time, doing the right things, according to new Director Herman Postma. In his maiden State of the Lab address last December, he accorded much of the credit for the Laboratory's current timeliness to the vision and farsightedness of its two previous directors, Floyd Culler and Alvin Weinberg. The full address leads off this issue.

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REVIEW

VOLUME 8, NUMBER 1 WINTER 1975

FEATURES

OAK RIDGE NATIONAL LABORATORY

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

State of the Laboratory-1974

By HERMAN POSTMA

FOR DIFFERENT REASONS, each of the past three State of the Laboratory addresses specified that year as a "year of transition," and, in fact, that must always characterize the work of an institution like ours, for without transition, without change in its work, it would not long be fulfilling its mission. However, 1974 for ORNL can also be called "the year of fulfillment," for the expectations of earlier years and the groundwork that was laid then are now in the process of being fulfilled; it has been a year in which the unique resources of the Laboratory are becoming recognized and more fully utilized to attack the crucial national problems in energy and environment.

Through the superb leadership of Alvin and Floyd and through their guidance, vision, and personal dedication, the tasks and directions chosen in years prior to 1974, along with the work of our excellent staff, have turned out to be immensely important. The goals set earlier are now achieving reality after five years of steady decline, much personal distress, and a deep sense of frustration in all of us that the obvious national problems were not being attacked in ways and with sufficient resources to bring solutions to a timely application. 1974 is the year in which we perceive an end to such dismay.

There are many external events which occurred in 1974 that already have or soon will shape the Oak Ridge National Laboratory further. I can only highlight a few:

1. The general public became acutely aware of the energy crisis. What perceptive economists and

technologists had been warning about for years finally hit home as the Arab oil embargo began and people had to wait in gas lines. With the price of energy rising by a factor of three, the public became further aware of the impact of energy on every aspect of their lives, and moreover the public now seems cognizant of the important role of technology.

2. The long discussed bill was passed on October 8, 1974, creating the Energy Research and Development Administration and the Nuclear Regulatory Commission. It has been significant in the evolution of that bill that the Oak Ridge National Laboratory and other multipurpose laboratories of the Atomic Energy Commission were held up as models of ways to carry out important work. The enlargement of our mission as an ERDA lab will ensure that ORNL will be in the middle of the action.

3. The national budgets for energy-related R&D have gone up and are close to the recommendations made in the Dr. Dixy Lee Ray report of a year ago. That report had strong input from Floyd Culler and Murray Rosenthal. Because of our overall capabilities in energy, the Laboratory's programs and budgets have been increased significantly this year (though inflation has wiped out at least half of the dollar increase).

4. A provocative external event (begun five years ago) is the serious questioning of nuclear energy. Though the Rasmussen report came out during this year and though we find an urgent demand for all types of energy, the critics of nuclear energy have intensified their efforts and are moving from the courts and licensing procedures into Congress by undertaking concerted and strong lobbying efforts. Indeed, it seems as if the battle is only beginning. The outcome of their effort upon this Laboratory, upon nuclear energy, and upon the country's ability to supply energy will be extremely important.

While these external forces have been building, there have been important happenings within the Laboratory; and tonight, I will concentrate upon them.

This year we developed our first long-range plan to direct our attention to those areas where we felt our work could make the most important contributions. In that plan, we stated the objectives of ORNL as follows:

"The major continuing objective of the Oak Ridge National Laboratory is to generate, analyze, and systematize new scientific knowledge and to develop new technologies that will offer our nation options for nuclear and other energy supplies and for more efficient systems for energy utilization, to perform research and development in support of other national needs where the Laboratory's experience or abilities permit us to make important contributions. Our programs will be aimed at systems that are compatible with environmental acceptability and commercial viability. Significant efforts will be made to disseminate our technology to industry for implementation."

In that framework, I will describe some achievements of significance at the Laboratory this year. In doing so, I will reveal many of the essentials that make the Laboratory productive and successful. To select the items for this address, I conducted an experiment. Rather than preselect a theme, I asked each Associate Director and Division Director to indicate the best work in his particular area of concern (and, contrary to logic, without establishing any scientific criteria as to what "best" really meant). For the last two months on Friday mornings, then, I scheduled appointments with the principals, to hear of their work. I should insert here that this was one of the happier occasions for me personally this year because I was able to share firsthand in the enthusiasm of the investigator as he told me of his work and its importance. In addition, I found so much of the Laboratory that is positive, enduring, and unique.

In singling out a few things for specific mention, I regret that other excellent work has to be omitted; and as you will agree, I cannot cover completely the work that was suggested.

Fission Energy

Though our effort during the last year has expanded somewhat in nonnuclear activities, most of what we do now and what we are destined to do in the near term is tied up strongly with nuclear energy. The most important areas in our fission work are those connected with the nuclear fuel cycle, reactor safety, and selected base technologies.

This year, the effort for developing a fuel recycle technology program for the high temperature gas cooled reactor (HTGR), which is to operate on the Th-^{233}U fuel cycle, has grown from \$2 to \$6 million.

The fuel cycle work is of particular importance at this time for several reasons:

— With the demise of Nuclear Fuel Services (NFS), the fuel cycle is not complete for any reactor system in the country.

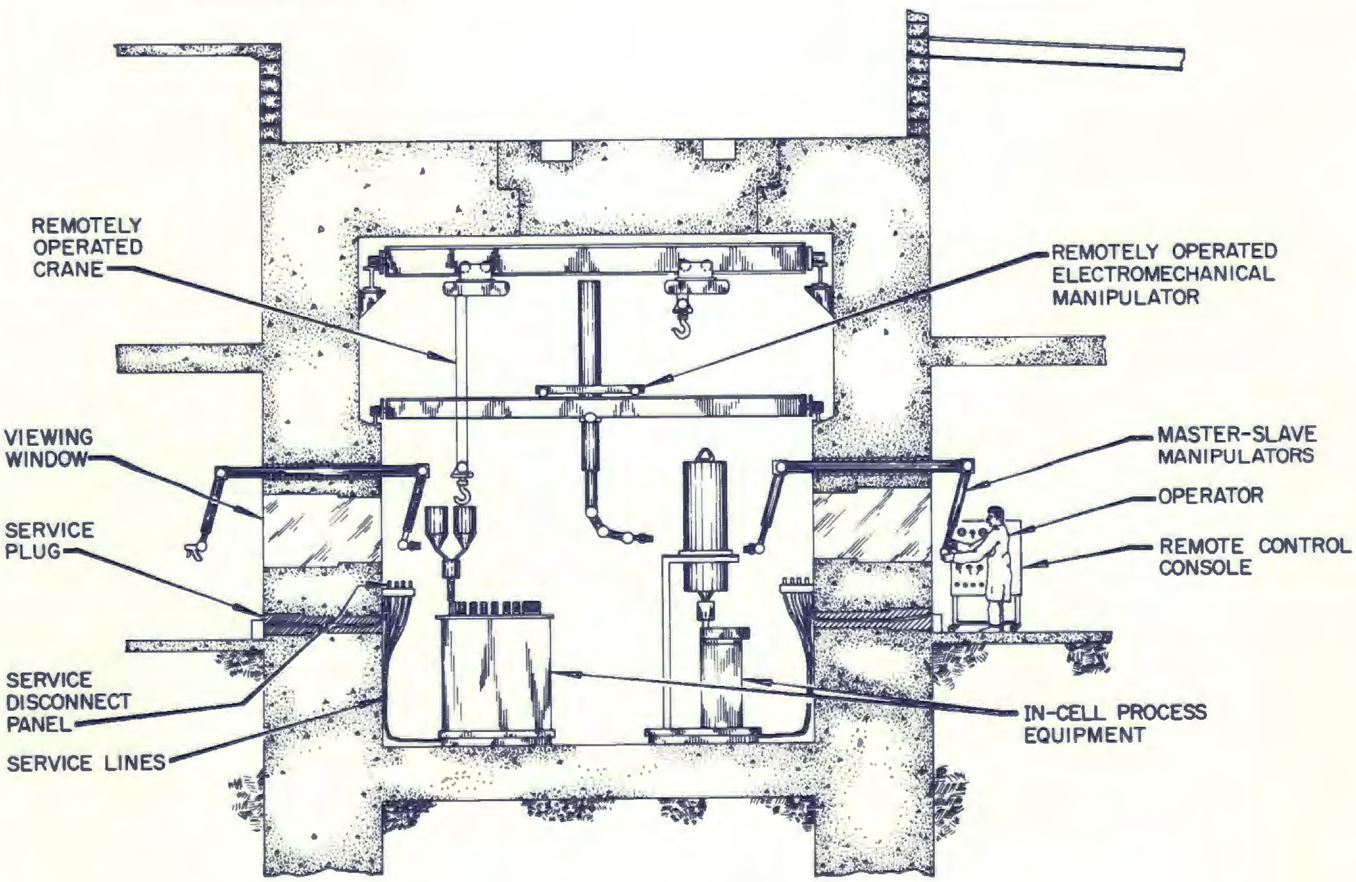
— A number of HTGRs have been sold by General Atomic Company, and, although they are based on the Th-^{233}U cycle, the technology to complete the fuel cycle is not in hand.

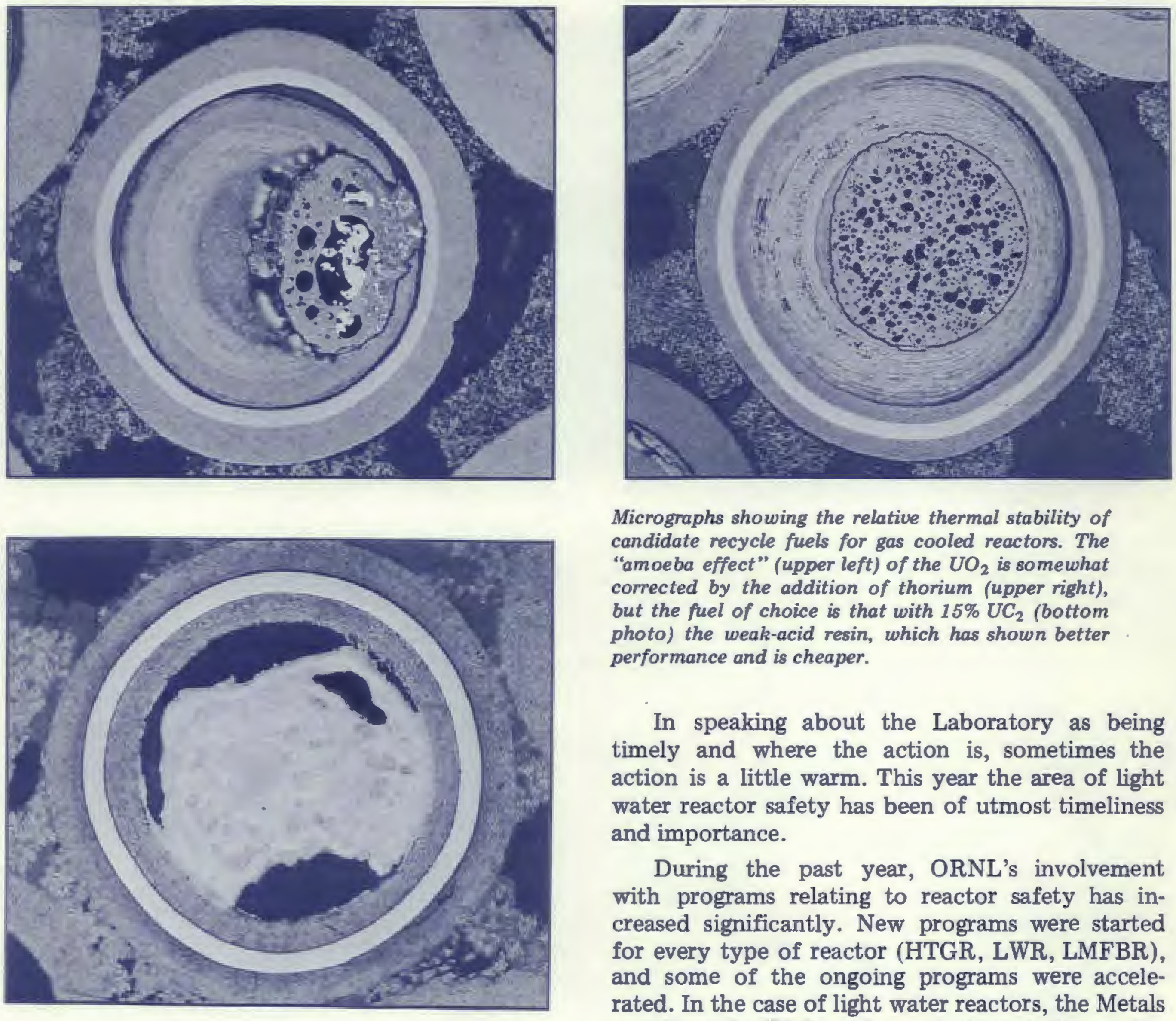
— The difficult licensing, accountability, and remote handling problems being solved here can advance fuel cycle technology for all reactor systems. The degree of difficulty might be indicated by the fact that GE is now considering the abandonment of a $64 million chemical processing plant that is brand new but inoperable because of design inadequacies in a largely proven LWR fuel cycle.

One of the major efforts of the program this year, undertaken by Pete Lotts of Metals and Ceramics and John Hill of General Engineering, with support from several ORNL divisions, was to complete the design of a pilot plant for refabricating HTGR fuel elements. Now estimated to cost $52 million and to operate in the period 1982—1984, the pilot plant will be installed at ORNL in TURF, a large hot cell facility completed several years ago for this purpose. One of the problems in design of such a plant is to select processes and fuel design that will be commercially acceptable in the 1980s. The process that is being developed, under the leadership of John Sease in M & C and Karl Notz in Chemical Technology, includes preparing fuel microspheres, coating these microspheres with pyrolytic carbon and silicon carbide, preparing the fuel rods that contain these materials, and, finally, loading and carbonizing the rods in the graphite fuel blocks.

The Chemical Technology and Metals and Ceramics Divisions have for years conducted programs to optimize processes and develop the fuels. Jim Scott, Frank Homan, Walt Eatherly, Terry Lindemer, and their coworkers this year completed an analysis of this work, resulting in a decision to use a resin-based fuel as reference for the pilot

A cross section of one of the hot cells in the TURF facility, showing the control that must be exercised during the production of fuel for gas cooled reactors. On the right is the coating operation, with fabrication facilities on the left.





Micrographs showing the relative thermal stability of candidate recycle fuels for gas cooled reactors. The "amoeba effect" (upper left) of the UO_2 is somewhat corrected by the addition of thorium (upper right), but the fuel of choice is that with 15% UC_2 (bottom photo) the weak-acid resin, which has shown better performance and is cheaper.

plant. They observed some migration of the kernel material (amoeba effect) in the oxide-base fuels and none in the UC_2. They found that the addition of thorium to the oxide-base fuel reduced the migration rate; but in spite of that, they concluded that (4 Th, U)O_2 (the former reference recycle fuel) might be unacceptable in some regions of the HTGR core because the migration rate indicated marginal performance. They found that a weak-acid resin had better performance and was cheaper than mixed oxide or the present commercial fuel made by a powder agglomeration and fusion technique. This new fuel development is acceptable to General Atomic as the reference fuel for its recycle plant.

