ORNL Annual Report

1965

OAK RIDGE NATIONAL LABORATORY

Operated by Union Carbide Corporation • for The U. S. Atomic Energy Commission

OAK RIDGE NATIONAL LABORATORY • 1965 ANNUAL REPORT

FOREWORD

The annual report of a very large laboratory becomes ever more difficult to prepare as the laboratory grows. To do justice in a reasonably sized report to the innumerable separate pieces of research at the Oak Ridge National Laboratory, with its operating budget in 1965 of about $82 million, is impossible. On the other hand, a very short report, of the sort published, say, by a large corporation, hardly can convey a feeling for the scientific and technological achievements of the Laboratory.

Faced with this dilemma we decided to try a new approach, and this Annual Report for 1965 represents our first attempt at a new style. In the first place, it was decided that the annual report should be kept relatively short – about 100 pages. Secondly, it was to be aimed at a literate though unspecialized scientific audience – such as the readership of *Scientific American* or *International Science and Technology*. Finally, and perhaps most important, the report was to be written by senior members of the technical staff, each of whom was to cover a certain part of the Laboratory's activities. The report therefore reflects, to some extent, the points of view and the scientific attitudes of the scientists responsible for each section.

I hope that the reader will find the report interesting and informative. I believe that our scientific editors have succeeded in conveying admirably the "feel" of Oak Ridge National Laboratory. All of us are grateful to them for recording so well a most exciting scientific year at ORNL.

Alvin M. Weinberg

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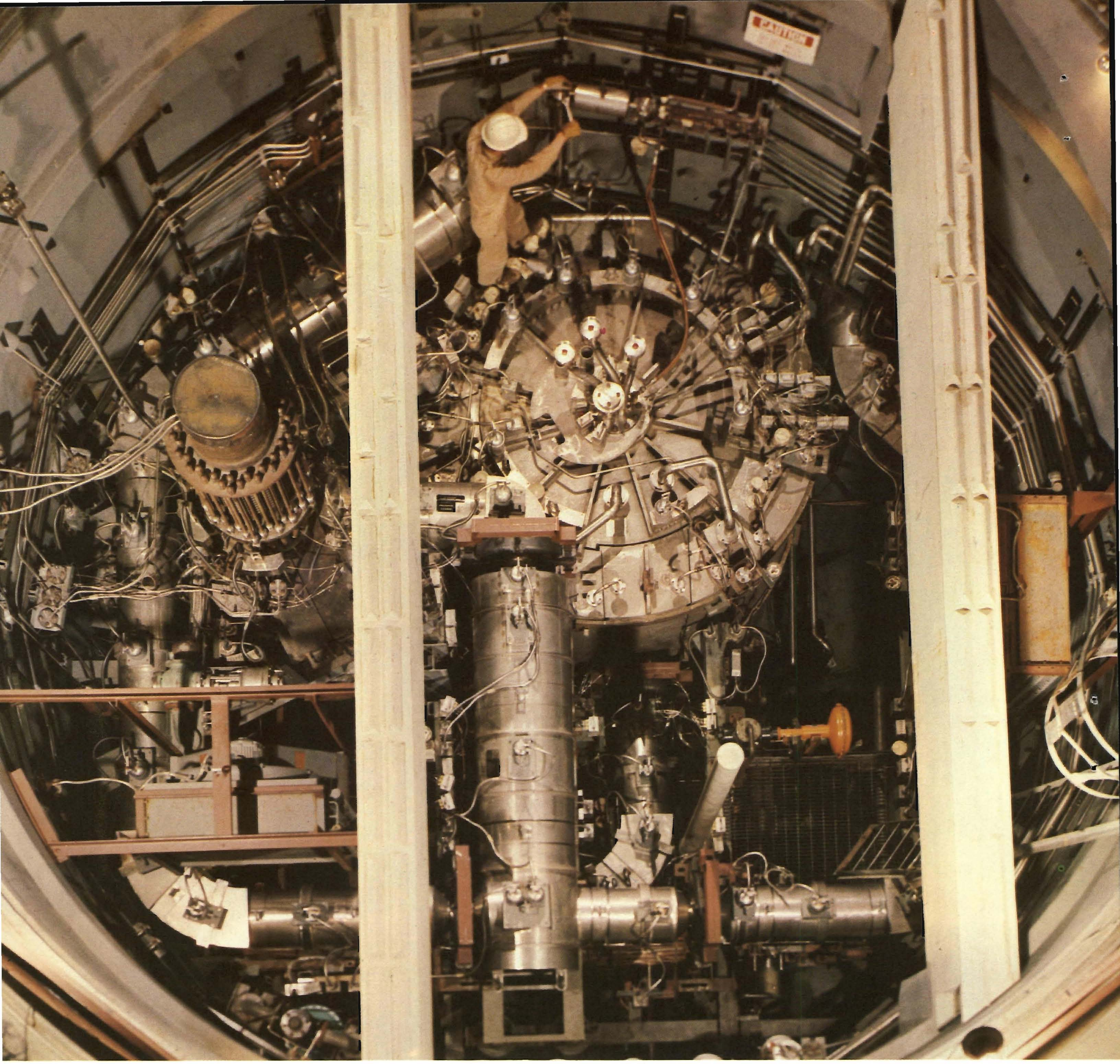
Editorial Board



The MSRE is shown here in its 24-ft-diam containment cell. The system through which the fuel salt circulates consists of the reactor, the pump, the primary heat exchanger, and the 5-in. pipes that join the components. The reactor access nozzle and control rod thimbles can be seen protruding from the thermal shield. At top left is the pump, and the primary heat exchanger can be seen in the center of the photograph.

The thermal shield is a double-walled stainless steel tank, with an 18-in. annulus between the walls. The annulus is filled with water and carbon-steel balls for primary shielding. The water circulates through the annulus at 100 gpm, removing heat generated in the shield. Thermal insulation and heaters line the inner wall and supply heat prior to reactor startup.

The 5-in. pipes, covered by heaters, that penetrate the cell walls above the thermal shield are a portion of the coolant-salt system; they carry reactor heat to the radiator in a cell outside the reactor cell. The coolant-salt pump is also outside the reactor cell. Reflective insulation-heater units, which can be replaced by remote manipulation, surround the pipes. Freeze flanges, connecting the components and pipes, are shown with clamps installed, which hold the flanges tight to form a gas seal.

All the equipment shown here was designed and installed so that the major components can be removed and replaced or maintained by well-developed remote-maintenance procedures. For example, the rotary assembly of the pump, the pipe heaters, control rods and drives, and graphite or metal test samples can be removed most easily. The pump bowl, the reactor vessel, the heat exchanger, and piping sections, in all of which the probability of failure is least, can also be replaced, but with some difficulty. *(See Flow Diagram on Page 59.)*

INTRODUCTION

Oak Ridge National Laboratory had its beginning as the historic Clinton Laboratories, organized and constructed with great urgency in 1943 to attack the problem of plutonium production. This mission was essentially accomplished by mid-1945; and, as national goals changed, the Laboratory undertook new tasks – development of research and power reactors, radioisotope production, processing technology development, and the setting up of strong basic research programs.

Today, the Oak Ridge National Laboratory, as one of the world's largest research and development centers, has a program that is broad, but whose elements generally pass one or more of the following tests:

the research bears on a problem of immediate or long-range national importance;

it makes use of the unique facilities of the Oak Ridge National Laboratory;

it utilizes specialized talents of the staff;

it contributes significantly to the store of basic knowledge in fields relevant to the release of nuclear energy or to other areas in which the Laboratory has responsibilities.

In 1965, several clearly defined missions occupied the attention of the Laboratory. To pursue these mission-oriented programs, a project, or horizontal, type of organization is most effective. This facilitates the mustering of skills, the construction of large equipment and facilities, and the meeting of deadlines. Project direction rests with a single individual, while the personnel comprising the projects are drawn from the divisions.

At the Oak Ridge National Laboratory, the divisions, which are vertical organizational entities, fall into two categories – research and operating.

The research divisions may be grouped somewhat homogeneously under seven disciplines. Five divisions are primarily chemically oriented; six divisions are mainly concerned with the field of physics; and five divisions are concerned – one each – with biology, health physics, mathematics, metallurgy and ceramics, and reactor engineering. At the close of 1965, the staff of the 16 research divisions numbered about 2700 people.

Research Divisions

Chemistry	*Solid State*
Chemical Technology	*Thermonuclear*
Reactor Chemistry	*Instrumentation and Controls*
Isotopes	
Analytical Chemistry	*Biology*
Physics	*Health Physics*
Electronuclear	*Mathematics*
Neutron Physics	*Metals and Ceramics*
	Reactor

Operating Divisions

Health	*General Engineering and Construction*
Personnel	
Laboratory Protection	*Plant and Equipment*
Technical Information	*Operations*

The research divisions receive invaluable support from the seven operating divisions, which perform craft work, operate reactors, look after personnel matters, and do a multitude of other tasks, thereby leaving the scientific staff free to pursue its goals.

The Oak Ridge National Laboratory's research program is highly diversified, yet it has a coherence which stems, in large measure, from the existence of a central mission – the utilization of nuclear energy.

If the 1965 fiscal budget were used as an indication of how the Laboratory expends its effort, about 90% would be found occupied with programs of the Atomic Energy Commission itself: about 44% of this portion devoted to reactor development and technology, 38% to physical research, 13% to the life sciences, 3.8% to isotopes development, 0.8% to nuclear education and training, and 0.3% to the peaceful use of nuclear explosives.

Although atomic-energy-related matters dominate the Laboratory's activities, the non-Atomic Energy Commission segment of the program is now about 10% of the total. These programs are carried out for such agencies as the National Institutes of Health, Department of Defense, Department of the Interior, and the National Aeronautics and Space Administration.

Two great strengths have evolved with the maturing of the Oak Ridge National Laboratory: a capability for dealing with the problems of difficult technology and a staff of distinctly interdisciplinary character. The former is perhaps best demonstrated by the Laboratory's having pursued – concurrently and without serious interference with one another – eight rather major projects in 1965. Development and construction of two nuclear reactors proceeded simultaneously. This was possible only because of the scientific and technical depth which the Laboratory has attained. The Laboratory's interdisciplinarity contributes greatly to its ability to solve complex problems by assembling teams of diverse scientific and engineering disciplines. For example, one such team of biologists, chemists, and chemical engineers set out to solve the difficult problem of separating ribonucleic acids on a large scale. From their combined experience came the idea of using chemical separations procedures similar to those employed in uranium processing. The problem is now well on the way to solution. Such cases of scientific interplay in complex problem solving are expected to become increasingly numerous in the future.

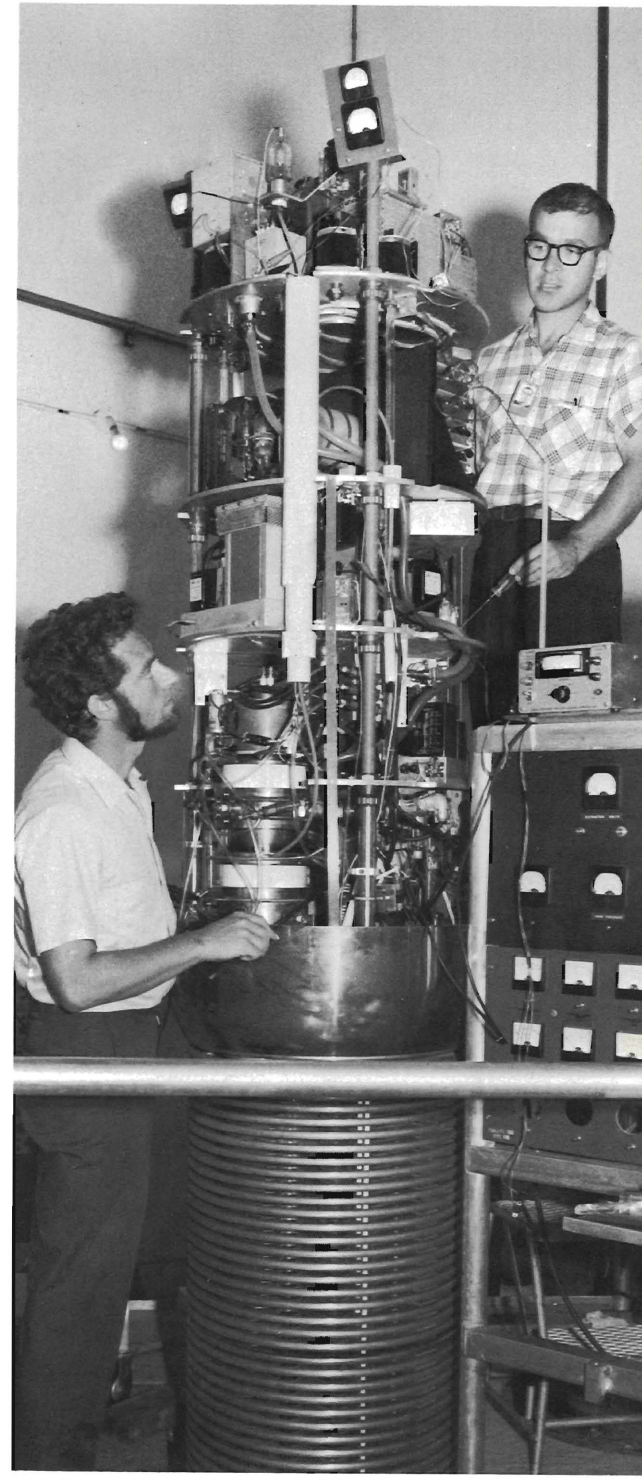
While the Laboratory's main purpose is the conduct of research and development, it feels strongly other obligations, two of which are deserving of mention. The first is a responsibility to participate in educational affairs. This is natural and desirable because the staff and facilities of the Laboratory constitute a significant fraction of the scientific resources of the region. The obligation is satisified in a number of ways: by staff members lecturing on Laboratory research at colleges and universities, by part-time teaching, by students performing thesis research at the Laboratory, and by the Laboratory's entering into cooperative undertakings with the universities. The Laboratory derives many benefits from its involvement in education: contact with the academic community and with bright young people, and stimulation of the staff members who combine teaching with research.

Secondly, the Laboratory has a strong obligation to assure that information developed at government expense is made available to the public freely and equitably. To fulfill this, it has devised special administrative procedures to supplement the established modes of communicating scientific information. Through its Office of Industrial Cooperation, as well as its regular information channels, the Laboratory tries to identify and disseminate information of possible commercial value. Just as in the case of education, there is a debt to be paid: this one to the taxpayer, who supports the institution.

Physical Sciences

Man's ever-increasing desire for control over his physical universe, to achieve his economic, sociological, and political goals, is reflected in the ever-increasing complexity of the technological missions of the Laboratory. In support of these missions, and in anticipation of the needs of the future, the Laboratory maintains a broad program of basic research covering the fields of physical science: physics, chemistry, engineering, metallurgy, instrumentation, and applied mathematics. New knowledge of the fundamental structure of matter, of the interaction of radiation with matter, and of the properties of materials; the synthesis of new compounds having improved properties; and the prediction of the effects of time, use, and radiation upon these properties – such items are the concern of basic research in the physical sciences.

The Laboratory would feel thoroughly justified in its support of basic research if the information itself were all that it received in return. But there is another product of the basic research program that is possibly as important as the generation of basic knowledge: through their proximity to and interaction with basic research, the mission-oriented projects have available many trained scientists who can, as consultants, focus their talents temporarily on applied problems and bring their knowledge of the fundamentals to bear so that more efficient solutions can be obtained. If necessary, they can also furnish more direct support by performing basic research which is immediately relevant. Both singly and in interdisciplinary groups of various sizes, these people have maintained a high level of productivity in research. Some of the studies are described in the following sections.



An essential ingredient of success in research is the continued development of experimental apparatus. The high-voltage terminal of the pulsed 3-MV Van de Graaff is a good example. Approximately one-fourth of the accelerator time is used for development and improvement. The physicists are shown testing an improved klystron bunching circuit.

PHYSICS

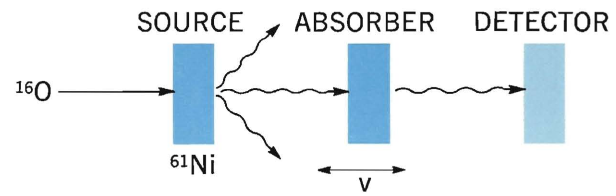
Research in physics at the Oak Ridge National Laboratory ranges from studies of fundamental particles to the structure of solids. Most of these studies are accurately described as basic research, and the remainder are identifiable as oriented toward answering specific questions raised in the Laboratory's mission-oriented programs.

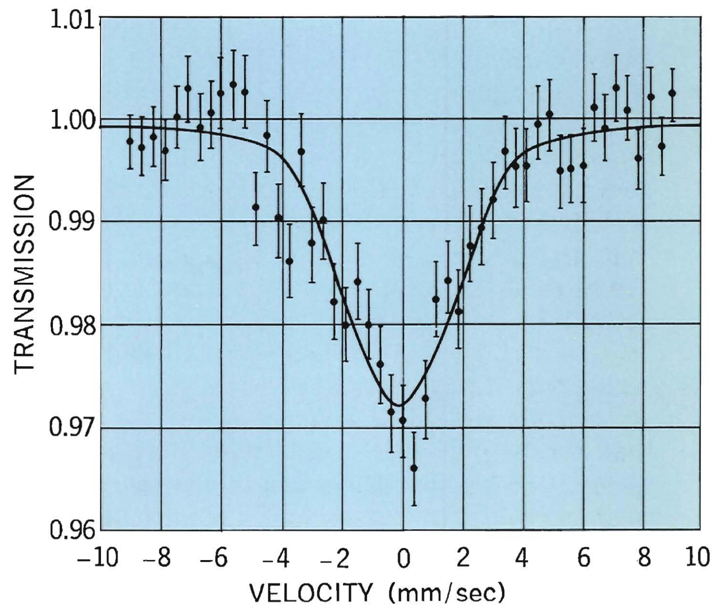
Nuclear structure physics is an area of primary concern. Various experimental and theoretical techniques are used to probe nuclei in order to elucidate the rules which govern their stability and determine their properties. The probes are neutrons, protons, and nuclei as heavy as iodine at energies from thermal to about 100 MeV. Results of this work have strongly influenced other disciplines such as astrophysics and reactor design. An important component of this research at Oak Ridge has been the development of new techniques such as ion sources, pulsed accelerators, solid-state radiation detectors, ultrapure single crystals, and special methods of theoretical analysis.

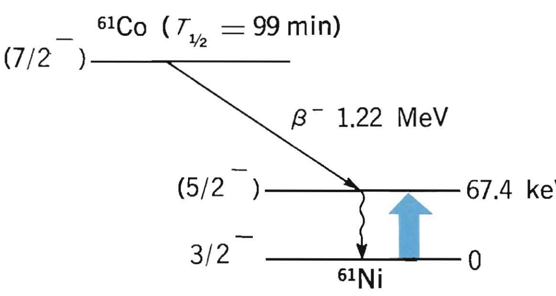
Radiation and radioactivity are not only subjects of study; they are also utilized as *tools* to understand atomic and solid structure. Neutrons at very low velocity are used to map out both the atomic geometry of solids and the magnetic fields inside solids. The Mössbauer effect is used as an ultrasensitive tool to investigate the nature of the radiation-emitting atom's environment. A rapidly developing area of interest has resulted from the combination of skills of nuclear and solid-state physics in the study of the structure of nearly perfect crystals. All classes of solids are studied: metals and alloys, semi- and superconductors, ionic and covalent crystals, ceramics, and organic polymers. Plasma physics is a subject of special concern at the Laboratory since knowledge gained from such studies is fundamental in the search for a controlled fusion reaction. Thus these studies have concentrated on high-temperature, high-density plasmas.

Mössbauer Effect by Coulomb Excitation

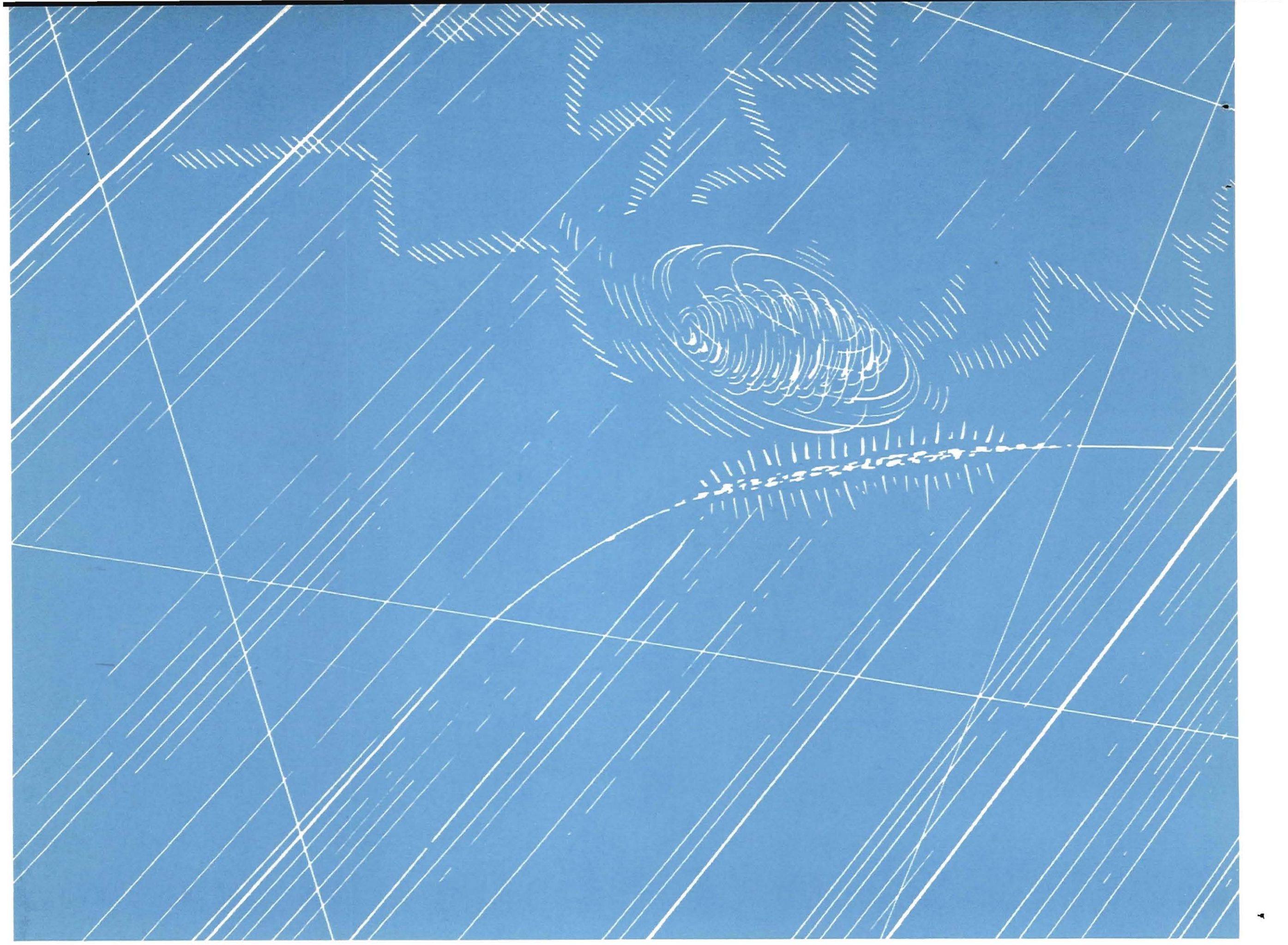
Normally, when a radioactive nucleus emits a gamma ray, the nucleus, like a rifle, recoils and shares some of the total energy released. However, several years ago Mössbauer discovered that under certain conditions an excited nucleus in a crystal lattice can emit a low-energy gamma ray with the whole lattice of atoms collectively recoiling, making the effective weight of the emit-







In the Mössbauer experiment a gamma radiation source is viewed by a detector placed on the far side of a slowly moving absorber. The transmission through the absorber is a strong function of the relative motion between it and the emitter. The radiation source, previously restricted to radioisotopes, has been greatly extended by using Coulomb excitation.



Coulomb excitation results from a "near miss" between an energetic charged particle and a nucleus. An actual collision does not occur, but enough energy and angular momentum are transferred through the electric field to "kick" the nucleus into an excited state. The nucleus then de-excites by gamma-ray emission, and these gammas are used in Mössbauer studies.

ting nucleus immensely greater (by a factor of about 10^{19}). Under these conditions the gamma ray carries *all* the energy, and if it encounters an unexcited nucleus of the same type, it has precisely the right energy to excite it. This is called "resonance absorption." The remarkable thing about this process is the almost fantastically small "width" in energy of the resonance. For example, if the relative velocity between the gamma source and the absorber is as much as a fraction of an inch per second, the small amount of energy added or subtracted by this motion shifts the gamma energy enough to no longer be in resonance. It turns out that the shape of the transmitted intensity as a function of relative velocity between emitter and absorber can disclose some intimate details of the emitting nucleus itself and also of the physical environment (such as local magnetic fields) nearby. Thus by including such nuclei in different materials one can study the internal properties of the materials in a very detailed way.

In the past, radioactive nuclei were used exclusively as gamma-ray sources in Mössbauer experiments. Many nuclei with otherwise suitable and interesting characteristics could not be studied because they were not available as part of a convenient radioactive decay. This limitation spurred a group of nuclear and solid-state physicists and metallurgists at the Laboratory to develop an alternative way of obtaining excited nuclei for Mössbauer studies. During 1965 they showed that the stringent restriction of convenient radioactivity can be bypassed for a relatively large number of nuclei by exciting them via Coulomb excitation. These studies have already shed light on the nature of the damage induced by charged particles as they plow through a solid such as germanium. In some nuclei, for example, iron-57 or nickel-61, one can induce the excited state in either of two ways, radioactive decay or Coulomb excitation. But in many other nuclei Coulomb excitation is the only feasible mechanism. It is hoped that this development, making available for in-

The Oak Ridge Isochronous Cyclotron Building

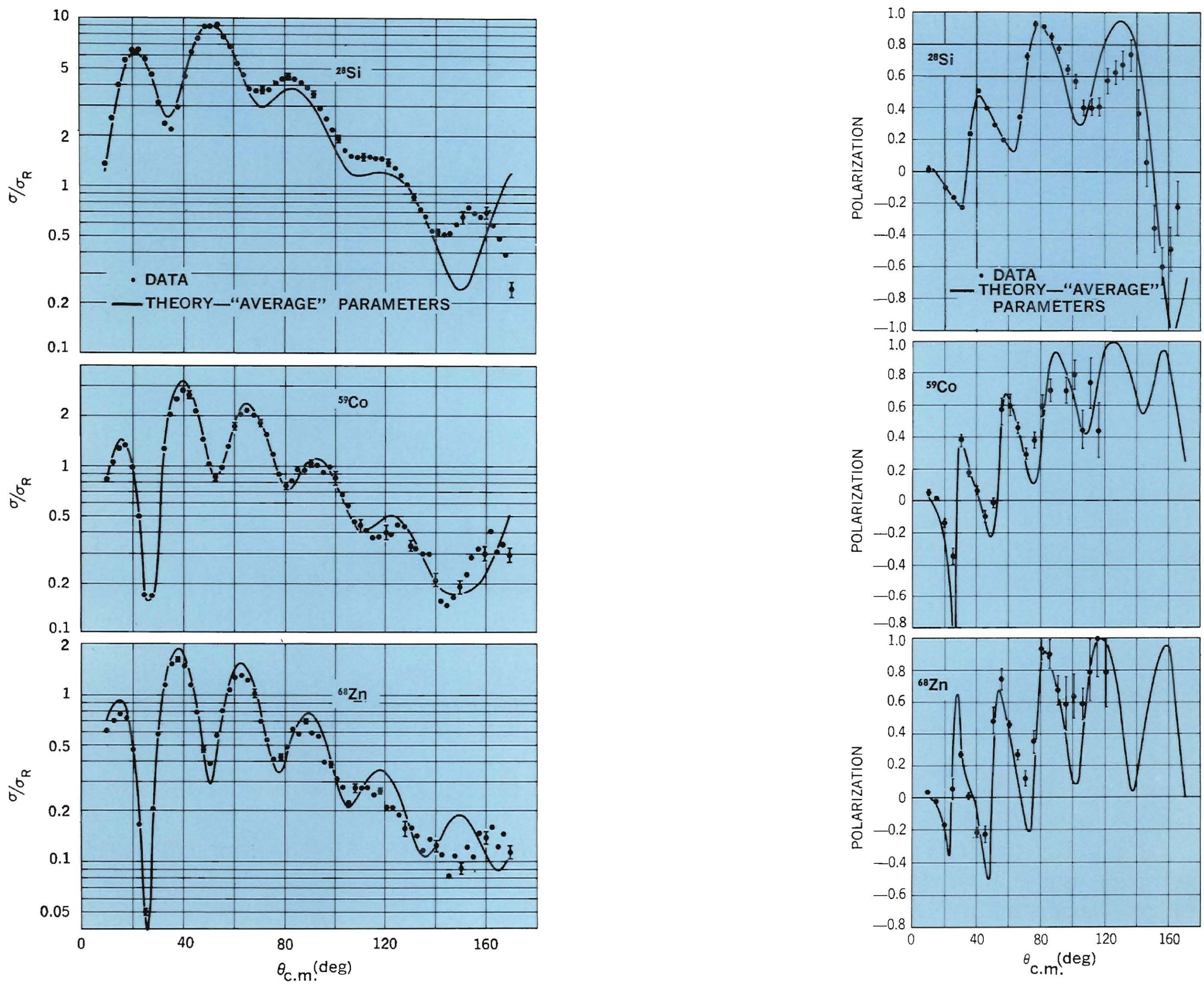
vestigation many nuclei not now amenable to study by the Mössbauer technique, may prove to be a powerful tool in metallurgy.

Experiments Using the New Cyclotron

During 1965 the Oak Ridge Isochronous Cyclotron came into its own as a powerful and productive tool for nuclear structure research. More than two dozen papers were submitted for publication or were published during the year on a variety of nuclear structure research topics that included studies on direct interaction, transfer reactions, elastic and inelastic scattering of charged particles, stripping and pickup reactions, and polarization. New experimental techniques brought to bear were a broad-range high-resolution (1:2000) magnetic spectrograph and special solid-state detector systems.

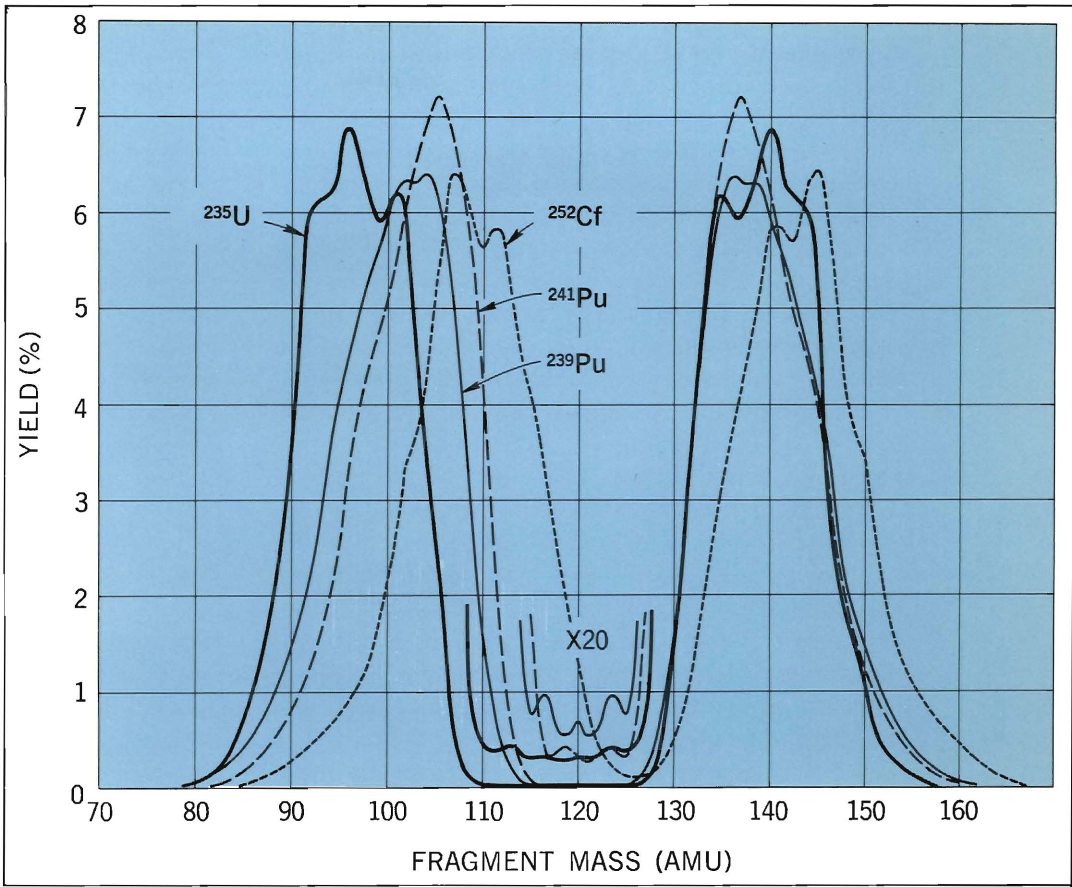
One of the most interesting studies was that of scattering cross sections of some medium-weight nuclei for polarized protons (protons whose spin axis is aligned in one given direction). This work was largely made possible with a new development in producing a beam of polarized protons that has increased the available flux by about an order of magnitude to the present value of 2×10^8 protons/sec (30% polarized). Briefly, this polarizing technique consisted in scattering the primary, randomly oriented proton beam in a calcium target and obtaining the secondary, polarized beam at about 25° to the incident beam. Also, and importantly, the energy spread of the polarized beam was decreased to only 500 keV, considerably smaller than that previously available.

The basic experiment that utilized the beam was the measurement of the polarization and elastic scattering cross section of a total of 11 even-even nuclei for 40-MeV polarized protons and also the elastic and inelastic scattering and asymmetry for even isotopes of silicon, iron, and nickel. From the study of such scattering it is possible to deduce information concerning the reaction mechanism operating in such nuclear collisions. Sample data from elastic scattering and polarization experiments are shown in the figure. The solid lines are theoretical (optical model) fits using values for real, central well, and spin-orbit potentials close to those obtained from systematics studies of other nuclear reactions. In this fit, only volume absorption was included; that is, it was not necessary to assume that the protons are "absorbed" any more near the nuclear surface than in its interior. Attempts to fit the inelastic scattering and polarization data indicate that complex coupling and deformation (viz., spin dependence) of the spin-orbit term of the optical potential are required to obtain a reasonable fit to the data. This means that a parameter (spin-orbit coupling) that previously was sufficient to fit theory to experiment has now been shown to be incomplete, and the insufficiency is related to the relative orientations of the proton and nuclear spin. The close collaboration between experimentalists and theorists on this experiment and its interpretation is vital in optimizing the rate of progress toward understanding nuclear interactions.



Results of nuclear structure studies using 40-MeV protons from the ORIC. The data are the elastic scattering cross section (left) and the polarization of the scattered protons (right) from silicon-28, cobalt-59, and zinc-68. The solid curves are optical-model fits using parameters obtained from systematics of other nuclear reactions. Similar studies of inelastic scattering showed that further refinements of the theory are needed to explain the data.

Pre-neutron-emission fragment mass distributions. Much of the structure in these curves is due to nuclear shell effects.



Advances in the Physics of Fission

It is perhaps a bit surprising, and in some respects disconcerting, to note that although we are currently quite far advanced in the engineering aspects of fission, the fundamental "nuclear physics" aspects of fission are almost not understood at all. For example, although we are able to design reactors with performance figures predicted in advance to surprising accuracy, no theory yet exists to explain such basic matters as the mass, charge, and energy distributions of the fragments formed when a nucleus divides in fission.

In research on the fundamental aspects of nuclear fission at the Oak Ridge National Laboratory, new experimental techniques have been used to determine more accurately some of the important basic quantities required in studies of fission and also to obtain fundamentally new information and data about the fission process.