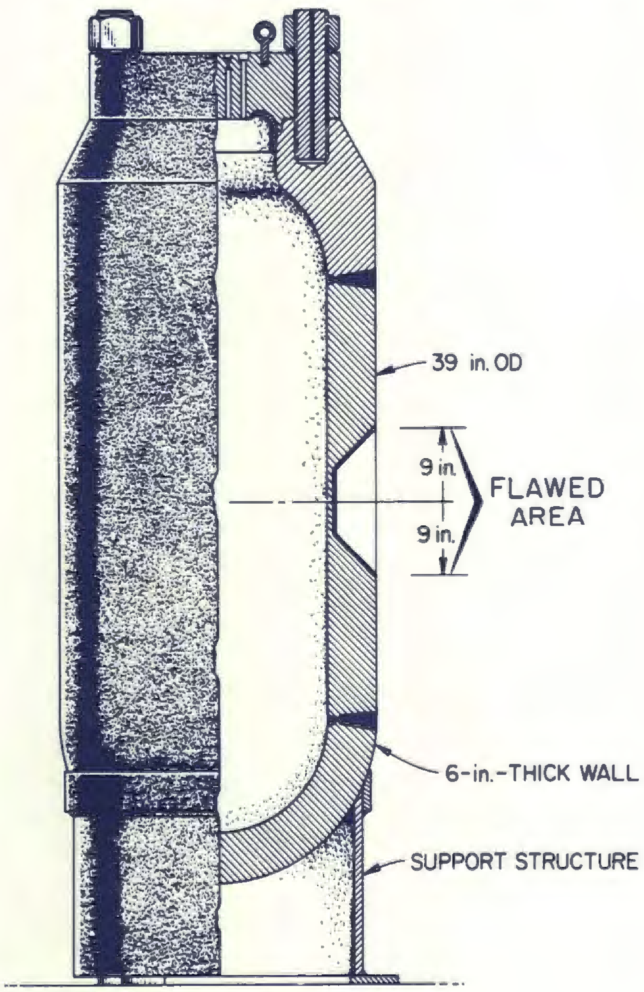
In speaking about the Laboratory as being timely and where the action is, sometimes the action is a little warm. This year the area of light water reactor safety has been of utmost timeliness and importance.

During the past year, ORNL's involvement with programs relating to reactor safety has increased significantly. New programs were started for every type of reactor (HTGR, LWR, LMFBR), and some of the ongoing programs were accelerated. In the case of light water reactors, the Metals and Ceramics Division is conducting studies on the metallurgical performance of Zircaloy-clad fuel elements during a hypothetical loss-of-coolant accident. As an outgrowth of the ECCS hearing and our earlier work, the Chemical Technology Division has re-initiated studies of fission product transport, and the Reactor Division is beginning an experimental program to evaluate core blockage.

But probably of principal value this year has been our role in assessing the margin of safety inherent in the steel pressure vessels used in all of the light water reactors currently in operation throughout the country. This program, which is identified as the Heavy Section Steel Technology Program (HSST), is a joint undertaking of the Solid Mechanics Department in the Reactor Division and the Steel Technology Group in M & C. It involves both experimental and analytical investigation of such material properties as fatigue crack propagation and fracture mechanics under both irradiated and unirradiated conditions.

An activity central to the program is the destructive hydrostatic testing of pressure vessels with 6-in.-thick walls, each of which weighs approximately 8 tons. These vessels are fabricated from the same low alloy steel forging and plate used in construction of commercial reactor vessels, and they are sized to provide a reasonable base for extrapolating the test data and analytical models to the full-size counterparts having wall thicknesses approaching 12 in.

Cross section of a pressure vessel that has been flawed for testing to failure in the Heavy Section Steel Technology Program. Pressures of more than three times design were required to burst most of the vessels flawed as deeply as this.



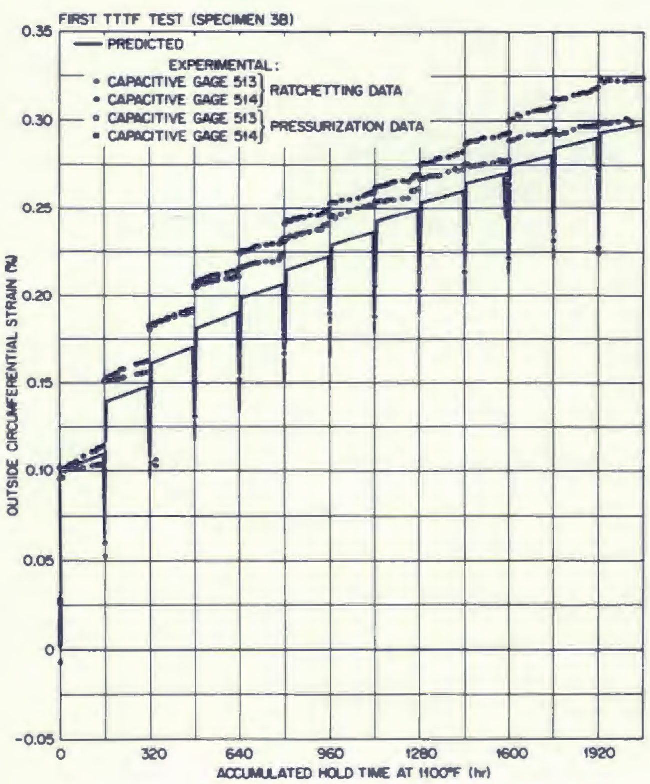
Prior to testing, one or more flaws are placed in the walls of the vessels. These flaws, which are deliberately sized to be significantly larger than those that are easily detected in the required nondestructive examination of operating reactor vessels, have varied in depth from 1.5 to 5 in. and have been up to 18 in. long.

To date, eight vessels have been tested. It is notable that each of these tests has required the combined support of all three Oak Ridge plants. Although it is an ORNL program, the Y-12 Plant has made significant contributions in developing electron beam techniques for installing the flaws, and K-25 provides maintenance support at the test facility, which is located in the old Gaseous Diffusion Power Plant. In all cases, even with these large flaws in the wall, overpressures in excess of 2.2 times design were required before failure occurred. In fact, in most tests like that shown in the drawing, an overpressure of three times design was required. The results of these tests have been most reassuring since the predictions of failure pressure and flaw extension have been accurate within a few percent. They have demonstrated that reactor-grade steels have a remarkable capability to tolerate large defects, thereby implying that there is a substantial margin of safety in operating vessels.

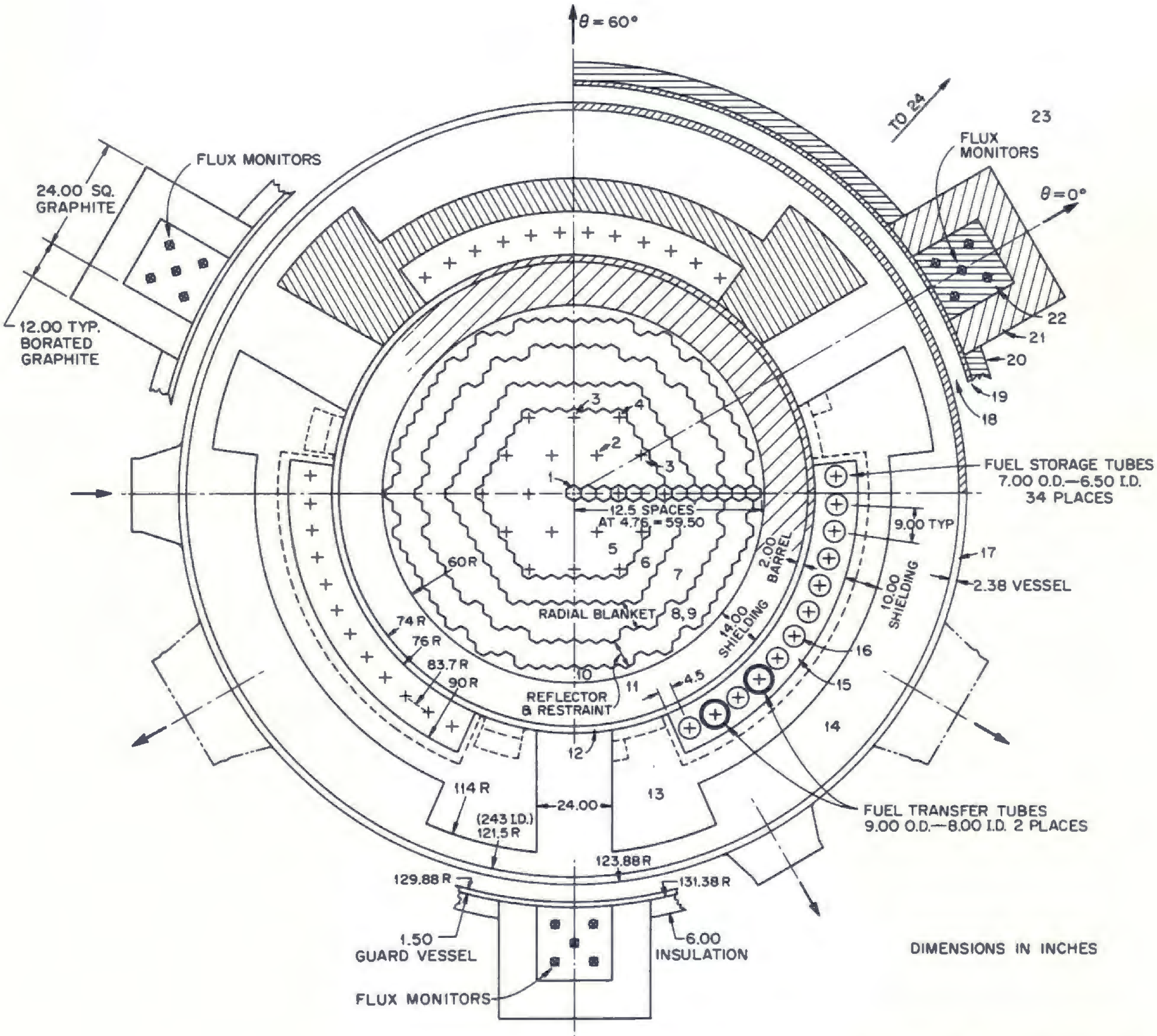
In the important area of developing the base technology for reactors, this year Reactor's Jim Corum and Chuck Brinkman of M & C determined and issued several Reactor Development and Technology (RDT) standards. These are guidelines and procedures for the design of nuclear system components at elevated temperatures, including giving supplements to the ASME code. Because of the combination of relatively high-temperature, transient thermal conditions and the very long design life (30 years) desired for LMFBR systems, the structural design methods and criteria are different from those already developed and used in light-water reactors. High temperatures significantly reduce the elastic strengths of the materials, and time-dependent creep and time-independent plastic flow occur. Inelastic behavior affects long-term structural reliability through creep rupture, incremental structural growth, ratchetting, cumulative material damage to interaction of these bucklings, accumulation of inelastic strains at welds, etc. This year, structural analysis criteria; descriptions, mathematical and analytical, of the material behavior; verification of the analytical methods and tools; and the issuance of design criteria and design guidelines were completed. One example appearing this year was that the ratchetting effect for pipe was measured by that thermal transient test, and the results were found to agree with the analytical predictions for inelastic effects. Since the analysis and procedures are used by FFTF and Clinch River Breeder Reactor (CRBR) designers, that agreement is encouraging. As Jim Corum pointed out, the agreement several years ago was fairly bad. Thus, a usable high-temperature design technology leading to a safe and reliable design has been developed in a very short time. In order that our concern about safety and long-term reliability of systems be answered at a very early stage, substantial effort must be put into the technology toward obtaining the necessary confidence and supporting evidence.

In a similar vein, through work in the Neutron Physics Division by George Flanagan and Fred Mynatt and in the Instrumentation and Controls Division by Bert Ackermann, quick answers were needed for the surveillance of CRBR reactivity while subcritical. Because of the geometry and environment of the vessel, it was difficult to decide whether the monitoring of the neutron flux levels should be done inside or outside the vessel. The stored fuel inside the vessel and the limited available access for detectors created difficulties for in-vessel detection. Through a cooperative effort with Westinghouse's Advanced Reactors Division in the design, Neutron Physics in the analysis and interpretation, and Instrumentation and Controls in measurement science and experiments, an effort was undertaken which solved the problem early. Because the neutrons originating from the spent fuel stored outside the core would have dominated the response of neutron detectors external to the vessel, new configurations were sought analytically and experimentally that would allow the simple detectors external to the vessel to be used. Complex computations using novel transport codes were backed up by experiments (usually the coldest part of the winter in the Tower Shielding Facility) that verified the concept. Here is a case where a Lab team, alert to potential problems, again combined its capabilities with those of outside groups to solve a problem in a very short time.

Agreement of experimental with predicted results in thermal ratchetting test on type 304 stainless steel. Severe thermal downshocks were administered to the pipe at one-week intervals, and the circumferential growth was then compared to that predicted by current design analysis procedures.



Beginning several years ago, there was considerable alarm about the effects of radiation on various alloys that would make up the reactor structures or the cladding of fuels. Fluences beyond 10^{23} n/cm^2 led to swelling of such magnitude that, if allowed to go unchecked over the design lifetime, would result in untenable dimensional change or alternatively require extensive redesign to overcome. The choice of type 316 stainless steel for the LMFBR seemed to be questionable, and alternatives were sought. Expertise in the Metals and Ceramics, Physics, Solid State, and Neutron Physics Divisions made it possible over the last few years to draw together a team, facilities, and techniques to study the effects of radiation by bombardment of the materials in question with accelerated heavy particles, creating in hours the same number of displacements of atoms within lattices that would occur in reactors in years. Recently, this simulation of neutron effects has jelled well, and meaningful data are being collected by the team composed of Mike Saltmarsh, Cleland Johnson, Francis McGowan, Rich Richardson, Nick Packan, Ed Kenik, Bud DuBose, and Jim Stiegler. Everett Bloom analyzed the swelling behavior of several heats of stainless



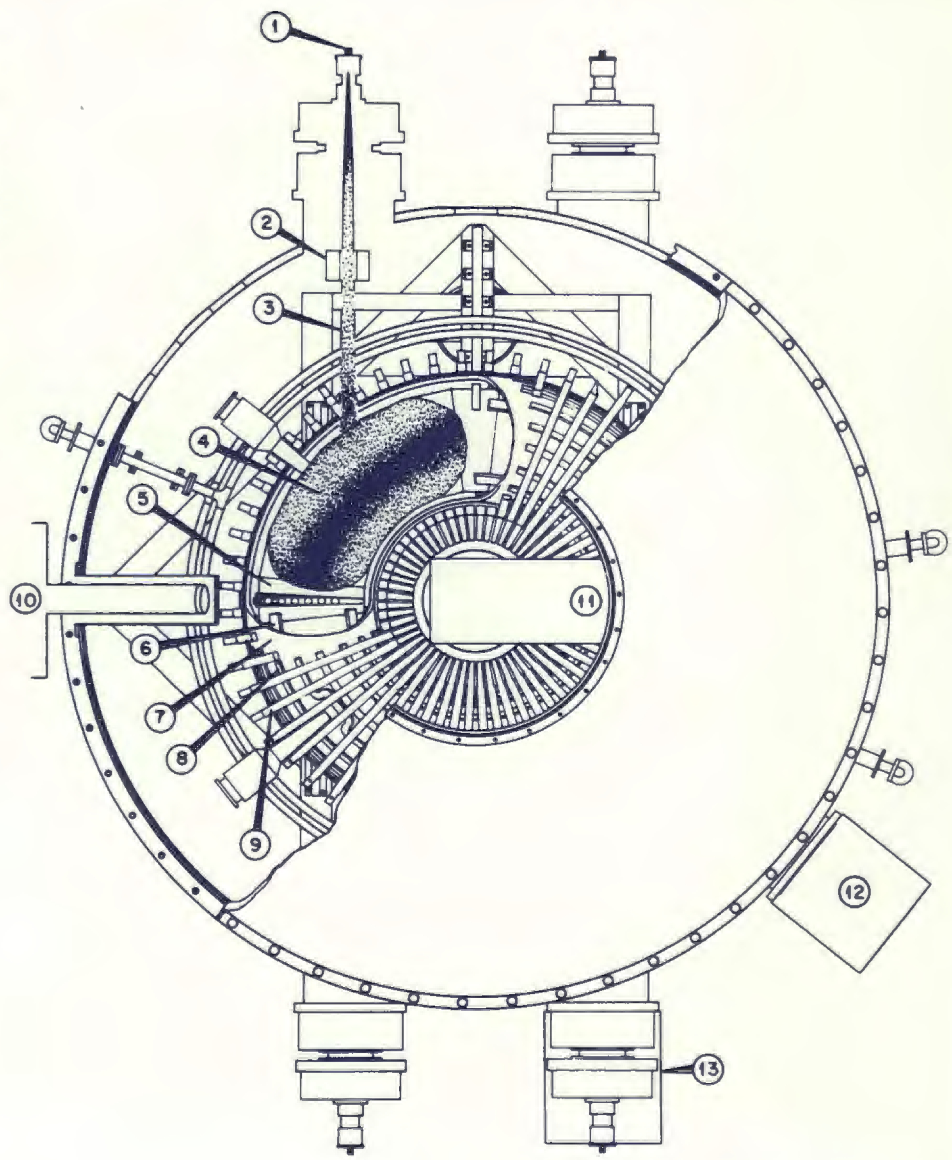
Horizontal cross section of Clinch River Breeder Reactor pressure vessel at midplane of core, showing the new geometry of external monitors and spent fuel storage that solved the subcriticality surveillance problem.

steel and devised a recipe of elemental ingredients that he hypothesized would reduce swelling. Initial irradiations using the simulation facility have verified the hypothesis by showing that the prescribed alloy can be classified among the small group of most swelling-resistant materials. In the proper accelerator, it is possible to screen materials fast and to qualify them for further investigations for eventual use in reactor design. Employing a number of disciplines and approaching the applied problem from the perspective of a long-term, basic point of view has resulted in a prompt screening method of immense value. The development of these alloys, their screening, and subsequent qualification constitute one more example in which the variety of talent available in a national laboratory can be called upon to bring about effective solutions.

Fusion

Some of the long-term, hoped-for solutions to the energy supply problem are those associated with the production of power from thermonuclear reactions. The work at the Oak Ridge National Laboratory has centered upon the tokamak approach, still the most popular magnetic confinement scheme though certainly outranked in news print during this past year by laser fusion, a process with which the Laboratory has little involvement. To heat plasmas to temperatures appropriate to those of reactor regimes, energetic neutral particle injection systems were devised as the most promising means of supplementary heating at the Laboratory; and in 1974, observations about the effects of the heating by these strong neutral beams have been obtained. Two energetic beams, themselves the result of an extensive developmental effort by Bill Morgan and his coworkers, were used to supplement the still larger ohmic heating of the Oak Ridge tokamak. It was found by George Kelley, Lee Berry, and Masanori Murakami that ion heating increases when injection takes place along the same direction as the flow of current coming from the ohmic resistive heating discharge. They observed that this ion heating is in agreement with theoretical predictions both in its magnitude (a 40% increase in heating) and in its scaling with the plasma density. However, when injection took

Schematic view of the ORMAK device showing the major elements of the experiment. The numbers indicate (1) a beam ion source, (2) beam neutralizing cell, (3) 26-keV H^0 beam, (4) plasma, (5) inner vacuum chamber, (6) vertical field coil, (7) conducting shell, (8) plasma current primary coil, (9) a toroidal field coil, (10) laser diagnostic, (11) iron core and limiter azimuth, (12) perpendicular neutral analyzer, and (13) parallel charge-exchange analyzer.



place counter to the current flow, it was much less effective and had a slightly deleterious effect upon the plasma. This was explained by Jim Callen and Jim Rome as being due to a new loss region for fast ions and the more subtle effects of that injection on the plasma itself.

With most of its armament in place, ORMAK is detailing the characteristics of the plasma and confinement properties. Our visiting committee calls it "probably the best." But through subtle plasma effects, there appears to be an enhancement in turbulence leading to anomalous transport of particles, particularly of electrons. Before great confidence can be placed in the scaling to larger fusion devices, these effects should be better understood.

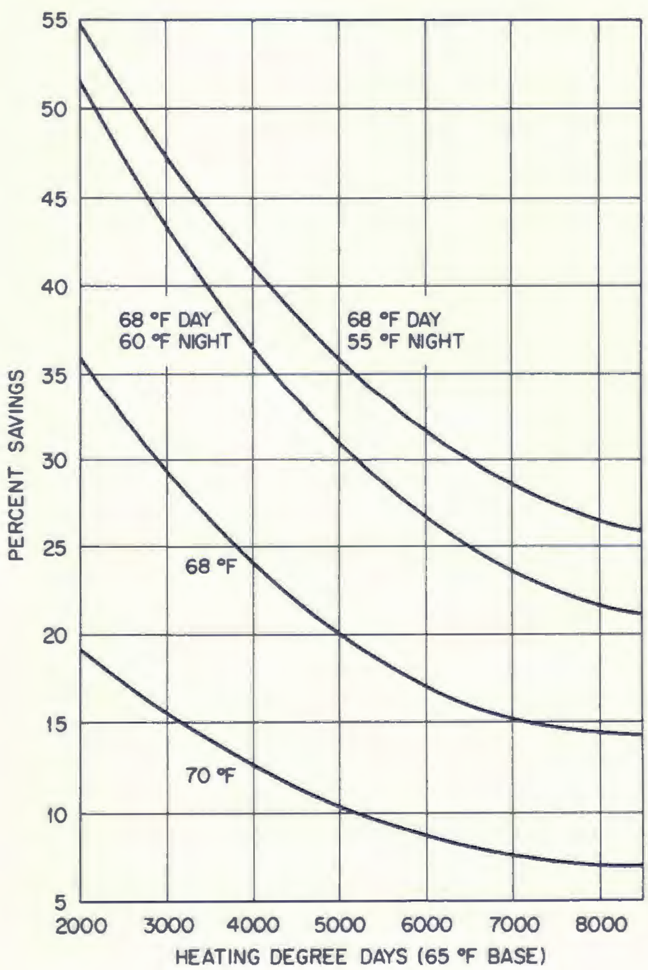
It was mentioned several years ago in the State of the Laboratory address that a new toroidal confinement device called the ELMO Bumpy Torus (EBT) was being built. EBT is an invention of Ray Dandl of I & C Division and is unique in the confinement world. The Bumpy Torus has been described as a toroidal magnetic trap in which microwave heating is used to produce a steady-state plasma, whose plasma pressure is nearly comparable to the magnetic pressure holding the plasma in. During the last year, that plasma has operated reliably and well. The system now has had observations that are consistent with the body of theoretical results developed for that concept; and significantly, the observed confinement times are those attributed to more or less classical (that is, understood) transport mechanisms with particle replacement times in the tens of milliseconds. This very novel and cleverly conceived plasma confinement device seems to be adequately described by the theory at this time. Again, this pleasing evolution is an outgrowth of the ideas developed in the basic research programs undertaken more than ten years ago.

Much of what the Thermonuclear Division now does and is increasingly being called on to do more of — development of beams, development of large superconducting magnets, and understanding of the nature of a fusion reactor — is involving other parts of ORNL to a still larger degree. Seven divisions within the Laboratory now lend their expertise to solving these problems. As one example, I'll relay an interesting mystery story. Slightly over a year ago, an investigator from Argonne asserted that, based upon his results, the impact of very energetic neutrons upon first walls of fusion reactors was so significant that large chunks of metal would be knocked off. In fact, the neutron sputtering rates of niobium walls would be so great as to require the replacement of those essential and intricate components in just a very few years. Intrigued either by the apparent defiance of energy conservation or by the unanticipated large amounts of stored energy at the surface of the solids, Mark Robinson of Solid State Division became rather concerned and conveyed this to several cohorts. In order to determine whether such unconventional physics was indeed taking place, Les Jenkins and Tom Noggle from Solid State set up an experiment with the cooperation of Mike Saltmarsh from the Physics Division. They rapidly built a novel neutron source based on the d-Be reaction using 40-MeV deuterons from ORIC. The neutrons simulate the energy spectrum found in the fusion reactor and are quite close to the spectrum used by the investigator from Argonne National Laboratory. They found in a carefully controlled experiment that the sputtering yields were much lower than those in the Argonne experiment and fit classical expectations. Their recent results obtained in a very timely fashion have been verified by both Reiner Berisch from Garching Institute (once a year-long visitor at ORNL) and also recently by an investigator at Battelle Laboratory. The agreement among these three groups and the disagreement with the published data are not yet understood. However, it is comforting, both from the understanding of the laws of physics of solids and in an applied way, that fusion nuclear reactor walls won't disappear (at least due to neutron sputtering) in a very short time.

Conservation

My remarks up to now have been concerned with short- and long-term technological problems and solutions of the *supply* of energy, though we know that in the near term the country must make large efforts to conserve energy. In one of our earlier anticipatory eras, we undertook research in that area, and the Laboratory, during the past few years, has contributed heavily to giving factual answers to decision makers. Besides performing timely studies, we also loaned people: Jack Gibbons, who headed up the conservation work in FEA, and Ric Hirst. Our farsightedness led us once again to where the action was to be. Energy conservation studies at the Laboratory contributed to an insulation study for conventional homes, room air conditioner efficiency studies, water heater studies, and heat pump evaluations. We are currently studying mobile homes, taking measurements of energy flow for heating and cooling under many conditions, and combining this with modeling of performance and analysis to determine what changes should be made to conserve energy. John Moyers indicates that these results led to recommendations for codes and standards through ANSI, FHA, and others. The group is not only concerned with the determination of present-day equipment but also is looking at modifications that might conserve energy. One practical question raised by these studies is, What would a change in home heating habits affect, such as turning thermostats down in the winter and up in the summer, setting them back at night, etc.? The results are already available to FEA, NSF, and TVA.

Curves show the energy saved by turning your thermostat down at night, between 10:00 PM and 6:00 AM.

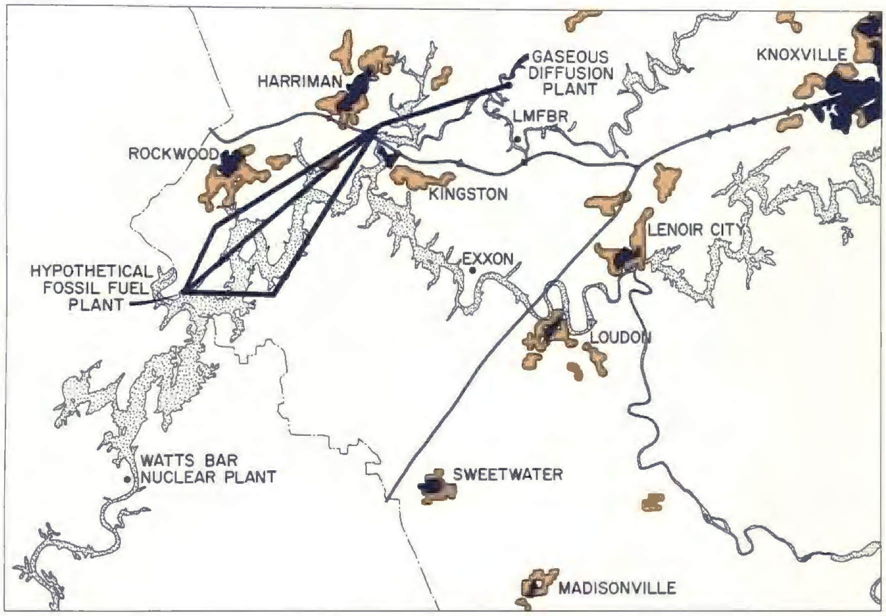


Social Studies

Our deep involvement at the Laboratory in determining environmental impacts is culminating in the writing of environmental impact statements for specific sites. This calls on our expertise in demography, economics, and understanding of social issues tied to technological developments. The work has evolved more and more to sophisticated modeling that will allow planning for a region, requiring an understanding of the goals, resource requirements, and impacts on whatever alternatives are available to that region. Within the new Energy Division, Pete Craven in the Regional and Urban Studies Department, together with the Environmental Sciences Division, Computer Sciences Division, East Tennessee Development District (ETDD), and TVA, has been developing analysis techniques to address planning questions on a regional scale. This effort was funded, in its embryonic form, by the National Science Foundation and the Department of Housing and Urban Development, but now the AEC is becoming more and more interested and needs the spectrum of disciplines of demographers, ecologists, economists, engineers, lawyers, mathematicians, planners, and political scientists.

Our group has focused primarily upon the East Tennessee Development District, a 16-county region of 700,000 people. Its particular concern now is with acquiring data, understanding the impact of changing population and employment levels, and increasing the relative attractiveness of the region for industrial development. A knowledge of the special distribution of activities in the region is required, which then permits environmental and social impact analyses. Forecasts for the changing land use patterns have been made, and it gets rather close to home. They have drawn up the forecast pattern for our local regional development, considering the impacts of several possible energy-related facilities: the Exxon Plant, the Clinch River Breeder Reactor, Watts Bar Nuclear Plant, and the hypothetical fossil plant somewhere on Watts Bar Lake. Computer simulations evaluate relative attractiveness of each region based upon 17 indices. The work has developed to such a point that the three diverse factors — socio-economic land use, environmental impact, and social impacts (as well as political influences) — can be factored

Shaded areas show projected urbanization by 1985 in the Knoxville-Oak Ridge-Rockwood region.



into regional planning. The program is now being extended to cover the Maryland Power Plant siting program, regional studies program for biological and environmental studies, and the new NRC Nuclear Center Site Survey.

Physical Research

Earlier I described one manifestation of particles penetrating matter and leading to radiation damage. Much of our fundamental work at the Lab is concerned with all kinds of radiation effects on all kinds of matter — solids, liquids, tissues, plants, etc.

A number of such experiments have been done by a team from Chemistry (Sheldon Datz and Herb Krause), Solid State (Bill Appleton and Tom Noggle), Physics (John Biggerstaff and Charlie Moak), and a group from The University of Tennessee — "the Clinch River wetbacks." To be more specific, they have been the first to examine the charge states of an energetic heavy ion while it is penetrating a solid. In one clever experiment, they looked at K x rays to indicate the charge state of the ion while it is in the solid. In single collision experiments with 80-MeV Ar^{q+} ions with SiH_4 (gas), it was established that the Si K x-ray production cross section depended exponentially on the charge of the Ar ion. The Si K x-ray production cross section, measured using a solid target, was then used to determine the charge state of the ion while inside the solid. The results indicate that the emergent ion must shed approximately 3 electrons.

The second aspect deals with the effect of ionic charge on the stopping power in a solid. Here the controversy concerned the effect of screening electrons from the Fermi sea on the effective charge. Normally it is not possible to isolate charge state effects in solids because of the very rapid exchange of electrons between ion and medium. However, when fast O ions (20 to 40 MeV) pass through crystal channels (that is a hometown finding), both the electron capture and electron loss cross sections are strongly suppressed; that is, the charge on many of the ions remains unchanged on their way through the crystal. Hence, pure interaction with conduction electrons may be studied. From this work it was shown, for example, that screening by conduction electrons has no effect on the stopping powers of these ions. An additional observation of interest here is that most of the electron capture by a channeled O^{8+} ion takes place either at the exit from the crystal *or* at the entrance.

Supposedly, one of the simplest interactions of radiation with matter occurs when protons of a few MeV interact with helium; yet, in the Health Physics Division, Sam Hurst, John Judish, Munir Nayfeh, Marvin Payne, and Brian Wagner, as well as James Parks, a consultant from West Kentucky

University, found new pathways in which energy is transferred amongst neutral species and ionic states of helium along with their reaction rates. Such fundamental studies have been going on for several years, but, surprisingly, this year two new and exciting applications arose from their work. In the high-power gaseous laser programs for fusion, weapon simulation, and isotope separation, we need to understand the methods by which lasing action between bound, excited states and repulsive ground states of molecules arise, particularly through the time-dependent coulomb field of a moving charged particle. Hurst, with support from our sister lab at LASL, is now looking at energy pathways in lithium-xenon mixtures and in metal vapors in order to search out new lasing media.