A breakthrough in experimental fission physics occurred several years ago when silicon solid-state detectors were developed. These have excellent energy resolution, fast response time, and high detection efficiency. However, progress was limited until a technique could be developed for producing "artificial" fission fragments of precisely known energy in order to accurately test and calibrate the detectors. Members of the High Voltage Accelerator Laboratory recently developed just such a technique using the 7-MV Tandem Van de Graaff, which produces beams of bromine and iodine at energies to above 100 MeV. Thus, for the first time such fundamental measurements as energy loss and range of heavy ions could be made.

Since it is inconvenient to calibrate every solid-state fission counter with heavy ions from a tandem accelerator, a secondary standard was developed, namely, the careful determination of the fragment spectrum from the spontaneous fission of californium-252. This technique was reported in 1965 and is already used internationally as a standard. Another absolute calibration was a simultaneous measurement of fragment energy (deduced from the pulse height produced in the detector) and velocity (found from its time of flight from source to detector).

Appropriate calibration and analysis of these data produced for the first time a kinetically measured (as opposed to radiochemical or mass-spectrometric yields) post-neutron-emission mass distribution in fission. The results showed up detailed effects of nuclear shell structure on the fission process that had only been grossly observed in previous measurements.

Armed with these techniques and calibrations, a series of experiments during 1965 vastly expanded and improved our knowledge of the fission process. For example, the average total kinetic energy released from thermal-neutron fission of uranium-235 and other nuclides was found to be lower than previously thought by as much as 10%. Even a change of a few percent in this quantity makes a very significant difference in fission theory calculations. Another result of the new measurements is knowledge of the fragment yield as a function of *pre*-neutron-emission mass. Neutrons from fission normally "boil off" from the highly excited fragments just after the fission event. With earlier techniques, such as radiochemical analysis, only the *post*-neutron-emission yields could be observed.

Another new experiment determined the number of neutrons emitted in fission as a function of fragment mass and energy. This is done without actually counting any neutrons by measuring the energies of both fragments as well as the velocity of one fragment and is an important technique, since direct neutron counting is impossible in high-excitation fission studies because of large neutron "backgrounds."

Finally, protons were used to induce the fission of radium-226. This is an interesting situation because radium fission results in a three-peaked mass distribution rather than the normal two peaks. A graph showing the number of neutrons vs fragment mass was observed to have a sawtooth shape, akin to the situation in low-excitation fission, even though the nucleus in this case, actinium-227, is excited to 18.3 MeV.

These results are providing some new insights into the nature of the fission process. However, even the most basic parameters and distributions still cannot be quantitatively predicted, and much remains to be learned about this most useful, but very mysterious, nuclear reaction.

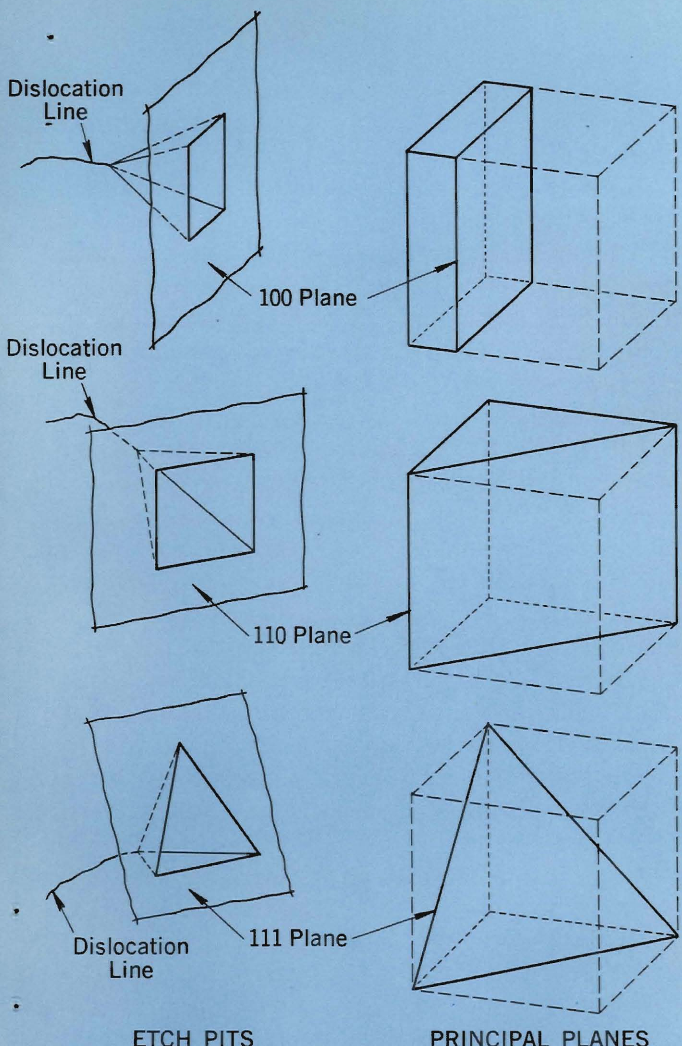
Neutron Capture Reactions and Astrophyics

Frequently in research the answer to one question not only raises several more but also answers other questions to which the original research was not addressed. An example of this is the study of reactions involving the capture of moderately fast (keV-range) neutrons by various elements. Several years ago physicists at the Laboratory became interested in doing this research because additional illumination of several nuclear models might be obtained from such studies and because the design of economic nuclear power reactors required knowledge of these cross sections. It was soon apparent that the results were useful in testing theories of heavy-element stellar nucleosynthesis (how elements heavier than iron were formed).

The answers to the original questions were exciting enough, but the close relations to astrophysics spurred the physicists on to develop even more sensitive and accurate techniques. Recent results with pure separated stable isotopes of tin, samarium, strontium, and zirconium, produced at the Laboratory, gave highly quantitative confirmation to the portion of the nucleosynthesis theory that accounts for a large fraction of our heavy stable elements. The experiment consisted in measuring the cross section, averaged over a Maxwellian energy distribution corresponding to a characteristic temperature $kT \approx 25$ keV, for the capture of neutrons by these isotopes. The predicted inverse relationship between these capture cross sections and the corresponding isotopic or elemental abundance for certain specific nuclides was confirmed. As a result of the confidence gained from this finding, new questions can be asked that begin one more iteration in the cyclical journey toward the understanding of our surroundings. The same technique is also being used to measure cross sections of great importance in the design of fast breeder power reactors.

Anomalous X-ray Transmission Investigations of the Perfection of Metal Crystals

In the past few years great success has been achieved at the Laboratory in growing nearly perfect single crystals of several metals, such as copper, niobium, and gallium. All of these metals are readily deformable and normally contain large numbers of dislocations, for example, 10^6 to 10^8 dislocation lines per square centimeter. Now they are being produced in such a condition that only 10 to 10^4 dislocations per square centimeter are present. Thus it has become possible to observe and study the behavior of these crystalline defects by selective chemical etching that reveals the positions at which the dislocations intersect the surface of the metal. On certain crys-



Some principal planes and etch pits in a simple crystal. Chemical treatment discloses dislocations and other imperfections as pits in the crystal surface.

tal faces the dislocation may be revealed as an "etch pit" in the form of a three-sided pyramidal cavity eaten into the surface; on other surfaces the etch pit may be a cube or a four-sided pyramid. The shape of the pit is determined by the crystal plane that is being etched.

Most recently it has been found that it is possible to see inside the bulk metal by use of the "anomalous" transmission of x rays. That is, when a crystal is sufficiently perfect, then the quantity of x rays that penetrate into the crystal (properly oriented) for anomalously long distances is greatly increased, and it becomes practical to take advantage of this phenomenon to reveal the presence of local crystal defects such as dislocations or vacancy clusters. This comes about because the defect interferes with the transmission of the x rays and hence reveals its presence by the absence of the transmission of x rays in the region of the defect. In a real sense the defect casts a shadow. If one takes two x-ray photographs (topographs) at slightly different angles, then one gets a stereoscopic view of the crystal interior, and one can by observation of the topograph effectively get a three-dimensional view of the defects lying in the interior of the crystal and can observe which planes in the crystal contain the dislocations. Also, the shape and extent of the dislocation are readily discernible by this technique. In addition, it is possible to observe the interaction of the defects with one another and to see how they behave when the massive crystal is deformed by bending, compression, or tensile straining.

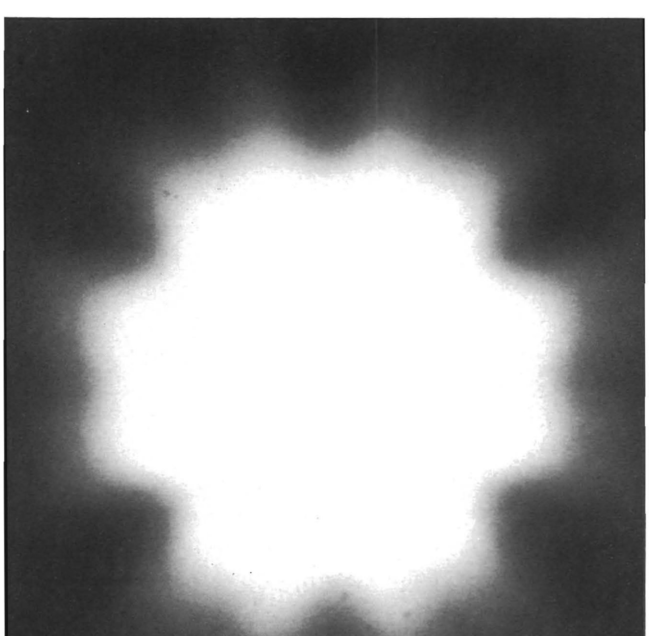
This technique promises to become important in evaluating the purity and perfection of crystals and should lead to a much better understanding of the effect of crystalline defects on the physical and chemical properties of crystals. These high-purity single crystals are very much softer than metals that are less pure and not so perfect, and so it is most difficult to handle them without altering their perfection. However, it has been found that subjecting the crystals to a moderate dose of neutrons pins the dislocations in place in the crystals, and thus the crystals become stronger and are much more readily handled. Furthermore, when the metal crystals are irradiated with fast neutrons for prolonged periods, then the intensity of the anomalously penetrating x radiation is reduced drastically, showing that other defects are being introduced into the lattice by the neutrons, probably vacancy or interstitial clusters. If the crystals are heated to 500°C, then the intensity of the transmitted x-ray beam is again restored. However, the heat treatment removes only the defects caused by the neutrons and does not remove the dislocations that were originally present. These studies are not only important in extending our basic knowledge of solids; they are also helping lead the way to new materials needed for the nuclear, space, and semiconductor age.

Channeling Effects of High-Energy Iodine Ions in Gold Crystals

During 1965 a series of experiments were performed in which energetic heavy ions, accelerated in the Tandem Van de Graaff, bombarded thin single crystals of gold. The information sought was the way in which the passage of these ions through the crystal depends upon the relative orientation of the ion direction to the lattice planes. It was found that the rate at which 40-MeV incident iodine ions lose energy can decrease by as much as a factor of 2 when the beam is aligned (to within a small fraction of 1°) to low-index lattice planes. The effect is called "channeling."

Ions traversing a solid lose energy by inelastic electron scattering, by collisions in which the ion becomes multiply ionized, and by relatively rare nuclear collisions. Multiple ionization was eliminated as a significant contributor to the difference in energy loss between channeled and unchanneled ions by actually measuring the charge distribution of the ions after they passed through a thin gold crystal. The conclusion is that the change in energy loss is related to the reduced average electron density in the channel. Photographic emulsion work showed that a low-divergence incident beam (0.05°) parallel to low-index planes, such as (111), (100), or (110), produces a divergent beam with a divergence of about 0.5°, spread into an ellipse whose major axis is perpendicular to the particular plane examined. The length and width of the ellipse are being studied both experimentally and theoretically in an attempt to correlate them with the interaction potential between the particle and the crystal. Transmission through other crystal axes can produce other patterns.

Autograph made by channeled ions emerging from a 700-Å-thick gold film. 40-MeV iodine-127 ions were transmitted through the single-crystal gold film parallel to the [011] direction. The bright central spot is the channeled beam. The dark diagonal bands in the diffusely scattered background result from "blocking" by the ($1\bar{1}1$) and ($11\bar{1}$) planes, the vertical band from the (100) plane, and the weak horizontal band by the ($01\bar{1}$) plane.



Since the effect of channeling is to decrease the number of small-impact-parameter (head-on) collisions, it might be expected that the radiation damage to the crystal would also be reduced if incoming ions were properly directed along lattice planes. A test of this was devised in which single-crystal gold films, 0.22 μ thick, were bombarded with collimated 51-MeV iodine ions. The resulting damage, observable with the electron microscope as spot structures, was *reduced by a factor of 14* for small angles between the beam and a lattice plane. The decrease in damage due to channeling was only observed for very small angles (1° or less) between the channel and the ion direction, which is in fairly good agreement with the predicted critical channeling angle. The damage reduction apparently results from a decrease in the number of collisions between the incoming ion and a *nucleus* in the lattice. These investigations are a collaborative effort involving a nuclear physicist, a physical chemist, a solid-state physicist, and others in which a pooling of several skills was requisite for a successful experiment.

Progress in Fusion Plasma Research

Man's seemingly unquenchable need for energy, which is now beginning to lean on nuclear fission, would be satisfied for thousands of years if we could only learn to harness nuclear fusion, since heavy hydrogen, found in ordinary water, would be the fuel. An additional advantage is that, whereas the products of fission are highly radioactive, the direct by-products of fusion are mostly helium, which is harmless, and tritium, which is used as additional fuel. The problem of making a fission reactor is simple compared with a fusion reactor. In fact, our sun is the only successful one in our neighborhood. If we are to tap this energy source on earth, we must learn to contain plasmas (mixtures of electrons and ions) at a temperature of many millions of degrees.

A series of fundamental experiments at the Laboratory have been designed to test our capability to build a fusion reactor and both to test and to help guide theoretical calculations aimed at understanding plasmas. In the Oak Ridge scheme, a steady stream of energetic ions is injected into a vacuum bounded by a magnetic field in the shape of a bottle. The object is to build up ion densities as high as possible. H_2^+ molecular ions from a 600-keV accelerator go into the magnetic bottle and are broken up by different mechanisms into H^+ and H^0 particles at 300 keV each. The H^+ particles are trapped in the bottle. A breakup mechanism used in early research was a carbon arc, but this also neutralized ions that had previously been trapped, limiting the maximum fast-ion density to 2×10^9 cm^{-3}, and was thus abandoned.

The next approach was the use of a very clean system with an excellent vacuum in order to increase the mean residence time of ions in the system. Calculations indicated that with a threshold value of 300 mA-sec the trapped ions would themselves dissociate incoming H_2^+ ions, and the plasma would then exponentiate; that is, it would build upon itself and automatically rise of its own accord. By various improvements the mean residence time was greatly increased (to as much as 2 min), and the threshold value was passed, but no sign of exponentiation was found. The reason was that the elusive, ever perplexing plasma had spread both radially and longitudinally, thwarting the desired increase in density.

A third series of experiments were then performed in order to understand the causes of the spreading. A new, subtle process called Lorentz dissociation was introduced, which enabled H_2^+ ions to be trapped about ten times as fast as previously. When applied, this new system forced the revelation of a plasma instability called the *negative-mass instability*, which had been previously explored in accelerator development. Thus, while these experiments have all been at plasma densities that are too low to be used for a fusion reactor, they have pointed the way to go. For example, the negative-mass instability can be overcome if the field in the magnetic bottle increases with radius, rather than decreasing as in a conventional arrangement. Also, both experiments and theory indicate that it is important to introduce large energy spreads into the injected ion beam, and theorists have also recommended new preferred geometrical shapes for the plasma volume. The net result of these investigations is that enough additional information has been gained to clearly point the way to the next important step in fusion research. The next experiment should involve injection of varied, low-energy (say 5 to 7 keV) atoms into a squat, fat magnetic bottle. With such a device it should be possible to break through to considerably denser, more stable plasmas than before.

Semiconductors in Radiation Spectrometry

The search for improved particle and gamma-ray detection techniques continues to be fruitful, especially with the use of semiconductors, since they possess inherently much better resolution capabilities than, for example, scintillation counters. Recently, attention has been concentrated in two areas: gamma-ray spectrometry using lithium-drifted germanium detectors, and improved resolution and noise performance of the specialized electronic circuitry associated with these detectors. One problem related to germanium detectors was that of increasingly unsatisfactory germanium raw material; the material as received showed diffusion constants that were barely one-thousandth of the usual value. This caused lithium drift times to become intolerably long and nearly shut down detector production. The physical mechanism underlying this variability was found to be dissolved oxygen in concentrations above 10^{14} atoms per cubic centimeter of germanium—an extremely small but important impurity! In the light of such studies, the suppliers of germanium have revised their production techniques, and satisfactory material has again become available.

Since an energy resolution of a few kilo-electron volts can inherently be obtained with semiconductor detectors, very sophisticated preamplifiers and amplifiers are required to take advantage of this property. The development of such equipment has been successfully pursued at the Laboratory for several years. During 1965 a transistorized preamplifier consisting of a wide-bandwidth, low-noise charge-sensitive input section and an output cable driving section was developed. The room-temperature noise level of this instrument is only 0.8 keV plus 0.06 keV per picofarad of detector capacitance. The amplifier is second only to the preamplifier in importance. The pulse shape must be carefully tailored to discriminate against pileup pulses from high counting rates as well as noise power distortion. To this end theoretical studies were made of pulse responses and signal-to-noise ratios of various transfer functions that could be synthesized into lumped-element electronic networks. One network gives the best achieved signal-to-noise ratio for published lumped-element shaped systems. A new experimental nuclear pulse amplifier has now been constructed following these principles; it has better overload, count rate, and signal-to-noise characteristics than previous amplifiers.

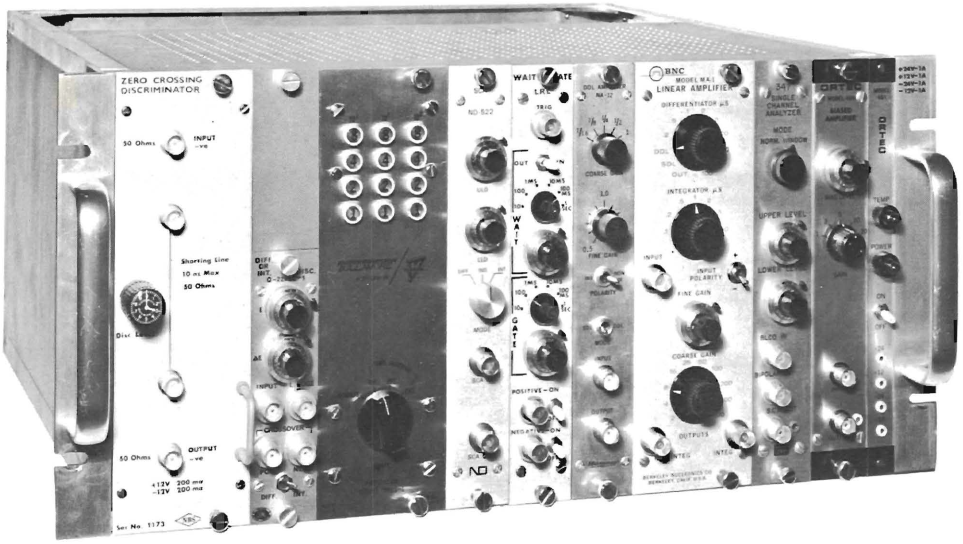
Progress on a Supercurrent Cyclotron Design

A new kind of cyclotron was conceived in 1962 by F. M. Russell of the Rutherford Laboratory while working at Oak Ridge. It was called the "separated-orbit cyclotron." One of its most important features is that the beam travels in separated orbits as it spirals outward undergoing acceleration. This allows one to extract 100% of the internal beam, a remarkable feat for isochronous cyclotrons. Another unique feature of the separated-orbit cyclotron is that it will deliver many times the beam current of any previous machine in the energy range between 100 and 1000 MeV. It will also have variable beam energy and continuous output, and thus it combines the best features of AVF (azimuthally-varying-field) cyclotrons and linear accelerators into one machine.

Although it appears feasible to design such a cyclotron to produce beam energies as high as 10 GeV, the present design concentration is on energies less than 1 GeV (1 GeV equals 1000 MeV). There are several reasons for concentrating on this energy range: (1) Present accelerators for 100 to 1000 MeV are frequency-modulated cyclotrons, which are seldom capable of delivering more than a few microamperes of relatively poor optical-quality external beam. Experimentalists are in sore need of greatly improved intensities for nuclear structure measurements (using nucleons, pions, muons, and neutrinos) in the 100- to 1000-MeV range. (2) A separated-orbit cyclotron can apparently be the most intense neutron generator ever built. For example, a 100-mA, 1000-MeV beam would produce a thermal-neutron flux density above 10^{16} neutrons cm^{-2} sec^{-1} in a tube 4 ft in diameter and 5 ft long. (3) Such a machine could serve as an injector to a future very high-energy accelerator. (4) At lower energies, say less than 200 MeV, the separated-orbit cyclotron could provide intense, very high-resolution beams for nuclear structure research.

The promise of the separated-orbit principle and the great success of experiments at the Laboratory with electron analog models have caused two other major laboratories (Chalk River, Canada, and the Rutherford Laboratory, England) to undertake complementary research programs. During 1965 at Oak Ridge a conceptual design study of a variable-energy multiparticle (25-MeV deuterons and 50-MeV protons) separated-orbit cyclotron was completed. This is a lower-energy stage of a three-stage facility for 50-, 350-, and 1000-MeV protons. In addition, the magnet geometry was modified, reducing both costs and alignment problems. The residual radiation levels to be encountered with high-intensity accelerators have been studied both experimentally and theoretically.

The Oak Ridge National Laboratory has been a leader in promoting the standardization of electronics used in nuclear instrumentation. During 1965 the investment began to return dividends in increased convenience for the experimenter. This photograph shows a standardized bin and power supply filled with various kinds of circuits manufactured at several national laboratories and seven private companies. The circutis plug into the common power supply and can be interconnected easily. Recent specialized instrument contributions from the Laboratory include a gamma monitor, an alpha monitor, a differential-integral discriminator, and a coincidence-anticoincidence unit.



MSRE computer. Automatic data-handling equipment and a digital computer are located in a room adjacent to the main control room of the Molten-Salt Reactor Experiment to provide rapid compilation and analysis of the process data. This equipment has no control function, but the high-speed scanning feature provides current information about all important variables and warns the operator of abnormal conditions.

Application of Electronic Data Handling to Experimental Programs

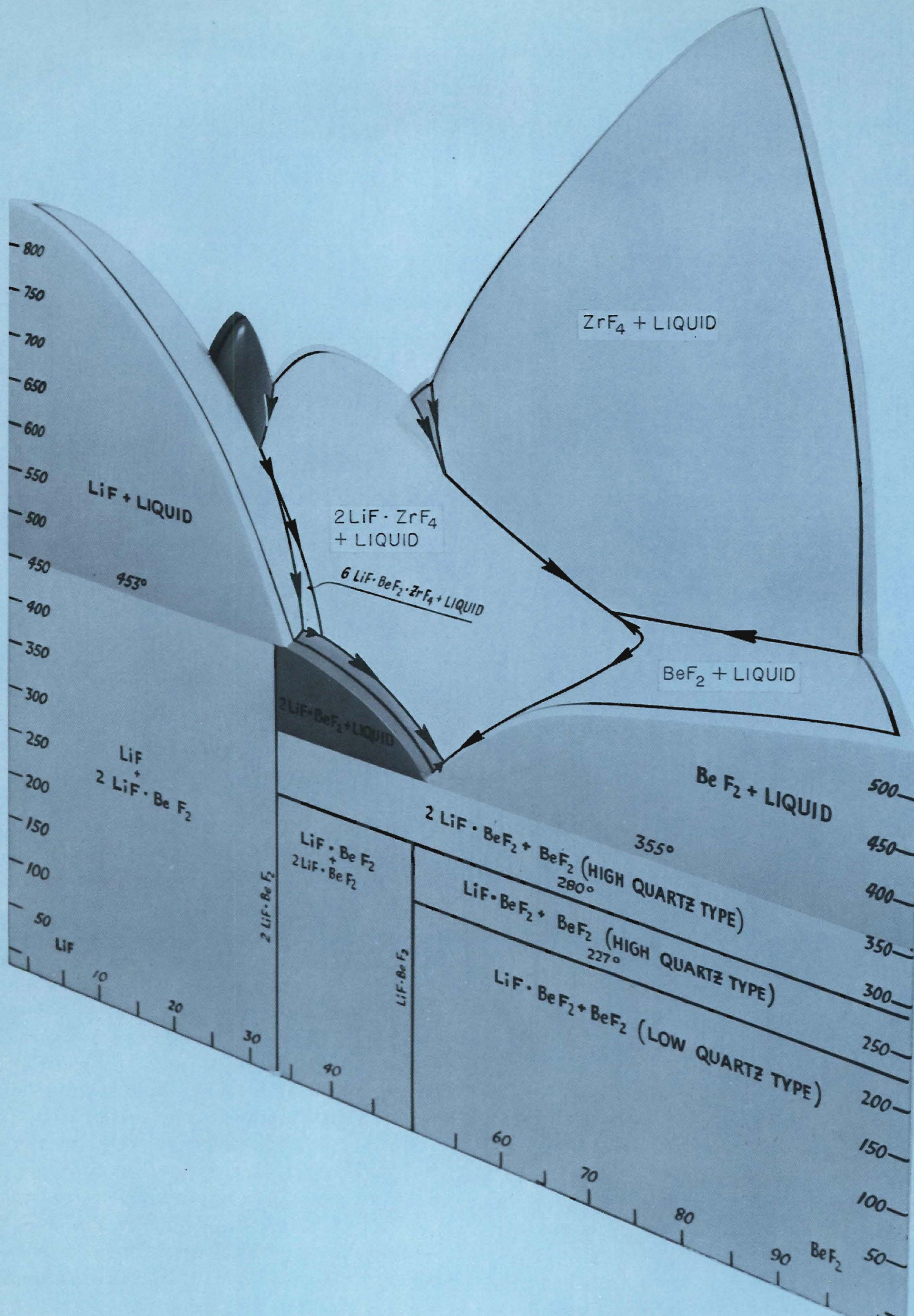
As the complexity of experiments grows, the researcher must increasingly depend upon mechanization of apparatus and electronic data processing. In a similar way the details which some theorists can now use meaningfully are so numerous and complex that a large, fast computer is absolutely necessary. The Oak Ridge National Laboratory is meeting these needs in two ways. First, a large, fast central computing center is available to all and is used for both short and lengthy calculations. This facility meets the needs of the theorists and also handles data analysis, short calculations, and other needs of the experimentalists. Second, small computers are being used at the location of major experiments and in some cases are actually on-line with the experiment. This is necessary because these experiments are so complex that they require very rapid data processing to guide the experimenter in adjusting his apparatus and in making decisions during the experiment.

Two major data systems were installed during 1965: (1) a centralized data-logging device which gathers data from experiments in the Reactor Division, and (2) an on-line process control computer being used for data gathering and analysis at the Molten-Salt Reactor Experiment.

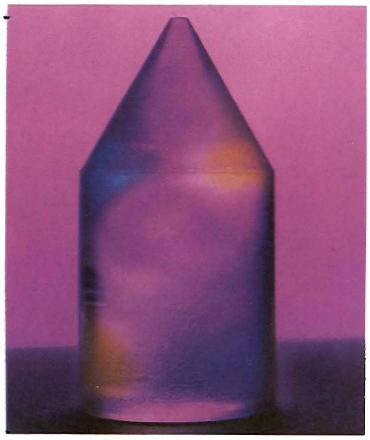
Methods of linking an experiment or data system to a computer through computer programming were studied. These methods included making a computer program do the editing and initial analysis of raw data. The several small on-line data acquisition and processing system installations throughout the Laboratory have been so successful that many other experimenters are contemplating and requesting equipment for automatically taking data from their experiments.

The design and installation of the first computer-controlled x-ray diffractometer at the Laboratory were completed in June 1965. By means of stored program control, the diffraction characteristics of various crystals are obtained automatically. This instrument allows more complex data to be obtained in considerably shorter times than was possible with older manual and semiautomatic techniques (see section on "Chemical and Materials Research and Engineering").

A small computer, located in the High Voltage Accelerator Laboratory (which contains two single-stage and one tandem Van de Graaff accelerator), has served as an off-line local data processor for several years. It became increasingly clear, however, that in some of the more complex experiments on expensive accelerators, information was needed in the course of the experiment in so short a time that only an on-line computer could do the job. Consequently, during 1965 data terminals were installed linking each accelerator to the computer, so that processed information can be obtained almost immediately.



This three-dimensional model of the phase diagram of the LiF-BeF_2-ZrF_4 system represents the end product of one important line of chemical and materials research – in this case, research which was important for the selection of the fuel solvent composition for the Molten-Salt Reactor Experiment. As mixtures of the three components of the system are cooled from the molten state, represented by the region above the top surfaces of the model, they reach temperatures corresponding to the model surface (the liquidus *surface); there a crystalline solid appears, of the composition indicated by the labels. The consequent change in liquid composition falls on a downhill pathway, ultimately following the arrows indicated on the diagram, until all the liquid has solidified at one of the low points on the liquidus surface. The diagram also shows the alterations which can occur in the solid phases as the temperature is lowered further.*



A 300-g high-purity single crystal of lithium fluoride, viewed in polarized light, reveals the absence of internal strains. As part of the Laboratory's Pure Materials Program, such crystals have been grown in varying isotopic concentrations of the lithium from 99.99% lithium-7 to 99.3% lithium-6 in order that solid-state physicists may determine the influence of isotopic composition on thermal conductivity. It is necessary to free the crystals from all contaminants; the concentration of manganese, a particularly troublesome impurity, has been reduced below 1.86 ppb, the limit of detection by neutron activation analysis. The thermal conductivity of specimens cleaved from these crystals has been found to approach the maximum theoretical value. This finding has thrown light on the mechanism of heat transport through crystal lattices.

CHEMICAL AND MATERIALS RESEARCH AND ENGINEERING

Chemical research at the Oak Ridge National Laboratory is concerned with all of the elements and many of their compounds, including the man-made heavy elements. Superimposed upon this is work aimed at understanding the properties of these materials in radiation fields of different types and intensities. Typical projects in chemistry include study of decay schemes, radiation chemistry, nuclear chemistry, the structure of matter, new separation techniques, and the chemistry of reactor fuels, materials, and by-products. The chemical engineers are concerned with the development, design, and scale-up of new processing methods and equipment. A principal interest of the metallurgists is the development of new and improved reactor fuels and materials.

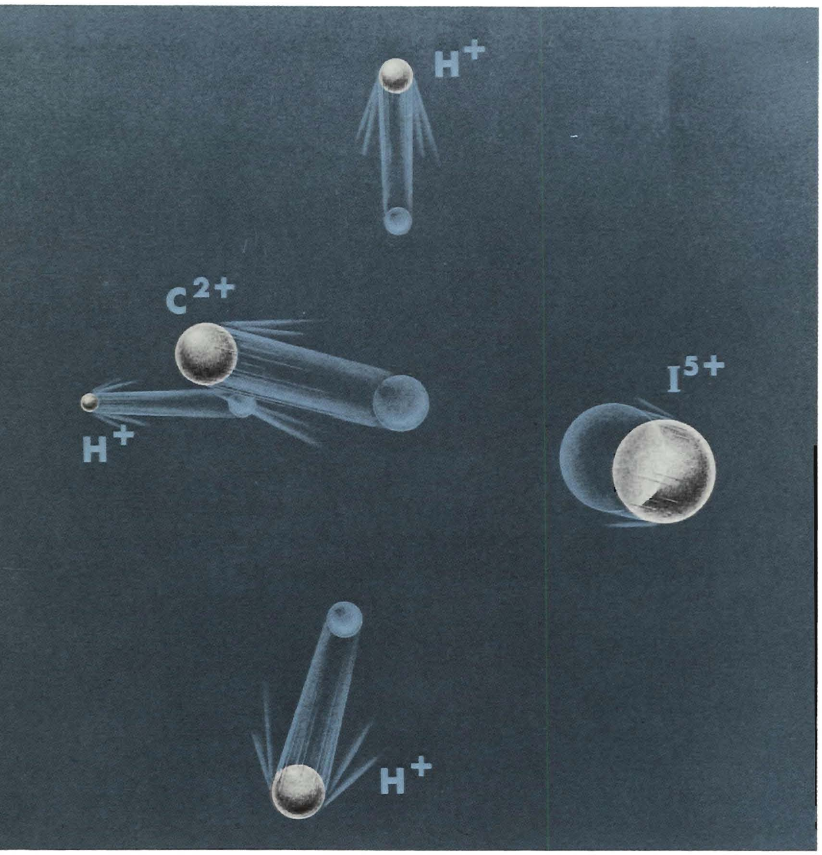
X-ray Interaction With Complicated Molecules

Chemists have long been interested in the consequences of the interaction of radiation with matter and in how such consequences can be avoided or used to advantage. Scientists at the Laboratory have recently, and for the first time, been studying in detail exactly what happens in the first steps when x rays interact with complicated chemical molecules.

The very first step is usually the ejection of one of the electrons. If the x ray has enough energy to make the interaction energetically possible, the one most likely to be ejected is located in the *K* shell, that is, the shell closest to the nucleus of the heaviest atom of the molecule.

The atom involved readjusts to the resulting hole by a series of cascading transitions in which electrons from the *L*, *M*, and *N* shells successively drop down to fill the vacant positions. These transitions are known as Auger processes. They are complicated because extra energy must be released in each step in the transition, since the *K*, *L*, *M*, and *N* shells have successively lower binding energies.

Although it had been realized that this extra energy would appear as additional ejected electrons, it had not previously been appreciated that there is a huge amount of ionization involved in the readjustment to the x-ray interaction, both by the initial atom and by its surrounding neighbors. From the Oak Ridge work, it is now known



This diagram shows the complete disruption of the methyl iodide molecule into positively charged fragments as a result of Coulombic repulsion. Only a single interaction of an x ray with an electron in the iodine atom is required to set off this molecular catastrophe; the initial expulsion of one electron is followed by an Auger cascade in which a total of ten electrons are ejected from the iodine atom. The ionized iodine atom then immediately captures all the bonding electrons previously required to hold the atoms together.

that as many as eight or ten electrons may be ejected from an iodine or a lead atom, leaving a very high positive charge on this atom. Electrons are rapidly transferred from the other parts of the molecule to give a collection of positively charged atoms in the irradiated molecule. This whole molecule then literally *explodes* because of the Coulombic repulsion of its several charged atoms.

The explosion products are identified with a specially designed mass spectrometer, in which the relative abundances of the different fragment ions and their recoil energies are measured. For example, it was found that on the average 11 electrons are ejected as the consequence of the initial interaction of an x ray with ethyl iodide (C_2H_5I). Hardly any molecular fragments were found, but rather only atoms of carbon, hydrogen, and iodine in various charge states. These monatomic ions were found to have considerable kinetic energies, some nearly as high as 100 eV.

A study of this highly destructive initial interaction of an x ray with a molecule may be of great importance with regard to certain biochemical systems. For example, in other laboratories, a strong correlation has been reported between the energy of an incident monochromatic x-ray beam and the observed radiation damage to certain iron-containing enzymes and to chromosomes which had been treated with an organic compound containing bromine; a large increase in the radiation damage was noted when the energy of the x ray was increased above the known threshold for interaction with the *K* shell of the heavy atom. The Oak Ridge work suggests an explanation for this correlation along the following lines: (1) Heavy atoms play vital roles in the functioning of these complicated chemical systems, (2) there is a relatively higher probability that an x ray will be initially absorbed through interaction with the electrons of such heavy atoms, and (3) the damage at the site of absorption will be very substantial but highly localized, thus blocking the chemical functioning of the system.

Is There An H_3O?

Everyone knows that the formula for water is H_2O, and chemists have had reason to believe that oxygen can hold no more than two hydrogen atoms in a stable, neutral molecule. During the past year, however, chemists at the Oak Ridge National Laboratory believe they may have found the H_3O molecule in the residual gas in a mass spectrometer. What they have actually seen is the ion H_3O^+, but it is extremely likely that this arises from neutral H_3O molecules. The first H_3O molecules found were believed to have been formed by surface reactions on the walls of the apparatus; subsequently, H_3O was made by a molecular beam technique in which surface reactions were absent. The molecule is definitely not the result of the reaction of H^0 plus H_2O^+. Analogous reactions were used to prepare what is believed to be D_3O. These new molecules may be in excited states rather than in the ground state, but, if so, their lifetimes are greater than 10^{-6} sec.