In turn, lasers are contributing in an experiment called "quickdraw." A pulsed dye laser has been installed at the Van de Graaff Laboratory in order to study excited atomic and molecular states. Pulses of protons from the Van de Graaff excite helium to various resonant and metastable states, and then a pulsed dye laser fires photons into the helium cell. The excited state can be selected by tuning the laser to find a two-photon photoionization process, and all the states of a given type are ionized thereby. By measuring this interaction, one has the absolute number of excited states surviving as a function of time. An exciting application of this work is the possible development of an extremely sensitive analytical system for measurement of environmental pollutants. In fact, ultrasensitive detection of one part in 10^{19} might be possible, and one might be able in this way to detect a single foreign atom in a cubic centimeter of a gaseous sample.

Our ability then to detect other effects as sensitively as we now detect radiation will open up whole new avenues of research and, at the same time, concern about the introduction of all substances into the environment.

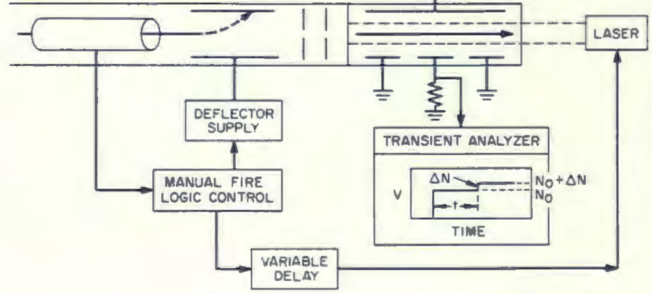
You probably thought after all these years that we knew everything we needed to know about fission of uranium, but we still had controversy in some areas until this year when some very elegant experiments were performed on ORELA by John Dabbs and Nat Hill of ORNL and a four-man group from LASL. They have used neutrons with energies in the range of 1 to 100 eV to measure the fission cross section of ^{235}U, which shows large fluctuations caused by the occurrence of a number of resonances in the compound nucleus of ^{236}U. Each of the resonances is characterized by assignments of widths, probabilities for fission, neutron capture, neutron re-emission, and spin values. The determination of spin values for these resonances has been a very difficult problem for a number of years, and, although several experiments have deduced them indirectly, the answers were conflicting. In this joint effort of two labs, they polarized neutrons and then polarized the ^{235}U target to measure directly the spin of 65 resonances in ^{236}U with neutron energies between 1 and 60 eV. Resonances are separated by a time-of-flight technique, and the polarization method is considered to be completely reliable. Results show 100% agreement with only two previous studies: one on 13 resonances using related polarization techniques and the other on 13 other resonances using a low-energy gamma ray ratio technique. Three other studies of the latter type gave poor agreement. The present techniques give both copious and correct results. The new spin assignments given to ^{236}U will be used to make theoretical fits to the ^{235}U fission cross sections and for reactor design calculations.

Life Sciences

We do much at the Lab that is concerned directly or indirectly with man (in the generic use of the word) and, in particular, with the effects of energy production and use on his environment.

This year John Poston, with the assistance of Paul Stansbury and Steven Garry, rebuilt a phantom man, and with much cleverness — and in keeping with Affirmative Action — made it modular so that with replacements it can be equally well

Schematic of "Quickdraw," the resonance ionization experiment that may lead to supersensitive (10^{-19}) detection of pollutants.



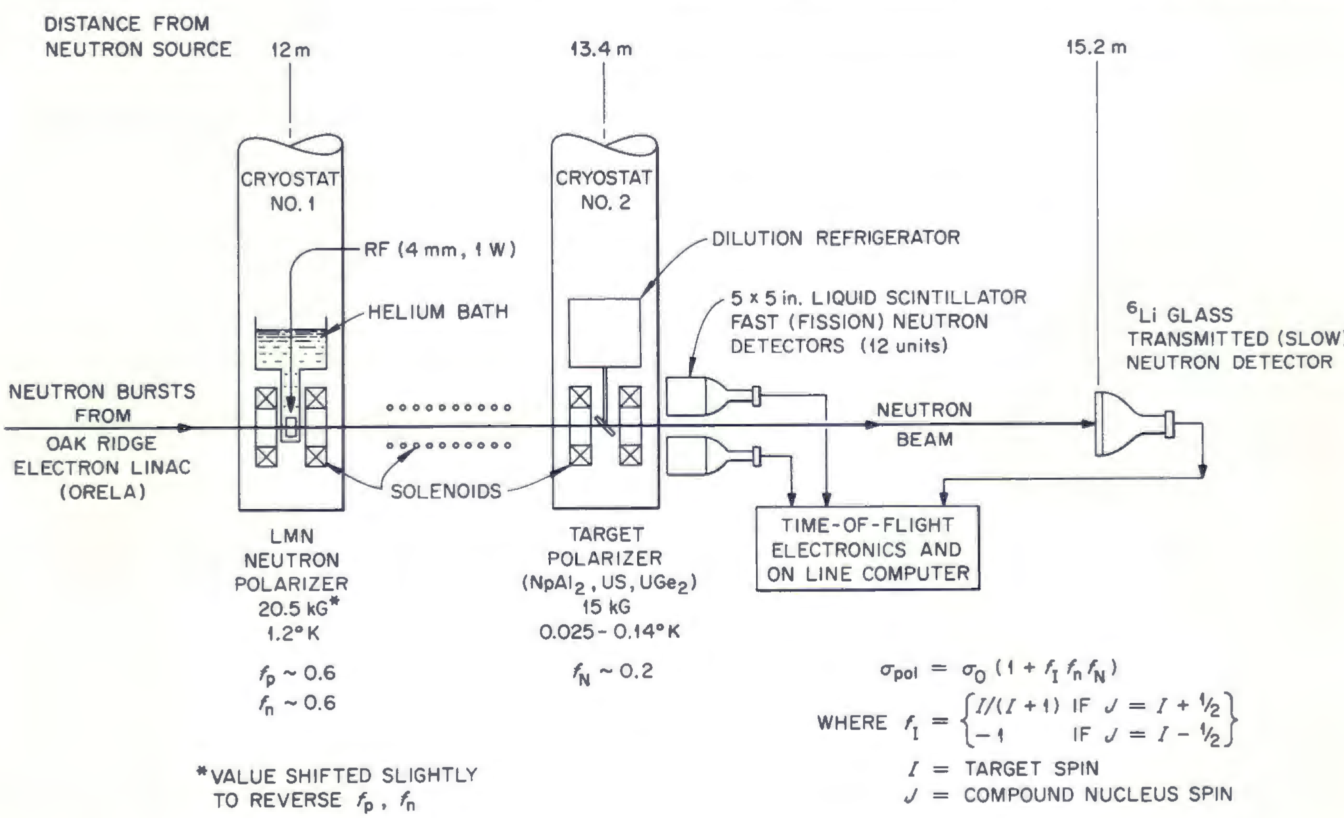
a woman. What is a phantom? A hypothetical standard man was first described in a computer program in order to predict the internal dose effects of radioactive materials on various organs — whether the internal dose arises from nuclear medicine doses or occupational exposure. Now the program has been converted to a 3-D plastic simulation, in which average sizes and shapes, densities, etc., were constructed for all the organs. With this reference human, experimental doses can now be measured and related to the computations to produce dose values to each organ for the relevant isotopes. This can lead to a minimizing of radiopharmaceuticals dose. This year the thyroid and bladder models were evaluated. External dose effects from x rays (too much TV) or emissions from power plants are under way, and a child phantom is expected next from the Poston family, presumably culminating from a nine-stage pregnant phantom woman.

This work leads directly to guideline setting by ICRP, NCRP, Society of Nuclear Medicine, and FDA.

Some of you may have noticed a lot of bugs at the Laboratory. Not things that bug people (though this year some people have told me there are such things), but rather bugs used in ways to help people. We have bugs that chew on sulphur in coal to remove it, as described by Dennis Chilcote in Chemical Technology; we have bugs that chew on cellulose to produce methane; and of course we have bugs disposing of our sewage on the back forty. But I'm going to talk about some other bugs.

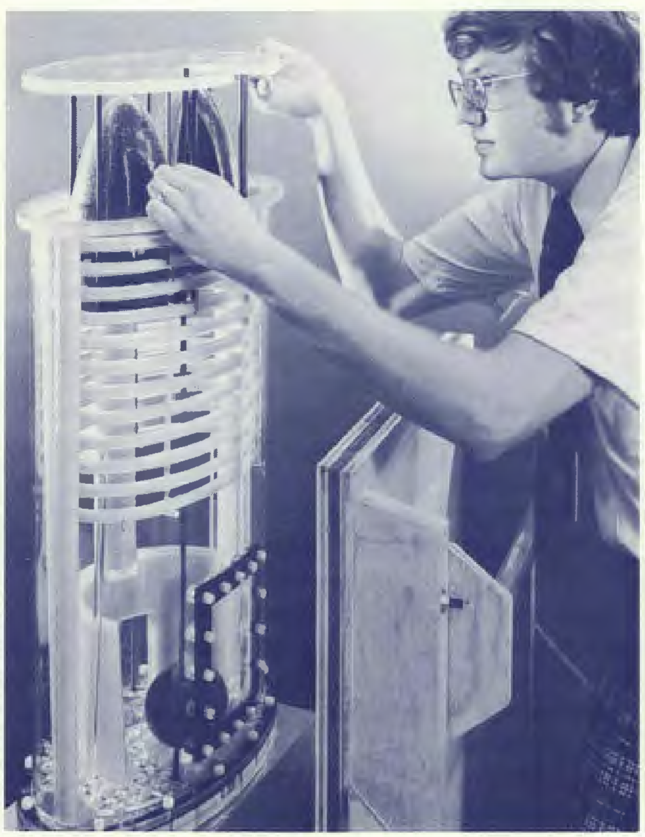
Perhaps it seems strange how a little basic research, some ground-up coal, a local problem at Y-12, and the ability to work with bugs can all be combined to solve a problem now and to lay the way for an important commercial process. First a little story. Little emphasis in the past has been given to the management of nitrates, compounds that might be metabolized to be cancerous to humans but are known to lead to eutrophication of lakes and streams. It is from the latter concern that Chet Francis of the Environmental Sciences Division became aware of the nitrate pollution problem within the nuclear fuel fabrication cycle a couple

Schematic of polarized fission experiments conducted at ORELA with Los Alamos team.



of years ago. A local problem arose in the R&D group at Y-12 when they felt their wastewater contained concentrations of nitrate greater than they wished released to their ponds. Production processes can generate large quantities of wastewater containing concentrations of nitrates greater than 5000 ppm; these include uranium milling operations and uranium oxide fuel fabrication plants. We expect other parts of the cycle as well to have large quantities of nitrate produced by nuclear fuel reprocessing plants. Fuel fabrication plants release as much as 4.5 metric tons of nitrate solution daily, which is disposed of directly into the water or stored in lined lagoons. Chet, along with Frank Brinkley and C. D. Malone of Tennessee Tech, has made it possible to use bacteria to denitrify these wastes, turning them into harmless elemental gaseous nitrogen and carbon dioxide. To obtain maximum denitrification, the special bacteria must be kept under optimum conditions. An energy source is necessary, usually a hydrocarbon, which supplies carbon for cell synthesis (methanol is the conventional choice); the pH must be right,

Steven Garry adjusts the phantom's shoulders in place above its lungs.



etc. What they did this year was to examine anaerobic columns for the ammonium diuranate process of the UO_2 fuel system (which yields nitric acid and ammonium nitrate). They showed that anaerobic columns are approximately 20 times as fast as continuous flowed stirred reactors.

After examining plastic beds and ceramic beads, he found that the use of anthracite coals appears to be a superior packing method, giving a greater surface area for microbial growth and no problems when the system is flushed. Through a series of experiments, they have been able to scale their models to a workable engineering design applicable for biological denitrification of high nitrate waste. Because of this work, the Y-12 nitrate problems seem to be well in hand; but in addition, this method applies directly to UO_2 fabrication plants. A column capable of treating 5 metric tons per day will be on the order of 4×4 m in size and very simple in design.

Ofttimes the Lab is where the action is (or has preceded the action significantly). For that example, the following story applies. More than 100,000 tons of chlorine are added yearly to the effluent stream of sewage, and more is added to the surface water, used for cooling condenser systems of power plants. It serves as a biocide to maintain efficiency.

There would appear to be a lot of data on toxicity of chlorine on aquatic life; but this is not true. Not only is the reaction of chlorine with natural waters poorly understood, but the methods used for analyzing residual chlorine fail to account for all the chlorine that was added.

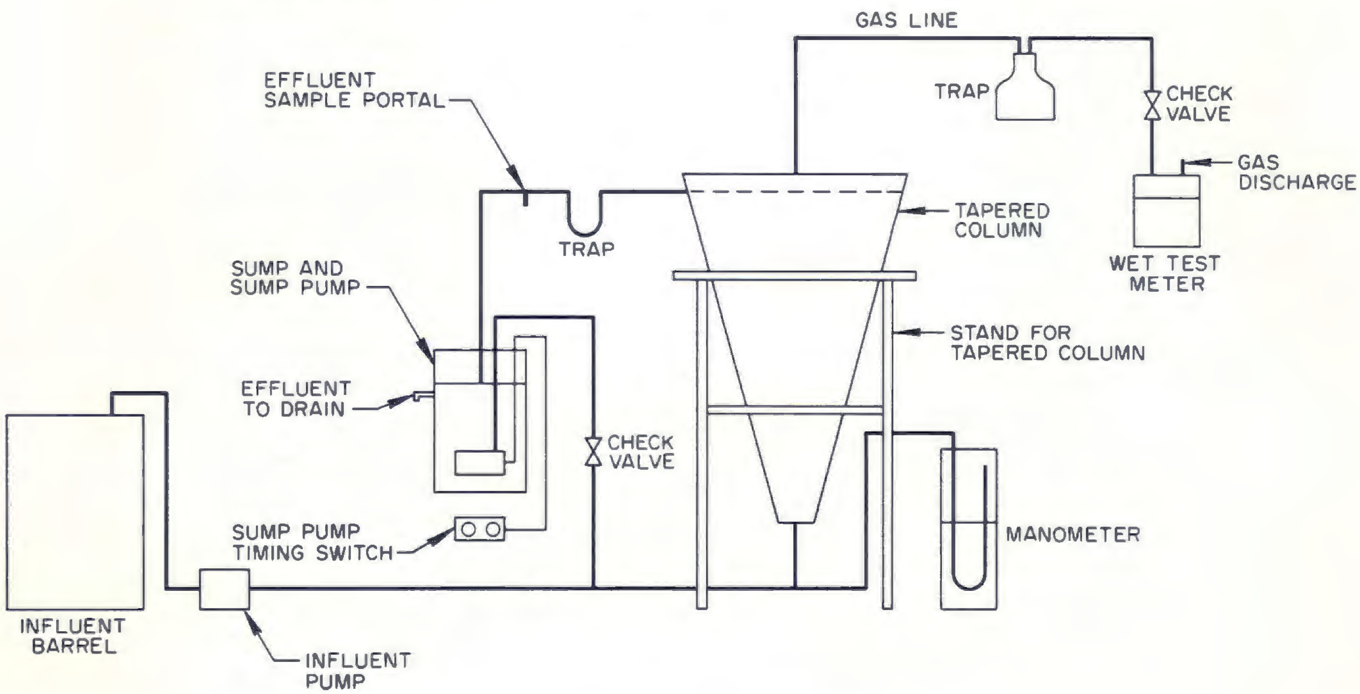
Bob Jolley and Jim Thompson of Chemical Technology have identified, via chromatography, 17 stable chlorine-containing organic compounds at low (μgm/liter) concentrations in sewage plant effluents. These are persistent compounds and suggest accumulation in receiving surface waters. But the toxicity of these compounds is unknown. To test that, Carl Gehrs and Dean Eyman of Environmental Sciences looked at the toxic effects of two species of stable chlorine-containing organics on carp egg mortality, on zooplankton, and on carp young deformations. In *Nature* this year, they noted the effects of two of these compounds on the hatching success of carp eggs. They added 4-chlororesorcinol and 5-chlorouracil to newly fertilized carp eggs. Some of these eggs were fertilized and water-hardened before addition of the toxicant, while others were fertilized in the test solutions. They found that the hatchability of the non-water-hardened eggs (our usual case) was significantly decreased by doses of the toxicant as low as 0.001 mg per 1000 ml of water, which is below the estimated concentration in sewage treatment plant effluents. These results are the first source of data on the toxicity of stable chlorine-containing organic compounds, and similar effects on zooplankton and deformed fish were indicated. Recently, EPA pointed out that there are problems with chlorine in drinking water. It turns out that the experiments by Jolley and Gehrs are the first real evidence of what the effects might be. These concerns of Jolley were reported by Ralph Nader. When the Laboratory is favorably mentioned by Ralph Nader, then we may have arrived.

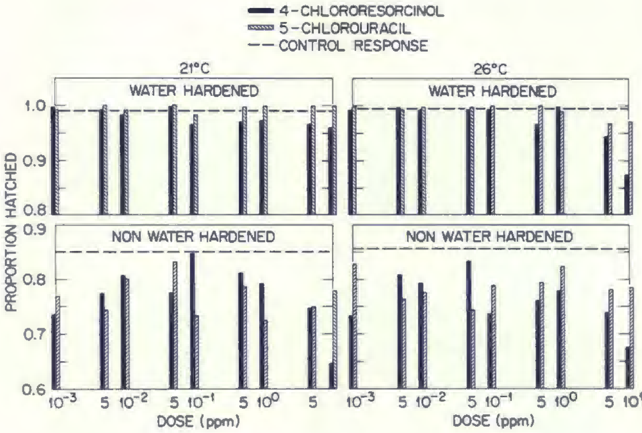
The effects of other effluents, more familiar, are receiving close attention in some very exciting work being conducted by Paul Nettesheim, Don Creasia, and Dick Griesemer of the Biology Division. They have been observing (using hamsters) which of our air contaminants act as promoters of lung cancer. Several important studies have come to fruition this year. In one study with over 1000 hamsters, they have demonstrated that iron oxide (Fe_2O_3) particles (these can come from brake linings or from a number of sources, particularly in industrial areas), when inhaled at the same time that a particular nitrosamine carcinogen, named diethylnitrosamine, is present, doubles the incidences of lung cancer.

Let me go over that again: iron oxide itself is not carcinogenic but, when in combination with a nitrosamine, the incidence of lung cancer is enhanced. Nitrosamines are normally manufactured by man in his stomach from the nitrate in water or hot dogs, etc., reacting with secondary and tertiary amines. We have already found earlier one place nitrates could come from (other than meats). From work by Willie Lijinsky in the Biology Division, we also are learning how nitrosamine carcinogens are formed in the stomach from these common nitrates.

In yet another inhalation study performed by Paul Nettesheim and his coworkers, NO_2 (a very common product of incomplete combustion of organic materials) seems to promote lung cancer markedly when the cigarette smoke carcinogen benzo-*a*-pyrene is present. Benzo-*a*-pyrene is one of the many carcinogens identified in auto exhausts as well as in tobacco smoke. Our related work in Analytical Chemistry on tobacco smoke identifies many more. This study further supports the view that there are pollutants, themselves not cancer-causing, which can significantly promote the risk

Using nitrate waste from a UO_2 fuel fabrication plant, this type of unit was capable of converting NO_3 to N_2 at an acceptable rate for industrial use.





Response of carp eggs to two different organic compounds containing chlorine, compared with control groups (dotted line), as expressed in hatching success.

of developing lung cancer. For example, three times the incidence rate occurs when NO_2 acts as a promoter for the benzo-*a*-pyrene.

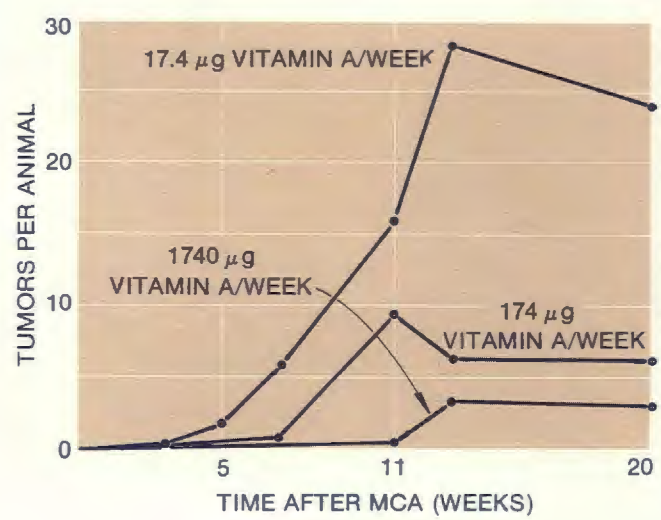
In yet another study, Nettesheim asks: What is it in the metabolism or nutrition of humans that allows some people to smoke as much as several packs a day and not contract cancer, while others are not spared? Through a series of experiments performed on rats last year, they found that an insufficient amount of vitamin A in the diet may produce a state of increased susceptibility to lung cancer induction. The data indicate that rats maintained on a diet that is low in vitamin A (but not so low as to cause any usual symptoms of vitamin A deficiency) have lung cancer incidence five times that of rats containing increased or high levels of vitamin A. Such increased susceptibility may exist in spite of normal vitamin A storage in the liver, if the carcinogen exposure occurs during low vitamin A intake.

In yet another experimental development, Nettesheim perfected the tracheal transplant technique. By transplantation, they can define a small target; accurate delivery of dose can be made to the intact mammal since the transplanted trachea is no longer part of the animal's vital organ system. Sensitivity achieved is about 50 to 100 times greater than that in other lung cancer models, so it is possible to detect lesions and to identify effects much sooner. Strange bedfellows — the interrelationship of the work being done in nitrates in Environmental Sciences for the Y-12 fuel storage problem, the nitrosamine studies in Biology being done by Lijinsky, identification smoking program within Analytical Chemistry with Mike Guerin, and now the work here, done by Nettesheim and his group on lung cancer. Together they combine to reinforce a broad attack on significant problems.

Our concern with man is not limited to present man but with future generations as well. Humans who have been exposed to agents that might cause base substitution mutations have been examined continually, particularly in AEC programs. Gerry Hirsch, Eddie Bailiff, and Ray Popp of the Biology Division and R. A. Conrad of Brookhaven collected and analyzed blood from 12 controls and 13 Marshall Island people who were exposed 30 years ago to different amounts of radioactive drift from Pacific tests at that time. Through elaborate purification techniques, they found a marked increase of isoleucine in the hemoglobin A which they conclude must have arisen through translation errors or somatic mutations during DNA replication, possibly a first observation that radiation may cause substitution mutations in human somatic cells.

But radiation is not the only insult that causes aberrations. Chemicals causing mutations are well known but have not so far received as much attention as radiation has. Gary Sega, working in

Data showing marked increase in susceptibility to lung cancer induction of rats on low vitamin A intake, as compared with rats on medium and high vitamin A intake, in terms of mean number of tumors per rat following administration of a known carcinogen.

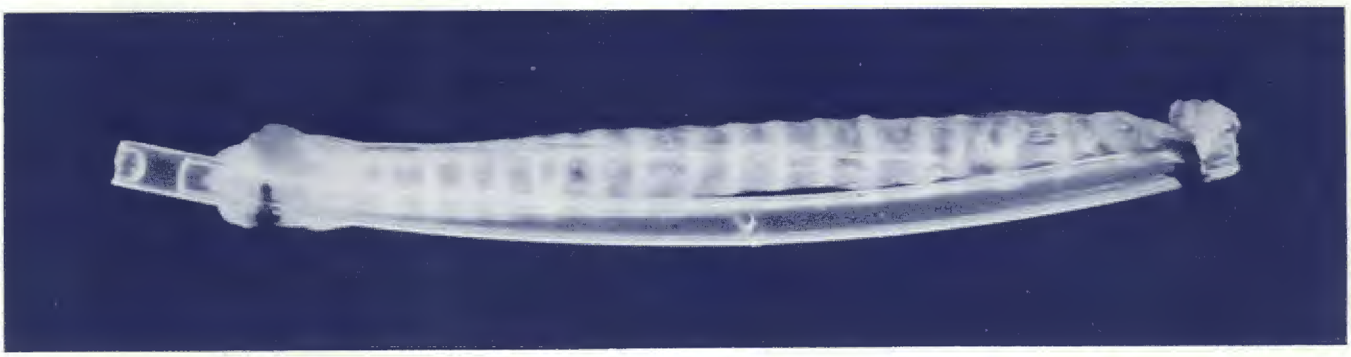


Bob Cumming's group in the Biology Division, has developed a rapid assay that detects unscheduled DNA synthesis in the germ cells of male mice exposed to mutagens and carcinogens. They are now examining a variety of agents to determine how well the detection of unscheduled DNA synthesis correlates with mutagenic or carcinogenic activity.

The statisticians will say that, in looking at only a couple of dozen projects out of 800 we have at the Lab, I shouldn't draw sweeping conclusions. But what are some of the common characteristics of the work I have described? Let me recapitulate:

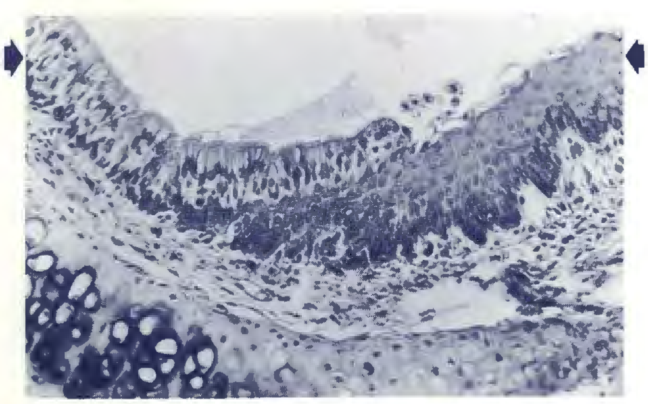
1. We find that new ventures begun in the last few years and for other agencies are now of importance and have direct applicability to the Energy Research and Development Administration and to the problems that needed to be solved.

2. Most of the projects described are multi-divisional in nature, in the scope of their research, and in calling upon the diverse capabilities of the Laboratory. Those things that had the greatest importance seemed to arise from cooperation amongst many disciplines.



Trachea from donor rat, ready to be transplanted into recipient as target for carcinogenic agents. Glass tubing on the side of the trachea is used to keep the tracheal graft straight.

Early phase of cancer development in tracheal graft. Arrow (N) on right points to normal epithelial lining; arrow (PC) on left indicates precancerous tissue extending toward the middle and undermining the normal mucociliary epithelium.



3. There is expanding and closer cooperation with other institutions: with K-25 and Y-12 where unique facilities and problems arise; with other national laboratories (Argonne, Los Alamos, and Brookhaven); with industry (General Atomic and Westinghouse); and of course, with universities.

4. We have an increasing involvement in those measurements that will eventually lead to standards in supplying basic information for regulatory bodies, for reactor standards, for dosimetry standards, for FDA, etc.

5. The interrelationships and contributions of "basic research" are relevant to what, all of a sudden, is an important applied problem in techniques, in facilities, in methods, in measurements, and in ideas. Investments made many years ago now are beginning to pay off in dividends to society.

6. The timeliness of work is obvious. The Laboratory is and has always been where the action is and anticipates well where the action needs to be.

7. There is an increasing trend toward greater knowledge and finer measurements *outside* the nuclear field. More importantly, what is happening is that we are obtaining a better understanding of the risk factors that are involved with everything we do in a complex society, whether adding chlorine or smoking; indeed, it may be that such refinements may lead to confusion of the public, and we must do our best to place all we do in a correct context and explain it well. As our instrumentation is improved, as our new techniques are perfected, and as our ability to look at the finer details increases, we will learn quantitatively much more about all things that impinge on our environment to increase risks.

In emphasizing the technical aspects of the Lab, I have so far ignored some essential ingredients and several outstanding achievements in the area of services indicative of the sophisticated backup that is necessary for all these other results to be obtained. Service given by many within the Oak Ridge National Laboratory has again been outstanding during the past year, causing our primary tasks to be performed with efficiency and dispatch. Some of those elements are especially worth mentioning. The Isotopes, Chemistry, and Chemical Technology Divisions manufactured an important isotope in quantity, plutonium-237, a short-lived gamma emitter that can be used as a tracer in many environmental and biological systems, thus avoiding many of the difficulties presented by its neighboring isotopes. Separation is now on a routine basis, and you can buy it by the microcurie any time you wish.

We had an elegant film, "The Bioengineers," produced at the Lab by Fleming Reeder and Ed Matney of the Motion Pictures Section in the Information Division; Ed has since resigned from ORNL. "The Bioengineers" picked off several awards this year, winning the *Industrial Photography* magazine's top award for R&D films; the Angenieux Award for the best creative cinematography; the Special Cup Award of the Ministry of Industry and Commerce at the 1973 International Educational and Television Film Show in Rome; and high honors in competition at several film festivals.

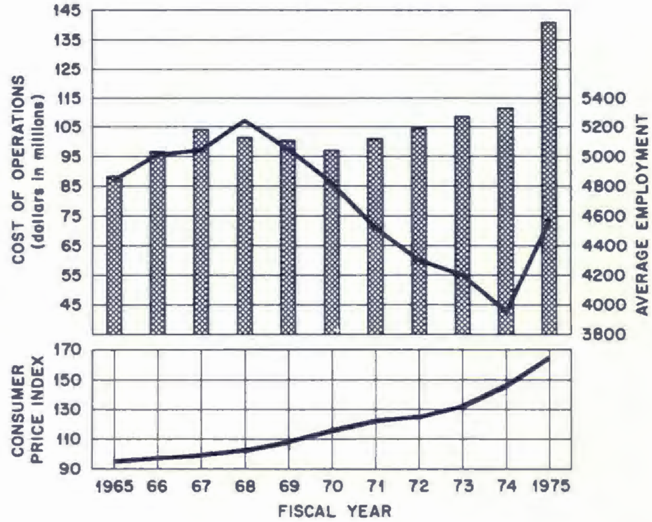
In another triumph, Jim McGuffey and Jim Robinson of Inspection Engineering attained N-Stamp certification from ASME for the Lab, making us first of all the national laboratories to be qualified for that ASME set of stamps. Through their work and the work of dozens of others in many divisions, we qualified on the first try, reaffirming the high quality in all that we do.

We have again this year published environmental impact statements, each time on a rush basis, but always with high quality and with timeliness — an outstanding tribute to many members of the Information Division's Publications and Records area. Of course, the many contributions from Engineering and Computer Sciences Divisions have intertwined in everything I've mentioned so far, supplying the sophisticated services that are necessary for any accomplishment. Once again, we find that the reliability of both the HFIR and the ORR has been uncommonly high, though this year ORR had an escaped capsule and the HFIR had a repair problem. Both events prevented us from attaining the 90%+ reliability of the past. Still, to the user, these are two of the most reliable reactors in the world, allowing the work to be done efficiently with little down time (aside from budgetary down times). We have seen our information centers grow this year, with consolidation of environmentally related information centers in a more functional mode, permitting expansion of their programmatic capabilities to supplying energy information, responding to Congressional requests, and helping other agencies, as well as serving the individual investigator.