The existence of H_3O, if established, will not be easy to explain. When an oxygen atom has formed two bonds to hydrogen in a water molecule (H_2O), it has used up all the likely places to put electrons (the neutral atom starts with six, and one comes with each hydrogen atom). Where to put the ninth electron from the third hydrogen is a puzzle, perhaps more difficult than the similar puzzle posed by the xenon fluorides.

There are one or two other routes by which H_3O^+ could be formed without requiring H_3O to exist. If one of these should prove to be the explanation, the problem of accounting for the existence of H_3O would disappear, along with the interest in the observation. These other routes seem unlikely, however, and the present experimental results are potentially so interesting that it seems worth while to present them as an example of research in progress even though an element of doubt remains.

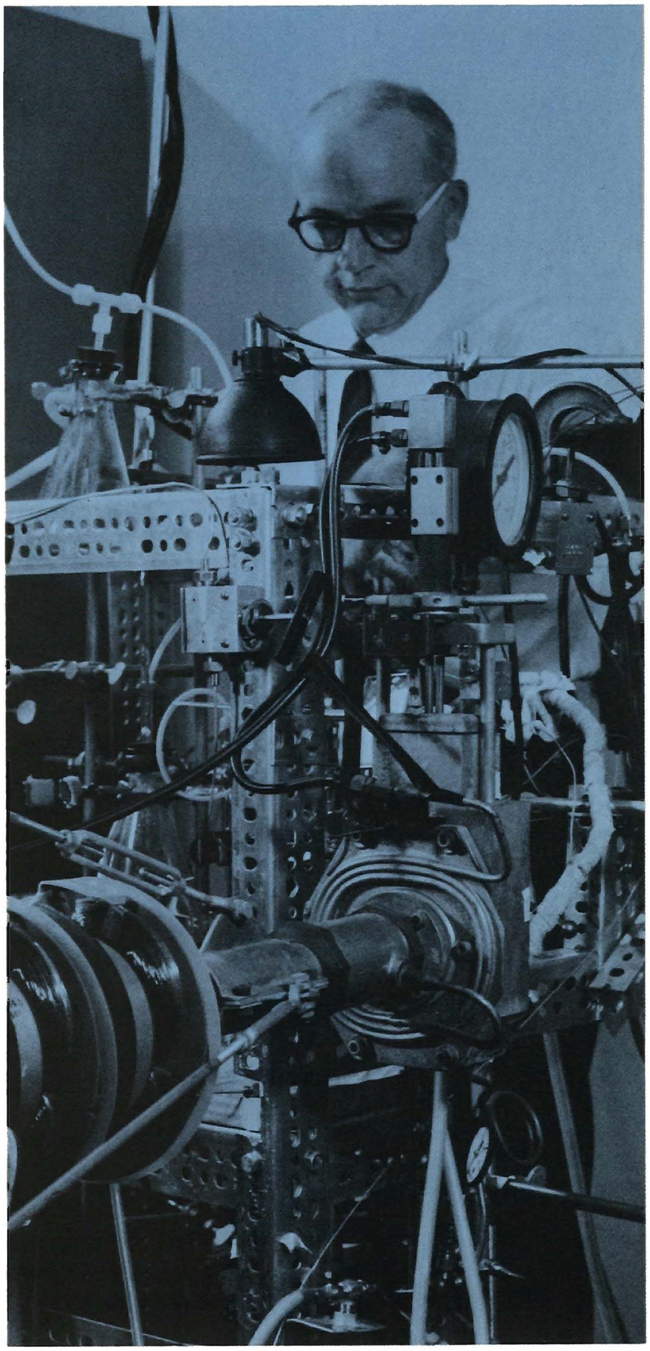
A research problem often goes through such a period of intense interest — interest which may prove to be justified and to lead on to new horizons, but which sometimes collapses upon further examination. This one is still at the tantalizing point of uncertainty.

Use of Basic Radiation Chemistry to Predict Radiation Effects on Reactor Water and Solutions

Water and aqueous solutions are decomposed at appreciable rates by radiations such as those from a nuclear reactor. Where water — usually with small amounts of added solute — is used as moderator or coolant for a nuclear reactor, it is essential to know the extent of such decomposition under the particular irradiation conditions imposed by operation of the reactor. Chemists at the Laboratory have found that the available information on radiation chemistry permits them to make estimates of the decomposition of water under the conditions commonly used in the coolant-moderator systems of research reactors: irradiation by fast neutrons and by beta and gamma rays, water temperatures below 100°C, dissolved hydrogen or oxygen in excess of the 2:1 stoichiometric ratio, and no withdrawal of gas from a gas phase.

From 18 chemical and radiochemical reactions — believed to include all those likely to be important for water in neutral or acid solutions — kinetic equations were derived in which the rates of formation and disappearance of each species were equated. The steady-state concentration of each of seven principal species was determined by solving these equations with a computer. The validity of the method and of the values employed for yields, rate constants, and activation energies was tested and verified by comparing the calculated values with those known experimentally for several systems, including the Oak Ridge Research Reactor and the Engineering Test Reactor. A similar approach has been used to assess the effects of irradiation on the coolant-moderator in the High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory. The energy deposited in the HFIR water by fast neutrons and gamma rays will average about 100 W/cm^3, an irradiation intensity higher than in previous reactors. Additional confirmation of the validity of the predictions now awaits high-power operation of the reactor.

Studies of stability of solutions under electron irradiation



Water Solutions at High Temperatures and Pressures

The behavior of water solutions at temperatures below 100°C has been examined by very many researchers. Although rigorous theories of solution behavior are still applicable only to solutions that are very dilute, these studies have produced a vast body of knowledge and many empirical correlations. In contrast, knowledge of the behavior of water solutions at high temperatures is largely lacking. This lack is distinctly undesirable, because our understanding of such significant and important processes as pressurized- and boiling-water reactor technology, water desalination, corrosion by high-temperature solutions, and geochemical synthesis of minerals requires knowledge of the behavior of water solutions at high temperature. More research at high temperatures might be helpful for another reason: the structure of water almost certainly becomes simpler (and solution theories probably become simpler, too) as the temperature rises and hydrogen bonding within the solution becomes less important. By the use of improved high-temperature solution theory, it may be possible to extrapolate to lower temperatures and account more successfully for the complicated low-temperature behavior than is now possible.

For these reasons chemists at the Laboratory have continued a selective experimental study of the solubility of such salts and bases as calcium sulfate, magnesium sulfate, and calcium hydroxide in solutions containing other electrolytes (such as sodium nitrate or sodium chloride) over a wide range of concentration at temperatures up to 350°C. These studies have revealed that the solubility of a salt such as calcium sulfate in dilute to very concentrated solutions can be described at the high temperatures with adjustment of only one normalizing factor.

Studies are also being made of the electrical conductivity of solutions of sulfuric acid and of sodium chloride in water at temperatures up to 800°C and pressures up to 4000 atm. These measurements (those at the higher temperatures are made on solutions in the supercritical fluid rather than in the liquid) show, for example, that the limiting equivalent conductances of many univalent salts increase by factors of 5 to 10 from 25 to 400°C and then become essentially independent of temperature between 400 and 700°C when the densities are kept constant by the application of appropriate pressure.

Mechanism of the Action of Inorganic Corrosion Inhibitors

Studies with technetium, a fission product element not occurring naturally, have added considerably to our knowledge of the way in which corrosion in aqueous solutions is inhibited by the action of widely used inorganic compounds. Technetium in the form of the pertechnetate ion, TcO_4^-, is closely analogous structurally to the permanganate ion, MnO_4^-, and the important corrosion inhibitor chromate ion, CrO_4^{2-}. It has long been known that the surface of a metal may be rendered inactive (passive) by making it the positive electrode (or anode) in an electrolytic circuit under suitable conditions of current flow. Some investigators have considered that inorganic inhibitors induce passivation by the generation of a similar current through their own reduction at the surfaces of the metal.

This hypothesis was tested at the Laboratory

Visual proof of the drastic reduction in corrosion rate caused by adsorption of unreduced TcO_4 ions on the surface of passive iron. Plain carbon-steel coupons were immersed in distilled water and in 5×10^{-4} M $KTcO_4$ + 10 ppm Cl^-. The specimen in distilled water soon disintegrated because of corrosion, whereas the specimen in TcO_4^- solution has undergone no detectable weight change in over 13 years since the exposure was started in January 1953.

in 1965 by anodically polarizing an iron electrode in the presence of inorganic inhibitors, but with the potential of the circuit controlled so that it was not sufficient to cause a significant reduction of the inhibitor. When careful measurements were made of the current densities and the accumulated charges, it was found that, in all cases, the normal passive state was attained rapidly. Nevertheless, the maximum initial current densities were very much less than those required for passivation in the absence of the inhibitor, and total charges of no more than a few millicoulombs per square centimeter were sufficient for inducing passivation. Neither pertechnetate nor chromate was capable of supplying more than a small fraction of the current density required for passivation in the absence of the inhibitor. Passivation was also achieved under some conditions with the use of permanganate, not normally considered an inhibitor.

These results are considered to present clear-cut evidence that reduction of the inhibitor is certainly not the only role (and probably not the major role) of inorganic inhibitors of this type. Adsorbed unreduced inhibitor anions probably induce passivation by exerting an electrostatic influence on the kinetics of the anodic processes at the surface of the neighboring metal atoms.

Computer-Controlled X-ray Diffractometer

The crystallographer has long been plagued with a tedious routine of data collection in which he literally became a slave to his machine. Now, a cooperative effort involving the Oak Ridge crystallographers and the specialists in computer technology has put an end to this slavery and has made it possible for the crystallographer to spend far more of his time in real scientific effort. A four-circle x-ray diffractometer that is controlled in a simple way by a digital computer has been in use since July 1965. During its first five months, this instrument measured the intensities of a total of 12,000 reflections from five different crystalline compounds.

Programs have been prepared to perform routines simulating manual operation of the diffractometer and thus to facilitate mounting and centering of the sample. If the unit cell or orientation is unknown, it is possible to search for reflections automatically. More often, however, a preliminary photographic investigation has been made so that the lattice parameters and orientation are known approximately. A reflection can then be located by automatic two-dimensional scan over the region in which it is expected.

Another program systematically sets the instrument to maximize the intensity and center the reflection in the counter. Instrument angles for two reflections located in this way serve to define the sample orientation. This information, together with the cell parameters, enables the computer to calculate angle settings for any given crystallographic indices, so that other reflections can be readily located. If desired, the measured instrument angles for several reflections can be used as observations for a least-squares program which refines the cell and orientation parameters.

A data collection program establishes the sequence of reflections to be measured and provides periodic checks of reference reflections. All the results are corrected for coincidence losses and for background counts. Finally, the data are punched on paper tape for further processing on a larger computer.

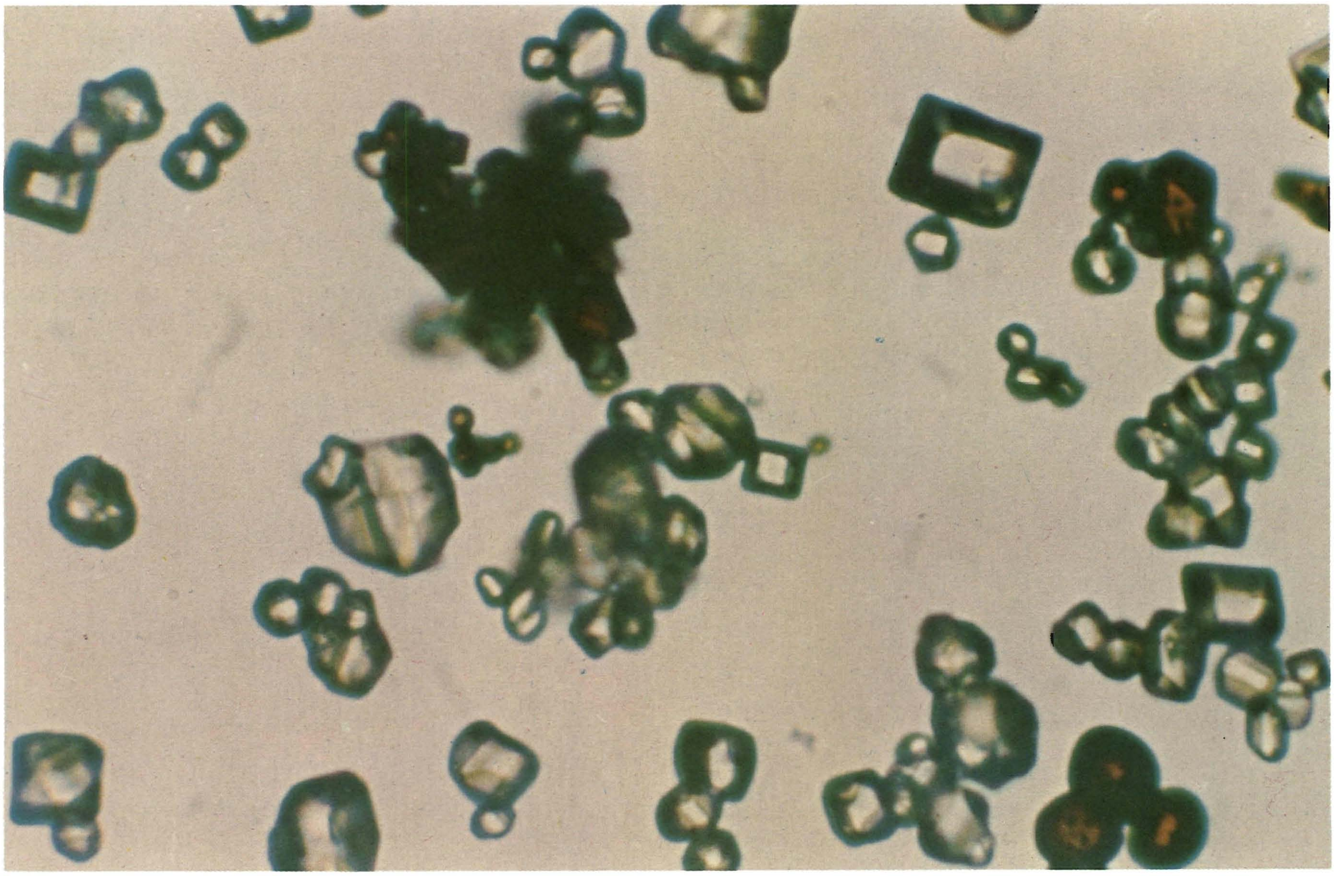
Reactions of Refractory Materials

Refractory compounds, of which many important ceramic materials are typical examples, undergo chemical reactions readily in the solid state if the temperature is made sufficiently high (1000 to 2000°C). Thus, chemical equilibrium among the possible phases is readily established at high temperature, and the definitive study of such phase equilibria is both rewarding and relatively easy.

At lower temperatures, however, the mobilities of the ions and the rates of solid-state reactions in refractories decrease markedly, becoming negligibly small at temperatures well above room temperature. Unfortunately, intermediate temperatures (500 to 1000°C) represent awkward middle ground. There the reaction rates are too slow for convenient study, but long-term use of the refractory (as in a high-temperature nuclear reactor) requires definitive information about the equilibrium species. Equilibrium behavior in this temperature range has frequently, and sometimes incorrectly, been inferred from trends in the data at higher temperatures.

Since zirconium dioxide (ZrO_2) and uranium dioxide (UO_2) are important components of nuclear fuels, they have been studied intensively, and their equilibrium behavior at 1400°C and above has been definitively established by direct solid-state reaction methods elsewhere. They dissolve in each other to form an extensive series of solid solutions. The excellent high-temperature results, in combination with (less certain) direct data at somewhat lower temperatures, suggested that marked solid-solution behavior (13 mole % UO_2 in ZrO_2 at 600°C) might persist to much lower temperatures, including the temperature range of interest to the Molten-Salt Reactor Experiment, whose fuel contains both zirconium and uranium. Because contamination of the fuel with water could lead to oxide precipitation, the phase behavior of those oxides in the 500 to 1200°C temperature range has been reexamined by the use of a novel technique which has provided unequivocal approach to equilibrium.

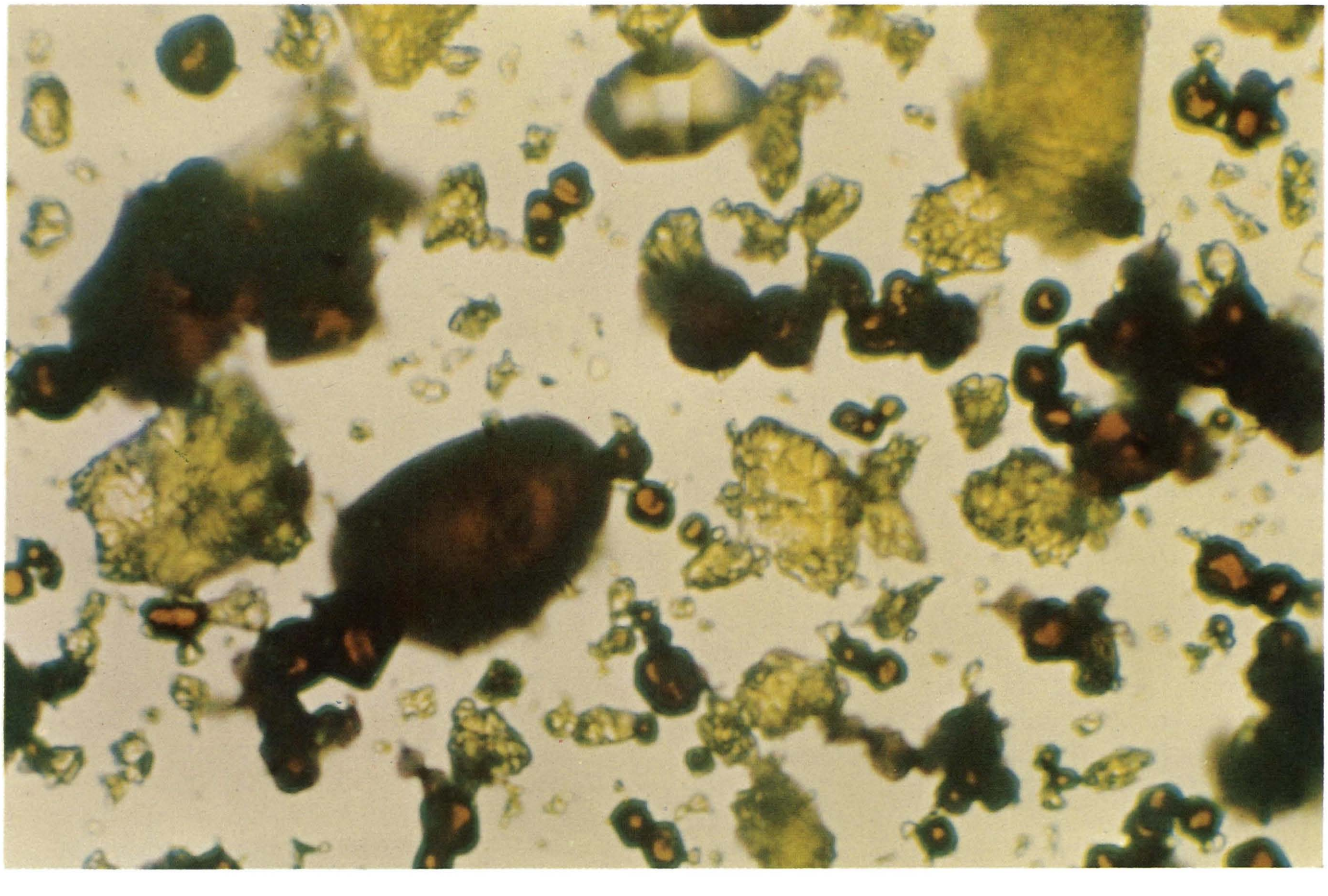
A molten fluoride mixture (LiF, BeF_2, ZrF_4, and UF_4), contained in nickel equipment, was used as a liquid medium in which to equilibrate the oxides; the liquid acts as a flux, dissolving



some oxides and precipitating others. Equilibrium was rapidly established and could be approached from both directions – solid solutions prepared at high temperatures decomposed into two phases, and pure oxides dissolved in each other. The data show that mutual solubility is barely significant below 1110°C; at this temperature ZrO_2 dissolves 0.2 mole % of UO_2, and UO_2 dissolves 0.4 mole % of ZrO_2. As this temperature is exceeded, ZrO_2 changes in structure from monoclinic to tetragonal, and the solubility of UO_2 increases sharply to 1 mole %. Further increases in temperature produce significant mutual solubility, and the values appear to extrapolate smoothly to the previously established equilibria at high temperatures.

These results are extremely reassuring to the Molten-Salt Reactor Experiment, as they confirm the expectation that the fissile uranium will not be precipitated in the presence of the larger concentration of zirconium fluoride that was incorporated in the fuel. The use of a molten salt flux to promote equilibrium between high-melting solids should prove useful in the study of other refractory materials.

Mixtures of uranium dioxide and zirconium dioxide after equilibration for 8 h in the presence of molten fluorides. The two pictures are photomicrographs of oxide crystals after equilibration; they have been washed in aqueous solutions to remove the fluoride salts. The picture on the left shows the well-developed red cubic crystals of UO_2 and the colorless monoclinic crystals of ZrO_2 (5 to 10 μ on edge) formed at a temperature of 1090°C, which is below the transition temperature, 1110°C. These crystals contain only 0.06 mole % UO_2 in ZrO_2 and 0.50 mole % ZrO_2 in UO_2.
The picture on the right shows the extensive formation of yellow solid solution at a temperature of 1118°C – just above the transition temperature; the monoclinic ZrO_2 has disappeared, and the yellow tetragonal ZrO_2 contains 2 mole % UO_2 in solid solution. The cubic UO_2 phase still contains only about 0.65 mole % ZrO_2.



The Ross Radioisotopic Light Source

A new concept in precision photometric analysis was originated in 1965. This technique introduces a new physical basis for measuring the opacity of colored solutions by utilizing the unusual spectral and emission properties of a beta-excited light source.

Although absorption photometry is one of the most valuable analytical methods available to chemists, its use has been generally restricted to the analysis of trace amounts of material. The precision of measurements previously available with conventional photometric instruments has not been able to compete with that obtained by other analytical procedures. The new concept provides such a high degree of precision that absorption photometry can now be extended to the analyses of macro concentrations of materials. Theoretically, there is no limit to the precision that can be reached with the new system.

The heart of the new system is the self-powered radioisotopic light source consisting of two components – a small amount of a beta-emitting radioisotope combined with a scintillating material (phosphor). The phosphor can be either liquid or solid, organic or inorganic; the radioisotope can be mixed with, deposited on, or located in the vicinity of the phosphor. Beta particles emitted by the isotope cause the scintillator to be excited, with the subsequent emission of visible light.

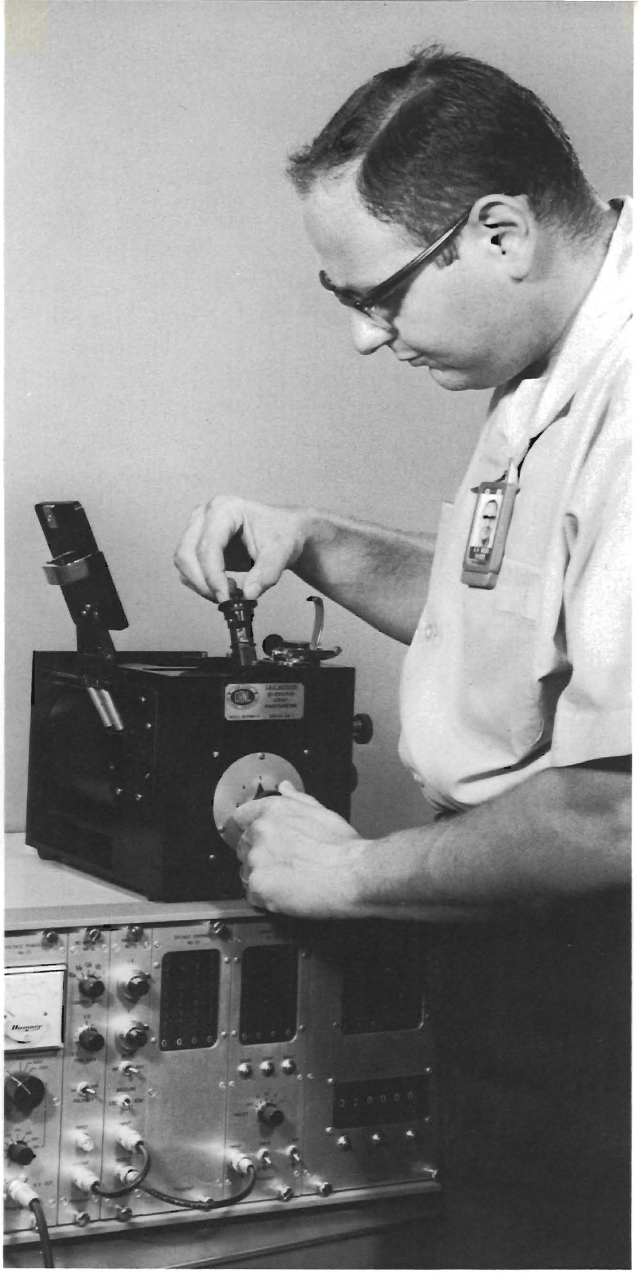
Under the influence of beta excitation, the light source possesses two important characteristics necessary for its use in this application. First, the visible light output from the source consists of a train of individual and discrete pulses rather than the continuous emission observed with a conventional light source. Second, the intensity of these pulses is not constant but varies from zero to some maximum value; the intensity of any given pulse depends on the energy of the beta particle causing it. These two properties of the source are essential for operation of the system.

If a colored solution is placed between the scintillator and the photoelectric detector, the intensity of each light pulse is reduced by partial absorption in the solution, and therefore a shift is produced in the pulse height distribution of the output from the detector. Discriminators may be introduced into the detector system so that only a segment of the pulse height distribution is observed. If the discriminator settings are suitably chosen, there is a simple relation between the counting rate and the concentration of the colored species in the solution.

The light source selected for the prototype instrument uses chlorine-36 dissolved in a liquid scintillator. The isotope has a half-life of 3×10^5 years, thus giving an extremely constant light output over its expected life of eight years. New sources are quite simple to prepare at low cost.

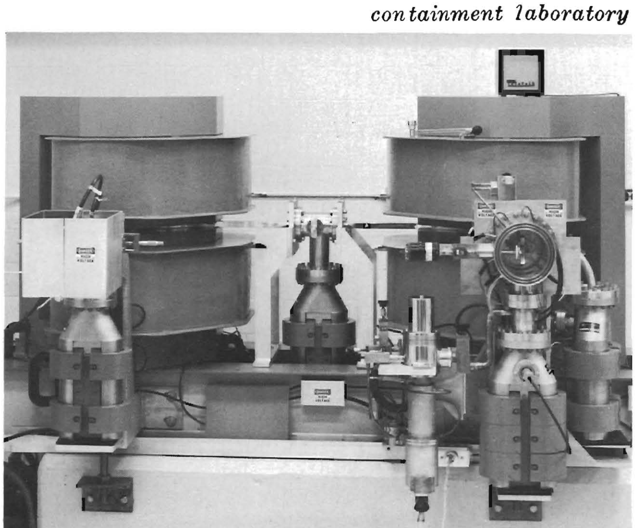
Since the output data from the system are digital rather than analog, maximum sensitivity and precision can be realized. The output also allows digital computing equipment to be coordinated directly with the analysis instrument.

For the future, the technique holds extraordinary promise of application to remote analysis, space and oceanographic explorations, and trace determinations of organic materials important in the study of biochemical processes involved in molecular biology. The technique can also be used to advantage in the more mundane problems of conventional photometric analysis.



Ross radioisotope light source

TRU mass spectrometer in alpha containment laboratory



Half-Life Values for the Radioisotopes of Californium

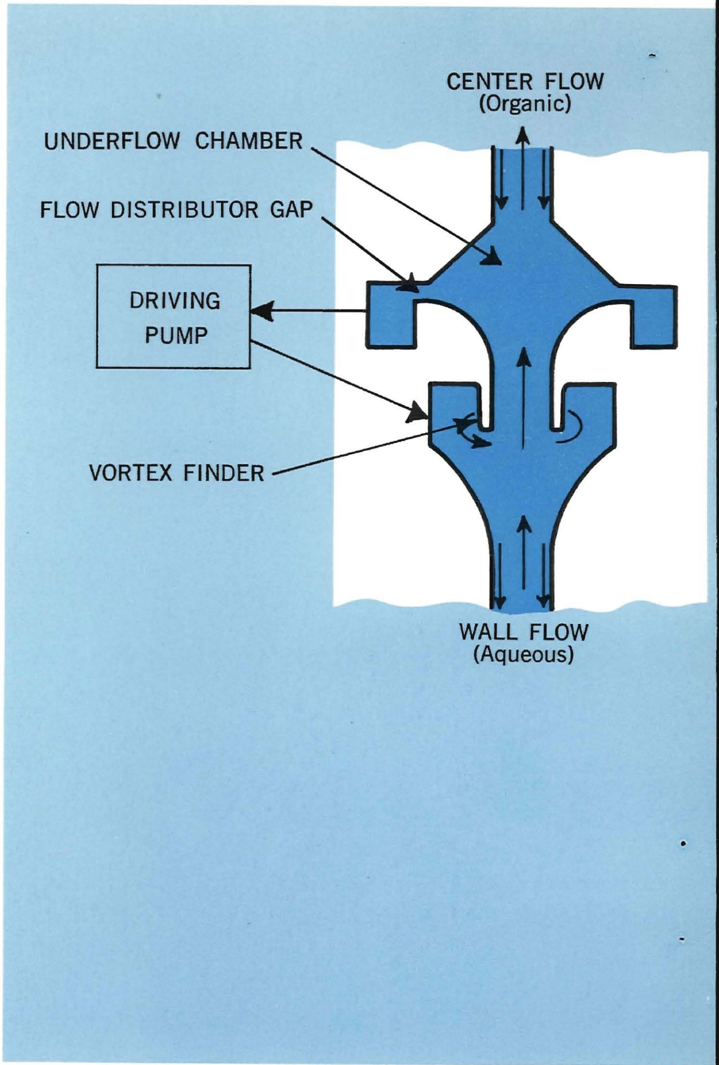
A reliable half-life value for a radioisotope is established only after many consistent data are obtained by numerous workers using unrelated methods. At the Oak Ridge National Laboratory, half-lives for the radioisotopes of californium were measured by mass spectrometry, a means different from and independent of the usual technique of radiochemical counting. This technique gives the total half-life, a composite of all the various modes of decay. With mass spectrometric techniques, measurements were made on 3- to 5-ng (1 ng $= 10^{-9}$ g) quantities of californium; the ratio of the mass of californium-252 to that of each of the other californium radioisotopes (249, 250, 251), which have longer half-lives, was measured three consecutive times, separated by about three-month intervals. The half-life of californium-252 was calculated from the changes in the mass ratios with time.

The half-lives of californium-249, -250, and -251 were similarly determined from measurements of the changes with time in the mass ratios of the curium isotopes (245, 246, 247, 248), which are the daughters of the californium isotopes 249, 250, 251, 252; the ratios of the other curium isotopes to curium-248 were measured. Curium-248 was used as a base line since it is the daughter of californium-252, whose half-life is believed to be the best known of the group.

The results are compared below with those found at Argonne National Laboratory by the use of a spontaneous-fission counting technique. The two methods have substantially confirmed each other.

Californium Radioisotope	Half-Life (years)	
	ORNL Value	ANL Value
249	315 ± 20	320
250	12.7 ± 0.3	13.2 ± 0.5
251	892 ± 88	
252	2.49 ± 0.2	2.646 ± 0.004

This experimental 11-stage stacked-clone contactor consists of a tandem series of hydraulic cyclones individually driven by pumps, as indicated in the inset. In each stage the whirling motion of the liquid produces a high shear field for extraction, a high centrifugal field for rapid phase separation, and countercurrent flow. This unit is a forerunner of units that will extract and decontaminate the heavy metals from highly irradiated reactor fuels, with contact times so much shorter than in conventional contactors that much higher radioactivity can be tolerated.

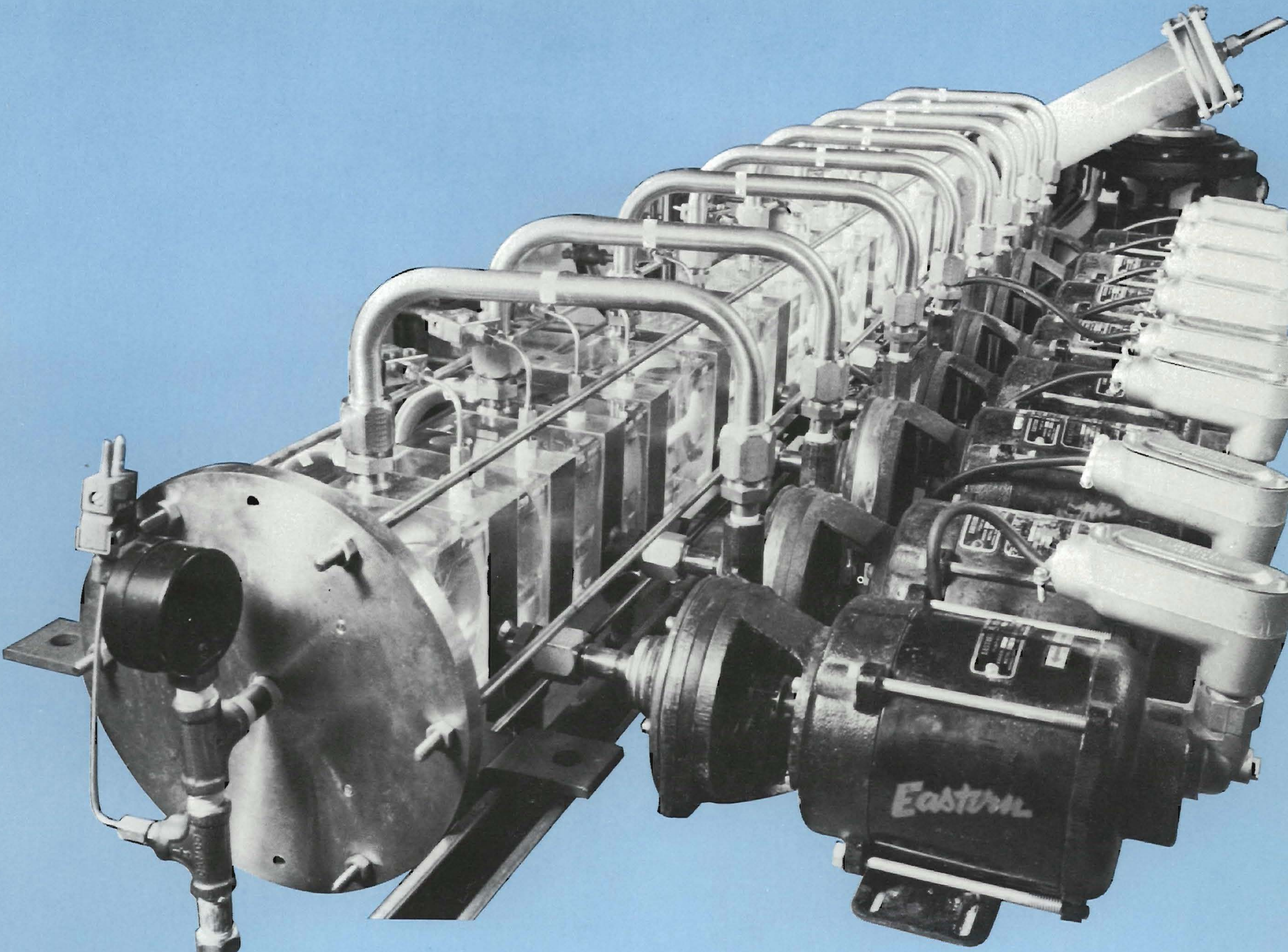


Separations Chemistry and Engineering

Separations processing is an important aspect of the atomic energy program because of the need for recovering and purifying uranium and thorium from ores, reprocessing reactor fuels, recovering fission products, separating transuranium elements, recovering metals critical to the make-up of fuel elements, etc. Of the several available separation methods, solvent extraction is used most widely because of its operational simplicity and adaptability to remote control. In a simple example of this method, an aqueous solution containing many different metal ions is contacted by an organic solvent. By appropriate choice of solvent composition, a single desired metal ion is taken into the organic phase, from which it is removed subsequently in pure form by contacting with a different aqueous solution.

The first large-scale use of solvent extraction for processing metals was in the purification of uranium concentrates for reactor fuels and diffusion plant feed. Later, chemical technologists at the Laboratory developed the highly effective Purex-type processes, which are now being used throughout the world to reprocess reactor fuels, and the Amex and Dapex processes, which are now used extensively throughout the uranium ore processing industry.

The wide choice of reagents and operating conditions continues to make solvent extraction a fertile field for research and development. Some recent advances at the Laboratory in *process chemistry* include the following: (1) recovery of the useful fission products (strontium, rare earths, cesium, zirconium, niobium, ruthenium) from reactor fuels; (2) separation of the man-made transplutonium elements formed in high-neutron-

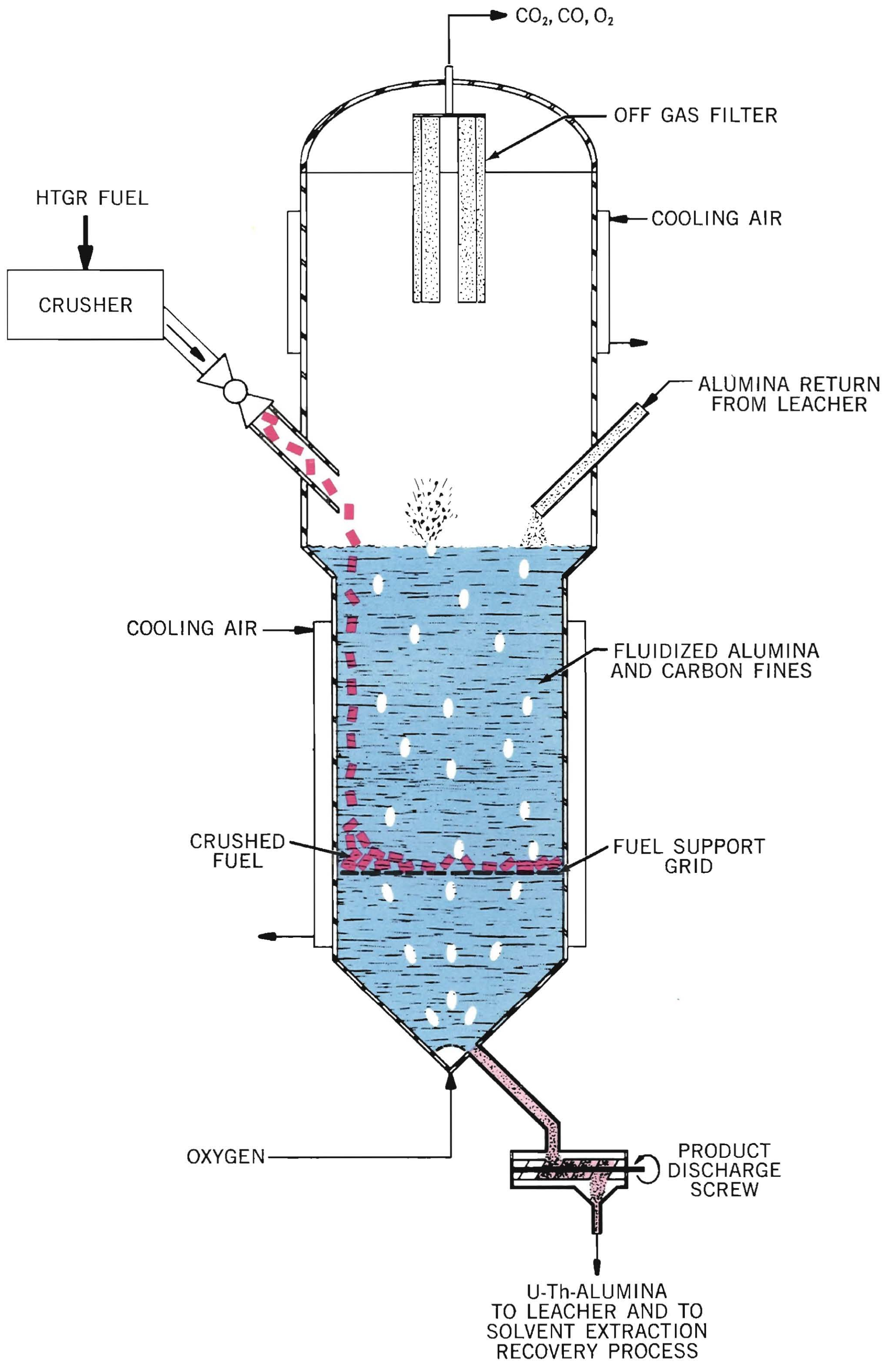


flux reactors; (3) production of the specialty metals cesium, rubidium, and beryllium from their ores; (4) identifying and testing further new extractants; (5) progress in controlling the degradation of extractants when exposed to radiation and reactive chemicals; and (6) progress in understanding the fundamental principles of solvent extraction by liquid ion exchangers.

An interesting *engineering* innovation has been the development of a stacked-clone contactor. In radiochemical processes, irradiation of the organic phase produces decomposition products that can reduce the efficiency of the operation. This effect is expected to be more pronounced in the future processing of power reactor fuels which will experience higher burnup and, thus, contain a much higher level of radioactive constituents than those produced previously. The stacked-clone contactor offers relief from the potential problem, however, because of the short time in which the organic and aqueous phases are in contact, namely, 3 sec per stage, as compared with 30 sec per stage in conventional contactors.

It is gratifying to note that the processes developed at the Laboratory have been found useful by private industry in applications to materials outside the main interests of the Atomic Energy Commission. Also, the success with solvent extraction in the atomic energy program has encouraged research on this technique by private industry, and several new solvents are now used on a large scale.

Meanwhile, solvent extraction continues to be studied at the Laboratory in conjunction with other important separations methods such as distillation, sublimation, adsorption, ion exchange and ion exchange chromatography, other chromatographic separations, and foam separation.



FLUIDIZED BED BURNER FOR HTGR FUEL

In the burn-leach process the crushed HTGR fuel is burned with oxygen in a bed of fluidized alumina particles at 700 to 750°C. The thorium, uranium, and fission products are leached from the alumina with 13 M HNO_3 *(plus 0.05* M *HF, if needed). The alumina, which provides good heat transfer in the burning step, can be recycled to the fluidized bed or stored as waste.*

Power Reactor Fuel Processing

After use in a reactor, spent nuclear fuel normally still contains valuable materials that must be recovered and reused. Thus, chemical processing to recover uranium, plutonium, and thorium is an important part of the nuclear fuel cycle. Processes developed and pilot-planted at the Oak Ridge National Laboratory are used for most fuel processing operations in the world today. These include the Purex process for uranium-plutonium, Thorex for thorium-uranium, and TBP-25 for highly enriched uranium-235. Other developments include the shear-leach head-end treatment, for preparing metal-clad tubular fuel rods for solvent extraction, which will be used at the first commercial processing plant in the United States – the Nuclear Fuel Services facility in New York State – and the chemical decladding methods to be used in Europe at the Eurochemic plant. At the present time, burn-leach and grind-leach head-end processes are being developed for graphite-type fuels for high-temperaure gas-cooled reactors (HTGR). In the field of nonaqueous process development, the fused-salt volatility process was pilot-planted at the Laboratory, and the fluidized-bed volatility pilot plant is now being built here.

HTGR FUEL PROCESSING

In the past year, emphasis has been placed on development of a burn-leach process as a head-end treatment to prepare HTGR fuels for solvent extraction. The HTGR, as typified by the Peach Bottom prototype reactor and the proposed power reactor for Colorado Public Service Company, is one of the most promising concepts of the Atomic Energy Commission's "advanced converter" reactor development program. A typical HTGR fuel, for example, uranium-thorium carbide or oxide microspheres coated with pyrolytic carbon and contained in a massive graphite element, is quite different from the metal-clad oxide fuel of pressurized- and boiling-water reactors, and requires special treatment. Before solvent extraction, it is necessary to remove, or at least break, the pyrolytic carbon coatings to permit dissolution of the uranium and thorium, and it is also necessary to separate the bulk graphite from the fuel. Existing processing plants are not equipped to handle this type of fuel, but provision for it will have to be made before this reactor concept can be competitive.

As developed here through the laboratory and small engineering scale, the burn-leach process involves crushing the element and burning the pieces in a fluidized bed of alumina particles. Removal of radioactive fission products from large volumes of off-gas is the primary problem with the process. The off-gases from the burner, primarily carbon dioxide and carbon monoxide, are passed through micrometallic filters, mixed with steam which is then condensed, and finally passed through absolute filters to remove essentially all fission products except the rare gases xenon and krypton. The xenon and krypton can be discharged safely to the atmosphere at most processing plant locations, though removing them also from the off-gas stream is under study.

A grind-leach process for HTGR fuel is also being studied. The fuel elements are crushed to millimeter size, then ground small enough to break the particle coatings (typically to 80 μ or less) in a roll mill. After leaching with nitric acid to dissolve the fuel, the finely divided graphite is stored as radioactive waste. The off-gas volume is much smaller than from the burn-leach process, simplifying off-gas treatment, but the handling and storage of large volumes of graphite powder containing fission products presents a serious problem.

MOLTEN-SALT REACTOR FUEL PROCESSING

Another very promising reactor concept, under development at the Laboratory, is the molten-salt breeder reactor. Continuous processing of the circulating core and blanket fuel salts with minimal delay is important to achieving attractive breeding ratios and doubling times with this reactor concept. Laboratory- and engineering-scale tests, and also the Molten-Salt Reactor Experiment itself as a hot pilot plant, are being used to study volatilization to recover the uranium-233, vacuum distillation to recover the valuable lithium fluoride and beryllium fluoride, and other methods for removing fission products and recovering the thorium. (See also the section describing the Molten-Salt Reactor Program.)

FLUIDIZED-BED VOLATILITY PILOT PLANT

In cooperation with Argonne National Laboratory and the Oak Ridge Gaseous Diffusion Plant, a fluidized-bed volatility process is being developed as an alternative to solvent extraction for recovering uranium and plutonium from low-enrichment UO_2 fuels. The principal contribution of the Laboratory will be a pilot-plant-scale demonstration with irradiated fuel to obtain data needed in design of a full-scale commercial plant. Design of the fluid-bed equipment is well under way, and major equipment pieces are under construction. Hot operation is scheduled for 1968–69.

Studies on Chemical and Metal Production Using Low-Cost Nuclear Energy Sources

Large quantities of low-cost nuclear energy in the form of electricity and steam will become available with the advent of big dual-purpose reactors that will generate power in addition to desalting seawater. Projected power costs are as low as 1.6 mills/kWh at the desalting site. This is less than most hydroelectric power rates, which currently fall in the range of 2 to 3 mills.

A program is in progress at the Laboratory to survey the chemical and metallurgical industries to determine which processes could use this low-cost energy. On the basis of both literature and laboratory studies, one very promising possibility is the manufacture of hydrogen by the electrolytic decomposition of water. Hydrogen is a key chemical since it is in heavy demand for the manufacture of nitrogenous fertilizer to provide food for the world's growing population. The cost of manufacturing ammonia for fertilizer, using hydrogen produced in recently developed electrolytic cells at low power rates, could be competitive with the cost of ammonia produced by a modern steam-methane reforming plant in localities where the price of natural gas is 34¢ per thousand standard cubic feet (average industrial price in the United States in 1963) or greater. Another phase of this nitrogenous fertilizer program concerns the direct fixation of nitrogen from air at high temperatures using a plasma jet technique.

Other possible industrial chemical and metallurgical products that have adequate market potential and require large quantities of energy for their manufacture include nitric acid, nitrophosphate fertilizer, iron, steel, ferroalloys and phosphorus produced in an electric furnace, arc process acetylene, calcium carbide, chlorine, aluminum, salt, and magnesium.

Waste Treatment and Disposal

The isolation of radioactive waste products from man and his environment is the goal of the waste-management research at the Oak Ridge National Laboratory. No one system will be uniformly applicable; therefore, methods have been devised to separate, homogenize with asphalt, calcine, and melt into a glass matrix the radioactive wastes. The wastes may then be injected into semipermeable shale formations as a cement-waste admixture or stored in impermeable salt mines for ultimate disposal. Since 100% of the waste products can be removed only at inordinate expense, it is fortunate that small nonhazardous amounts may be released safely to the environment.

WASTE TREATMENT

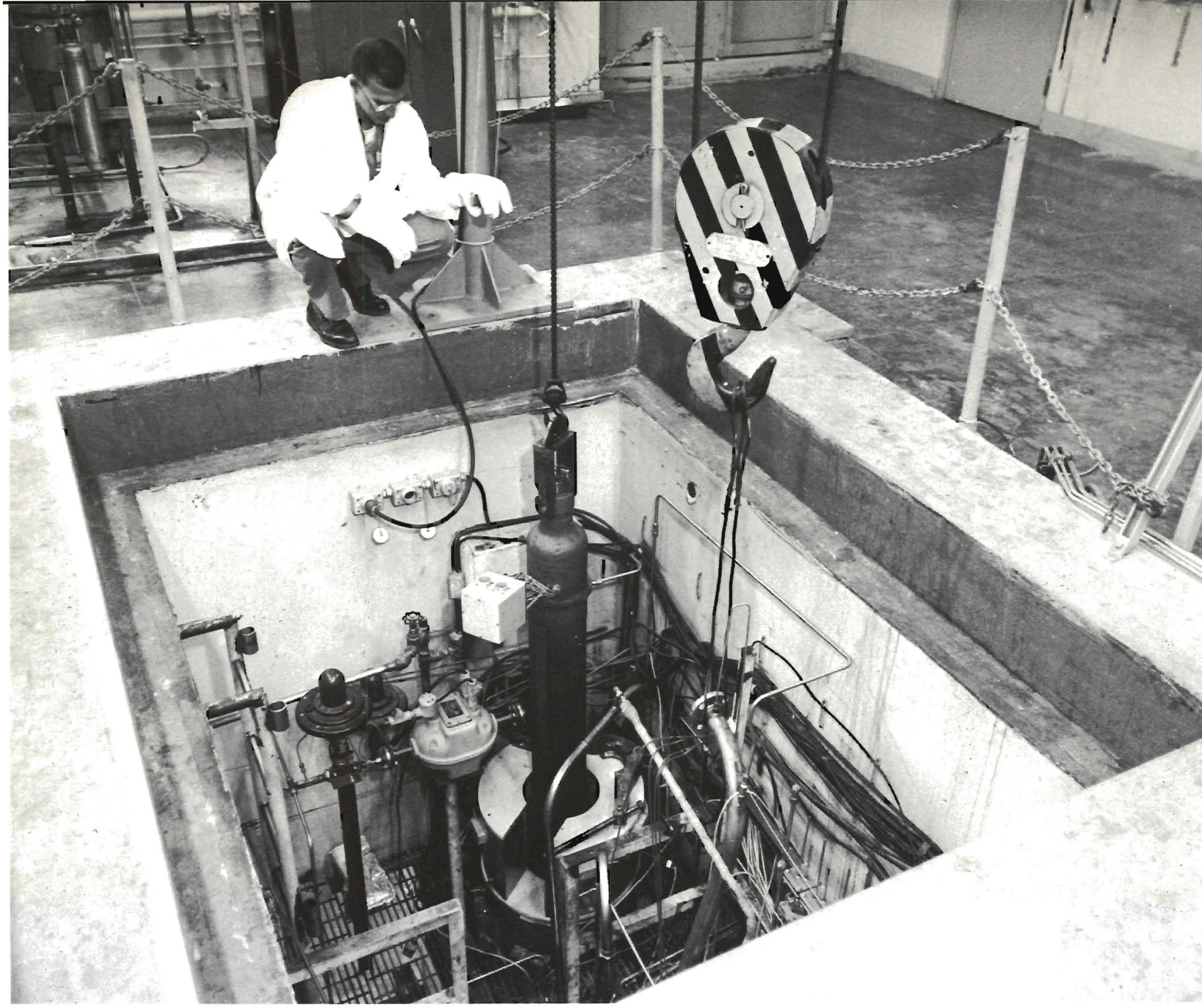
Low-Level Radioactive Waste Treatment

Processes are being developed for removing traces of radioactive elements from large volumes of water prior to discharge to surface streams. Past practice has sometimes relied upon dilution of the wastes by these streams to lower the pollution to drinking-water levels. A newer concept under study consists of decontaminating the water to drinking-water levels prior to discharge. Alternatively, the decontaminated water may be reused rather than being discharged, and in this regard the research is applicable to the recycle of nonradioactive industrial and urban waste waters, where essentially complete demineralization and clarification are required. A water recycle process is now being developed which consists in (1) clarification by zeta-potential-controlled additions of the coagulant, alum, and the coagulant aids, activated silica, and a nonionic polyelectrolyte; (2) demineralization by cation-anion exchange; and (3) sorption of remaining radioactive and nonradioactive contaminants by granular-activated-carbon treatment. Overall decontamination factors of 1000 to 10,000 are achieved for all major radionuclides, including cobalt-60 and ruthenium-106. Up to 2400 volumes of a low-salt-content waste can be treated per volume of cation resin.

Incorporation of Intermediate-Level Radioactive Waste in Asphalt

Incorporation of waste in asphalt or other plastic media and storage or burial of the material is being studied as a general method for treating all types of intermediate-level waste. This proce-

Hydrofracture plant, showing elevated dry storage tanks, injection well cell, and high-pressure injection pump capable of achieving 6000 psi at 100 gpm.



Removal of a pot containing calcined simulated high-level radioactive waste from the furnace. In actual practice the pot would be sealed by welding and shipped to a permanent disposal site.

Drawing a sample of asphalt containing simulated intermediate-level radioactive waste from the mixer-distillation unit. Liquid wastes are mixed with emulsified asphalt, and the water is removed by distillation. The radioactive solids remain in the asphalt.

Waste transporter and 25-ton shield in salt mine at Lyons, Kansas, in position to place solidified high-level wastes into floor of mine using remote-control pendant.

dure is simple, inexpensive, relatively insensitive to the waste type, and largely independent of local geologic and hydrologic conditions. The product may be shipped to a burial site or stored or buried locally. The product is extremely insoluble in water, and less than $\frac{1}{10000}$ of the radioactivity is leached per day from a given sample. Since this is only 1 or 2% of the amount leached from a similar cement product, the material currently used to incorporate waste prior to burial, the use of asphalt may prove to be a safer disposal method. The process consists in adding waste directly to emulsified road asphalt at temperatures up to 100°C, raising the temperature to about 160°C while stirring, and draining the product into a steel barrel which serves as a storage vessel.

The radiation stability of asphalt limits the amount of radioactivity which can be incorporated. Initial studies indicate that asphalt should be satisfactory up to at least 10^8 rads of absorbed radiation.

Calcination and Conversion to Glass

Three solidification processes have been developed for converting wastes from plants processing spent reactor fuels. In the pot calcination process, the waste is evaporated to dryness in a stainless steel pot and then calcined at 900°C. The pot is then welded shut and shipped to an ultimate disposal site. In the alternative processes, glassmaking fluxing additives are added to the waste so that a highly insoluble, glassy mass is formed on evaporation to dryness and heating to 900°C. Development of the calcination process has been completed, but further work is required on the glass processes to minimize corrosion. Both phosphate glasses and lead borosilicate glasses have been investigated.

DISPOSAL IN GEOLOGICAL FORMATIONS

Disposal by Hydrofracture

Laboratory intermediate-level wastes, mixed with cement and admixtures, have been successfully injected into fractures developed 800 to 1000 ft below the ground surface. The Experimental Shale Fracturing Disposal Plant was used for the second year to determine the maximum volume of an injection, the minimum height between injections, and the possibilities of multiple injections into a single slot.

More than one injection has been made in a single slot, and injections of 150,000 gal of wastes have been made in six slots 8 ft apart. These results indicate that it will be possible to achieve economic disposal by hydrofracture techniques using large volumes of waste per injection and closely spaced injections. The intermediate-level wastes from the Laboratory will be evaporated; then it is planned to dispose of the residues in fractures.

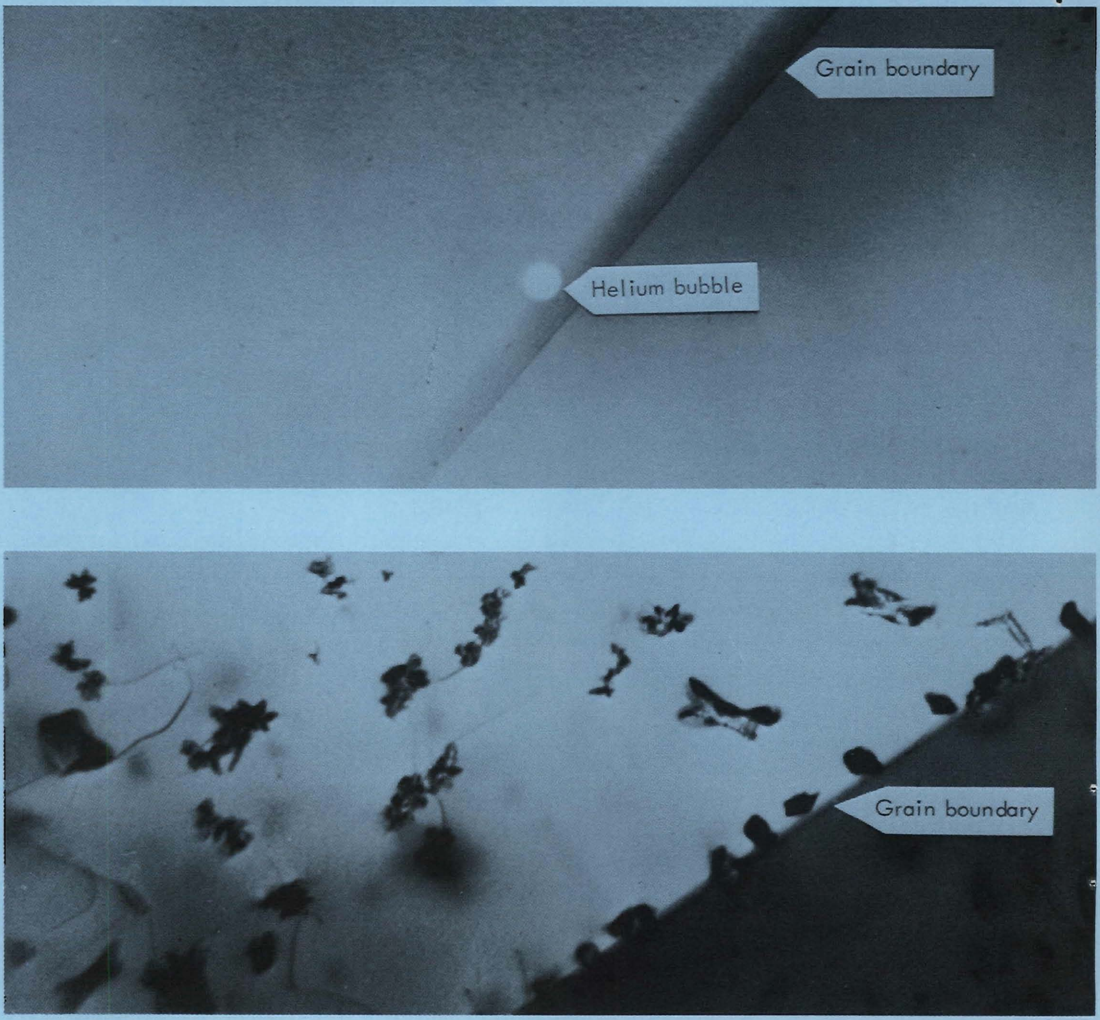
The cement-waste mixtures have been enhanced by the use of various clays with specific retention capabilities for the nuclides of interest. In addition, antifoaming and set-retardant mixtures are added.

Disposal in Salt Formations

Disposal of solidified high-level radioactive wastes in rock-salt formations is considered to be the best approach to the solution of the ultimate disposal problem. In November 1965, 14 Engineering Test Reactor fuel assemblies containing over 1,000,000 curies of fission products were lowered, unshielded, 1000 ft to specially mined chambers in the out-of-service Carey salt mine in Lyons, Kansas. The demonstration uses the irradiated fuel assemblies, because suitable solidified high-level wastes are not yet available.

The specially mined rooms are in a typical mine configuration but above the usual working level of a bedded mine so that the fuel assemblies may be stored in pure salt. The assemblies with auxiliary heat input are arrayed in such a fashion as to simulate a room full of long-cooled fission products. A duplicate array with electrical heating only serves as a control. The transfers with unshielded fuel assemblies were completed using remote controls and resulted in less than 200 mR as the maximum dosage to personnel involved in the transfer operation.

Preliminary results indicate an almost immediate transfer of thermal stresses from the floor to the adjacent pillars and to the roof. This has resulted in an increase in the rate of separation of the 2-ft-thick salt layer from the shale parting immediately above it. The total separation is less than 1 in., while separations as great as 1 ft have been observed elsewhere in the mine. The quick transference of stress from the floor to the roof confirms the preliminary design of backfilling the excavated rooms in an actual operation immediately after filling.



Transmission electron micrographs of irradiated and annealed stainless steel, showing effect of titanium addition. Upper photo shows one of the helium bubbles responsible for high-temperature embrittlement. Lower photo shows lack of bubbles on the grain boundary of the modified alloy. It also shows particles of the titanium-bearing precipitate that is believed to have trapped the transmutation-produced helium.

ENVIRONMENTAL STUDIES

The extent and mode of movement of radionuclides off soil surfaces by runoff and erosion and into the soil profile by infiltration will determine to a large measure the hazard potential of soil-deposited nuclides from fallout, routine operations of nuclear facilities, and peaceful uses of nuclear explosives. To obtain a more realistic estimate of these effects, small field plots were deliberately contaminated with cesium-137. The plot surfaces were bare soil, clipped meadow, and tall meadow. After 53 in. of rainfall in one year, the cesium loss from the bare plot was almost twice as great as from the clipped meadow and almost five times as much as from tall meadow plots. The losses were experienced mostly during five intense rainfalls during the winter and spring seasons. The soil losses also occurred during that time, as predicted by theory. At the end of the year, the concentration of cesium-137 in the vegetation was one one-billionth of that in the original vegetation, indicating no cycling of the cesium into the grass grown on these deliberately contaminated plots. The specific activity of the soil lost from the bare plot was only one-sixth of that of the soil lost from the vegetation-covered plots. This higher activity is primarily due to the large leaching loss from the vegetation and litter and the smaller amount of erosion.

Mechanical Properties Research

Metals and other materials used in nuclear reactors are subjected to environmental conditions more severe than those encountered in most other technologies. The Laboratory therefore has a continuing program studying environmental effects on the ability of materials to maintain their mechanical functions. The major recent emphasis has been on the effect of radiation on the strength and ductility of structural metals and graphite. Two important recent accomplishments in this area have been the explanation and alleviation of the high-temperature radiation damage in stainless steel and the demonstration that graphite under irradiation deforms to accommodate in-service strains.

IRRADIATION OF STRUCTURAL METALS

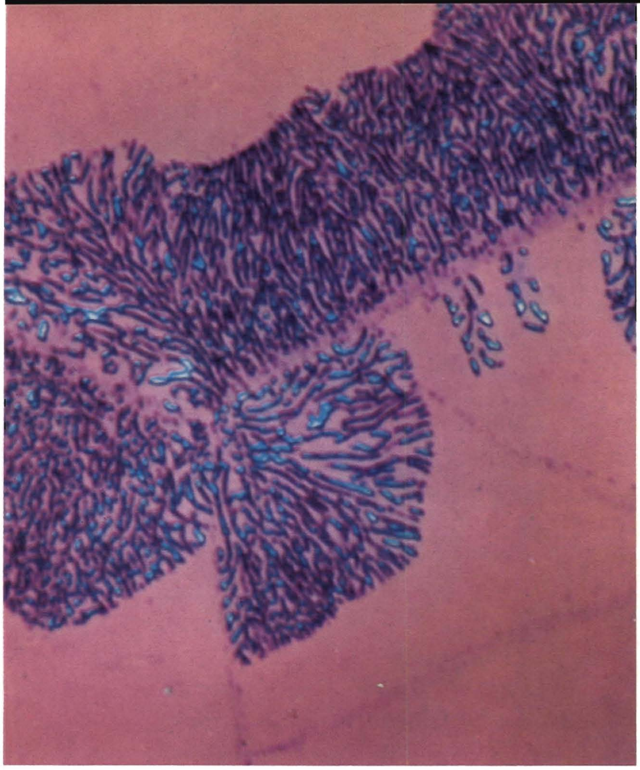
The most commonly observed effect of radiation in metals is an increase in yield strength (resistance to permanent deformation in short-time tests) and a decrease in ductility (ability to deform rather than fracture under loads exceeding the yield strength). These effects arise from atoms being displaced from their normal positions by collisions with high-energy neutrons. This type of damage is observed only when the irradiation occurs at temperatures below half the absolute melting point. At higher temperatures the atoms are so mobile that the equilibrium structure is maintained during irradiation or restored during postirradiation annealing.

A second type of damage was observed when irradiated iron- and nickel-base alloys were tested at temperatures high enough to anneal out the first type. They were severely embrittled without much change in strength. The high-temperature damage was of primary concern because it occurred in a common service temperature range for these materials. Work at the Laboratory and elsewhere traced this damage to grain-boundary accumulation of helium bubbles; the helium came partly from alpha particles produced by the thermal-neutron reaction $^{10}B(n,\alpha)^{7}Li$.

Recent experiments at the Laboratory have both improved understanding of the high-temperature damage to type 304 stainless steel and shown ways to decrease it. First, preirradiation heat treatments that reduced the grain size improved the postirradiation ductility. Purification of the alloy from boron did not eliminate the damage but decreased it to a level that was unrelated to the residual boron concentration. In this way a substantial part of the damage was traced to (n,α) reactions of other elements, notably iron, nickel, and nitrogen, with the fast neutrons that are invariably present in a reactor. (This type of damage becomes especially important in fast reactors.) A major improvement in postirradiation ductility came from incorporation of small amounts of titanium in the alloy. This element combines with boron and other elements to form a fine dispersion within the alloy grains. The dispersed particles trap helium at sites that are away from the sensitive region and are too numerous to permit bubble formation. Also, helium from boron is formed at these sites rather than at the grain boundaries. The maximum improvement in postirradiation ductility was obtained with 0.2% titanium in the stainless steel. In another method the dispersion of up to 0.1% aluminum oxide in the steel improved postirradiation ductility. This addition either refines the grain size of the steel or provides sites where helium can segregate.

IRRADIATION OF GRAPHITE

Graphite demonstrates a relatively complex dimensional instability under irradiation. Thus, graphite moderator blocks subjected to thermal gradients and fast-neutron flux gradients will experience differential dimensional changes that can introduce large strains in the graphite. These strains in many cases are larger than the normal fracture strains for graphite. However, it has been observed at the Laboratory that graphite will undergo irradiation-induced creep (permanent deformation on prolonged exposure to stresses too small to cause significant strain in short-time tests). With this as a possible way of accommodating the dimensional changes, in-reactor creep experiments are being made to measure the magnitude of the creep strain. For example, it has been found that graphite, which normally fractures at strains of about 0.2%, will absorb strain in excess of 0.45% under fast-neutron irradiation. Thus graphite can be used as a moderator in reactors with less fear of damage to complex mechanical shapes.



Microstructure of zirconium-niobium alloy with superconducting properties enhanced by heat treatment. Sufficient heating in the range 600 to 950°C converts a portion of the alloy to a mixture of layers with two different compositions. Alloys so treated can carry heavier currents in the superconducting state than the same alloys as produced commercially at present.

Enhancement of Superconductivity by Metallurgical Treatment

The commercially important niobium-zirconium superconducting alloys (20 to 60% zirconium) are normally given a precipitation heat treatment before final severe cold working to obtain the highest critical currents in high magnetic fields. Recent studies at the Laboratory have shown that additional large increases in critical current in these alloys can be obtained by subsequent heat treatment to form multiphase microstructures. Heating for sufficient time in the temperature range 600 to 950°C will cause the cast, annealed, or cold-worked single-phase structure in these alloys to transform to a lamellar structure consisting of a zirconium-rich phase and a niobium-rich phase, resembling the microstructure known as pearlite in transformed steels. Independent control of the distribution and volume fraction of the lamellar structure and of the platelet thickness and spacing within that structure can be obtained by appropriate choice of composition, initial grain size, amount of cold working, heat-treating time, and temperature of transformation. A maximum increase of nearly 20 times the critical current has been produced in commercial niobium–33% zirconium alloy by heat treatment at 750°C, transforming 30% by volume of the alloy to the lamellar product. After this treatment, there is a continuous grain-boundary network of the lamellar structure, and the platelets of the zirconium-rich phase are between 0.1 and 0.2 μ thick with an interlamellar spacing of 0.6 μ.

High-Temperature Physical Property Measurements

Knowledge of high-temperature physical properties enables realization of the full capabilities of materials, particularly in uses such as nuclear fuel elements, where heat conduction limits performance. However, useful measurements of these properties are time consuming, difficult, and expensive, so that data for high temperatures are very incomplete. The Laboratory has been filling this void by developing diverse and accurate measurement methods and using theoretical interrelationships to permit reliable prediction of properties difficult to measure. Recent accomplishments include a thorough study of the thermal conductivity and other properties of tungsten and the development of a very rapid method for measuring specific heat.

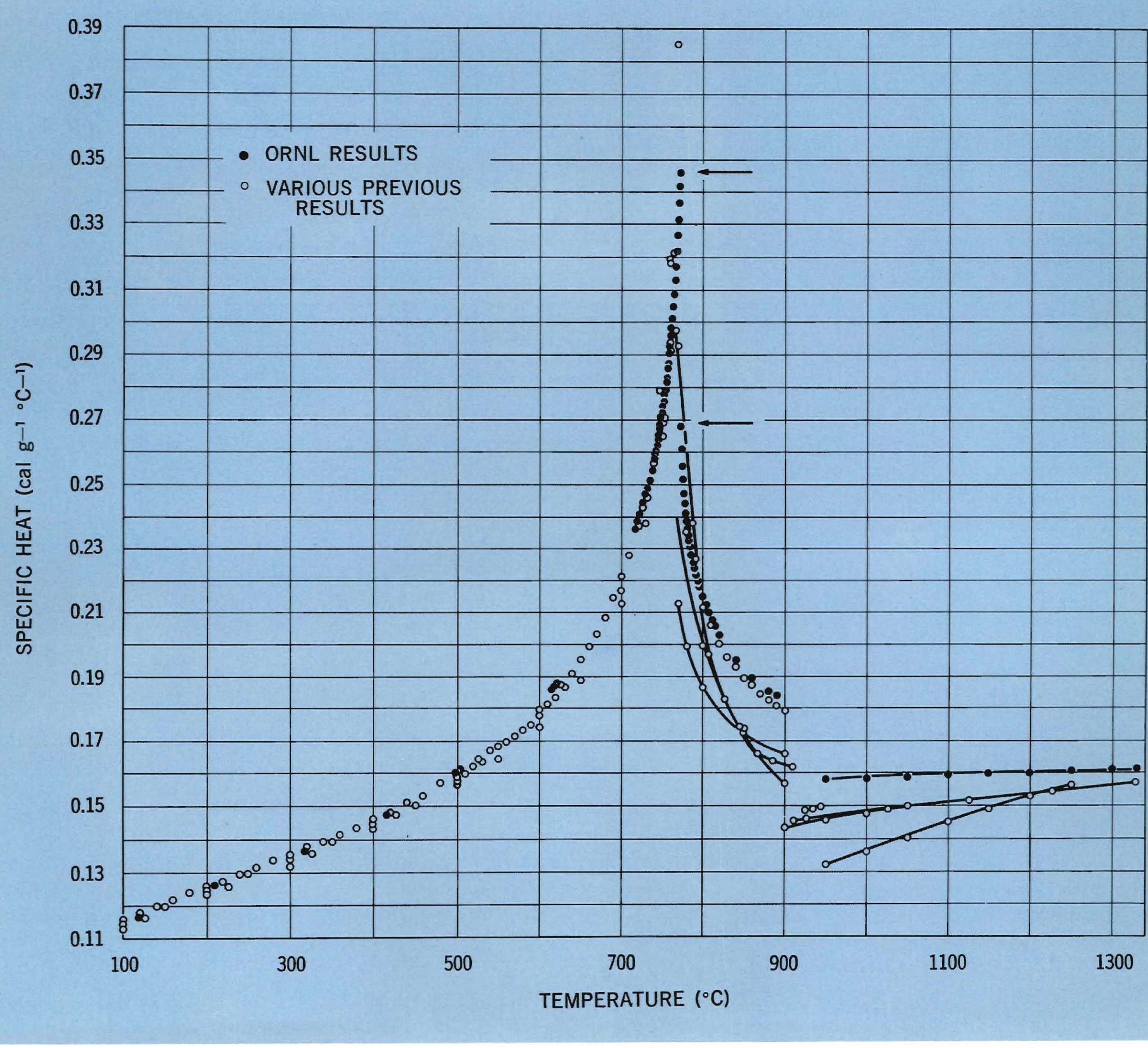
PHYSICAL PROPERTIES OF TUNGSTEN

Tungsten, because of its high melting point, is a material of especial interest in reactor technology. Thermal conductivity measurements have been made on a large, pure, and dense tungsten specimen in a radial heat flow apparatus. Thermal conductivities accurate to within ±1.5% were obtained between −200 and 1000°C; the values decreased monotonically with temperature. In the range 350 to 800°C, these data are the first to be obtained by a reliable method. Simultaneous measurements of electrical resistivity and thermoelectric power of this tungsten in the range −269 to 1400°C were used to calculate the electronic portion of the total thermal conductivity and to predict the thermal conductivity to 1400°C to a certainty of better than ±3%. The calculated lattice thermal resistivity was not the expected linear function of temperature, and became excessive when extrapolated to the melting point of tungsten. These disturbing factors may be caused by a more complicated relationship between electronic thermal conductivity and electrical conductivity than customarily used. Fortunately, a method of treating the data was found that removes the disturbing behavior of the lattice thermal resistivity. This extension of theory has indicated that the precise behavior of electrical resistivity to high temperatures holds the key to a consistent analysis of heat transport mechanisms. Measurements are now being extended to 2200°C.