So, during this year 1974, the Oak Ridge National Laboratory has grown with quality — in programs, in people, in money, and in accomplishments (and, by the way, in the cost of doing business). Even with the rapid turnaround during the past year, the capacity for work and room for people at the Laboratory is still far below its peak of 1968. With the abundance of excellent ideas and our eagerness and with the quality of our personnel, I am sure that we can do much more to solve the national problems than we have so far been permitted to do.

The Laboratory this year also changed in a number of ways that, undoubtedly, will shape the manner in which work is done. This year, for the first time, we drew together a long-range program plan that depicts for ORNL what the directions and main emphases ought to be. We undertook late last year a rather deep internal soul searching about the way in which we care for our human resources. The results of an attitude survey taken last year have had important impacts upon the Laboratory. The work done by divisional and Laboratory committees has led to important changes in the

The bars in the upper graph show the Laboratory's operating expenditures in millions of dollars; the black line indicates the average employment each year. Bottom graph shows change in cost of doing business.



way we now do things; yet much more needs to be done and will be done. We have seen this year the establishment of a seed money account. This money, to be used for funding new ideas in areas that have yet to be brought to the stage at which they can attract programmatic interest, has already proven to be important to the Laboratory and will, over the years, undoubtedly change our programs. Also, during this year a number of management changes were made, reflecting the changing character of the Laboratory. We have two new Associate Laboratory Directors, including the new Associate Director for Advanced Energy Systems, formalizing our new directions. We have four new division directors, one heading the new Energy Division, in recognition of the growing importance of energy to the Laboratory, particularly in nonnuclear technology. Several new programs have been formally established: LMFBR Fuel Reprocessing, reinstitution of the Molten Salt Reactor Program, and the Coal Program. Also, important new line items were funded, such as the National Heavy Ion Laboratory, a project we sought for seven years and one that now places us in the forefront of this vital physical sciences area; a new environmental sciences building; and changes in the Biology Division and waste disposal facilities.

The Future

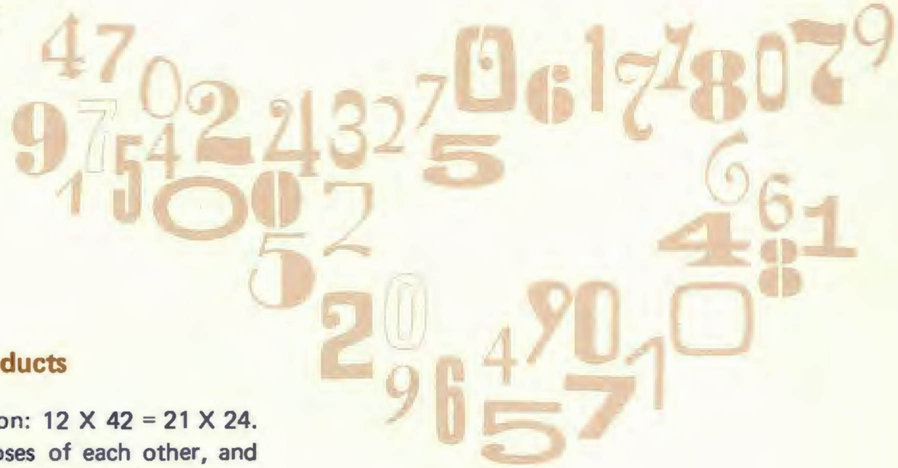
The Oak Ridge National Laboratory will change in important ways under the impact of ERDA and NRC. Growth and new programs are certain. I do not believe there is any conflict of interest in our doing work as the developers of technology for ERDA and in measuring impacts and assuring safety for the separated Nuclear Regulatory Commission, in its regulatory and safety work. The Laboratory as a whole is in an excellent position to contribute compared with other research institutions, with universities, and with not-for-profit establishments, and it has even been called "an oasis in the midst of economic uncertainty." We anticipate a stronger growth in the nonnuclear component of the Laboratory's business, both in technology and in areas of basic research. In any case, we expect that applied and development technologies (both nuclear and nonnuclear) will grow much faster than the more fundamental sciences. This is short-sighted perspective, for much of the basic science work of the past has come to be exceedingly valuable for the things now going on, and we must continue to bank that wealth of capability. Nonetheless, the basic sciences will, for the next few years, not grow much in size but undoubtedly will change in mix and emphasis.

ORNL is in the right place, doing the right thing at a critical time.

The Oak Ridge National Laboratory will flourish and contribute if, and *only if*, it continues to accomplish excellent work in the important areas. That can happen only if our excellent people, backed up by outstanding services, continue to excel as they have in 1974. It has been a personal pleasure to point to samples of the health, vitality, and strength of the Lab in 1974.

Take A Number.....

BY V. R. R. UPPULURI



Integer Products

Consider the product relation: 12 X 42 = 21 X 24. Here 12 and 21 are transposes of each other, and likewise 42 and 24 are transposes of each other. Since 12 X 63 = 21 X 36, we say that the pair (12, 63) satisfies our product relation. Of course there are obvious pairs like (11, 11), (12, 21), etc. Among two-digit numbers, one can find all the nontrivial pairs to be (12, 42), (12, 63), (12, 84), (13, 62), (13, 91), (14, 82), (23, 64), (23, 96), (24, 63), (24, 84), (26, 93), (34, 86), (36, 84), and (46, 96). Each pair satisfies the product relation illustrated above.

Consider any pair, say (46, 96). In the number 46, the digits 4 and 6 have 2 as a common factor, and 46 = 2 X 23. Similarly 96 = 3 X 32. Now, we note that 23 is the transpose of 32. Similarly, in any pair, if the common factors are removed, then the numbers left over will be transposes of each other.

Now, let us consider three-digit numbers. Since 102 X 402 = 201 X 204, the pair (102, 402) satisfies our product relation. We also have pairs like (102, 603), (102, 804), etc. One can obtain all such pairs in the case of three-digit numbers. The above-mentioned property for pairs with two-digit numbers is also valid for pairs with three-digit numbers, but it is not valid for four-digit numbers. This is another good example in which induction does not go beyond three.

Absolute Primes

A positive integer is said to be a prime if the only divisors of that number are itself and unity. The numbers 2, 3, 5, 7, 11, 13, 17, . . . are some of the primes. In 1974, Bhargava and Doyle of Kent State University defined an absolute prime to be a number such that every permutation of its digits is also a prime. Thus, 113 is an absolute prime, because all the permutations of this number (131, 311, and 113) are also prime. Though 19 is a prime, its permutation (91 = 7 X 13) is not a prime, and therefore 19 is not an absolute prime.

Using a computer program search, Bhargava and Doyle found the following few absolute primes among the first million positive integers: 2, 3, 5, 7, 11, 13, 17, 31, 37, 71, 73, 79, 97, 113, 131, 199, 311, 337, 373, 733, 919, 991. They also proved that no absolute primes using all the four digits 1, 3, 7, and 9 exist. Nothing else seems to be known about absolute primes.

Dan Nelson and Stan Auerbach pore over the plans for their new building as they have been doing now for over a year. In the foreground is a model of the ill-fated round ecology building. Note that their lighting is localized, in keeping with the energy conservation philosophy that governs the new building's design. For other conservation tricks, read the following transcribed monologue of how Stan finally came to acquire enough space for the ORNL ecologists.

Ecology's 20-Year Space Program

By S. I. AUERBACH

HOW DOES ONE DESIGN an appropriate facility for environmental research useful for both multidisciplinary and interdisciplinary activities? This is a problem we've been addressing for about 12 to 14 years. It seems as if we've been in the building design business almost since the day I first came to the Laboratory in 1954. It's sort of fantastic. I arrived in August and was assigned to Building 2001. Within six months my supervisor, Ed Struxness, said, "You're going to have a second laboratory; design it."

We moved into that lab and within three months he said, "Stan, Metallurgy is taking over part of this building, and you're being moved to Y-12 to an old cafeteria building there. Metallurgy's going to pay for it. Here's the money; design yourself a new set of laboratories." And so we set about to design new laboratories — this was in 9711-1 — and moved in there.

In two years we were out of space again, and we drew up plans for use of more space there — it was a large building — and by 1960 or 1961 we were told, "You may be coming back to X-10; you'd better think about it." As a result we started designing a new facility to be adjacent to Building 3504 where we now have a small greenhouse. This location was to comprise 10 to 25,000 sq ft of lab and field facility, to cost between \$100 and \$200K. We didn't get approval for it.

At about that same time they were designing the south wings of 4500, and so Ed Struxness and I went into a huddle and said, "Let's make a pitch for Building 2001." We began work on 2001 that year, remodeling it after the Health Physics Division moved out — which is how it came to pass that six years after moving to Y-12 we came back to 2001, exchanging about 8000 sq ft of lab space for 22,000 sq ft.

The early 60's marked an era of much talk of expansion in the air at the Laboratory. This was when Kennedy was president, and Alvin Weinberg was looking ahead to the future to all the roles that the Lab could play; he encouraged me to keep thinking about future needs in the environment, and the National Labs' possible missions in that area.

At that time I made the acquaintance of two engineers in the long-range planning department of the General Engineering Division, Welles Stanley and C. M. Carter, and, as we discussed space problems, they encouraged me to think about designing a new building — bear in mind, we'd just moved to X-10. I said, "Don't you think it's a bit premature?" But they assured me that it takes about 10 years to get a building. At the time I kind of chuckled, but I didn't realize how true those words were.

So Welles and Mitch Carter and I, with an architect consultant (Ed Sakrison) they had engaged, put our heads together on designing a building. I had already given considerable thought to what kind of a building would be best for an interdisciplinary program. I had pretty well convinced myself, on the basis of my 7 to 8 years' experience in guiding this ecology program, that the key to successful interdisciplinary programs is continuing interaction among the investigators. This may sound trite and obvious, but it's one of the hardest to achieve among scientists, because they are all individualists. They all may profess to want to interact, but, if you don't set up both a managerial mechanism and a housing mechanism for it, you're not going to have it easily.

So I decided that one way to get this feature was to work with a circular design. No corners, and the scientists can always interact. Now that may sound way out, but I began to look into this seriously, and I found that there was a small amount of literature on the subject and that a number of people had even done calculations showing that the number of interactions among individuals, based on random contacts during the day, in a circular building as opposed to the classical rectangle, was considerably greater. So much so that as a result of this, the AEC at LBL had built, with U. of Cal., a round biochemical organic lab under Prof. Melvin Calvin. When I asked him (Calvin) for his rationale, it turned out to be the same as mine.

So I put the architect to work on a circular design, and, as word of what we were doing seeped through the engineering hierarchy, there was a

Architect's drawing of the new Environmental Sciences building, to be erected in 1976 at the west end of the X-10 area, next to Building 1000. The square annex at the entrance is an auditorium.

certain amount of controlled panic. I gathered together a series of serious documents on circular construction in the U.S. and brought it to the attention of the ORNL engineers; to my gratification, the more they got into it, the more enthusiastic they became. The result was the conceptual design of the famous round building, which we completed in 1965. It was to be a functional facility reflecting our research role in ecology, a combination of laboratory, field, and computer simulation. The cost estimate for a three-story, round building was about $7.5 million (1965 dollars), based on a building that was about 25 to 30% larger than the present one, about 130,000+ sq ft, still probably more expensive today than the currently proposed building. At that time it was kind of shocking, and we estimated that, if we removed one floor, we could bring it down to about $5.5 million or so. It would be more than double that now, although there have been a lot of round buildings built since then and the design is not considered to be as innovative today.

I still feel that it was a design that would have enhanced the Laboratory's architecture tremendously, but it didn't go, and the reason it didn't go was not entirely because of the design. The nation's change in administration at that time brought a decrease in environmental budgets, and the AEC environmental programs were not yet ready for any large-scale construction; they just couldn't justify it, they felt, and I remember we were asked, "Can't you come up with a building for about $3 million?" I believe our exercise then was to take that round building and try to convert it into a rectangle. We took a look, as a matter of fact, at the building design that was planned for the Civil Defense Project. Our site location then was behind the 6000 area, next to the Transuranium Research Laboratory site. Shortly after, they built the TRL, pre-empting some of the grounds we had our eye on, so we decided to look elsewhere.

From 1965 to 1970, we vacillated between Y-12 and X-10 in our site considerations. There was much talk. Every year the building was being scoped and rescoped, but it wasn't climbing very high in the priorities of things. On the assumption that it ought to be moved near the Biology Division, we had a ground plan for the building to be at the east end of Y-12, where the pistol range is. We were going to take the targets out and mount a building on the hillside, with a big neon sign, "ECOLOGY'S HERE!" Seriously, all that period was one in which nothing was happening; the Lab was in a plateau, and it was not until the advent of the environmental interest in the 1970s that we could begin again to persuade management and the AEC into taking another look at this building. It was at that time that we were taken out of the Health Physics Division to become the Division of Ecological Sciences.

In the summer of 1972 we were told to attack the building design seriously; our building went up to number one priority at the Laboratory, and also in Washington. Jim Liverman, by then in Washington, was the driving force; when the Lab put this up for consideration, Jim said, "OK, get with it," and we took the money out of operating to work up the conceptual design. When the AEC started moving as well, they pulled in A. M. Kinney, the architectural engineering firm working on the Museum.

It was 1972, and AEC considered it important to have a detailed conceptual design that would provide a more valid cost estimate in time for the congressional hearings in November and December. So we were given the months of August and September and part of October essentially to redesign the building; we worked with Kinney and the General Engineering Division to come up with an adjusted cost estimate.

Now, in designing this version and in working with the Kinney architects, we tried to include many of the ideas we had incorporated in the original circular building. We emphasized the need for compaction and interaction, and at the same time hoped we could maintain an attractive building — although there is just so much you can do to dress up a rectangle and still maintain its functional attributes. The architect did a good job in looking at the most efficient way to compact the laboratory's space, and the most efficient way turns out to be a very prosiac layout of labs and offices, but one which provides the greatest concentration of people possible in the smallest amount of space. Furthermore, in order to get around the propensity of individuals to bury themselves in corners (thigmotropism), we assigned all the corner offices to supervisors.

We had designed the round building to serve as the functional center for a network of field operations, in that samples and field collections flow into the building, flow to the laboratories, move from the labs in the form of data down to the computers, and then out in the form of publications. We tried to keep that kind of logical flow in this building; it is designed so that trucks can enter at the first door and unload their samples, materials can be processed there and then moved up into the laboratories. We will now have the greenhouses and thermal labs close by, so we'll use light electric vehicles to move materials between the buildings. We will have our own remote computer facility in the building. We have designed what is essentially a completely self-contained, organizational entity. This may be at variance with what has been traditional at the Laboratory, but my experience has taught me that if you want to have an interdisciplinary unit that works effectively, it's got to be housed with all of its ancillary and related support functions under one roof. And so, in our new building, we have an auditorium, a canteen, analytical chemistry facilities, an instrument shop, a machine shop — everything at hand.

Kinney completed the conceptual design, coming up with a cost estimate in the neighborhood of $11 million, and there was much agonizing immediately, so we had to go through some exercises in reducing the costs. We argued that inflation was going to be a major factor, but the word came down from on high that you can only use certain numbers for factoring inflation (we felt they were unrealistic). Anyway, we had to cut the building down to $8 million, and in this stage it went up for authorization.

As it turned out, in that autumn of '72, the Nixon administration wasn't ready for funding, and so, although it was mentioned in the Hearings Record of the JCAE, it didn't get approval. The next year, the AEC Biomedical and Environmental Program flashed the green light; our building was its number one priority, and we were asked to update the estimate. Based on the same design, the estimate was raised to $8.8 million, which is where it is now, although I think again the inflation factor wasn't looked at heavily, and our concern is whether we're going to have enough money. But it went through authorization hearings with no difficulty, then through the appropriations. Then just about the time it got approval, the energy crisis hit us. Dan Nelson's first reaction to this was, "Maybe we ought to use this building as a demonstration of energy conservation, employing novel methods of energy use."

We began to probe around, and, of course, we found an enthusiastic contingent at the Laboratory who thought it was a good idea. We didn't get the same enthusiasm, however, from the ORNL engineering design groups. Part of their lack of enthusiasm was based on their very practical consideration and knowledge of the appropriations and budgetary process. The basis of their concern, and incidentally that of ORO, was expressed something like, "Don't fool around with the stated specifications: you may lose the whole building."

Fortunately, however, the whole Federal establishment began to be very concerned about energy conservation, and we learned, through Jack Gibbons, about an engineering consulting group that was doing a lot of work on advising building engineers about energy conservation. At about the same time we learned about them, the AEC's construction group also heard of them and called them in to meet with AEC engineers, saying "We want to try to put energy conservation factors into new construction."

So this group, Dubin and Associates, undertook to look at our design and come up with suggestions. They gave us a long list of potential energy-conserving ideas and also suggested that the engineers work with other corporations and agencies that have used computer programs to analyze buildings for efficient energy use. In these programs, various alternatives are evaluated in context.

What about solar energy and such mechanisms? I guess we had to drop those because there was no way of funding them. We would have to have both technologies — conventional as well as solar. If we add solar later, we will just couple them to existing units, and this would just be for heating and cooling components of the building. One reservation here is that most solar-heated and -cooled buildings are office buildings, or some variation on office buildings. There are none yet that are major laboratory buildings, which have so much greater demand for air turnover, because of hoods, glove boxes, and other special facilities.

They did come up with a number of ingenious ideas. They have put in what they call a "runaround cycle," actually a heat exchanger that extracts the heat as it leaves the stack and recovers it for use in the building. Also, the air conditioning has been designed so that the hoods will receive at their faces unconditioned air from the outside, emitting 70% outside air and 30% room air. From a health and safety standpoint, it's a significant improvement over the conventional type of exhaust now used. It is also a big saving. The building will have separate fan systems for the perimeter offices and each laboratory; there will be much more insulation in the roof and walls than has been heretofore required, along with a reduction in window space. We're still discussing to what extent we will reduce the lighting in quantity and intensity, but it will be reduced somewhat from the handbook numbers. The idea is to light functional areas, localizing the intense light only where it is needed. With such selective lighting, there will be many more switches, so people can get into the habit of turning off unused lights. (The idea of putting timers on lights was rejected). The savings will be significant. Based on the engineering department's analysis, the total energy conservation is going to be about 42% over the original design. We're going to save about 5 to 6 million lb of ORNL steam per year that we had earlier required and over four million kW/year. In money, that represents about $65,000 a year, based on today's power rates. As energy costs move toward doubling, the savings will be increasingly significant.

All the energy conservation tricks have not yet been incorporated into the building, because a number of the ideas and suggestions are simply offered as criteria to the new architect-engineer. He in turn is going to evaluate them, we hope improve on them, and give us his opinion on their use.

The widespread interest taken in this approach was indicated in the large number of bidders on the building. As many as 85 architectural/engineering firms submitted proposals in response to the AEC's request. The successful firm is new to AEC construction. I'm optimistic about their moving ahead and trying even more schemes in energy conservation, because the need is now widely recognized in the architectural and engineering community. Interest in this is growing. If I have any concern, it is that we may be restricted by the funding process, although the new design will save on capital construction cost — almost $160,000.

Their calculations indicate that they can reduce the requirement for chillers and compressors by more than half — a big saving, both in machinery and space. In addition, we gain 3000 sq ft of space, and, ironically enough, we are being put in the position of having to justify the additional room accorded us by our economies. We have made it clear that we aren't taking it out of the building.

Things have a way of sometimes happening at about the right time. The fact that under ERDA the national labs are all to be ERDA labs gives us a decided advantage. This new environmental sciences laboratory will put ORNL in the position to be a leading, if not *the* leading, environmental national laboratory. We will have the facility; when the time comes, we will have the space, ready to work on the full gamut of energy-related environmental problems.

Another philosophy that I incorporated very early in the design of this building is that of inherent maximum flexibility, as opposed to trying to customize the laboratories to meet the current needs of the investigators. My goal here was the widest possible versatility of function. Of course, this philosophy can work a hardship when you are faced with having to justify a specific added area. If you designate an area, say, for use as a microbiology laboratory, and you put germfree rooms in there, along with all the other necessary features, the spot is then committed. The dilemma of such customized areas is severalfold. Cost is one problem; the change in programs and people over a 5- to 10-year period is another. Many years ago we came to the conclusion that a general chemistry laboratory is the most flexible type of laboratory for most kinds of research. This philosophy operates as a kind of insurance against obsolescence. Nevertheless, we will have a number of unique labs — in water research, for instance. These tank rooms require special waterproof floors, drainage, spring water, and lighting. But in general, the concept is one of flexibility. We anticipate that the building will hold a total staff of around 200, including technical, support, administrative support, and professional.

The schedule calls for breaking ground October 1, 1975, and occupying the building by the end of the summer 1978. There is a possibility, of course, that the current economic scene might motivate the successful bidder to push this pretty hard to minimize the impact of inflation.

And so it has taken us 20 years to go from that single small laboratory in Bldg. 2001 to this new facility. There are those who say, somewhat cynically, that when you finally get approval to build a new building for a program, you are really erecting the program's mausoleum. I do not believe that is the case in this instance. Twenty years has seen ecology emerge on the national scene through the efforts of a large number of dedicated, interested people, from a relatively little understood area of science to a discipline whose role in society is now well recognized. I believe that the new building will enable the Laboratory to continue its already large-scale contribution in this important area of science.

BOOKS

By ALEX ZUCKER

"... Monuments of Unageing Intellect"

The Ascent of Man, by J. Bronowski. Little, Brown and Co., Boston, 1974. 448 pp. $15.

Ours is a culture without celebrations. Public ceremony honoring past greatness is cynically dismissed; pride in collective accomplishments is proclaimed jejune. Who now sings with Whitman, "I celebrate myself, . . . I am an acme of things accomplished, and an encloser of things to be"? Even private ceremonies are muted; weddings and funerals are so often but civilized shadows of joy or sorrow. The birthdays of our two most revered Presidents are fused into one impersonal motoring holiday on a Monday in February.

Bronowski is not such a one. His love for man's accomplishments, his awe at this great achievement of evolution on earth, are everywhere in his latest book, *The Ascent of Man.* The book is one long celebration of "nature's unique experiment to make rational intelligence prove itself sounder than the reflex." When Bronowski discusses the accomplishments of Newton, Erasmus, or Blake, he does not so much describe them as exult in them. Every step along the route that culminated in man is applauded. We can hear Bronowski cheering for the blue-green algae as he recounts their invention of sexual reproduction that introduced into life the magic number "two" over a billion years ago.

On the face of it, *The Ascent of Man* is a history of science. It is a reproduction in book form of a thirteen-part series Bronowski did for BBC television in 1973. The illustrations are indeed superb, as one would expect from such a visual approach, but the star of the book is man. Science is stretched to encompass all that is worthy: art, music, and most especially poetry, are part and parcel of the genetic makeup. Bronowski really reaches for it when he says, "It is something of a shock to think that [a sense of] justice is part of the biological equipment . . ." The illustrations really work. How many histories of science juxtapose Mycenean masks with a multiplex input receiver (both are gold); and how many relate the exquisite mosaics of the Alhambra to the symmetries in a fluorite crystal, and then to a most ingenious proof of Pythagoras' theorem (all three exploit spatial symmetries).

The celebration of scientific achievement here, as in so many other books on the subject, is through intimate glimpses of selected heroes of the trade. There is a measure of *déjà vu* in this, but, if the themes are worn and familiar, the grace notes are inimitably Bronowski's. Because the author is a scientist who has worked in mathematics, physics, and most recently in biology, we are treated to a much greater understanding of how discoveries are eventually made. There is a story about Szilard, for example, which tells how he invented the principle of the nuclear chain reactor in 1933 while waiting for a traffic light to change at a street corner in London. He was responding to a challenge: In a recent lecture Rutherford had stated categorically that the energy of the nucleus could never be usefully employed. The word "never" turned on the iconoclast is Szilard, and he correctly speculated that, if a nuclear reaction were initiated by a neutron and if two neutrons were emitted in the process, one would have an exoergic chain reaction. He filed for a patent in 1934. Or, moving from physics to biology, Bronowski wonders, By what intuition, luck, secret knowledge, or subliminal observation, did Mendel chance to experiment with precisely seven independent traits of the sweet pea? He could not have known that the sweet pea has seven chromosomes.

The heroes are human. The spark of insight that culminated in the theory of evolution struck two British naturalists simultaneously. Neither Wallace nor Darwin was a professor; both were observers and lovers of nature who independently produced this great human achievement. In Bronowski's account Wallace is so much the more attractive person — generous, adventurous, undeterred by catastrophe. While Darwin retires from the world after his one great adventure on the *Beagle*, Wallace spends years collecting flora and fauna in the world's most inaccessible places.

Finally in triumph he emerges from the years in the jungles of South America and the Malay archipelago, not with cases of exotic species, but with the shining gem of a new idea. A new step in the ascent of man.

What precisely is it, asks Bronowski, that has made man so successful? What has driven him to paint bisons on cave walls, to spend his energies erecting cathedrals, to decode the spiral structure of DNA? From his earliest toolmaking efforts, something has motivated man to explore, to experiment, to persevere in unorthodox approaches that had no apparent survival value — all this in the face of enormous social obstacles and the frustrating, intractable nature of the material. To account for this desire to ascend, Bronowski identifies two characteristically human traits, biological properties of this awkward neotenic animal. According to Bronowski, "... one trait above all others ... [is] his immense pleasure in exercising and pushing forward his own skill." Isn't this really why many of us do research and derive such pleasure from it, in spite of the frustrations, the difficulty of the task? We enjoy our own skill, we passionately want to do what we can do best, and we scarcely notice how hard we work or how great the odds are against us. The second trait, Bronowski says, is man's ability to delay decisions in order to collect enough knowledge. We are future oriented, we project ourselves down the corridor of time, and we prepare for what is to come. Without this, there can be no civilization, there can be no science.

The quest for knowledge, the ascent of man, has its obstacles, and Bronowski pounces on them with his accustomed panache. He hates Hegel, rigidity, orthodoxy, despotism, social orders that deny individuals the right to pursue their skills. "There is an age-old conflict between intellectual leadership and civil authority," he says.

He chooses John von Neumann to explore the pitfalls of the modern alliance between science and government. Von Neumann "was the cleverest man I ever knew, without exception, [Fermi was the second cleverest] and he betrayed his own calling." Instead of pursuing his skills and advancing knowledge, von Neumann began to work for industry and for government; he was seduced to seek the center of power. Bronowski now turns bitter. "Johnny von Neumann was in love with the aristocracy of intellect ... a belief that can only destroy the civilization we know ... we must be a democracy of the intellect ... not perish by the distance between people and power by which Babylon and Egypt and Rome failed."

There is much truth in Bronowski's warning. Much of the recent alienation of young people from science is caused by their accurate perception that science has been co-opted by government. Science will cease to be the free carrier of the human spirit when it becomes a pawn of public policy.

Bronowski is dead. He died last year at the age of 66. He leaves behind this book and the television series; no man could have done better. No man saw more clearly the heights to which humanity can ascend. No man saw better the great unity among morals, aesthetics, and science, the total achievement of man. Yet in his last chapter there is a voice nearly of despair: "... I am infinitely saddened to find myself suddenly surrounded in the west by a sense of terrible loss of nerve, a retreat from knowledge ...." He, like many of us, could not understand why at its very peak western civilization now seems reluctant to carry forward the ascent of man. We have seen such a flowering of rational intelligence, so many giant steps in the ascent of man, we must not now turn away from the road that has brought us here. I return to Whitman, "Of life immense in passion, pulse and power, ... The Modern Man I sing."

(Jacob Bronowski and a BBC film crew came to ORNL in the summer of 1971 to film parts of the Laboratory in the course of preparing the television show on which his book is based. Public Broadcasting System is currently showing it here on Tuesday evenings. Bronowski, r., is photographed here at the Graphite Reactor in conversation with William R. Casto at that time. — Ed.)

Bill Appleton, shown here in the Solid State Division's accelerator facility in Building 3003, went as a graduate of the University of Missouri to earn his Master's and Doctor's degrees at Rutgers, The State University of New Jersey. He intended to get his Ph.D. in low energy nuclear physics to take advantage of the newly acquired Tandem Van de Graaff accelerator purchased by Rutgers in cooperation with Bell Telephone Laboratories, but just then the phenomenon of channeling was being discovered at ORNL, and that became his thesis material. After acquiring his doctorate, Bill stayed on as a Bell Labs employee to do ion scattering and channeling research on the Rutgers Tandem and finally moved to Oak Ridge late in 1967. He is a member of Solid State's Ion Bombardment Group and is gratified to find himself on the very crest of the wave of technology that is emerging with the newly developing heavy ion implantation science.

Ion Implantation:

A new technique in materials research

By B. R. APPLETON

ION IMPLANTATION is a relatively new and exciting technique in materials science. Armed with the ion sources, accelerators, and electronics developed in low energy nuclear physics research, investigators in numerous disciplines are discovering that energetic ion beams can be used to alter and study the near surface properties of materials in a selective and often unique manner. Introduction of impurity atoms into a solid can alter or even dominate the electrical, mechanical, chemical, optical, magnetic, or superconducting properties of the material. The tremendous potential of ion implantation derives from the fact that many of the inflexible physical constraints imposed by normal materials preparation techniques (such as solubility limits and diffusion rates) can be circumvented when the impurity atoms are implanted into the solid.

— Since the impurity ion beam is mass and energy selected from an accelerator, the species, quantity, and purity of the implanted ion can be precisely controlled.

— The profile for a monoenergetic ion beam implanted in an amorphous substrate will be Gaussian in shape, peaked at some mean range or depth, which can be varied by varying the incident energy. By changing the energy and dose, a wide variety of implanted profiles can be achieved.

— Ion implantation is a non-equilibrium process. Thus, any ion can be implanted into any solid, independent of solubility limits or the physical properties of the substrate.

— Since ion implantation is not dependent on substrate temperatures, one is no longer limited by diffusion mechanisms.

Two possible limitations of the ion implantation method are the limited range of the ions and the radiation damage caused by the ions. The mean range and range straggling are functions of the ion's mass and energy and of the target material, but for most available implantation facilities only the first few microns of solids are accessible. This restricts ion implantation effects to the near surface regions of solids. An energetic ion penetrating a solid loses energy by inelastic collisions of the incoming ion and its electrons with the electrons of the solid (inelastic stopping) and by elastic collisions of the ion with the target atoms (nuclear stopping). Both mechanisms can cause radiation damage in solids. In some applications this attendant damage causes unwanted side effects, while in others it is the radiation damage which produces the desired change in materials properties.

Channeling and Ion Scattering

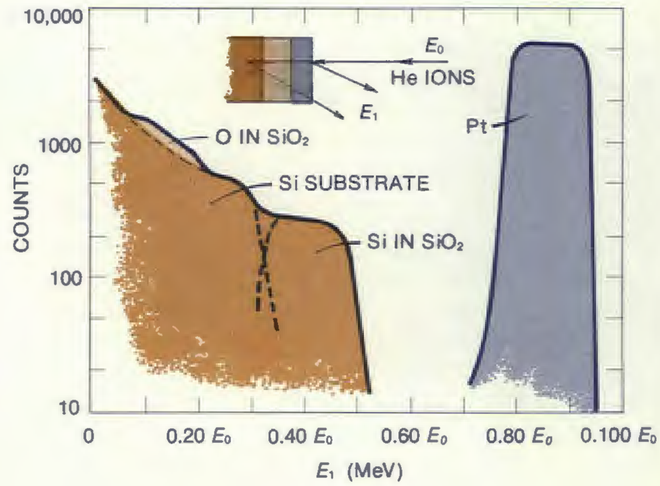
No discussion of ion implantation is complete without a discussion of the phenomenon of channeling of ions in single crystals. Historically, it was the discovery of channeling that provided the impetus for the basic research investigations leading to ion implantation. From a practical standpoint, so much of ion implantation is done in single crystal materials that a thorough understanding of channeling is essential. Finally, as we shall see, the combined effects of channeling and ion scattering provides the researcher with a very versatile tool for analyzing his ion-implanted materials, using ion beams from the same accelerator system.