SPECIFIC HEAT OF IRON

Specific heat is a fundamental quantity needed to calculate other thermodynamic properties. The Laboratory has therefore developed and tested a rapid pulse-heating calorimetric technique for measuring the specific heat of any electrical conductor between 100 and 900°C. A direct current is used to self-heat an instrumented specimen suspended in a constant-temperature blackbody vacuum chamber. To measure the specific heat of a solid, the current flowing through the specimen is increased suddenly, and the time dependence of the specimen temperature change and power dissipation is recorded to within ±0.1% accuracy. Results on an iron specimen agreed within ±2% with those of other studies from 100 to 900°C, except at the Curie point, where a previously undetected 33% discontinuity in the specific heat was found. These measurements are being extended to other ferromagnetic materials, and their theoretical implications are being examined.

The specific heat of iron as a function of temperature, as measured by a pulse-heating method. Note the specific heat discontinuity at the Curie point, indicated by arrows marking points representing two measurements at essentially the same temperature in the same experiment.

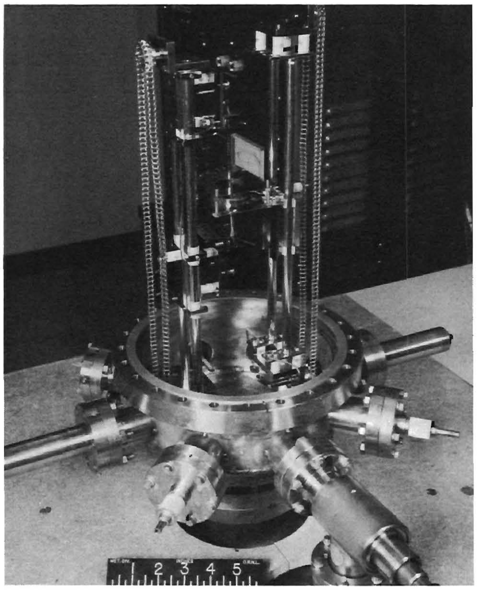


Zirconium Crystal Research

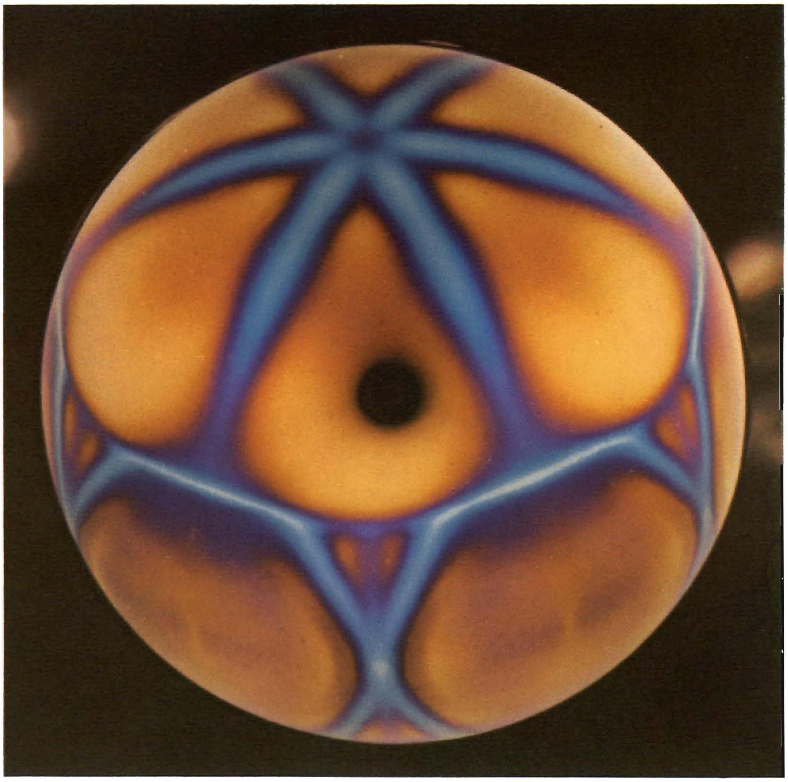
Metallurgists at the Oak Ridge National Laboratory have pioneered the use of zone refining with electron-beam heating for purifying zirconium and growing single crystals. Recently a unique high-vacuum electron-beam zone refiner has been used to prepare crystals of unusual purity. Measurement of the low-temperature electromagnetic properties of these crystals has contributed to the understanding of the nature of the electron energy bands in zirconium.

The device has also been used to prepare superconducting alloys of zirconium, hafnium, niobium, and tantalum, some extremely pure and others having known additions of typical impurities. Studies of such specimens have shown that particular impurities play a significant role in determining current-carrying capacity in strong magnetic fields.

Electrical discharge machining has been used to form zirconium crystals into spheres for study of directional effects on various properties, such as oxidation rate. Use of a sphere not only permits obtaining the same information on one specimen that would require many flat specimens but also assures that no crystallographic plane is overlooked. From the large variation in oxidation rate observed for small differences in crystal direction, large differences in the oxidation rate would be expected for different lots of the same polycrystalline alloy with seemingly minor differences in preferred orientation.



Electron-beam zone refiner for extreme purification of reactive metals, shown with the stainless steel bell jar removed. In this device a very sharply focused electron beam melts a short zone of the rod-shaped specimen. Unique chain-drive elevators are coupled magnetically to the exterior to give free and independent motion of the electron gun and the specimen without trapping of gas. As the molten zone moves along the specimen rod, some impurities are swept to the end of the rod, while others evaporate into the ultrahigh vacuum. In the sharp temperature gradient in the wake of the molten zone, the metal forms sizable crystals. Measurements of the electrical resistance of zirconium crystals prepared in this way indicate that they contain only one-third to one-half as much impurity as the best previously available zirconium.



A single-crystal sphere of zirconium, oxidized in air 20 min at 360°C. Sufficiently thin oxide films exhibit interference colors, which are a measure of their thickness. In this photograph the light blue indicates the greatest thickness of oxide, 800 Å. Thinner films are successively dark blue, purple, brown-yellow, and gold (350 Å). The color pattern clearly demonstrates the anisotropy of oxidation. The center of the six-pointed star is the basal pole, where the surface consists of the closest-packed plane of atoms in the crystal. On this plane the rate of oxidation can be two to four times as great as for directions only 20° away. The black circle is a reflection of the camera lens and is unrelated to either the oxidation pattern or the perfection of the crystal.

Biological Sciences

Work in the biological sciences at the Laboratory is centered in the Biology and Health Physics Divisions. The work in the Biology Division has emphasized the action of radiation and, more recently, of chemicals on living things at various levels from the whole animal to the molecular. The investigations are designed not only to explore these specific problems but to contribute to basic knowledge in such fields as biophysics, biochemistry, genetics, immunology, experimental pathology, and developmental biology. Important recent developments are cooperative programs with the National Institutes of Health and the National Aeronautics and Space Administration. There has been an increasing trend for collaboration with the chemical technology and engineering specialists of the Laboratory in solving problems requiring large-scale isolations and containment.

The work in the Health Physics Division has as its purpose the protection of man and his environment from unwarranted radiation exposure. Because of this wide-ranging charter, the research activities extend from fundamental studies of the interaction of radiation with matter to dosimetry, to transport and accumulation, to effects on the biosphere, and to engineered systems to prevent the spread of radioactive materials.

Representative examples of these various kinds of work are given in these pages, but they can give only an incomplete picture of the broad scope of the biological work at the Laboratory.

Biology Division, Oak Ridge National Laboratory

BIOLOGY

No Radiation-Induced Cancer in Mice Exposed Prenatally

A correlation has been reported between exposure of pregnant women to diagnostic x irradiation and an increased risk of cancer to their exposed children. Biologists at the Laboratory have not confirmed this association in the one mouse strain (RF) tested in experiments thus far. In fact, life expectancy, as well as the incidence of leukemia and other neoplasms, was affected relatively little in mice that were exposed during various stages of fetal development, whereas such exposures lead to marked effects in mice irradiated after birth. The significance of these results for human beings may be complicated by the absence in immature mice of neoplasms analogous to the childhood cancers which have been reported to be associated with prenatal irradiation in man.

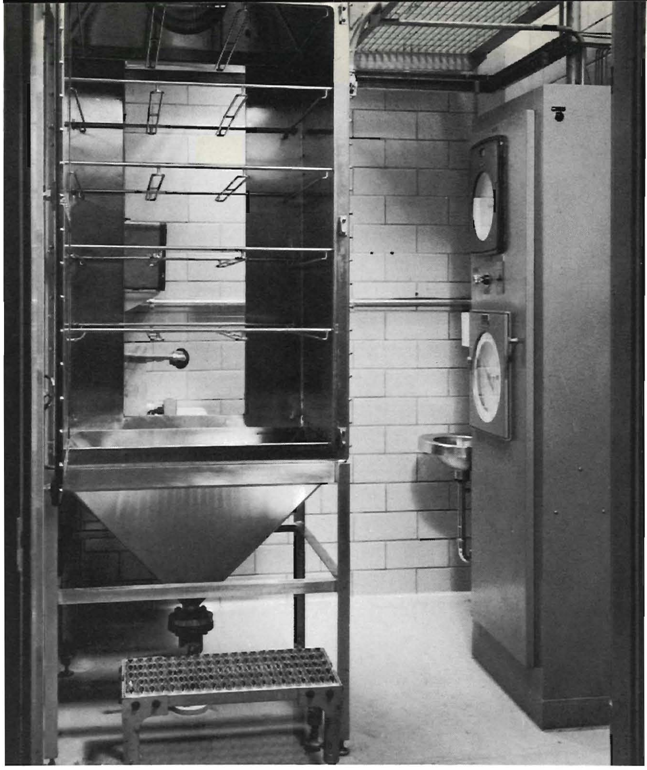
Pregnant mice were exposed to fixed levels of x irradiation at a definite time during their 20-day gestation period, whereas pregnant "control" mice were treated identically except that they were not irradiated. After treatment, the two groups were returned to their cages, and their pregnancies were allowed to come to term. Their litters were weaned at three weeks of age, caged by sex and treatment, observed thereafter throughout life, and autopsied at death. It was found that exposure to 50 or 150 R of whole-body x irradiation at 9.5, 12.5, or 17.5 days in gestation or to 300 R at 17.5 days in gestation neither significantly increased mortality *before* birth, nor increased the incidence of leukemia and other diseases *after* birth. These findings substantiate earlier data that had also failed to reveal significant carcinogenic effects induced by irradiation of mice during gestation.

The observed resistance of the mouse fetus to life shortening and carcinogenesis contrasts with its generally high sensitivity to other types of radiation injury. The explanation for the observed lack of susceptibility is being sought in further experiments and may provide important clues as to the mechanisms of radiation-induced life shortening and cancer.

Chemical Inhalation Carcinogenesis

Increasing emphasis is being placed on the detrimental effects to man of atmospheric pollution. One example of this is the worldwide increase in the incidence and severity of lung cancer, which, in part, seems to be related to environmental conditions. Such factors as virus infection, atmospheric pollution by chemicals in the form of aerosols in both urban atmospheres and work environments, and possibly radiation have been implicated. These epidemiological observations indicate the need for studies aimed at establishing the significance of these factors and elucidating the biological and biochemical changes that finally give rise to lung cancer. The objective of the joint Atomic Energy Commission–National Institutes of Health Inhalation Carcinogenesis Program is an examination of the role that these factors play in the experimental induction of pulmonary tumors in mice. Correlated with this will be a study of the effects of viruses and chemicals on the various systems in the animals.

The experimental design is to subject six-week-old C57/BL6 mice to either an initial insult of radiation, influenza virus, or both sequentially, and upon recovery to expose the animals either to a gasoline smog or to an inorganic chemical dust in inhalation chambers daily throughout their life-span. At appropriate intervals, animals will be killed, examined for lung-tumor induction and growth, and compared with suitable irradiated, virus-infected, and washed-air control animals. Success is heavily dependent on both knowledge and control of the chemical, biological, and viral condition of the animals. To supply the necessary high-quality animals for this work, an isolation breeding colony has been established that is free of bacteria pathogenic to the mouse, of nine mouse viruses, and of endo- and ectoparasites. Currently, studies have been started in six inhalation chambers, each containing 540 mice that are exposed daily according to the protocol. An IBM data-recording system has been devised to aid in controlling the breeding colony, and a program is under development to record all pertinent chamber data and bacteriologic, virologic, histologic, and pathologic information. At present, the exposure time has not been long enough and the animals are not old enough for any marked changes in the lungs to be seen.



Inhalation chamber for studying effects of carcinogenic aerosols

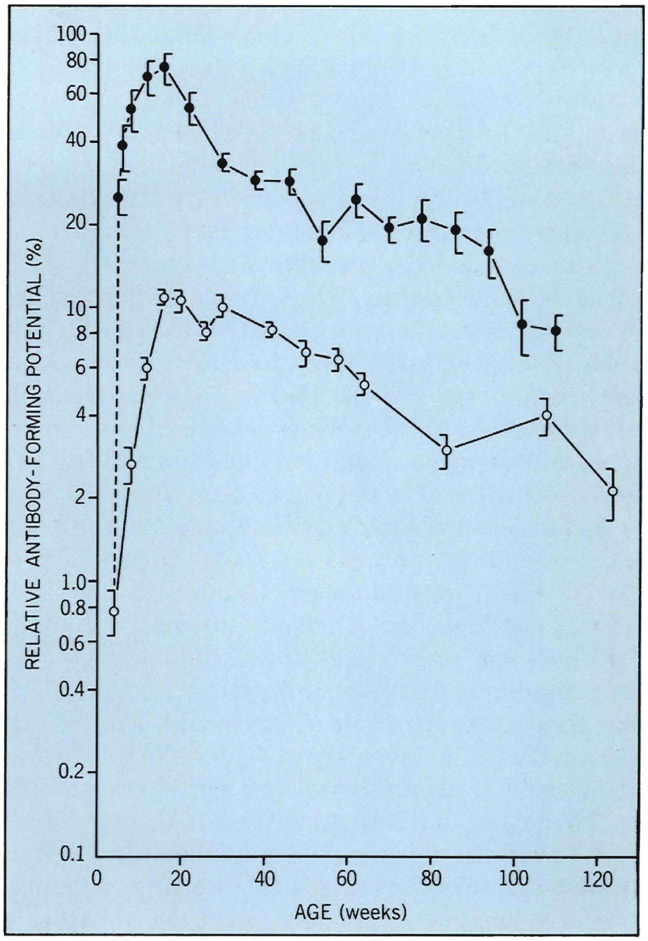
Transfer of mice from holding racks to inhalation chambers for exposure to carcinogenic aerosols

Growth and Senescence of the Immune Mechanism

The immune system is known to play an essential role in aging. Therefore, quantitative studies are being conducted on the changes in this system with age in mice. The capacity to respond to antigens increases rapidly during the early life of the mouse. Previous work showed that the potential of the spleen to form antibody after the *first injection* of a specific antigen increases by a factor of up to 600 between one week of age and the time of immunological maturity at about six months of age. This increase in potential was shown to result primarily from increase in the number of antigen-stimulable progenitor cells in the spleen.

More recently this same increase in potential has been detected for the so-called secondary response. When mice were given a priming injection of antigen at one month of age and their potential to form antibody in response to a second injection of antigen was followed thereafter as a function of age, there was an even faster growth of progenitor cells. Thus within a week after priming, this potential increased 32-fold. The age of peak potential for response to a second injection of antigen coincides with that for response to a first injection.

Beyond the age of maximum numbers of progenitor cells in the spleens of unprimed and primed mice, there was a steady decline in the number of progenitors. In both, the number of progenitor cells declined to half in ten months. The loss of progenitor cells was considered to be indicative of senescence of immune potential and to reflect an increasing inability of the animal to cope with foreign materials—especially severe infections. These results suggest that "banking" of progenitor cells for a later transfer back into the animal after it has become old, thus effecting *immunologic rejuvenation,* may now be an exciting possibility.



Relative primary and secondary antibody-forming potential per spleen as a function of age of mice. Maximum response of 100% is equivalent to the highest observed 6-day $\log_2$ titer of 12.0. ○, primary response; ●, secondary response; vertical bars are standard errors.

Mutation Frequency in the Mouse

Major changes in the estimation of genetic hazards of radiation have been made in recent years as a result of research on a number of factors that have turned out to have marked effects on radiation-induced mutation in mice. Until the late 1950's it was generally held that the frequency of radiation-induced mutations was *independent* of dose rate. In 1958, however, it was discovered in Oak Ridge that radiation dose rate *did* affect mutation frequency in the male (spermatogonia) and female (oocytes) reproductive cells of the mouse. Recent studies indicate that the genetic risks from small radiation doses, like those from low dose rates, may be lower than had been estimated on the basis of mutation frequencies from large doses at high dose rates. Increasing evidence has been obtained indicating that the reduced mutation frequency at low dose rates may be due to repair of premutational damage. This suggests that the mutational process may be affected by many more factors, including naturally occurring variables, than was heretofore supposed. One example of this is that the dose-rate effect is greater in females (oocytes) than in males (spermatogonia). Certain dose fractionations in spermatogonia have been found to have an augmenting effect on mutation frequency that is quite large when the fractions of the dose are separated by critical time intervals.

The qualitative nature of the mutations induced by x rays in oocytes differs from that in spermatogonia, the relative frequency of deficiencies, for example, being higher in the former. A similar difference occurs between neutron- and x-irradiation-induced mutations within the spermatogonial stage alone. Qualitative differences of this sort tend to invalidate a reliance on solely quantitative measures of comparison, such as relative biological effectiveness.

In females the interval between irradiation and conception has recently been shown to have a profound effect on mutation frequency. The frequency is high in offspring of matings made within a few weeks of exposure, but drops to approximately control levels in later matings. This has been convincingly and strikingly demonstrated for fission-neutron irradiation. There is some indication of a similar effect with gamma and x irradiation, but tests with gamma and x rays are hampered by rapid loss of fertility at the doses necessary for easy measurement of mutation frequency.

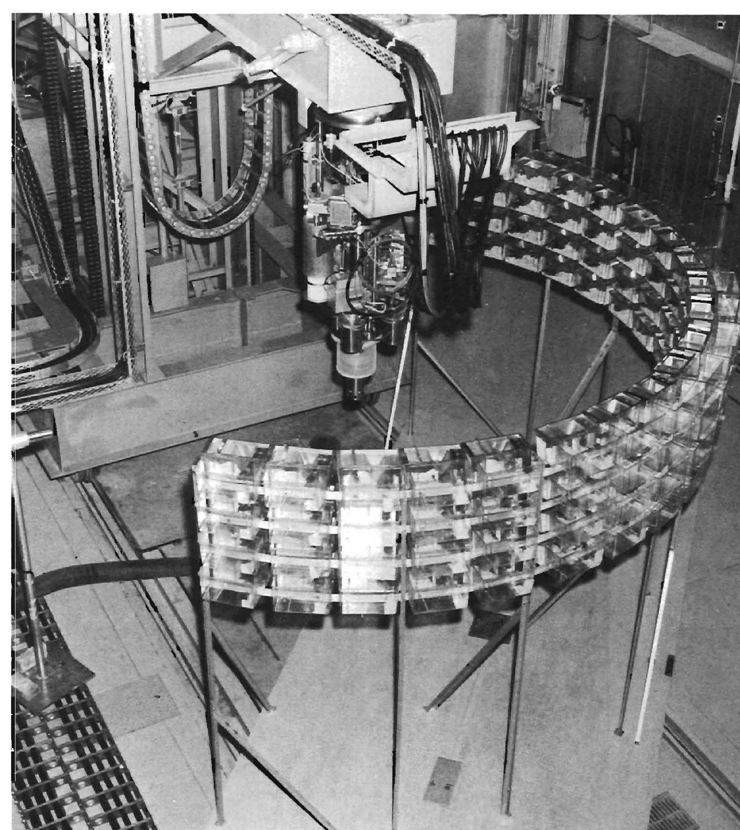
The dose-effect curve for mutations induced by fission neutrons in spermatogonia shows a descending slope after a certain peak effect. The same phenomenon had been found for x rays, but the effect occurs at a much lower dose level with neutrons. With fission neutrons, no dose-rate effect on mutation has been found in spermatogonia, but there is some evidence of a dose-rate effect in oocytes.

Gemini Blood Experiments

Samples of human blood, in a specially devised container, accompanied the Gemini III astronauts on their three-orbit flight in March 1965. The blood samples were used to determine the combined effect of weightlessness and radiation. The experiment was carried out at the request of the National Aeronautics and Space Administration under an interagency agreement between that agency and the Atomic Energy Commission because data from previous space flights, both ballistic and orbital, had suggested an increased radiation hazard in space due to some unknown factor. Mutation, chromosomal aberration production, and cell killing had been reported at much higher levels than would have been predicted from the radiation exposures received during flight. This unpredicted radiation effect (if it actually existed) could have been due to synergistic interaction of radiation with the unique environmental features of space flight.

The only test of this possibility was to perform a radiobiological experiment during a space flight. Human blood was chosen as the biological material because the effects of dose, dose rate, quality of radiation, and various environmental factors on the production of chromosome aberrations have been thoroughly studied, and because the data could be directly applied to the question of space-flight hazards. Phosphorus-32, a beta-active radioisotope, was selected as the source of radiation.

The experimental unit consisted of blood sam-



Mice exposed to fission neutron radiation in the Health Physics Research Reactor for mutation frequency studies by the Biology Division.

ples stored in plastic holders, source plates on which the phosphorus-32 had been deposited, and an instrument for recording time, temperature, and radiation intensity. These components were sealed in a small housing mounted on the hatch of the spacecraft. The flight crew actuated the unit after the spacecraft was in orbit and a state of weightlessness had been reached. For comparison, a control series of blood samples was also irradiated; these were identical to the experimental samples and were irradiated at the same time, but they remained on the ground during the flight. Blood samples taken from the Gemini III flight crew before and after the flight were also analyzed.

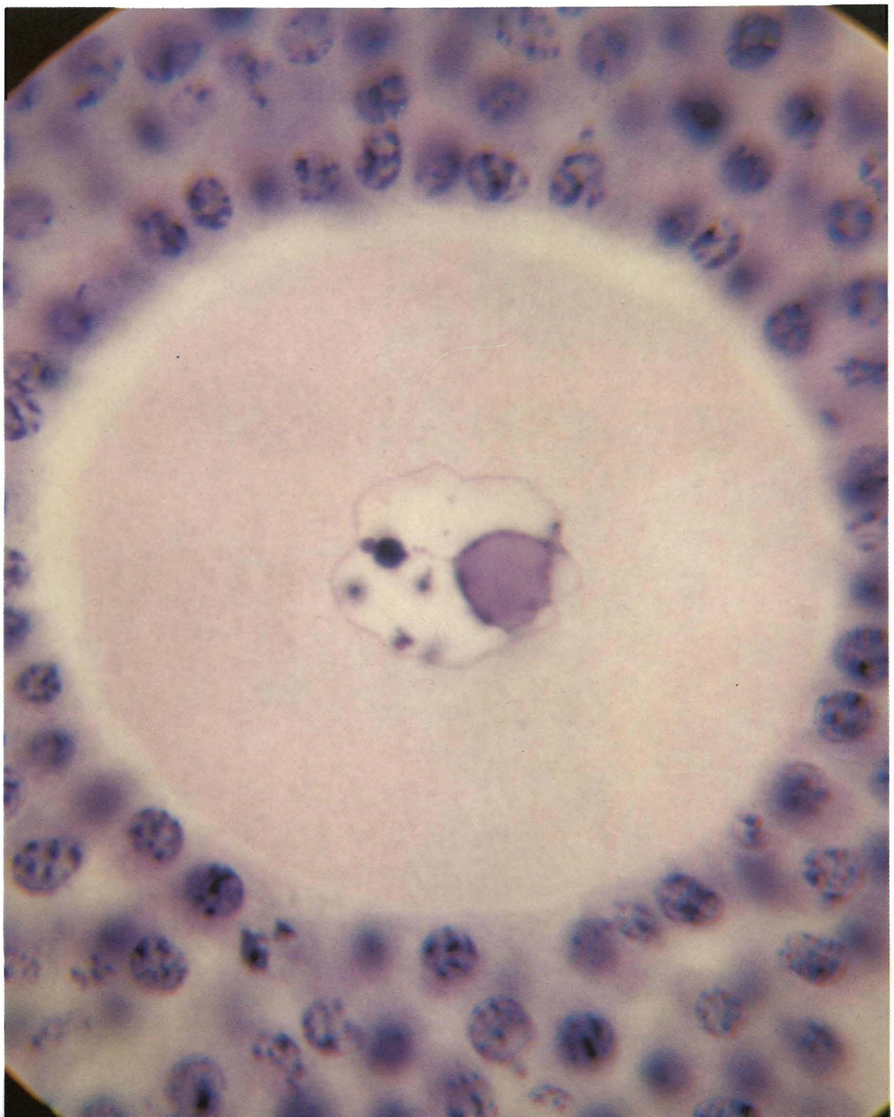
The parameters measured were the frequencies of the various types of single- and multiple-break chromosome aberrations. As expected, the blood samples obtained from the astronauts after the flight showed no increase in aberration frequency. This finding makes it unlikely, at least for genetic systems such as the one used for this experiment, that the radiation encountered during such a space flight has an unprecedented effect.

The irradiated samples yielded the expected types of aberrations, that is, ring chromosomes, dicentric chromosomes, and deletions. The ring and dicentric yields for the flight and ground

(Text continued on page 52.)

Photograph of a chromosome set from the Gemini III project.

An oocyte in the ovary of a female mouse.

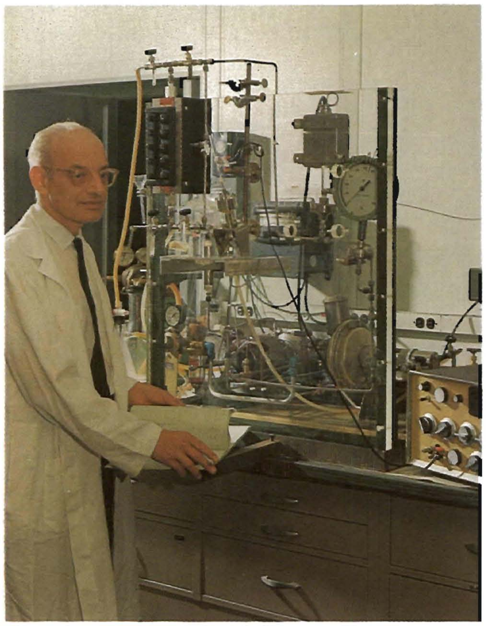


Awards

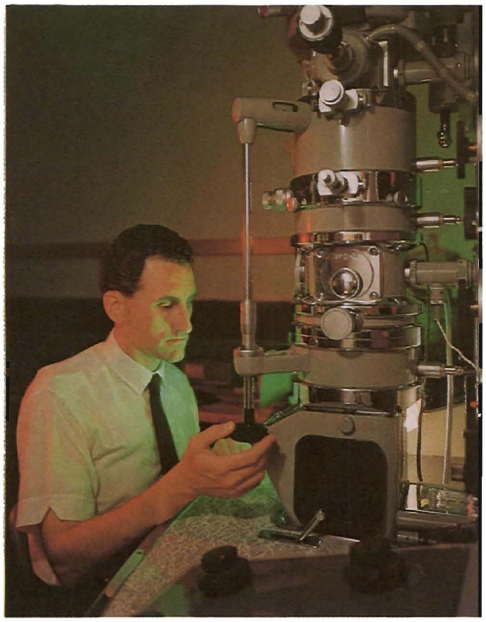
Two ORNL staff members were recipients of the E. O. Lawrence award in 1965. The award is made annually to honor scientists for recent meritorious contributions to the field of atomic energy. Floyd Culler received the award for his important contributions in the development of processes for the recovery of irradiated nuclear reactor fuels. He was formerly Director of the Chemical Technology Division and is now Assistant Laboratory Director for Engineering.

Arthur Upton was recognized for his outstanding contributions to radiation biology and to the pathology of radiation injury. Dr. Upton is Chief of the Pathology and Physiology Section of the Biology Division.

Kurt A. Kraus received the American Chemical Society Award in Chromatography and Electrophoresis in recognition of his outstanding contributions to the field of ion exchange. Dr. Kraus is Director of the Laboratory's Water Research Program.



P. R. Bell was awarded the Edward Longstreth Medal by the Franklin Institute. The award was made for Bell's investigation of the complex phenomena associated with scintillation spectrometry and for his work leading to the practical, routine use of spectrometry in medicine. His instrument facilitates accurate diagnosis by rejecting scattered radiation. Dr. Bell is primarily responsible at present for the DCX-2 experiment in fusion research.



Kenneth Farrell was presented the Andrew Carnegie Silver Medal by the American Society for Metals on behalf of the Iron and Steel Institute of Great Britain for his contribution to the knowledge of hydrogen embrittlement of steels. Mr. Farrell is a metallurgist in the Electron Microscopy Group of the Laboratory's Metals and Ceramics Division.

Eugene Guth received the Eugene Cook Bingham Award for his important contributions to the theory of rubber elasticity. Dr. Guth is on the staff of the Laboratory Director.

control experiments did not differ significantly from each other. The yields of deletions in the flight experiment, however, were roughly *twice* those found in the ground control experiment and the previous control experiments. This difference is statistically significant. Furthermore, both the physical evidence and the aberration data contradict the possibility that the flight and ground samples received significantly different radiation doses.

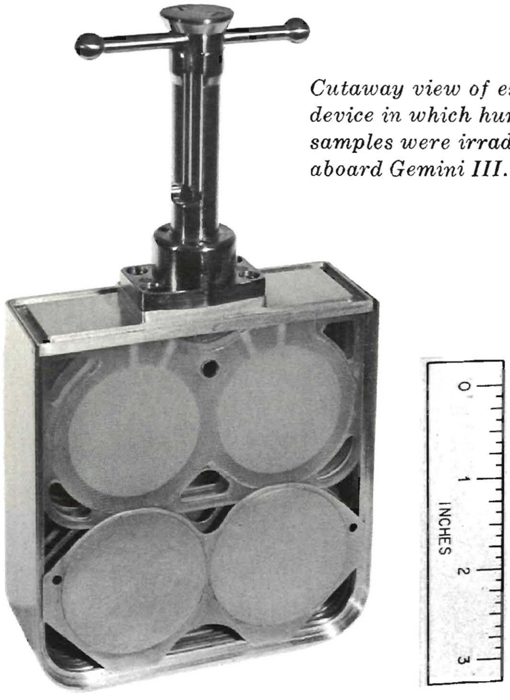
It appears, then, that some space-flight parameter does, in fact, interact synergistically with radiation. Additional experiments are planned for the Gemini series which will help to further elucidate this effect.

Photoreactivation and Mutation Induction in *Neurospora*

Photoreactivation of ultraviolet-induced lethal and mutagenic damage has been known for some time in bacteria. Many, though not all, cases of photoreactivation result from enzymatic splitting of the pyrimidine dimers induced in deoxyribonucleic acid (DNA) by ultraviolet. Similar photoreactivation of mutagenic damage has been analyzed in detail at the Laboratory for one particular genetic locus in the mold *Neurospora.*

Previous work had shown that the mutations at this locus could be subdivided into several categories on the basis of their ability to complement each other's metabolic deficiencies when present together in a common cytoplasm. These classes differ markedly from one another in the frequency of specific genetic alterations, as judged by studies on reversion to normal using chemical mutagens of known action. Certain classes include mainly base-pair substitutions, whereas others contain a large proportion of single base-pair insertions and deletions or of deficiencies for a whole section of the chromosome.

The present work demonstrates that all complementation classes are equally decreased by photoreactivation. Thus the initially photoreactivable lesions must be able to produce more than one kind of final mutational alteration. If, as seems quite probable, the initial photoreactivable lesions are pyrimidine dimers in DNA, then this single type of lesion must be able to produce more than one kind of mutation.



Cutaway view of exposure device in which human blood samples were irradiated aboard Gemini III.

Repair of DNA

An important finding in recent years, and one in which the Laboratory has played an important part, is that cells have enzyme systems to repair the damage induced in DNA by radiation and probably also by some chemicals. Molecules of DNA, the repositories of hereditary information found in all cells, are made up of unique arrangements of four main chemical groups: thymine, adenine, cytosine, and guanine. Ultraviolet light, which is often used to kill bacteria, apparently causes damage in many cases by rearranging the thymine groups in a DNA molecule. Normally, thymine groups are not linked to one another, but ultraviolet light produces such links. These "errors" (thymine dimers) in the extremely long DNA chains are apparently recognized by certain enzymes and cut out of the chain. The "censored" sections removed from the "injured" DNA are then replaced by resynthesis of new DNA in the original sequence. How this is done is still uncertain, but it may be related to the double structure of DNA. The latter consists of two matching sides twisted around one another like a twined rope. If one strand is damaged, the other still has clues to the correct sequence.

In some of the viruses that infect bacteria (bacteriophages), the sensitivity to ultraviolet light was known to be genetically controlled. Experiments here have recently confirmed that this gene activates the excision mechanism through a process similar to the enzymic systems previously found in bacteria.

In two types of phage studied, the higher resistance of one (T4 phage) to ultraviolet light over the other (T2 phage) was associated with one particular gene, namely, the *v* gene. It has been shown that phages having this gene carry information that enables an infected bacterium to repair ultraviolet damage in phage DNA in the dark. Since the type of damage was similar to that repaired by photoreactivation – a process involving monomerization of pyrimidine dimers – it was predicted and confirmed that the *v* gene acts by an excision mechanism similar to that found in bacteria. This confirms the common nature of this repair mechanism and provides new opportunities for its control.

Large-Scale Biochemical Separations

In living cells, amino acids are assembled into long chains, or polymers, called proteins, which comprise much of the material of the cells. It is known that the sequence of amino acids in a protein determines the chemical and physical properties of the protein, and that the sequence is very exactly controlled by the living cell as the protein chains are formed. A particular group of nucleic acids, called transfer ribonucleic acids (tRNA's), transports the amino acids to the growing protein chain and must contain "information" that identifies the specific amino acid required to produce the correct amino acid sequence. At the Laboratory a group of biochemists and engineers has been studying methods for the preparation of samples of pure tRNA's so that more can be learned about the nature of the "information" storage and action.