In the early 1960s Mark Robinson and Dean Oen of the Solid State Division were doing computer simulation calculations on the penetration of energetic heavy ions in solids. They found that ion ranges were greatly increased when the ions were incident parallel to a low index axial direction in a single crystal because of the orderly arrangement of the atoms. Energetic positive ions directed along an axial direction undergo a series of gentle, correlated collisions with the symmetrically arranged rows of atoms and take on oscillatory trajectories in the open regions (channels) between these rows. Up to 98% of a well collimated beam of ions can be channeled and never approach closer than about 10^{-9} cm to atoms on normal lattice sites. Hence, any interactions that require closer distances of approach are greatly suppressed or nonexistent for channeled ions. Because of their reduced stopping power, for example, channeled ions have been observed to penetrate 50 times as far as the same ions in an amorphous solid. Thus, channeling can significantly affect the implanted profile and adds an additional measure of flexibility which can be used to advantage or avoided by misorienting the single crystal.

Much of the phenomenal success of ion implantation has been a result of the improved understanding of the physics of the implanted system gained by ion scattering-channeling investigations. Ion scattering provides a means of identifying implanted species, because the recoil energy of a backscattered ion is a function of the mass of the scattering atom. The energy loss of the ions is a measure of the depth of the scattering atom beneath the surface of the solid, and the scattering yield is a measure of the atom concentration. Consequently, an analysis of backscattering energy and yield can give the elemental composition of a wide variety of implanted materials. Furthermore, since channeled ions are sensitive to crystal perfection, the modification of scattered ion distributions as a result of channeling can be used to study radiation damage to the single crystal and to determine the lattice sites of implanted impurities. These features make ion scattering-channeling measurements ideal for determining the profile (range), concentration, lattice sites, and elemental composition of implanted materials or thin film composites.

Semiconductors

The most impressive success of ion implantation to date has been in the area of semiconducting materials. Most semiconductor devices require

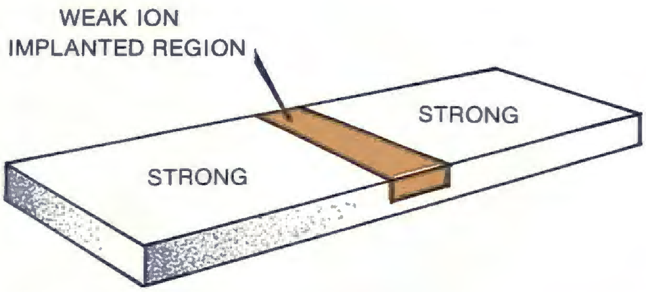


Ion scattering is a valuable complementary technique to ion implantation, as shown in this typical analysis of a thin film composite of Pt and SiO_2 on a Si substrate performed by Rutherford backscattering of 1-MeV He ions. The mass specificity of the Rutherford scattering process allows one to separate the Pt, as well as the O and Si in the SiO_2 layer, from the Si substrate. The depth resolution arising from the energy loss processes allows one to determine the thicknesses of the Pt (760 Å) and SiO_2 (4400 Å) films. The relative yields of O and Si in the SiO_2 layer verifies that the chemical composition is two O atoms per one Si atom.

selective doping of silicon or germanium with impurity atoms, a task ideally suited to ion implantation. The profile of implanted ions can be accurately tailored by varying the energy and dose of implanted species. Much shallower and sharper junctions are possible, and the attendant radiation damage can be annealed at temperatures well below those necessary for diffusion. Ion implantation has not only resulted in new semiconductor devices (such as high frequency transistors, improved MOS transistors, and integrated circuits) but it has proved to be a better and more economical means of fabricating many conventional devices, increasing the yield in some cases by two orders of magnitude. Ion implantation has literally revolutionized the microelectronic device and integrated circuit industries. A micro device with surface dimensions the order of microns (millionths of a meter) is possible only if the impurity atoms can be introduced to within less than a micron of the surface, and such precision can not be accomplished by thermal diffusion techniques. A portable hand-held calculator made possible by ion-implanted integrated circuits weighs about ¼ lb and costs $30 today; a comparable mechanical calculator in 1955 weighed about 50 lb and cost $1200. The portable calculator market has exploded into a billion-dollar-a-year industry in just three years. Similar sophisticated advances in everything from color television to computers could be cited. The use of ion implantation in industry is steadily increasing, and the time may not be far off when integrated circuits are "written" on minute silicon chips by computer-controlled implantation systems.

Superconductivity

Superconducting materials are of major importance in a number of projected technological applications, such as superconducting magnets for confinement systems in controlled thermonuclear reactors and high-energy accelerator systems; high power applications like superconducting transmission lines, energy storage coils, and rotating machinery; and in fabrication of superconducting circuit elements and computer memories. Because the superconducting state of materials exists only at very low temperatures, a major consideration as to the feasibility of these proposed applications is the refrigeration cost/benefit tradeoff. Consequently, the development of alloys that become superconducting at higher temperatures is a primary goal of present research efforts. Recent experiments have demonstrated that some metastable alloys created by ion implantation have much higher transition temperatures than the same alloys fabricated by normal metallurgical techniques. Palladium saturated with hydrogen by heating in a high-pressure hydrogen gas becomes superconducting at temperatures lower than 1.2°K; if the saturation limit of this Pd-H alloy is exceeded by implanting additional hydrogen at liquid helium temperatures, the superconducting transition temperature can be elevated to 9°K. The same study found that the Pd-D metastable alloy fabricated by ion implantation had a still higher transition temperature of 11°K, and that Pd-Au or Ag-H or Ag-D implanted systems had transition temperatures of 16°K — only six degrees less than the highest known transition temperature. These studies of metastable alloys are significant for two reasons. First, since Pd is not even a particularly



The ion-implanted Josephson junction is simple to fabricate, rugged, and reproducible. The strength of the link can be accurately controlled by varying the implanted ion dose, and the junction can be miniaturized.

good superconducting material, the results achieved by ion implantation are quite encouraging. Second, the number of alloy systems which can be investigated is practically unlimited because of the nature of ion implantation.

Equally exciting are the possible applications of ion implantation to superconducting electronic devices and computer memories, which have taken on a new importance with the invention of the Josephson junction. The Josephson effect is a superconducting property that can be used to generate and detect electromagnetic radiation ranging from radio frequencies through the infrared. Josephson junctions are formed when a weak superconducting link is established between two strong superconductors. Devices using weakly linked superconductors are capable of measuring magnetic fields as small as 10^{-11} gauss and voltages as small as 10^{-17} volts. They have a great variety of applications as mixers, harmonic generators, and parametric devices. Many techniques have been used to produce weakly linked superconductors, but recent experiments at several laboratories indicate that weak links formed by implanting ions in a superconducting thin film may be the most promising. This process produces devices in which the weakness of the link can be directly controlled by the implantation dose, and the devices are rugged, reliable, reproducible, and simple to fabricate. Josephson junctions are particularly suitable for storage of digital information because of the extremely rapid switching times (10^{-11} sec). Ion implantation will make fabrication of extremely small devices possible, and the combination should lead to large-scale memory and logic circuits in the future.

Solar Conversion

Ion implantation and the related techniques of ion scattering are particularly applicable to the materials problems associated with conversion of sunlight to electricity. Solar conversion cells were among the first devices to be fabricated by ion implantation methods, because of the superior performance obtained with the sharp junctions achieved by implantation. In order to be economically feasible, future solar cells will have to be fabricated as thin film devices. Ion implantation is ideal for thin films because of its accurate control of depth and dose of the dopant atoms and its avoidance of the problems of thermal processing. Even the electrical contacts can be implanted. Ion scattering is also a nondestructive method of analyzing the composition of such thin film devices. Entirely new materials can thus be investigated for higher conversion efficiency by doping various solids with impurity atoms to produce energy bands that respond more efficiently to the solar energy spectrum. Optical transmission and reflective coatings for solar devices can be selectively changed by ion bombardment or implantation. The ultimate success of solar conversion schemes may well depend on significant advances in conversion efficiency or materials cost, and ion implantation appears to be one of the most promising avenues of research. Surprisingly, little basic research has been performed in an effort to discover improved solar conversion devices.

Other Applications

It is not practical to list all the applications of ion implantation, but several broad categories deserve mention so that the areas just discussed can be viewed in the proper perspective.

Mechanical Properties of Materials

- Alteration of the surface coefficient of friction
- Creation of surface alloys
- Modification of wear rates
- Increase in surface hardness
- Fabrication of adherent surface films
- Selective ion etching or ion sputtering of surface

Chemical Properties of Materials

- Formation of new surface compounds (Fe_3O_4, SiC, etc.)
- Corrosion retardation or enhancement
- Alteration of electrochemical behavior
- Selective oxidation

Optical Properties of Materials

- Selective alteration of the refractive index by ion damage or implantation
- Fabrication of buried optical wave guides, couplers, and mixers
- Semiconductor integrated optics
- Acoustic-optical devices

Magnetic Properties of Materials

- Superconductivity
- Fabrication of high transition temperature superconducting materials such as Nb_3Ge
- Alteration of the properties of magnetic films by implantation
- Formation and control of "magnetic bubbles" in magnetic garnets

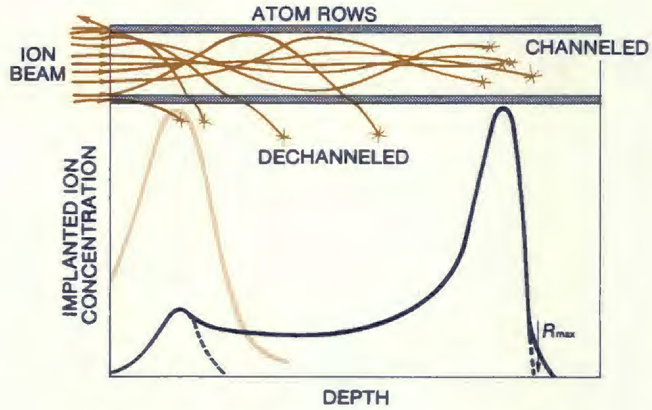
Electrical Properties of Materials

- Semiconductors
- New microelectronics, integrated circuits, and systems
- Solar conversion devices
- Enhancement of catalytic properties of surfaces
- Fabrication of transparent conducting layers
- New semiconductors
- Tailoring of conducting regions into insulators
- Semiconductor charged particle detectors

Future Prospects

The most refreshing aspect of ion implantation to me as a research scientist is that it is a classic example of the supportive nature of basic research to useful applications. The impressive exploitation of ion implantation in semiconductor technology was supported by years of basic research, four international conferences, and innumerable books and journal publications; this research, in turn, was only possible because of the experimental equipment developed in low energy nuclear physics research and the impetus provided by the seemingly unrelated discovery of channeling. This is undoubtedly the same pattern that future developments in the field will follow.

National laboratories provide an ideal environment for ion implantation research because of their interdisciplinary nature. Meaningful alteration of a particular property of some material or fabrication of a new device requires, in addition to a proper ion implantation facility, a thorough understanding of the various aspects of ion-solid interactions, radiation damage, etc. Correspondingly, a similar expertise in the relevant disciplines is required to evaluate the induced property change or device characteristics. This probably explains why much of the pioneering research to date has come from establishments such as AERE Harwell, and IBM and Bell Labs in the U.S., where large, coordinated ion implantation efforts are supported. Most of the current work in areas other than semiconductors is still in the basic stage, but all indications are that ion implantation is destined to have a significant impact in research and industry.



When an amorphous or polycrystalline solid is bombarded with a monoenergetic ion beam, the ions come to rest and form a depth distribution in the solid, like the shaded curve in the above figure. The mean range and width of the implanted ion distribution can be varied by changing the ion energy, ion species, and target material. Essentially the same distribution is obtained if the ions are implanted in a single crystalline target that is purposely misoriented so that the ions encounter the target atoms at random. If, however, the single crystal is oriented so that the ion beam is incident parallel to a low index planar or axial direction as illustrated at the top of this figure, the resulting implanted ion distribution is drastically altered. Now, because the target atoms are symmetrically arranged, the incident ions undergo correlated collision with the atoms. A few percent of the ions make close collisions with the surface atoms, are deflected through large angles, and contribute to a small random peak at the same depth as that for the misoriented implant. The remaining ions experience a series of correlated small-angle collisions with the lattice atoms and acquire oscillatory trajectories in the open regions (channels) between the rows or planes of atoms. Because these channeled ions have greatly reduced stopping powers, their ranges can be ten to fifty times greater than randomly directed ions. Not only does the channeling effect add a new variable to ion implantation, but, because it is sensitive to crystal perfection, it has been used as a sensor of radiation and to determine the exact lattice sites of implanted impurities.

Awards and Appointments

Listed in this department are awards, appointments to scientific review and advisory committees of national significance, fellowships in societies, honorary degrees, and other ways in which members of the ORNL staff have achieved recognition. Your cooperation in keeping the *Review* informed of relevant information will be greatly appreciated.

Named to a three-year term on the Space Science Board of the National Academy of Sciences' National Research Council is **Peter Mazur**. The Council's Commission on Natural Resources has appointed **David E. Reichle** to a three-year term on its Environmental Studies Board. In this capacity he will also serve on the Committee for International Environmental Programs.

Myron T. Kelley is this year's recipient of the American Chemical Society Award in Chemical Instrumentation, a cash stipend of $2000 sponsored by Sargent-Welch Scientific Company, for his work in computerization of analytical systems and the instruments he has designed for nuclear analysis.

Photographer **Bill Norris** has been elected to the National Council of the Professional Photographers of America, Incorporated, an office he will hold through 1976.

A new technical journal, *Hydrometallurgy*, published by the Elsevier Scientific Publishing Company, Netherlands, has invited **Charles F. Coleman** to serve on its Editorial Board.

Two new program directors have been named at ORNL: The Coal Technology Program will be headed by **Jere Nichols**, and the Fuel Recycle Program for the LMFBR is under **William Burch**. Both programs are newly formed.

A. Seaton Garrett, Jr. has been appointed Assistant Medical Director for the Laboratory.

Gregory J. Yurek received the American Society for Metals' Henry Marion Howe Medal for authoring the paper of highest merit published in the American Institute of Mining, Metallurgical and Petroleum Engineers' Transactions.

Robert W. McClung was invited to present the Lester Honor Lecture, a biannual distinction, to the annual meeting of the American Society for Nondestructive Testing.

Frances Ball has been elected to the office of Secretary to the Electron Microscopy Society of America.

Newly elected fellows: **L. G. Christophorou** to the American Physical Society; **E. T. Arakawa** to the Optical Society of America.

Richard Griesemer has been appointed Chairman of the Committee on Animal Care Standards for the National Academy of Sciences. **J. B. Storer** is Chairman of the Science Advisory Board to the National Center for Toxicological Research of the Environmental Protection Agency.

The crystal model in the foreground in Bill Appleton's accelerator laboratory in Bldg. 3003 shows the lattice structure that permits the channeling of accelerated particles, a phenomenon first remarked at Oak Ridge National Laboratory. The discovery motivated the research that has led to many technological innovations, an example being the kind of miniaturization used in the production of handheld calculators. Another step may be print circuits no larger than a micron in width. For the story of this basic research that was once considered to be of little practical value, see Appleton's article on page 28.