A novel reversed-phase column chromatographic system has been devised especially for separating the tRNA's. When samples of the mixed tRNA's are caused to move down the column by a salt solution, they separate, and individual tRNA's may be recovered in a nearly pure state.

Samples of two different purified tRNA's, one that transports phenylalanine and one that transports leucine, have been prepared from 450-kg batches of *Escherichia coli,* a bacterium. This is the first time that relatively large (100-mg) samples of various species of pure tRNA's have been available for biochemical and physical-chemical study.

Biochemical experiments are being carried out to identify the mechanism of "information" action and the active sites in the tRNA's; physical-chemical experiments are under way to determine the size, configuration, and chemical composition of these molecules. The data will be of value in learning how the growth of protein chains is controlled in all types of living systems.

Multiple Aminoacyl-RNA Synthetase Systems

As pointed out in the preceding section, a major problem in biology is the translation of a sequence of nucleic acid bases, constituting the genetic code, into a sequence of amino acids in proteins, the final gene products. The integrity of this translation is maintained by two classes of molecules: tRNA's and the enzymes known as aminoacyl-RNA synthetases. There are distinct synthetases for each amino acid, and these enzymes are responsible for the correct attachment of a specific amino acid to each of the species of tRNA. Each tRNA may then recognize a unique base sequence code word and position an amino acid for inclusion into protein. Although it was clear that several species of tRNA, corresponding to more than one code word, occur for most, if not all, amino acids, it was generally accepted that a single synthetase existed for each amino acid, regardless of the number of tRNA's involved.

We have recently found, however, that functionally distinct synthetases exist for certain individual amino acids in *Neurospora crassa.* Two synthetases specific for L-phenylalanine have been separated by hydroxylapatite column chromatography, as well as by gel filtration techniques. In addition, the two phenylalanine-specific tRNA's have been resolved by countercurrent distribution, and each was found to be specifically aminoacylated by only one of the two phenylalanine synthetases. Similarly, two synthetases for L-aspartic acid have been separated (by DEAE-cellulose chromatography) and were found to differ in their specificity for the subspecies of aspartic acid tRNA. Analysis of the synthetase activities for all amino acids has been carried out following DEAE (diethylaminoethyl) chromatography of soluble protein preparations from both *Neurospora* and *Escherichia coli,* but no other cases of multiple synthetases have been found.

Thus it would appear that the multiple synthetases for phenylalanine and aspartic acid play some unique role in protein synthesis, perhaps by contributing to the mechanics of regulation or polypeptide chain initiation. These possibilities are currently being investigated.

Molecular Anatomy

The Molecular Anatomy Program, sponsored jointly by the Atomic Energy Commission and the National Institutes of Health, is specifically concerned with the development of the basic biophysical tools required for the mass dissection of cells down to the molecular level. The first tool developed under this program was the zonal ultracentrifuge. Numerous modifications of it have been utilized for the isolation of subcellular components including nuclei, mitochondria, microsomes, polysomes, ribosomes, and viruses. Since large volumes of material may be handled in these centrifuges, they are well suited to the preparation of high-purity vaccines. A number of new vaccines produced with these systems are now being tested in man. Additional new larger-capacity zonal centrifuges will be required if these vaccines are to come into general use. These are now under development in the Oak Ridge Gaseous Diffusion Plant.

A new separation scanning technique (termed the s-ρ method) allows subcellular constituents to be separated on the basis of sedimentation rate and density independently. Most known viruses have physical properties distinct from those of normal subcellular constituents, and may be separated by the s-ρ method. The method is therefore directly applicable to the problem of searching tissues for previously unisolated viruses such as the human hepatitis virus. In addition, automated chromatographic and electrophoretic systems have been developed for protein, nucleic acid, nucleotide, and simple carbohydrate separations.

HEALTH PHYSICS

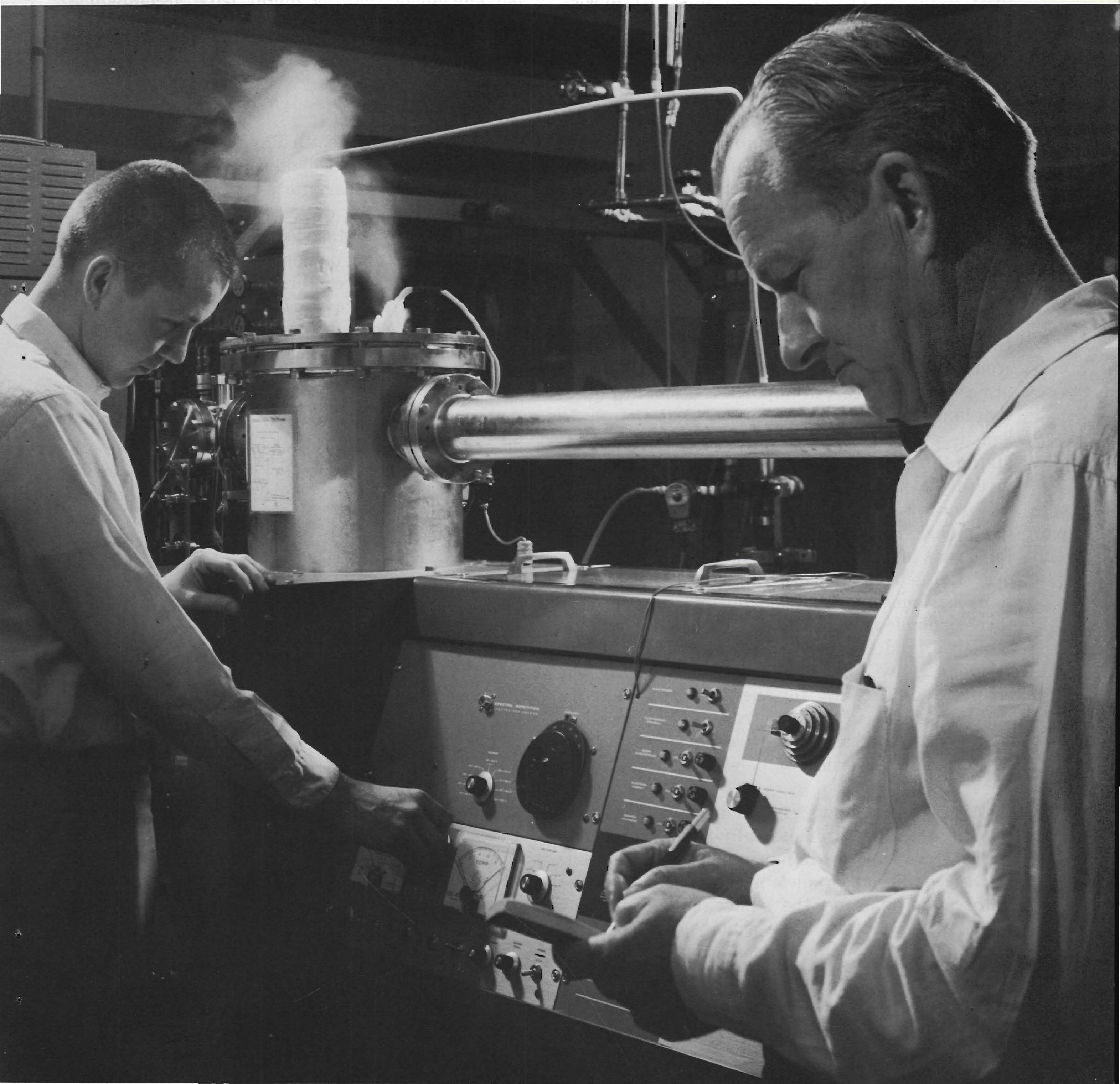
Interaction of Low-Energy Electrons With Matter

All kinds of radiation in their interaction with matter ultimately produce low-energy electrons. Thus, an understanding of the interaction of low-energy electrons with atoms and molecules is basic to the study of how radiation affects matter. In work now in progress at the Laboratory, electrons having energies below 10 eV were produced as electron swarms or as monoenergetic electron beams, and the following information was obtained.

The various ways through which low-energy electrons are captured by molecules were distinguished, and the corresponding probabilities for electron capture were measured for a number of organic molecules. In particular, halogenated benzene derivatives, in capturing an electron, dissociate to produce negative halogen ions even when the energy of the electron is almost zero (less than the thermal energy). This result threw light on the existing controversy on the reactivity of chemical carcinogens, since the various arguments were based on the assumption that the halogenated benzene derivatives (which were used as a standard of reference to compare electron capture by carcinogens) do not dissociate when they capture low-energy electrons. A new method was developed, which, for the first time, allowed determination of the capture cross section as a function of electron energy for the various types of electron capture. When these techniques were applied to the study of the electron-accepting capacity of biologically interesting molecules, temporary electron capture was found to be of extreme importance. A number of molecules were found to capture electrons only for a short time: 40 μsec for nitrobenzene and 25 μsec for sulfur hexafluoride, for example. From the lifetimes of these temporary negative ions and the corresponding probabilities of the processes, information was obtained about the molecular structures and the electron affinities of these molecules.

Experiments have shown that when electrons pass through a gas containing molecules with permanent dipole moments, the electrons interact with the molecular dipoles. In theory, the elastic scattering of electrons by the dipole should account for the total interaction with most, but not all, of the molecules in the gas. With water and hydrogen sulfide, however, the measured interaction is found to be larger than the theoretical by about a factor of 2. To interpret this result, a theory of electron capture by polar molecules with simultaneous rotational excitation of the dipole was worked out. In this process, temporary negative ions are formed, which subsequently decay and release the electrons. The capture-release process represents, in effect, an elastic scattering, which increases the total electron-molecule interaction. The theory shows that, among the molecules with which measurements were made, water and hydrogen sulfide have properties that make capture probable.

Lifetimes and electron attachment cross sections for low-energy electrons on organic molecules are studied with a time-of-flight mass spectrometer.



In solids our understanding of the various modes of energy loss by low-energy electrons (0 to 10 keV) is only semiquantitative at present. To improve this understanding, probabilities for the interactions of electrons with electrons and ions in aluminum metal have been estimated, using simple theoretical models for volume and surface plasmon excitation, single-electron excitation, etc. These interactions give rise to large numbers of secondary, tertiary, and higher-order electrons, each of which has similar possibilities for interaction. Preliminary calculations of the attenuation of an electron beam in foils a few hundred atoms thick compare favorably with experimental results. Calculations made originally for 0- to 100-eV electrons are currently being extended to higher energies. Such multiple-collision calculations are necessary in order to obtain a better understanding of single-collision cross sections in this range of energies, because single-collision experiments are extremely difficult, if not impossible, to perform. The mechanisms of these interactions are of interest in assessing human exposure.

Effect of Ionizing Radiation on Ecological Fitness

In addition to the dose to and effects on man, studies of the effect on the environment are of utmost importance. An important ecological question underlying all environmental radiation problems is whether chronic exposure to low-level radiation affects the fitness of a population to survive in its environment. A bloodworm population (*Chironomus tentans*) inhabiting White Oak Creek has been exposed to approximately 230 rads/year of chronic environmental radiation for over 120 generations (15 years). In this population, chromosomal polymorphism, produced by three endemic chromosomal inversions, is well established, and the frequencies of these three inversions have not fluctuated seasonally or changed significantly for the past five years. In addition, apparently as the result of irradiation, there is an increase in new chromosomal aberrations, but these do not persist for very many generations.

Others have shown, in studies of laboratory populations, that chromosomally polymorphic populations are superior to monomorphic populations in their ability to produce a greater biomass and more individuals on the same amount of food. Since in some cases large acute doses of radiation may decrease chromosomal polymorphism in a population, a comparison of the chromosomal polymorphism in the chronically irradiated natural population of *C. tentans* was made with a nonirradiated population. It appears that the exposure of these organisms to chronic irradiation at a level capable of producing a detectable increase of new chromosomal aberrations has not affected the frequencies of the endemic inversions, or, if there was an initial effect produced on the frequencies of the inversions by ionizing radiation, the population has compensated for it. Thus there is no indication that radiation produces a decrease in preexisting chromosomal polymorphism such as might have accompanied a decrease in fitness.

Sensitivity of Pines to Fast-Neutron Irradiation

The effects of the Health Physics Research Reactor, which is unshielded, on the surrounding vegetation has been under study by Laboratory ecologists since the start of reactor operations in May 1963. After 15 months, Virginia pine showed evidence of radiation damage out to a distance of 120 ft from the reactor. The foliage was discolored; the tree crowns had the thinned-out appearance of poor needle growth; and needle length, which is an excellent criterion of damage, showed a marked decrease. This retardation of needle growth occurred in a cumulated fast-neutron dose range of 120 to 250 rads. These doses for damage to pines were delivered sporadically and are extremely low in comparison with data from other forest experiments. Our knowledge of the effects of fast neutrons on biological materials is limited, and these results primarily emphasize the high degree of sensitivity of certain organisms in the natural environment.

Reactor Technology and Desalination

The program in reactor technology at the Laboratory covers reactor types for a wide range of applications and includes two reactors which were completed and put into operation during 1965.

The successful operation of the Molten-Salt Reactor Experiment represents a milestone in efforts to develop this concept as a thermal breeder. Likewise, the startup of the High Flux Isotope Reactor and operation of the Transuranium Processing Facility represent significant steps in the programs for studying the man-made elements heavier than uranium.

Along with these efforts and general studies of advanced systems and nuclear safety, the Laboratory has also been occupied with the problem of finding an efficient means for desalting seawater. Through fundamental chemical studies of this process, and through the conceptual design of multipurpose reactor plants for this application, advances of technology have been made during 1965 in this important area.

MOLTEN-SALT REACTOR PROGRAM

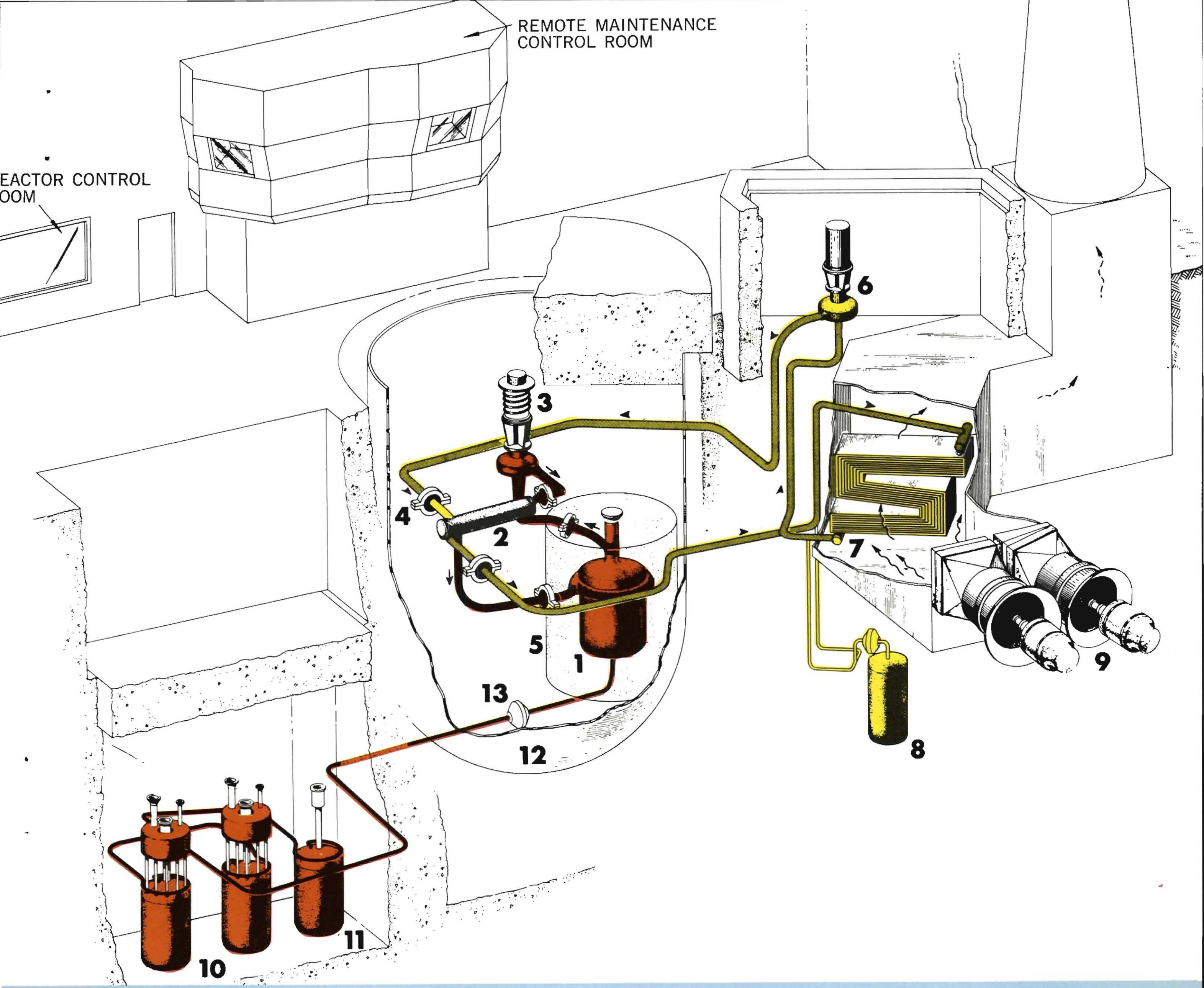
A technological goal of great significance is the development of nuclear reactor systems that will produce electric power at low cost and, at the same time, produce more fissile material than they consume – by the process known as breeding. The Oak Ridge National Laboratory has committed a major reactor development effort to what it considers the most promising route to this goal: the molten-salt thermal-breeder concept, in which low-cost thorium is converted into valuable fissile uranium-233.

The first major achievement in this program has been completed during the past year with the construction and the beginning of the operation of the Molten-Salt Reactor Experiment (MSRE), a 10,000-kW reactor, built for the purpose of demonstrating the practicality of the use of molten fissioning fuel. (The first molten-salt reactor was built at the Laboratory in 1954 as part of the Aircraft Nuclear Propulsion program.)

To apply the molten-salt (or fluid-fuel) concept to the production of electric power and the accomplishment of breeding, a short-range development program has focused attention on conditions which would

1. prevent corrosion of the container material,
2. improve the efficiency of the nuclear processes by the use of graphite as a moderator,
3. demonstrate the compatibility of fissioning fuel with the graphite and the container metal,
4. increase the reliability of the operation of all mechanical and electrical systems,
5. provide inexpensive remote maintenance on the radioactive portions of the system.

A longer-range supporting research program has concentrated on a study of chemical reprocessing of molten-salt fuel and blanket systems, so that the economically exciting possibilities of continuous, on-stream removal of neutron poisons and bred material can be realized.



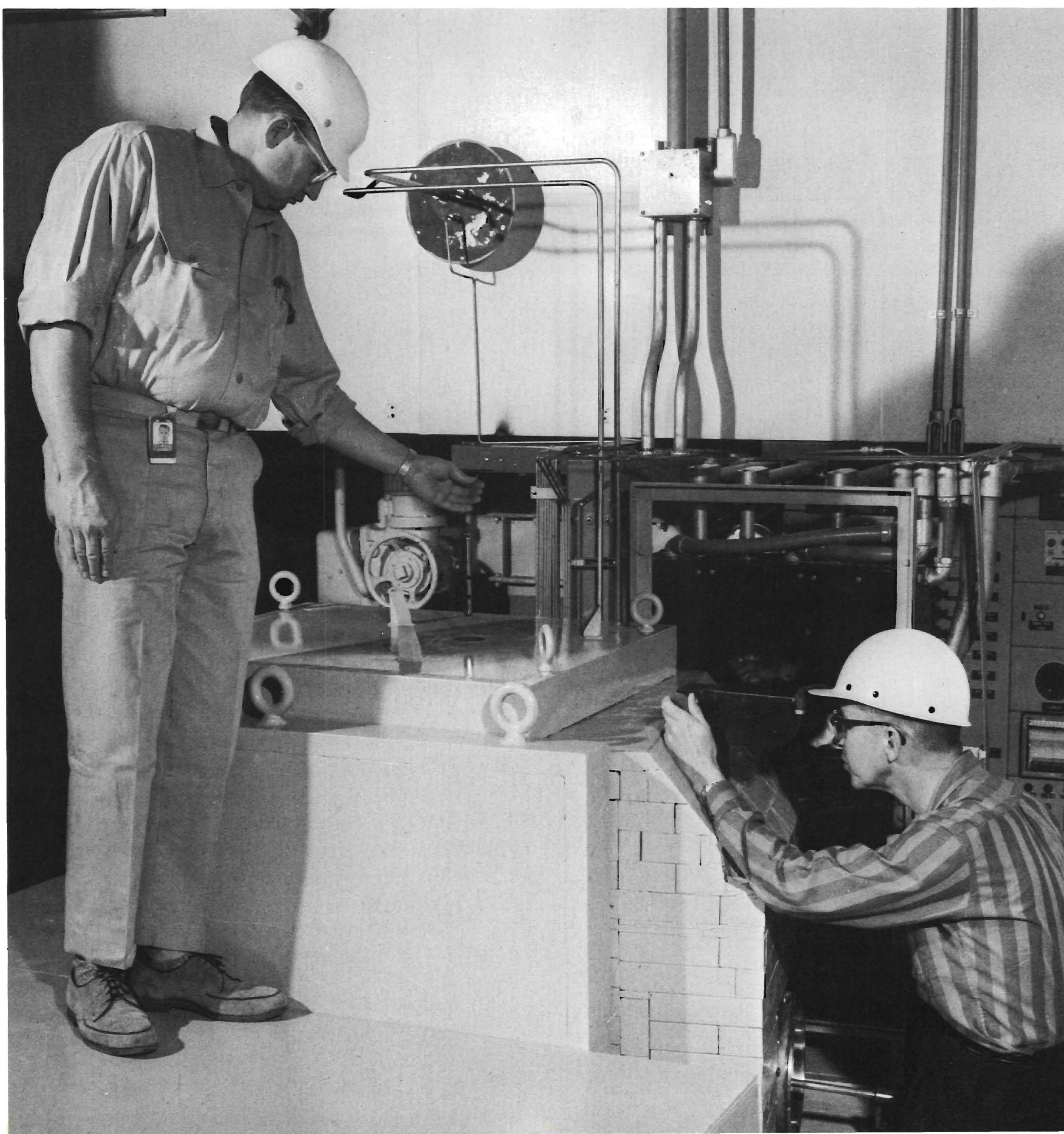
In the MSRE system, molten fluoride fuel in the primary loop forms a critical mass in the reactor vessel (where it heats from 1175°F to 1225°F), from which it is pumped to the shell side of the heat exchanger and back to the reactor. In the heat exchanger, fuel heat transfers to a similar but unfueled molten fluoride salt coolant in the secondary loop, in which the coolant circulates to an air-cooled radiator, then to a pump, and back through the exchanger tubes. The salt in each loop can be drained to the drain tanks by heating freeze plugs in the drain lines (in which there are no mechanical valves). The entire primary loop is sealed in a steel containment vessel that is 31 ft high, 24 ft in diameter, and 1¼ in. thick, except where penetrations make a 2-in. thickness necessary. The fuel drain piping and tanks are in a different pit from the reactor, but this pit has the same integrity as the reactor containment vessel.

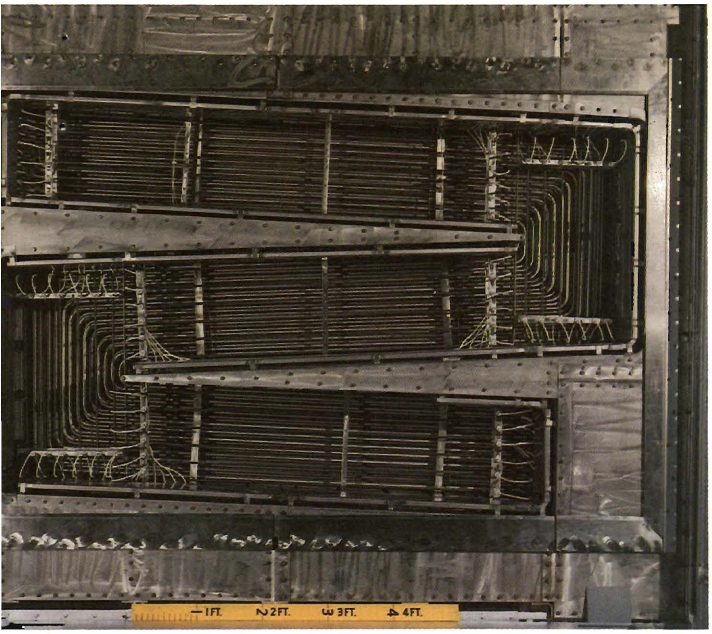
1. Reactor Vessel
2. Heat Exchanger
3. Fuel Pump
4. Freeze Flange
5. Thermal Shield
6. Coolant Pump
7. Radiator
8. Coolant Drain Tank
9. Fans
10. Fuel Drain Tanks
11. Flush Tank
12. Containment Vessel
13. Freeze Valve

Molten-Salt Reactor Experiment

The Molten-Salt Reactor Experiment was planned to demonstrate that the desirable features of the molten-salt concept can be embodied in a practical reactor which can be constructed, operated, and maintained with safety and reliability. Additional objectives are to provide the first large-scale, long-term high-temperature

MSRE sampler-enricher. The simplicity of the fuel recharging machinery for molten-salt reactors is illustrated by the small capsule held by the operator at the left; this capsule, containing a small quantity of enriched uranium in the form of a solid cylinder of frozen salt, is lowered by a windlass into the pump bowl. Perforations in the capsule wall permit the molten fuel in the pump bowl to dissolve the enriched salt charge. A simple copper bucket, lowered and then raised by the same windlass, recovers a sample of the molten fuel for analysis. In operation, a lead shield surrounds the inlet of the tube connecting the sampler-enricher station with the pump bowl.





Radiator for the MSRE. Heat is removed from the coolant-salt mixture in this air-blast heat exchanger and dissipated through a metal stack to the atmosphere. The coolant salt, molten lithium and beryllium fluoride, flows through the tubes, which are 3/4 in. in diameter and 30 ft long. Their walls are 0.060 in. thick. The tubes, formed into an "S," are arranged in 10 banks of 12 tubes each. Cooling air is supplied by two axial-vane blowers with a combined capacity of 200,000 cfm. Quick-acting doors are located on each side of the radiator, dropping automatically should the flow of coolant salt or fuel stop, thereby preventing the coolant from freezing in the coils. Electric heaters inside the radiator provide heat for startup and keep the salt molten in the tubes when not circulating. The temperature of each tube is monitored by thermocouples.

tests, in a reactor environment, of the combination of fuel salt, graphite moderator, and the high-nickel-base alloy which is used as structural material in molten-salt systems.

The MSRE critical experiments and the zero-power experiments were finished early in the year. The reactor performed very well; agreement between the calculated and the measured parameters was excellent. During the approach to criticality, the MSRE was operated with fuel salt at temperatures near 1200°F for 1100 h with no mechanical difficulties. The salt remained uncontaminated, and there was no corrosive attack on the metal in contact with the hot salt.

Preparations for power operation involved numerous adjustments, inspections, and tests of reactor auxiliaries and some of the primary systems, and sealing and testing of the containment. After the completion of this work in mid-December 1965, the reactor was operated for about a month with experiments performed at power levels below 100 kW. Again, agreement between theory and experiment was excellent, and the reactor was considered ready for approach to full-power operation.

Research and Development

Radiator in operation at 1200°F. This photograph of the incandescent radiator tubes was made from the inlet duct while coolant salt was circulating at 1200°F. The brighter lines are hotter electrical heaters.

The long-term compatibility of fissioning fuel and graphite must be established to provide a proper basis for breeder reactor operation. To this end, an in-pile thermal convection loop experiment has been planned in which operation for an indefinite period of time can be achieved while samples of salt are periodically removed and replaced with fresh salt. A prototype of the loop was constructed and operated in out-of-pile facilities for more than 6000 h at about 1200°F. The adequacy of the design features appears to have been thoroughly established, and the installation of an in-pile version of the loop at the Oak Ridge Research Reactor is now under way.

The section on "Mechanical Properties Research" discusses the extensive research program directed to learning the cause and planning the cure for the radiation embrittlement of iron- and nickel-based alloys. Since the construction of the reactor vessel, with its associated fittings and piping, involved the use of several different heats of the INOR-8 alloy, each of which could behave differently as a consequence of different boron impurity concentrations, representative test samples were examined from each heat; the results indicate that the probable lifetime of the MSRE reactor vessel and piping is well over 20,000 h – far more than enough for the testing which is planned, but still much less than is now achievable by control over the conditions of manufacture of the alloy. Surveillance specimens have been placed in the MSRE for periodic removal and testing to confirm the predictions as to safe exposures for MSRE materials.

Brazing methods have been developed for joining molybdenum to graphite, and prototype tube joints have contained molten salt successfully for periods of 500 h at 700°C and pressures up to 150 psig. Such joints will be useful in the fabrication of breeder reactors.

Chemical studies have revealed that vacuum distillation offers a simple, inexpensive route to the purification of irradiated reactor fuel after the uranium has been removed (as uranium hexafluoride) by the well-established Fluoride Volatility Process. In this distillation the more volatile and valuable beryllium fluoride, zirconium fluoride, and lithium-7 fluoride are removed, leaving behind the fission product rare-earth trifluorides, which are less volatile. Design and development work on this process is under way so that it can be demonstrated on the MSRE after a meaningful concentration of fission products is built up by power operation.

Other preliminary chemical studies have given results which suggest that the major neutron poison xenon-135 can be largely avoided by the chemical removal of its 6.7-h precursor, iodine-135; that it may be possible to extract the rare-earth poisons into molten metal instead of removing them by distillation; and that it may be possible to remove protactinium, the precursor of fissile uranium-233, by a precipitation or reduction process. The applicability of these potentially simple avenues to continuous on-stream chemical reprocessing is receiving increasing attention for ultimate use in the next phase of the reactor development program, a prototype breeder.

Molten-Salt Breeder Reactor Design Studies

Associated with the research and development program, a conceptual design study has been made of a Molten-Salt Breeder Reactor power plant to produce 1,000,000 kW of electricity. The results showed that a privately financed MSBR plant should be capable of achieving a specific inventory below 1 g of fissile material per kilowatt of electric power; a doubling time (for breeding enough fissile material to start another reactor) of 10 to 20 years; a capital cost below $115 per kilowatt of electricity; fuel-cycle costs below 0.5 mill/kWh, including costs of an on-site processing plant; and a total power cost of about 2.7 mills/kWh for investor-owned utilities. The total power cost under public ownership would come to about 1.7 mills/kWh.

The reference design concept is a two-region, two-fluid system, with the fuel salt separated from a thorium-containing blanket salt by graphite tubes. The energy produced in the reactor fluid is transferred to a secondary coolant-salt circuit that couples the reactor to a supercritical steam cycle (essentially the steam cycle used in the latest coal-fired plant of the Tennessee Valley Authority). On-site fluoride-volatility and vacuum-distillation processing would be employed to separate uranium and valuable salts from fission products in the fuel; fluorination would be used to recover fissile fuel from the fertile blanket region. Refabrication of the fuel involves only uranium reduction and dissolution in the carrier salt. The combination of a fluid fuel with ease of fuel movement and accompanying potentially simple, inexpensive processing and refabrication schemes should make it possible for molten-salt reactors to achieve low fuel-cycle costs at high processing rates – the condition required for operation of thermal reactors as high-performance breeder systems.

Development of a protactinium removal scheme for the blanket region of the MSBR could lead to power costs of 2.6 mills/kWh, a fuel-cycle cost below 0.4 mill/kWh, a specific fissile inventory of 0.7 g/kW, and a fuel doubling time of 13 years.

Naturally, the longer the power industry delays the introduction of breeder reactors, the more our reserves of fissile fuel will be depleted to supply the needs of the nonbreeder nuclear reactors. If the molten-salt breeder reactors are developed to commercial application by 1985, calculations show that the overall power industry would require less fissile fuel to get started on than is already estimated to be available in the form of low-cost fissile fuel reserves. Thus the goal of worldwide cheap power for the foreseeable future appears to be within our reach, although not yet quite within our grasp.

The transuranium production complex, located about two miles southeast of the main laboratory area. The large building near the center of the picture houses the High Flux Isotope Reactor. The tower for cooling the water that circulates through the reactor is at the right behind the ponds. The building behind the exhaust stack is the Transuranium Processing Plant (TRU). At the left, beyond TRU, is the Thorium-Uranium Fuel Cycle Development Facility, which, when completed, will be used by the Thorium Utilization Program. The low building at the left of the road contains offices. The Cumberland Mountains are in the background.

THE HIGH FLUX ISOTOPE REACTOR AND TRANSURANIUM ELEMENT PRODUCTION

The transuranium program at the Oak Ridge National Laboratory is part of the national research effort on the scientifically exciting manmade heavy elements. A principal role of the Laboratory in this program is the production and separation of sizable research quantities of americium, curium, berkelium, californium, einsteinium, and fermium.

The heavy-element production cycle begins with the irradiation of plutonium-239 in the reactors at the Savannah River Plant. This irradiation produces plutonium-242, which is sent to the Laboratory.

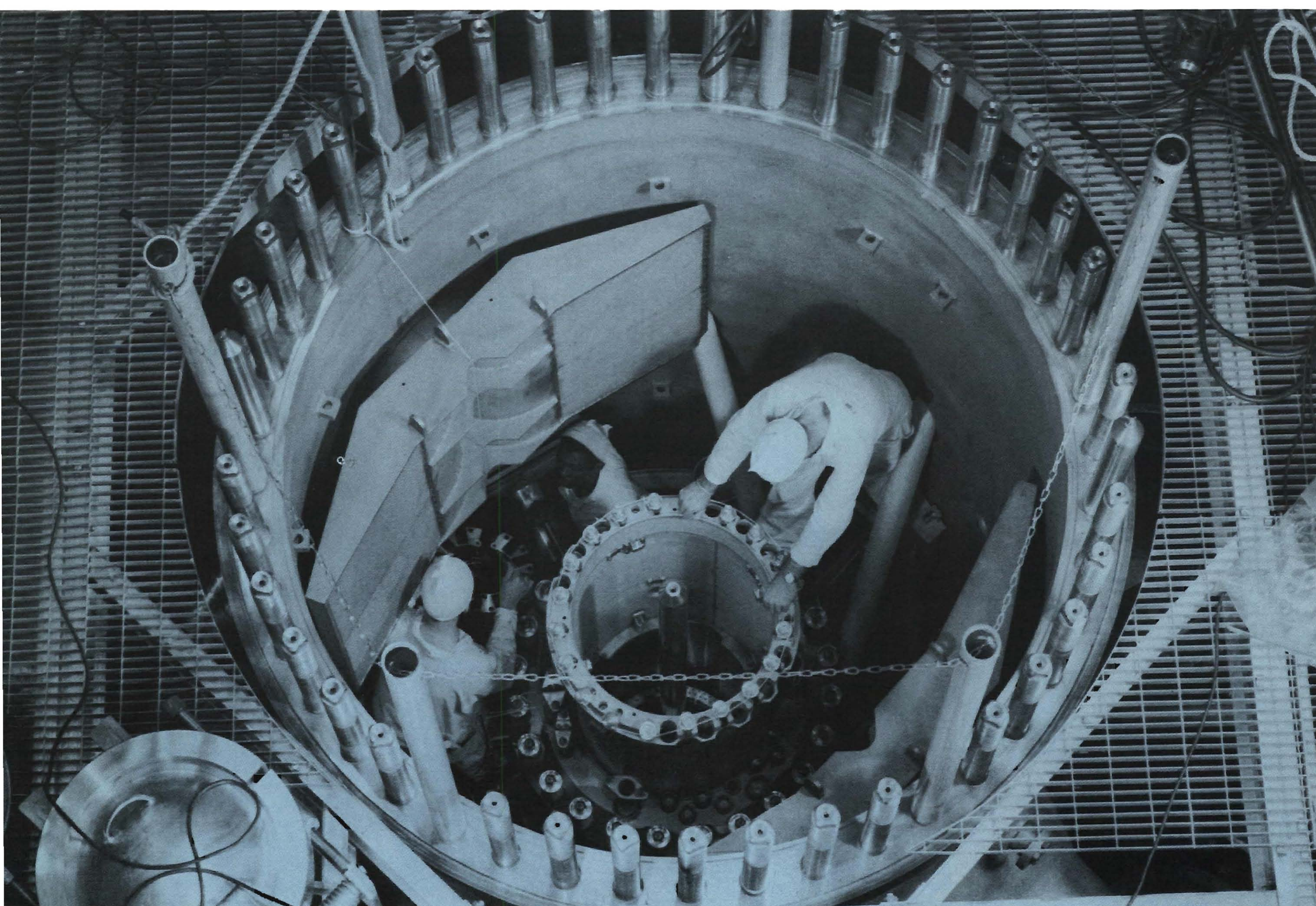
At the Transuranium Processing Plant (TRU) the plutonium-242 is fabricated into pellets of plutonium oxide and aluminum powder. These pellets are loaded into target rods for irradiation in the High Flux Isotope Reactor (HFIR).

After a suitable irradiation period in the HFIR, which may be 12 to 18 months per rod, the targets will be transferred to TRU for chemical separation of fission products and transuranium elements. Some of the americium and curium isotopes will be fabricated into recycle rods for further irradiation in the HFIR to produce heavier elements. The transuranium isotopes produced in this program will be made available to the Transuranium Research Laboratory here and to other research laboratories doing work in this field throughout the United States. From the HFIR-TRU combine it is expected that grams of californium, hundreds of milligrams of berkelium, tens of milligrams of einsteinium, and about a microgram of fermium will eventually be recovered annually.

Californium-252 is often used as a yardstick for the production program because it is the heaviest isotope produced with a long half-life. It decays by alpha-particle emission with a half-life of about 2.5 years and also emits large quantities of neutrons from spontaneous fission. The neutron source strength of 1 g of californium-252 is over 3×10^{12} neutrons/sec, comparable to that of a 25-W research reactor.

Since the HFIR was undergoing tests during 1965, an irradiation program was carried out in a High Flux Demonstration Run at Savannah River as a means of further advancing the overall production program. This irradiation of 565 g of plutonium-242 will continue through the first half of 1966 to produce a few milligrams of californium and associated heavy elements.

Craftsmen completing assembly of components inside the HFIR pressure vessel. The top head of the vessel has been removed for easy access.



Cerenkov radiation coming from the HFIR pressure vessel as the reactor operates at a power level of 20,000 kW, 20% of its eventual power output.

High Flux Isotope Reactor

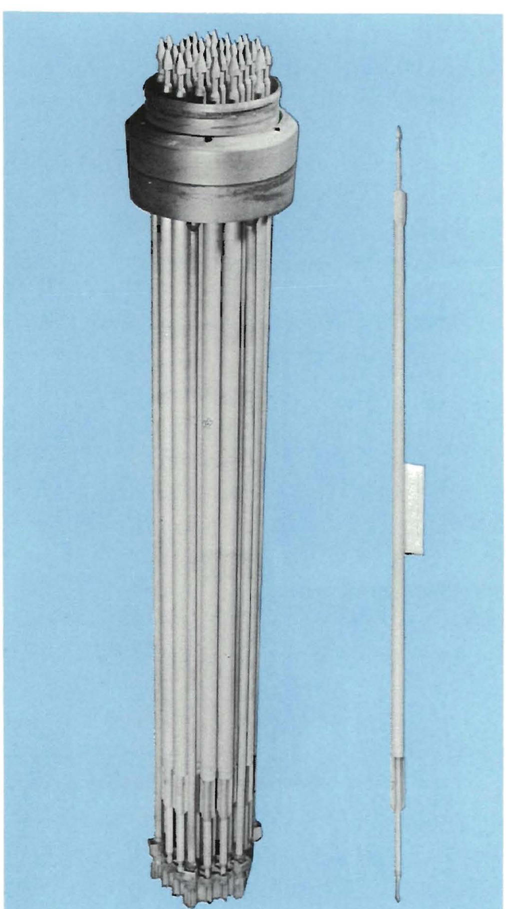
Construction and preoperational testing of the HFIR were completed in the first half of 1965. Numerous mechanical and hydraulic tests confirmed that the coolant systems and reactor components operated as designed.

After an extensive checkout of the instrumentation, the HFIR achieved initial criticality in August 1965. Following the initial criticality a thorough "zero power" nuclear experimental program was conducted to investigate the nuclear characteristics of the HFIR, to compile generally useful data associated with the routine operation of the reactor, and to provide the operators with experience on the operating reactor.

Typical experiments conducted to investigate the nuclear characteristics of the reactor are as follows: (1) reactivity shutdown margins, (2) control rod reactivity differential worth, (3) isothermal temperature reactivity coefficients, (4) reactivity worths of various targets and voids in the flux trap, and (5) effect of flow and pressure on reactivity and reactivity stability.

After completing the "zero power" tests and calibrations, the reactor was readied for power operation. With the system pressurized to 600 psi and with full flow of cooling water (about 16,000 gpm) the power level was gradually increased to 20,000 kW. At intermediate steps, heat power calibrations and instrument checks were made. As the reactor power was increased, scientists from Argonne National Laboratory cooperated in a series of spectral analysis and intensity measurements to collect source data for the shielding design of the Argonne Advanced Research Reactor. Performance of the reactor was quite satisfactory. In view of the smooth startup of the HFIR, operation at its full design power of 100,000 kW is anticipated about the middle of 1966.

Scene in HFIR control room during the approach to the initial criticality.



Target rod holder assembly with a target rod beside it. The complete assembly consisting of 31 rods is located in the center of the HFIR fuel element during reactor operation.

Transuranium Processing Plant

Construction of the TRU and installation of process equipment were essentially completed this year. At the same time, the first small quantities of the heavy actinide elements (berkelium, californium, and einsteinium) were processed in an existing hot-cell facility. This material was recovered from one prototype target rod which was removed from the Savannah River High Flux Demonstration Run in September. While there was only 5 μg of californium in the rod, this was a sufficient quantity for process flowsheet testing prior to full-scale operations in TRU.

Three cells in TRU are devoted to the equipment required for the remote fabrication of recycle americium and curium into HFIR target rods. Final preinstallation testing of this equipment was completed this year in a manipulator mockup which was operated as an integrated unit. Oxides are fabricated into an aluminum-cermet pellet and inserted into a rod on which an end cap is subsequently welded; the rod is then collapsed onto the pellets to obtain good heat transfer. Finally a hexagonal spacer-can is installed over the rod and several inspections – x-ray, leak check, and dimensional – are made to ensure that the rod meets the stringent requirements for insertion in the HFIR. The mockup work showed that these fabrication steps could be done remotely to provide a satisfactory target rod. During the year also, hot-cell examinations of three prototype rods showed that the design and fabrication techniques produce a rod capable of withstanding the most severe conditions in the HFIR. The three rods, containing $^{239}PuO_2$, were irradiated at the maximum heat fluxes expected to be encountered in the HFIR with no evidence of dimensional changes, excessive corrosion, or other problems. Fission-gas release in all cases was less than 5%.

Full-scale operations of the TRU facility are scheduled in 1966.

SPACE REACTORS

During 1965 the Oak Ridge National Laboratory continued to do research and development on a number of specific aspects of reactors for space application in support of broad programs being carried out at other installations of the Atomic Energy Commission and the National Aeronautics and Space Administration.

Auxiliary Power Sources

The principal objective of the effort at the Laboratory is to provide lightweight, long-lived sources of large quantities of electricity for space vehicles. This energy would be used for life support, experimental observations, communication, and vehicle propulsion.

The waste heat from the nuclear power plants must be rejected to space, and in order to accomplish this rejection with a sufficiently small radiator, the nuclear reactor and radiator must operate at exceptionally high temperatures – in the range of 500 to 2500°F. High-temperature reactors permit efficient conversion of heat to electricity, while the high temperature in the radiator permits release of the waste heat from a small radiating surface.

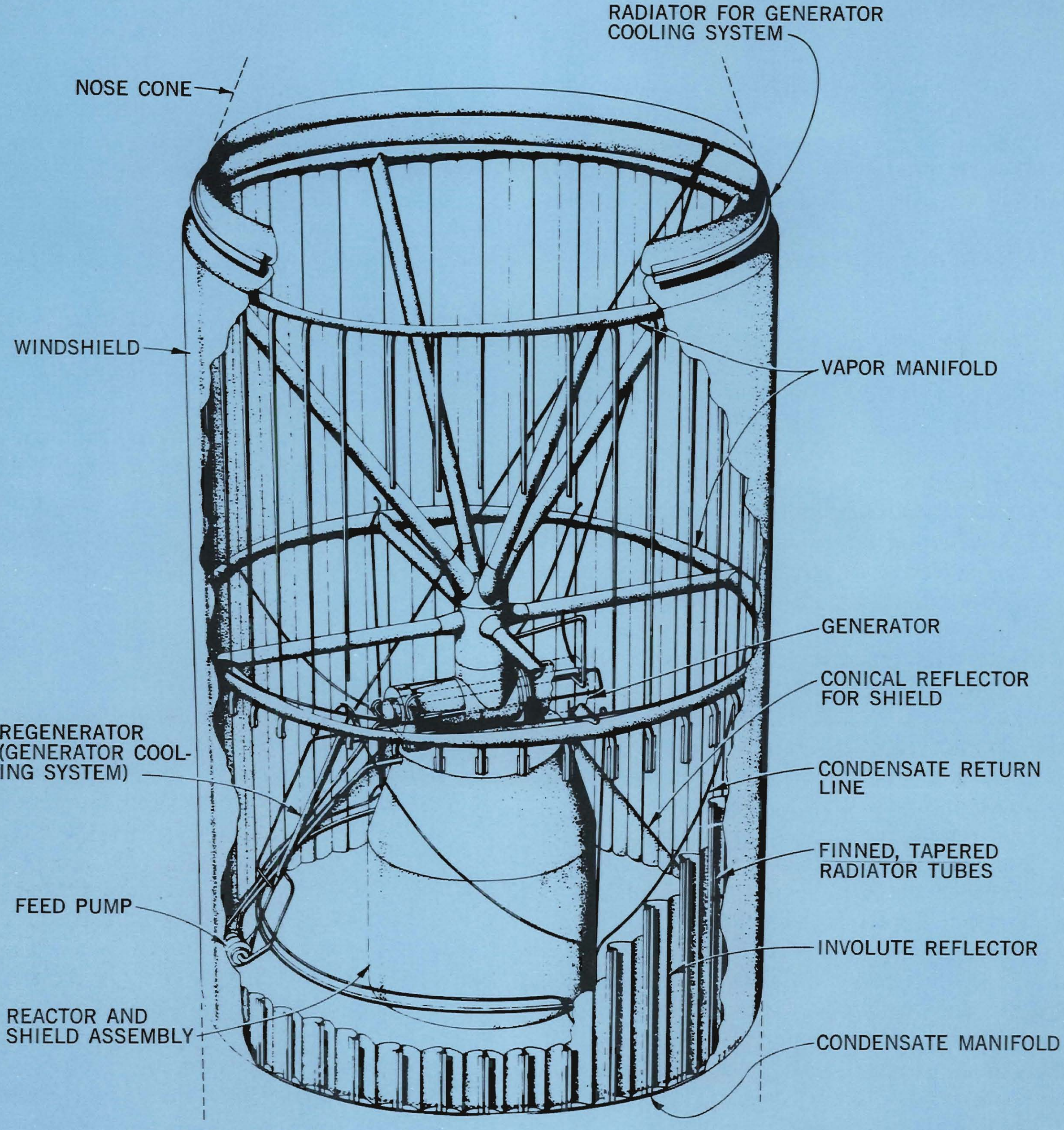
As would be expected, one of the problems encountered with reactors under these conditions is the provision of materials which will withstand the high temperatures and intense radiation fields for long periods of time. Consequently, work at the Laboratory has been directed toward the development of fuel materials which will not undergo large distortions, release radioactive waste products, or impede the flow of the fluid which transfers heat from the nuclear reactor to the power-plant boiler. Studies have also been made to define conditions under which these very hot fluids, such as liquid alkali metals, may be used to carry out their heat transfer function without excessive corrosion of structural materials. Thus far it has been demonstrated that boilers can be built from alloys of refractory metals such as columbium and tantalum, so that very hot vapors from boiling alkali metals such as potassium can be provided to drive turbines.

Designers must assure that excessive amounts of radiation from the nuclear reactor do not reach the crew of the vehicle or adversely affect the performance of the instrumentation or pay load. To accomplish this, shields must be placed between the nuclear reactor and the sensitive areas of the vehicle. These shields, unless carefully designed, however, can be excessively heavy. With this in mind the Laboratory has for several years been conducting a program to develop calculational methods, adjusted and checked by experiment, that will allow the design of effective shields of minimum weight for all types of reactors and missions.

Nuclear Rocket

The Oak Ridge National Laboratory has also conducted research and development to advance the technology of the nuclear rocket. The thrust for this device is supplied by hydrogen, which must be heated in a nuclear reactor to temperatures of about 4000°F. It can then impart far greater thrust per unit weight than can be achieved by the use of chemical fuels. Materials strength is a problem at these temperatures. Graphite is being used as the main structural material for the fuel elements, and the Laboratory is conducting an experimental program to better determine and understand some of its pertinent properties.

Nozzles for nuclear rockets must have somewhat different geometry than those of chemical rockets, and this led to too many nozzle failures in the early nuclear rocket development tests. On this problem the Laboratory provided consulting services to the National Aeronautics and Space Administration and the nozzle manufacturers and also conducted experimental work on fabrication techniques. This program contributed considerably to entirely successful nozzle performances that have recently been achieved.



Reference design for a launch-package version of the Medium-Power Reactor Experiment.

THE MEDIUM-POWER EXPERIMENT–A BOILING-POTASSIUM REACTOR

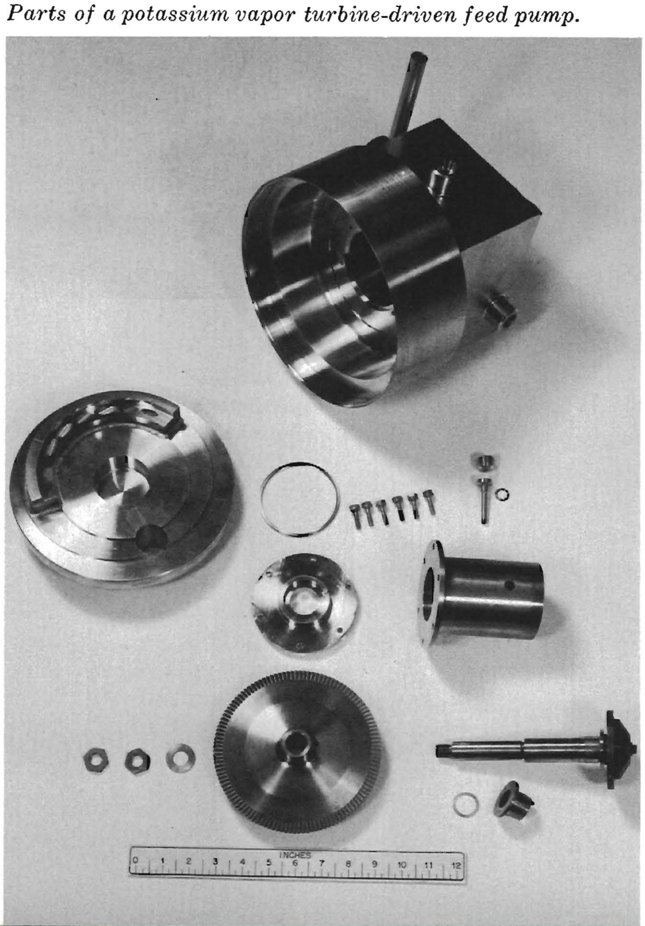
A small program aimed at the development of a stainless steel boiling-potassium-cooled space reactor has been under way at the Laboratory since 1961. The objective of the program is to develop a power plant in the form of a single-loop system with an output of 100 to 200 kW (electrical). This system was chosen since it requires a minimum number of components and hence gives a maximum reliability and a minimum specific weight. While the principal objective has been to develop the system for use in space vehicles, there are clearly a number of other applications for which a compact, lightweight, and highly reliable system of this kind would be attractive.

Illustrations of the reference design for a flight package show the manner in which this power-plant package would be installed in a launch vehicle. Potassium vapor from the boiling reactor passes through the turbine and thence to the condenser, which is in the form of two banks of finned, tapered tubes running parallel to the axis of the cylindrical power plant at the outer perimeter.

The outstanding accomplishment in 1965 has been a 2500-h run using a reduced-scale system designed to test key components, including the radiator and the free-turbine-driven feed pump. The components of this turbine included a 6⅜-in.-diam turbine wheel and a 3-in.-diam pump impeller made of molybdenum alloy. The unit ran red-hot on potassium-lubricated tungsten carbide bearings for over 2500 h with no indications of any loss in performance.

A new and larger test unit has now been designed and partially constructed to make possible a ground test of a full-scale, flight-type radiator for the reference design of the launch package.

Parts of a potassium vapor turbine-driven feed pump.



REACTOR STUDIES AND EVALUATIONS

During 1965 the Oak Ridge National Laboratory continued to assist the Atomic Energy Commission in evaluating immediate and long-term objectives of the reactor development program through the evaluation of specific reactor designs, the development of proper design criteria, the selection of technical proposals that merit further attention, and the study of general guidelines by which the relevance of various programs may be judged. The scope of this activity includes analysis of the principal engineering and physics characteristics of various reactor types so as to evaluate feasibility, estimate costs, and establish performance with respect to particular criteria.

A major work completed during 1965 was the evaluation of 1,000,000-kW (electrical) heavy-water-moderated organic-cooled reactors (HWOCR) as power-producing systems. Both uranium and thorium fuel cycles were considered. Atomics International and Combustion Engineering, Inc., provided a design for the uranium fuel cycle, and the Babcock and Wilcox Company furnished two designs for the thorium fuel cycle. The wide range of factors studied included engineering; design; thermal efficiency; capital costs; methods and costs of fuel processing, preparation, and fabrication; fuel-cycle costs; materials performance; reactor physics; and reactor control requirements of the proposed power plant. For each plant the evaluation also covered the feasibility of operation at design conditions, the evaluation of development problems, and the probable power cost after development. On the basis of the studies, areas were specified where research and development work should be emphasized.

The HWOCR physics studies also included evaluation of physics calculational methods and optimization of the fuel-cycle cost and associated nuclear performance for the different reactor core designs. Analog computer studies of the reactor kinetic behavior were carried out, providing basic information regarding control and safety problems of reactors having a positive coolant-temperature coefficient of reactivity.

The results of the study indicated power costs for investor-owned plants of about 3.5 mills/kWh for the uranium fuel cycle and about 4 mills for the thorium cycle. In the latter case, however, the costs could probably be reduced by about 0.2 to 0.3 mill through increases in fuel exposure and decreases in fuel-recycle costs. Most of the components described in the conceptual designs can be built with present-day manufacturing technology or would require at most a moderate extension of present technology. The reactor components and the refueling machines will require special development, but unusual problems in the fabrication of these components are not expected.

Based on evaluation of the thermal and hydraulic performance of the reactor cores, the outlet coolant temperature would not exceed about 700°F in a practicable system. The mechanical properties of the fuel cladding are of particular concern in these reactors, since it is fabricated from relatively new material, for which the allowable design stresses have not been completely determined. This material, called SAP, consists of aluminum oxide dispersed in a matrix of aluminum metal; in particular, additional information will be required before the effect of low ductility and brittleness on its structural properties can be evaluated.

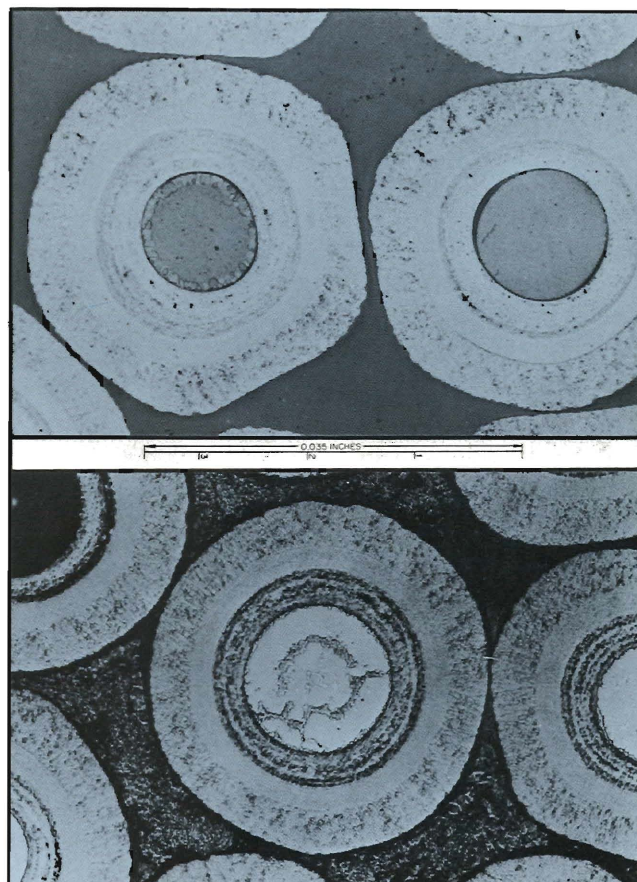
The positive coolant-temperature coefficient of the HWOCR imposes severe demands on the operation of the safety and control systems, and careful design work will be required for this system to perform satisfactorily.

ADVANCED GAS-COOLED REACTOR PROGRAM

The high-temperature gas-cooled reactor, which has been under development at the Laboratory and other sites, shows excellent promise for use as an advanced converter to conserve fissile materials. Feasibility for the concept is currently being demonstrated by several reactor experiments both in the United States and abroad, and a prototype reactor is now planned for construction in Colorado. Accordingly, emphasis in the Laboratory's program for this reactor has shifted from original basic development of coated-particle fuels to advanced refinements in particle formation and coating technology to economically meet the needs of more specific applications. The recovery of uranium-233 from irradiated thorium and its reprocessing for further use also are important economic factors for this reactor. Thus, emphasis is being placed on the development of technology suitable for remote operation.

The sol-gel process is an important development by the Laboratory for this application and is discussed in the section on the Thorium Utilization Program. Photomicrographs illustrate the excellent behavior obtained with UO_2 microspheres from the sol-gel process, when coated with three layers of pyrolytic carbon in a fuel particle designed for very-high-burnup service. After one irradiation at 1600°C in which 25% of the atoms were burned up, it was observed that there had been no significant damage. A second phase, probably consisting of fission product elements, was found after this high consumption of uranium-235 had occurred. None of the coatings failed during this irradiation, which involved several hundred particles, and the average fractional release of the fission product gas krypton-88 was only 4×10^{-8} at the end of the test. Several similar irradiation tests of both UO_2 and $(U,Th)O_2$ particles, mostly with two-layer coatings, have consistently shown favorable results to relatively high burnup. One test of loose $(U,Th)O_2$ fuel particles contained in a graphite cylinder was conducted in a recirculating helium-cooled loop for a period of nine months. Very low fission product release was observed, despite the presence of oxidizing impurities in the loop at levels which were considerably higher than those expected in reactor service.

A mathematical model which has been developed to predict the fission product retention of pyrolytic carbon coatings shows considerable promise and is expected to be a useful tool in the optimization of coating preparation. This model has been tested in a preliminary way by correlation with irradiation experiments. By use of these mathematical relationships, it is expected that the design of coatings can be tailored to specific reactor service and that the most economical coating techniques can be established.



Pyrolytic-carbon-coated sol-gel UO_2 microspheres. (above) Unirradiated. (below) Irradiated at 1600°C to 25% burnup of the uranium atoms. The photographs show the excellent stability of this type of fuel. Note that a second phase is apparent in the UO_2 particle of the irradiated material due to the high consumption of uranium-235 and that the spherical particle fell out of one coating (upper left) during metallographic preparation. Except for the second phase in the fuel particle, no effects of the severe irradiation exposure are apparent.

THORIUM UTILIZATION PROGRAM

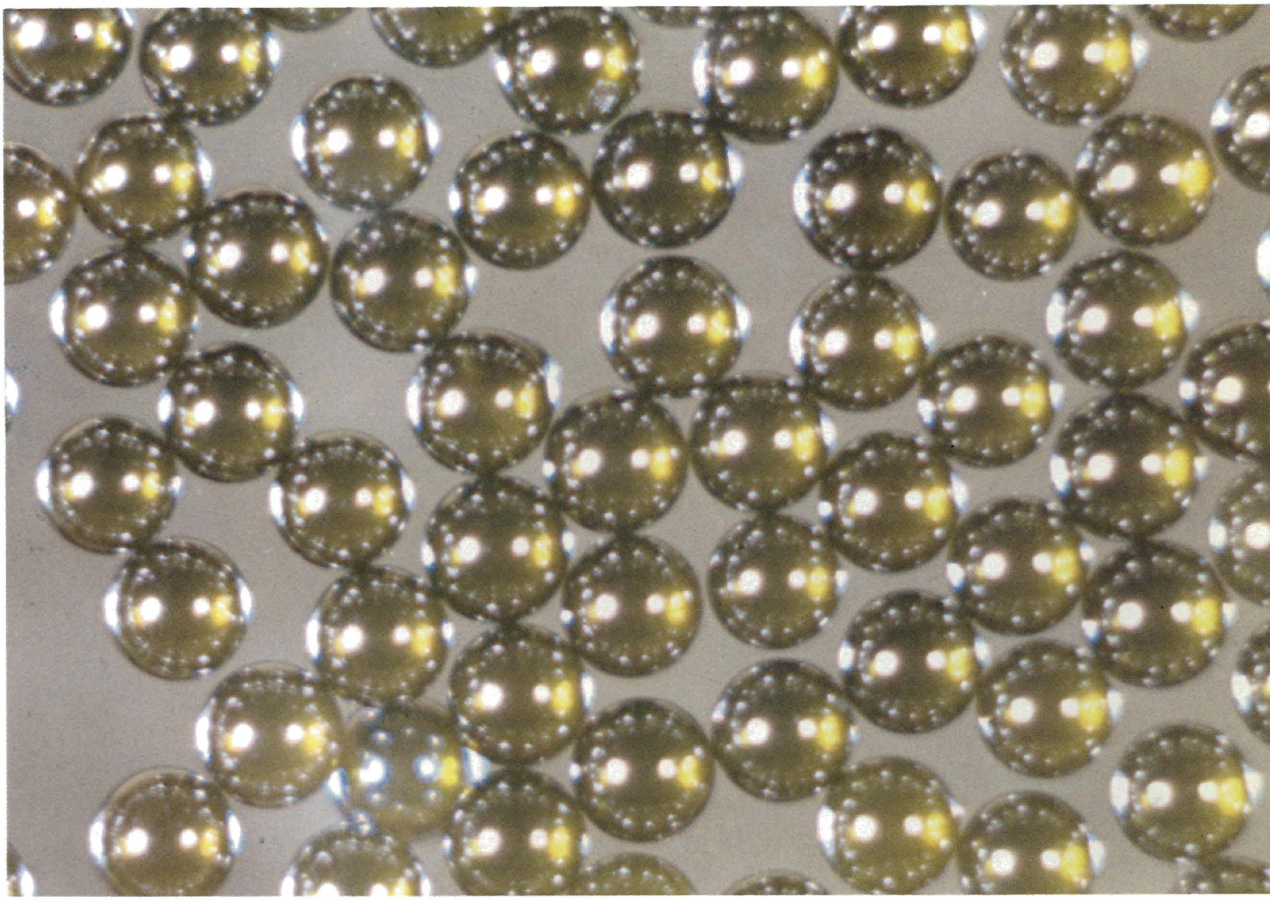
Optimum utilization of the world's energy resources is a matter of vital concern. The thorium utilization program at the Oak Ridge National Laboratory is aimed at the prudent and economical exploitation of the vast thorium reserves in the United States and other parts of the world. Through its conversion to uranium-233, which is a fissile isotope of uranium, thorium can be made into a source of energy which will last for thousands of years. The technology being developed for the thorium–uranium-233 cycle can also be applied to the uranium-238–plutonium-239 cycle.

Important savings in the cost of energy can be realized from improvements in the fuel cycle, that is, the operations involved in processing the burned thorium or uranium fuel from the reactor to remove the fission product poisons which have accumulated in the fuel, making new or reconstituted fuel, disposing of the radioactive waste poisons, and returning the fuel to the reactor. The fuel-cycle programs under development at the Laboratory are directed to this end. Unlike the mildly radioactive natural uranium and thorium, the recycle fuel materials will be highly radioactive. Consequently, it will be necessary to handle these materials remotely, and to achieve economy in remote operations the handling process must be comprised of simple steps. A major technological advance toward this objective in recent years is the discovery of the *sol-gel process*, and much of the current work on the thorium utilization program is concerned with this technique.

The formation of a sol as an intermediate step in preparing fuel by the sol-gel process makes possible the convenient extension of this process to the production of microspheres for the important class of fuels used in high-temperature gas-cooled reactors. These fuels employ a dispersion of small, carbon-coated spheres evenly distributed through graphite. These spheres may be either oxides or carbides of uranium and thorium, and are generally 0.004 to 0.02 in. in diameter. The carbon coatings may be in several layers, varying in thickness from about 0.002 to 0.006 in. Studies are also being made to extend the process to the preparation of other types of fuels, such as those that contain plutonium oxide or carbide.

Adaptation of the entire fuel cycle to remotely controlled operation is of principal interest at the present stage of development. If carbon-coated spheres are the desired product, then remotely operable, high-throughput sphere coaters are needed. Development of such coaters is one of the most challenging unsolved problems in the fuel cycle, and a variety of coater concepts are under study.

In the coating process a hydrocarbon gas is thermally decomposed to carbon and hydrogen. The carbon deposits on nearby surfaces, and the hydrogen passes out as an exhaust. In most common use is a packed bed of spheres which are fluidized to produce a uniform flow of particles through the region in which the deposition of carbon is occurring. To achieve a uniform thickness of coating and a carbon structure of the appropriate characteristics, several variables must be controlled within narrow limits. The problem of achieving this control in an automated remotely operated device has not yet been solved. A further complication is the need to scale the device from the normal laboratory size to the prototype of a large production coater. Engineers are evaluating various concepts to determine which can be most easily designed for remote operation and which offer the best overall economics as a fabrication device.



The 250-μ-diam spheres are a solid solution of ThO_2–20% UO_2. They were prepared by mixing ThO_2 sol with UO_2 sol, forming the sol to gel microspheres, and firing in a reducing atmosphere at temperatures up to 1400°C. The spheres, which are transparent, will each support 1200 g (2.6 lb.) before crushing.

These two pieces of conical equipment are used to dry the microspheres formed by the sol-gel process. A porous metal filter located at the plane where the upper and lower cones are bolted together supports the wet gel microspheres. Heat is applied by passing steam through the coils wrapped around the cones. Simultaneously, a stream of hot gas is passed over the wet spheres to carry off the water and the alcohol used in the sphere-forming operation. After drying, the gel spheres are fired to dense oxide in the furnace.

It is an interesting and surprising development that carbon coatings may be applied to thorium and uranium oxide spheres and that no chemical reaction with the oxide takes place. Since the carbide is more stable than the oxide in the presence of graphite, a basic thermodynamic instability would appear to be inherent at the fuel operating temperature. However, metallurgists reasoned that the carbon coating would contain the gases formed as a reaction product between the carbon and the oxide, stopping the reaction by a mass action effect, and that only insignificant conversion would occur. Their hypothesis has been tested by heat treating particles in the laboratory and in numerous irradiation tests and has been found to be correct. This is fortunate, because the carbide preparation step is eliminated and the problems attendant to the notorious reactivity of the carbides with air and water are avoided. In addition, the more refractory oxides appear to provide much superior irradiation behavior. (See section on Advanced Gas-Cooled Reactor Program.)

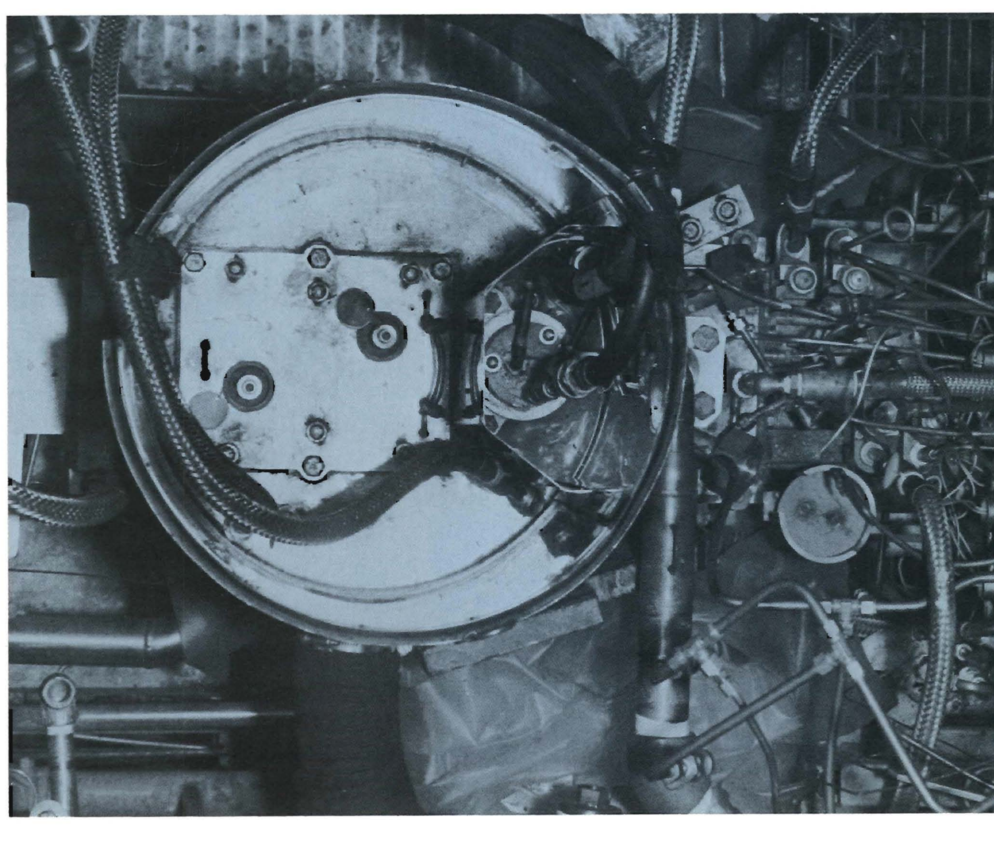
The Oak Ridge National Laboratory's efforts on this program will culminate in a facility in which the complete technology for reprocessing, reconstitution, and refabrication of fuel elements containing uranium-233 can be developed and demonstrated.

NUCLEAR SAFETY

The construction of large nuclear power reactors in populated areas involves the reconciliation of opposing economic and safety viewpoints. The lack of definitive information on the degree of safety of particular reactor concepts and facilities has forced the use of extremely conservative assumptions in the evaluation of acceptable sites. The Nuclear Safety Program is directed toward a better understanding of the behavior of fission products during all phases of serious nuclear accidents. The information developed through controlled experiments will allow the use of more realistic safety assumptions in the evaluation of reactor sites.

In water-cooled reactors (most of the power reactors in the United States), the loss-of-coolant accident is the maximum credible one. The events that occur in this accident are rupture of the primary coolant circuit and loss of coolant, subsequent heating of the reactor core by decay heat, melting of the cladding, melting of the fuel, release of fission products, and transport and dispersal of fission products throughout the containment system. The processes by which fission

Remote unloading of fuel from Nuclear Safety Pilot Plant furnace. Fuel is being transferred into a shipping container using remote tools.



Top of furnace in Nuclear Safety Pilot Plant. Photograph taken after fuel had been removed from furnace, line connecting furnace to model containment vessel had been removed, and a decontamination line had been connected in its place.

products would be released are complicated by unpredictable changes in core geometry and environment as the events proceed. Extensive experimentation has been carried out both in-pile and out-of-pile to study the behavior and characteristics of fission products released from the reactor under simulated accident conditions and to control, insofar as practical, their subsequent release to the surrounding area.

Nuclear Safety Pilot Plant

The Nuclear Safety Pilot Plant is a facility for studying the behavior of fission products in a simulated containment vessel. It will bridge the gap between the laboratory-scale experiments and tests on a full plant scale.

To date, three series of experiments have been conducted: in the first, iodine was released both with and without the aerosol from molten UO_2; in the second, trace-level-irradiated stainless-steel-clad UO_2 was melted; the most recent employed UO_2 which had been impregnated with selected stable elements and radioisotopes to simulate the chemical concentrations in the aerosol that would be associated with the melting of high-burnup fuel.

In all the tests, which included a variety of ambient atmospheres, iodine was released principally as I_2 under oxidizing conditions, whereas under reducing conditions a greater fraction of HI was produced. In no instance was much iodine associated with particulates, although in many instances significant fractions were observed to be in forms (e.g., methyl iodide) that are more difficult to retain. In experiments directed toward the behavior of other isotopes as well, higher percentages of iodine, strontium, and ruthenium were transferred to the containment vessel under oxidizing conditions than under reducing conditions. Reducing conditions did enhance the transfer of cesium and cerium, but the iodine release still predominated.

The concentration of isotopes in the simulated containment vessel has been observed as a function of position and time for the release conditions described above, in combination with a number of vessel conditions. Tests have been made (1) in an air or steam-air atmosphere, (2) with and without recycle filtration, and (3) with and without water sprays. In all instances significant decreases in the concentrations of the airborne fission products were observed.

TREAT Fission Product Release Studies

Smaller-scale reactor transient experiments are performed in the TREAT facility (Transient Reactor Test), located at the National Reactor Testing Station, to study the release of fission products from fuel that is heated and melted rapidly, thereby simulating an accident involving a nuclear excursion. Various components of the equipment are designed to simulate the core, the pressure vessel, the containment vessel, and the filter and charcoal cleanup system of a typical large power reactor.

The most recent transient experiments again indicate that only a relatively small fraction of the nongaseous fission products escape the melt region. The test series includes meltdowns in inert gases, wet air, high-pressure steam, and liquid water using stainless-steel- or Zircaloy-clad UO_2 with moderate burnups varying from tracer level to 40 MWd/ton.

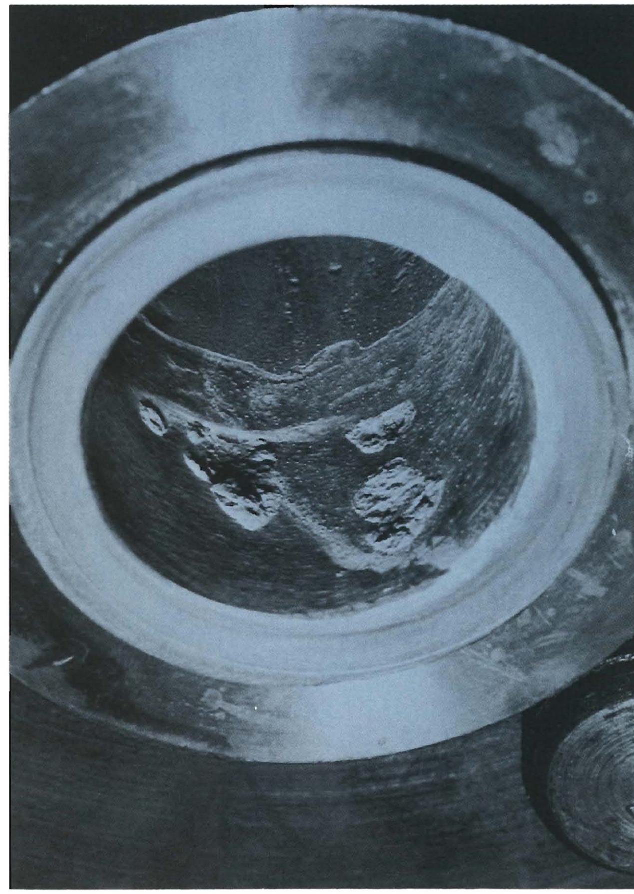
The fraction of nonvolatile and moderately volatile fission products escaping from the melt zone is substantially lower than corresponding releases in experiments simulating loss-of-coolant accidents. The lower releases are believed attributable to the fact that in the TREAT experiments the fuel melts very rapidly and does not remain molten sufficiently long to permit vaporization of the fission products.

Retention of Methyl Iodide by Charcoal Under Accident Conditions

The controlling hazard in nuclear reactor accidents is generally considered to be radioiodine. To minimize its escape from reactor containment vessels the containment air may be recycled or discharged through charcoal beds, which remove the iodine. However, recent experimental work in both the United Kingdom and the United States has demonstrated that a small fraction of the iodine is frequently in the form of methyl iodide (CH_3I) and that charcoal sorbs this with low efficiency, particularly if the gas phase contains moisture.

It was recently discovered at the Laboratory that commercially available charcoal, on being impregnated with nonradioactive iodine, became quite effective in removing methyl iodide from moist air. With this treatment, charcoal beds seem capable of coping with the iodine species expected in reactor accidents.

DESALINATION



Pits in flow area of titanium loop piping.

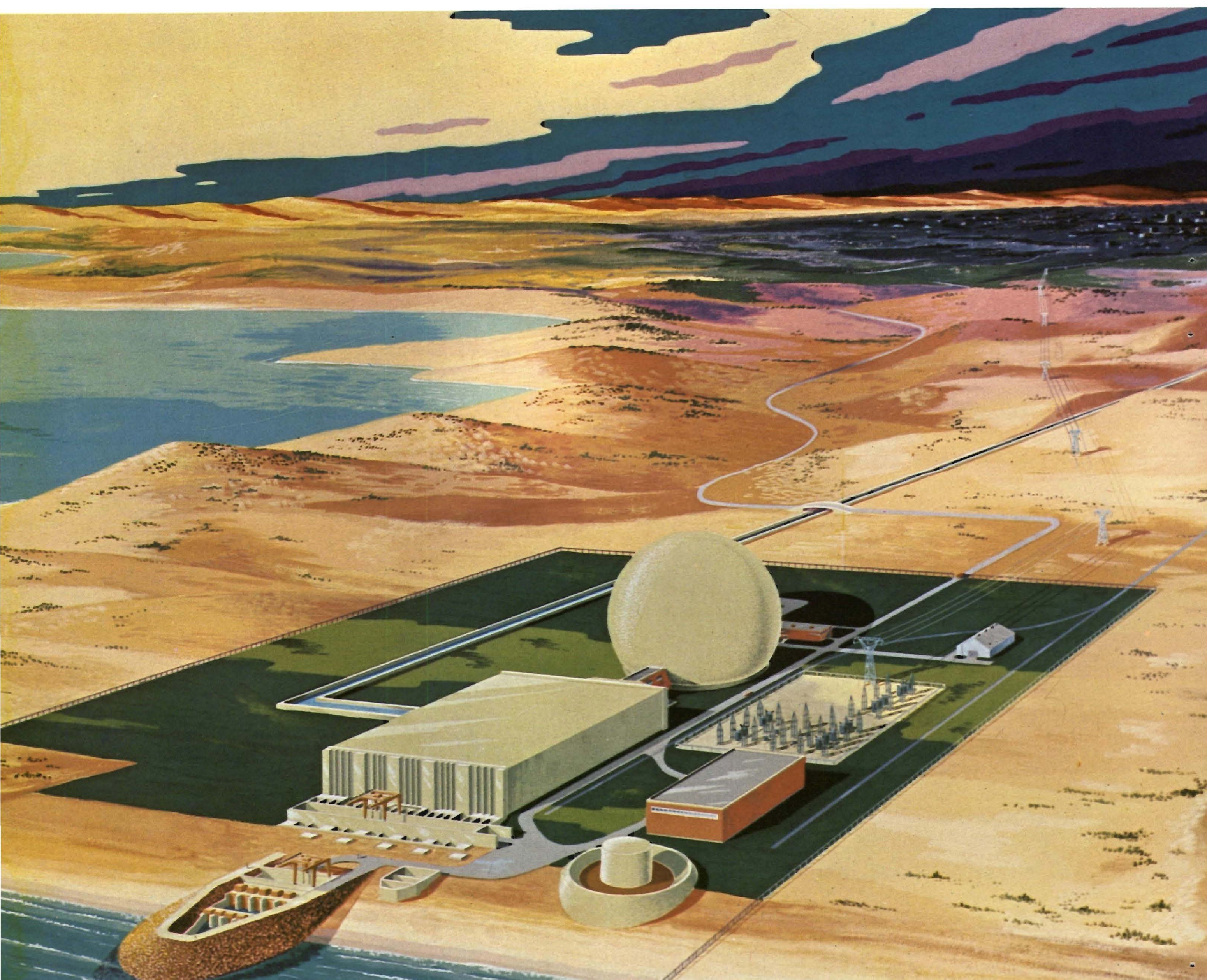
Water Research Program

The Office of Saline Water, in the United States Department of the Interior, has traditionally been strong in areas of basic desalination research. Under its sponsorship the Laboratory has over the past several years developed a fruitful program of water research designed to provide information pertinent to desalination. Research areas have included studies of properties of aqueous multicomponent and water-organic mixtures; phase relationships; reactions and transport phenomena at surfaces, including corrosion; separation processes, including membranes; electrodes; boundary-layer studies; and turbulence promotion.

In 1965 a considerable fraction of the Water Research Program was concerned with the development of hyperfiltration, or reverse osmosis. In hyperfiltration, desalination is achieved by forcing a salt solution under pressure through a membrane that passes water more readily than salts. Usually, membranes are cast from special organic materials, such as cellulose acetate. While the Laboratory's program has been concerned with developing new membrane materials and deepening our understanding of the mechanism of salt rejection, the most interesting development came when it was found that hyperfiltration membranes can be deposited dynamically from solutions containing selected additives as these solutions pass over porous surfaces that will support the membrane. With these dynamically created membranes, extremely high fluxes of water (hundreds of gallons per square foot per day) can be obtained with reasonable salt rejection.

With such high-flux membranes, the rejected salts tend to "pile up" at the interface, and their removal becomes a problem. This concentration polarization, however, can also be a problem at much lower production rates. For several years the program has included studies of boundary-layer phenomena, with special emphasis on the development of turbulence promoters which, with modest expenditure of energy, could alleviate con-

ORNL concept of a dual-purpose plant for desalting seawater and producing electricity. The large rectangular building houses a single-effect multistage flash evaporator producing 250,000,000 gpd of distilled water from the sea. The sphere is the nuclear powerhouse, in which a 3,300,000-kW heavy-water-moderated organic-cooled reactor produces steam to heat the seawater and to generate 675,000 kW of electricity. The small rectangular building and nearby tank are for production and storage of sulfuric acid, which is used in large quantities for pretreatment of the seawater feed stream.



centration polarization. Emphasis was on what have been called "detached turbulence promoters," that is, promoters elevated above the interface, which now show promise of being useful not only in hyperfiltration but also in promoting heat transfer across heat exchanger tubes.

Severe localized corrosion of titanium at high temperatures in saline waters has been observed. In an attempt to understand this unexpected behavior of titanium, high-temperature loop experiments (100 to 200°C) have been carried out, whereby the electrochemical behavior of titanium and other metals and alloys was observed in flowing salt solutions. Polarization curves measured for several commercially available titanium alloys show that a breakdown or pitting potential exists at sufficiently high potentials for all the alloys. Increase of temperature drastically lowers the pitting potentials of the alloys. Plots of pitting potential as a function of temperature are reproducible and quite characteristic of each grade of titanium alloy; they show clearly which alloys are superior in tendency toward pitting attack.

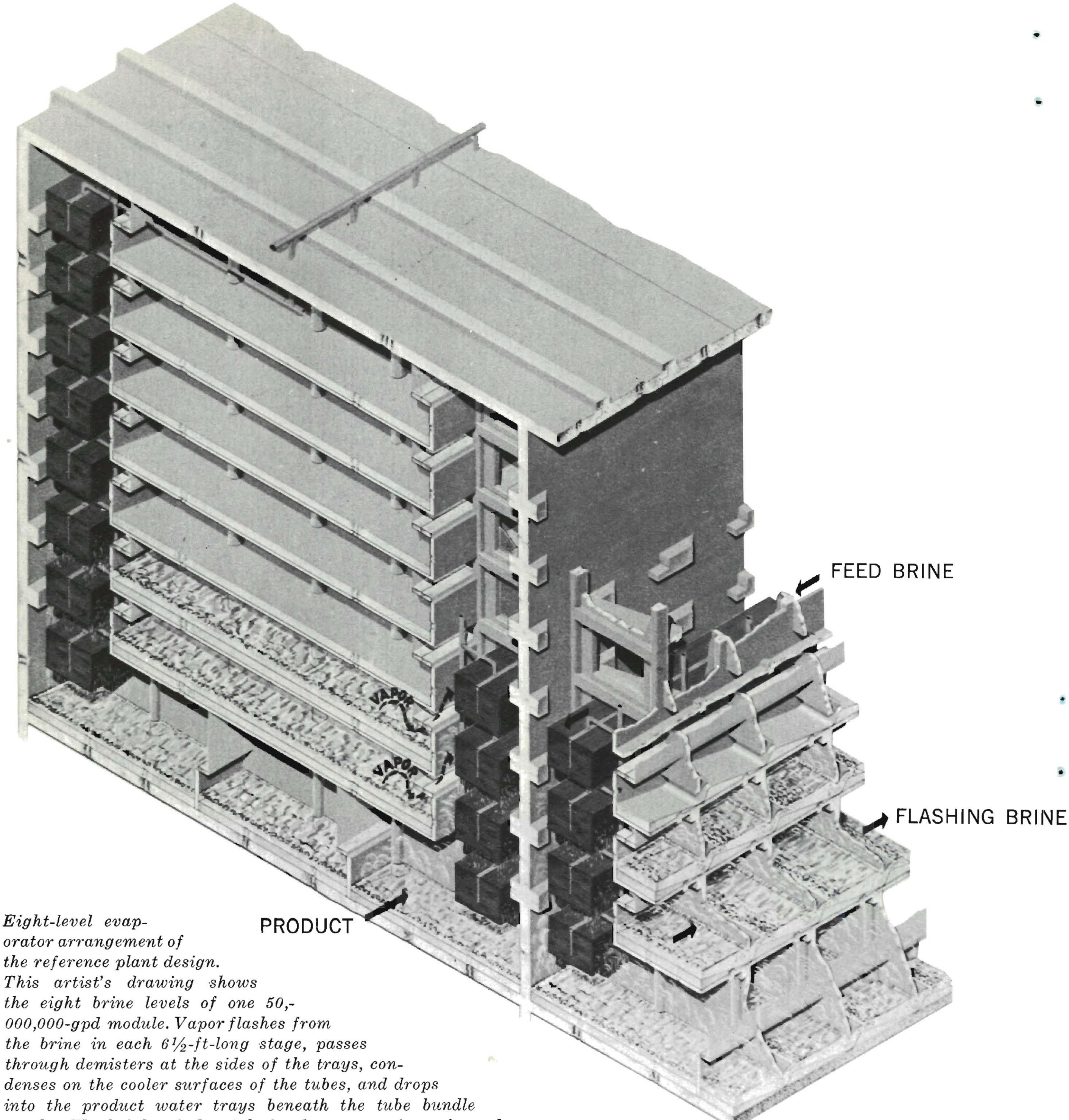
Nuclear Desalting Program

A broad program of nuclear desalination development was established in 1965, with support by both the Atomic Energy Commission and the Distillation Division of the Office of Saline Water. The distillation processes that have been used for many years to produce fresh water from the sea have been comparatively expensive. A major portion of the cost of distilling seawater is associated with the heat required to boil the water. Since nuclear energy shows promise of providing heat at low cost in very large installations, the coupling of a nuclear heat source with a distillation plant appears very promising for lowering the cost of desalting seawater.

Nuclear desalination activities supported by the Office of Saline Water cover the range from theoretical and experimental studies on heat transfer, seawater deaeration, prevention of salt scale, etc., to conceptual design studies of evaporators and cooperative programs with industry to develop specifications and costs of evaporator components. The Laboratory's activities on evaporator components include studies on valves, vapor compressors, demisters, deaerators, tubing fabrication, and tube bundle design.

Heat transfer studies have resulted in improved heat transfer systems for both multistage flash and vertical tube evaporator concepts. One improved heat transfer system for multistage flash evaporation combines turbulence promotion on the liquid brine side of the tube with dropwise condensation promotion on the steam side of the tube to greatly increase the overall heat transfer coefficients. Similarly, one improved heat transfer system for vertical tube evaporation combines better boiling film coefficients, through treatment of tube surfaces to provide active nucleation sites, and better condensing film coefficients, through the use of special tube surface configurations.

The conceptual design developed at the Laboratory for a multistage flash evaporator resulted in a plant design that uses current technology at a reduced cost. Important features of the design are (1) the use of a steel-lined concrete evaporator shell costing about half as much as steel shells, (2) the use of tube bundles that run the full length of the evaporator and thus eliminate costly water boxes and their associated pressure losses, and (3) the concept of multilevel construction, whereby the high cost of the evaporator shell and piping runs for very large plants is greatly reduced.



Eight-level evaporator arrangement of the reference plant design. This artist's drawing shows the eight brine levels of one 50,000,000-gpd module. Vapor flashes from the brine in each 6½-ft-long stage, passes through demisters at the sides of the trays, condenses on the cooler surfaces of the tubes, and drops into the product water trays beneath the tube bundle stacks. The height of the eight-level structure is 51 ft, and the width of the brine trays is 33 ft. There are 40 stages in the heat recovery section shown above, with continuous tubes in the condensers through all 40 stages, a total length of 273 ft.

Nuclear desalination activities supported by the Atomic Energy Commission include studies on types of very large reactors that could supply energy for producing both electricity and fresh water; problems concerned with the coupling of the reactor to the turbogenerators for producing electricity and to the evaporators for producing fresh water from the sea; the analysis of the factors involved in siting a large plant from the standpoints of safety, site availability, and cost; and systems analysis investigations that utilize computers to predict the performance of various plant designs and to evaluate the overall economics of the dual plant complex.

Isotopes Development Center

The Isotopes Development Center has production and development programs in three principal areas: radioisotopes, stable isotopes, and special research materials.

De-emphasis of radioisotope production at the Laboratory in favor of commercial radioisotope producers continued at an accelerated pace in 1965. Thirty-two radioisotopes, or about 30% of the total catalog items, have been withdrawn from production and distribution. Nevertheless, 1,280,706 curies of radioisotopes were distributed from the Oak Ridge National Laboratory in 1965. With the exception of carbon-14, radioisotope sales are declining markedly, but the increasing demand for cobalt-60, cesium-137, and isotopic power sources in large government-contract programs somewhat obscures the declining trend in overall radioisotope sales by the Laboratory. On the other hand, sales of stable isotopes and special research materials rose 29% in 1965.

In the radioisotopes research and development program, isotopic power assumed a preeminent position. Research on radioisotope production methods and characterization declined, with more emphasis being put on radioisotope applications, information services, and safety testing.

Isotopic Power

Isotopic power and heat source fuels are needed primarily for space, undersea, and remotely located electrical generation systems. The physical properties of highly radioactive source materials (e.g., thermal conductivity, melting point, density, heat capacity, and vapor pressure) must be determined for use in designing isotopic power systems. Chemical properties of radioisotope chemical compounds at high radiation levels and high temperatures must also be determined in developing reliable fuel forms capable of withstanding temperatures up to 2000°C. Compatible fuel forms and container materials must be found to assure containment of the highly radioactive isotopic power fuels during long missions, often in hostile environments.

In 1965, about 35 g each of pure curium-244 and americium-243 were recovered from solutions containing 3.5 kg of rare-earth contaminants and made available to researchers throughout the country. In addition, about 10 g of curium-242 was produced (1200 W) for use in isotopic power studies.

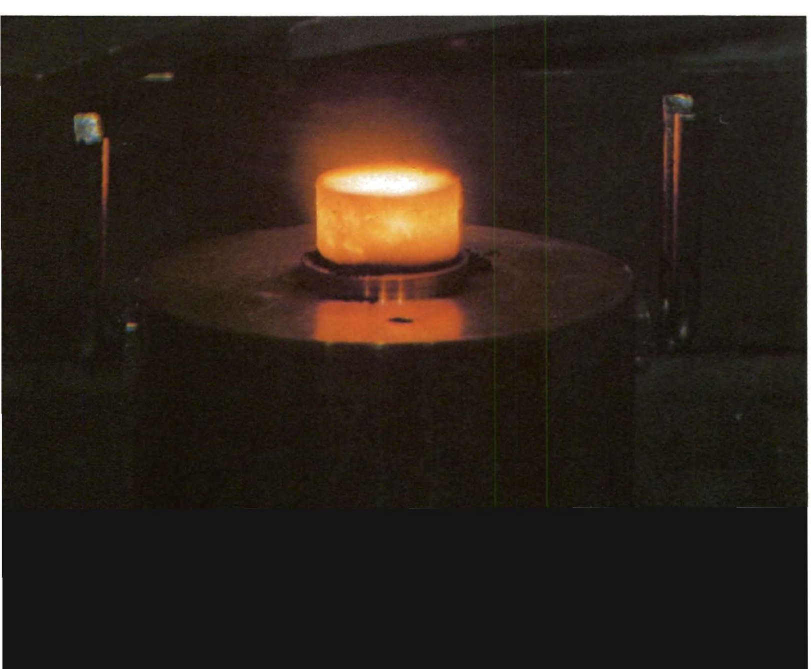
The isotopic power fuels development programs included processes for the production of compounds of curium-244, curium-242, strontium-90, and cerium-144, and characterization of these compounds. An encapsulated pellet of curium-242 was utilized as a high-temperature heat source in an experiment to generate electric power in a thermionic converter (SNAP-13).

The sealing of isotopic power capsules made of refractory metals, such as tungsten, advanced markedly with the design and testing of electron-beam equipment for welding relatively thick-walled capsules containing highly radioactive isotopic fuels by remote control.

Cerium-144 Beta Source for Direct Electrical Conversion Experiment

A cerium-144 source in the form of a thin-wall cylinder was developed for use in a direct electrical conversion device. In an experimental model, cerium as Ce_2O_3 was deposited in voids of a preformed graphite cylinder; silicate was added, and the cylinder was heat treated to firmly bond the materials into the graphite. Twenty thousand curies of cerium-144 will be used to produce a source of this type for use in an ion propulsion

Curium-242 oxide pellet containing about 8500 curies. The pellet, formed by cold pressing, is a source of heat so concentrated that it is incandescent while resting on a cool surface. The curium-242 in the source is a portion of the largest quantity of this isotope ever purified and formed into a single concentration.



This strontium-90 beta-ray source was prepared for the Marshall Space Flight Center of the National Aeronautics and Space Administration to simulate space radiation in studies concerning the effect of electron radiation on spacecraft components. A uniform flux of more than 2 × 10⁸ electrons cm⁻² sec⁻¹ at 2 in. from the source was obtained over an effective area of 20 × 40 in. A total of 81 stainless steel tubes, each 20 in. long and ⅛ in. in diameter, with walls 10 mils thick, were loaded with about 10 curies of strontium-90 and spaced on ½-in. centers on an aluminum backing plate. Less than 1.4% of the total radiation from the source was bremsstrahlung. Source modules of this type may be combined in various geometries to produce radiation chambers as large, for example, as the living room in the average house.

experiment by the National Aeronautics and Space Administration.

Isotopic Enrichment of Krypton-85

A pilot unit for isotopically enriching fission product krypton in krypton-85 by thermal diffusion was put into operation. The unit is expected to produce about 3000 curies/year of 40% krypton-85 from feed material containing about 4% of the desired isotope. Krypton-85 is of interest in commercial applications, such as radiation-activated phosphors for luminous signs, wear testing, leak testing, gas flow measurements, and aircraft position-detection devices. Enrichment will greatly enhance its usefulness.

Heat Source for Undersea Life Support Experiments

The United States Navy needs a heat source that can be used to warm divers who work for long periods under water in connection with undersea research programs. A 530-W (thermal) strontium-90 source (84,000 curies) which had previously been used in a thermoelectric generator test was used to make a prototype heater for evaluation by the Navy. A container was fabricated consisting of a 3-in.-thick inner depleted-uranium shield surrounded by a finned 3-in.-thick steel outer shield and pressure shell. In use, the container will be placed inside an open insulated cylindrical container filled with water, which in turn is mounted in a submerged chamber anchored to the ocean floor. A diver can swim into the chamber and warm himself in the heated water in the insulated container.

Radioisotope Source Safety Testing

The steadily increasing use of radioisotope sources in research and manufacturing has made it desirable to define those safety characteristics of source capsules which are important in ensuring that radioactive material does not leak to the surrounding environment during normal use or in the event of accidents. Several hundred source capsules of various types were subjected to a variety of mechanical and temperature tests to determine their containment integrity. A simple method of classifying sealed sources according to their structural characteristics was developed.

Testing of specific sources, as requested by the Atomic Energy Commission, continued throughout the year. Examples of these are commercial ice-detector probes to measure ice formation on aircraft control surfaces and stainless steel ring sources for controlling automatic machining equipment. It was found that the design of the ice-detector probes was marginal for their intended use because of their low impact resistance, while the automatic machining sources are probably more than adequate for their intended use.

A ten-year test of the rate of tritium release from commercial luminous paints under various conditions continued. The tritium studies so far have shown that the rate of release of tritium from all the paints tested is relatively high during the drying period and that the release rate from dried paints increases steadily with increasing temperature.

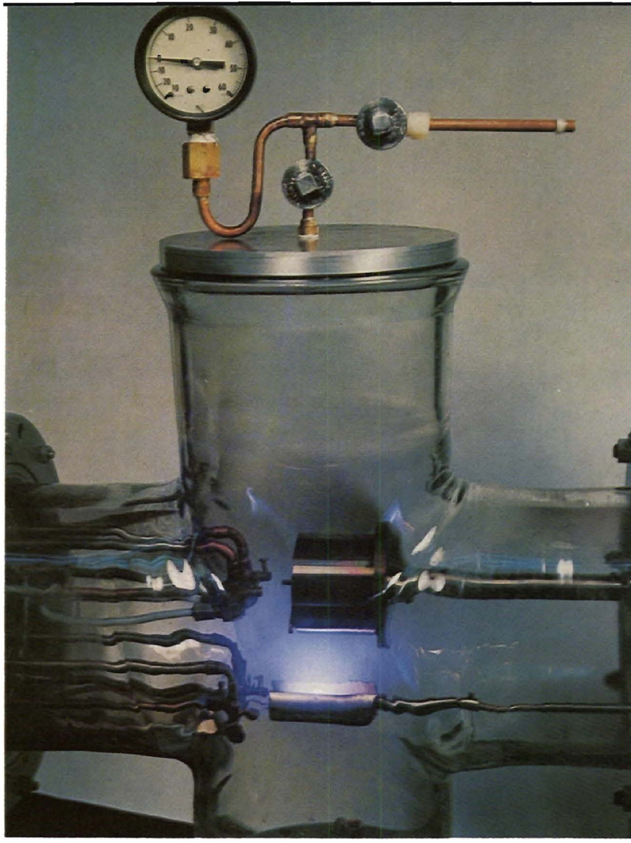
Electromagnetic Separation of Isotopes

Approximately 50 elements are processed routinely in the electromagnetic isotope separators to yield materials having as much as 30-fold isotopic enrichments and in some cases reducing specific isotopic contaminants to the parts-per-billion level. The isotopically separated materials are extensively used in basic research and are of growing importance as target materials for radioisotope production.

Seventeen thousand grams of enriched isotopes of 21 elements were processed during the year for a great variety of scientific uses throughout the world. Mercury-196, for example, was separated in quantity and at purity levels needed for production of radioactive mercury-197, used in location of brain tumors and in other important medical diagnostic procedures. Two calutrons are operating on a full-time basis at increased efficiency levels to meet the requirements for mercury-196.

A technique was developed for the in situ washing and subsequent reuse of calutron components contaminated in radioisotope separations. One separator was used successively to process 21 g of americium and 48 g of plutonium for separation of americium-242, plutonium-244, and plutonium-238. In the three runs involved, 800 curies of alpha radioactive material was processed, the largest amount of radioactive material processed thus far in an electromagnetic separator.

Methods were developed for using a calutron beam for direct ion implantation in targets such as silicon. About 3000 targets containing both stable and radioactive implanted elements were prepared for commercial research groups to be used



Evaporation of PuO_2 onto a fission chamber cylinder. Amounts of material with a surface density greater than 1 mg/cm^2 can be deposited by this electron-bombardment technique. The cylinder is rotating at 100 rpm to enhance uniformity.

in research on semiconductor materials. This type of work, as well as that involving high isotopic enrichments, will advance rapidly upon completion of a sector-type electromagnetic separator now under development which will provide five times the mass dispersion of standard calutrons.

Special Research Materials: Targets for Accelerators

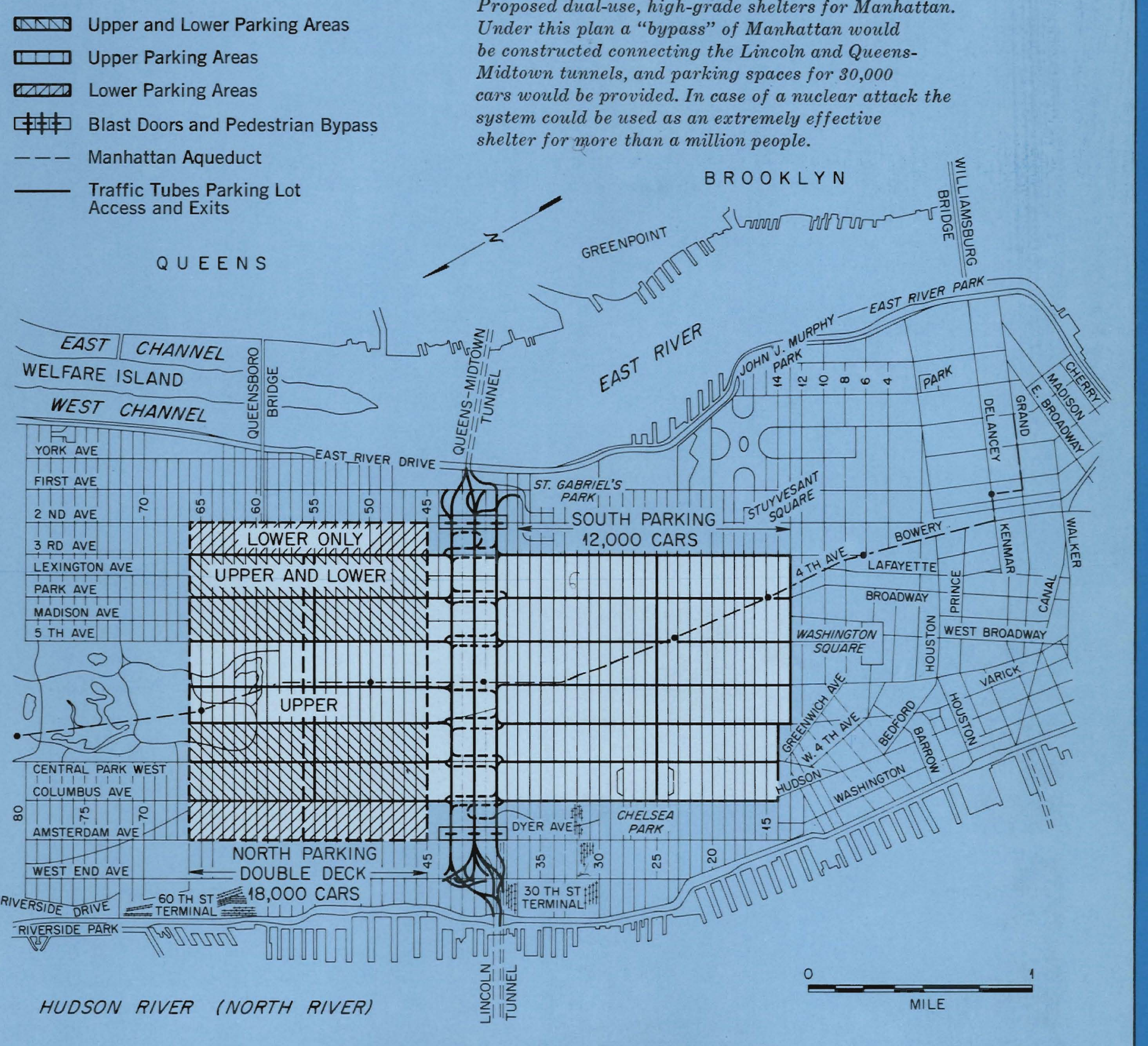
The major objective of the target program is to prepare highly specialized research materials for use in particle accelerators throughout the United States for neutron interaction studies and for many other kinds of basic physical research. The materials prepared vary from extremely thin films to heavy samples weighing a kilogram or more. Research and development efforts are directed toward development of techniques for preparation of thin films or other unusual physical forms of materials and the characterization of isotopic targets to determine the atom content of desired nuclide and impurities present with high accuracy.

Refractory elements, which have crystal structures of low ductility and great hardness, are difficult to form into thin films, and in many cases these elements have not heretofore been satisfactorily formed into targets. Vacuum-evaporation–vapor-condensation techniques were used to produce thin-film forms of elements such as silicon, germanium, and chromium. Techniques were developed by which all the refractory elements can be prepared as targets. Notably, it was found that when the refractory elements were extremely pure, they had properties comparable with those of the more ductile elements. An important factor in the technique was found to be the selection of a substrate on which condensing vapors have adequate mobility (usually limited by temperature and substrate crystal structure). The possibility of forming films having areal densities between 50 and 1000 μg/cm^2 is also strongly dependent upon the vaporization source. Careful selection of evaporation crucible materials and use of electron-bombardment heating yielded films with an impurity content usually less than that of the initial evaporant.

The preparation of radioisotopes into target forms was confined almost entirely to alpha-emitting materials. Because of the hazards encountered with these isotopes (e.g., plutonium, americium, curium, and californium isotopes) relatively inexpensive vacuum evaporation systems enclosed in glove boxes were developed to reduce the cost of equipment that often must be discarded after use because of contamination. A typical system is the combined ion and titanium-sublimation pumping system in which gram quantities of $^{241}AmO_2$ were reduced to the metal with an impurity content below 100 ppm. Many kinds of thin-film targets, using carbon films as the substrate, were prepared for the study of fission fragments and for scattering experiments.

In some instances only submilligram quantities of man-made heavy elements (e.g., californium-252) were available for target and/or source preparation. In order to use such small quantities of valuable material, a vapor collimation technique was developed by which (using 100 μg of starting material) over 30% of the vapors could be condensed uniformly onto the substrate. This method provided samples of californium and curium that were previously unavailable to Commission laboratories for research purposes. Because actinide oxides have very low vapor pressures, high temperatures are required to achieve vapor deposition of these materials in thin-film form. Development of electron-bombardment heating techniques permitted thicker film deposits than those attainable by electrodeposition with comparable adhesion and uniformity.

Civil Defense



Proposed dual-use, high-grade shelters for Manhattan. Under this plan a "bypass" of Manhattan would be constructed connecting the Lincoln and Queens-Midtown tunnels, and parking spaces for 30,000 cars would be provided. In case of a nuclear attack the system could be used as an extremely effective shelter for more than a million people.

PROPOSED DUAL USE SHELTERS FOR MANHATTAN.

Interconnecting Traffic Tubes and Underground Parking Areas.

The complexities of current and projected continental defense systems to deter or counter possible aggression are not only overwhelming but also subject to rapid change due to technological innovation. This is particularly true for systems in which machines are used to counter machines, as in, for example, the antimissile vs the missile. Civil defense effectiveness is not so subject to technological change, but its projected effectiveness is very difficult to estimate in that it involves a man-machine system. A small but highly diversified group has been assembled at the Oak Ridge National Laboratory to study (1) the feasibility of developing civil defense systems that will be effective against the kinds of threats expected in the 1970's, (2) their social and political impact, and (3) their interaction with advancing technology in general and other defense systems in particular. In addition, careful study is being placed on the possible symbiosis between, for example, urban traffic problems and personnel shelters that would be effective against both prompt (blast, thermal, and radiation) and delayed (fallout) effects of weapons. These considerations have also prompted investigations of basic nuclear weapons effects, techniques for underground highway construction, the willingness and ability of society to plan for extreme situations, the range of response by various governments to a variety of possible defense decisions by the United States, and the technological scope and nature of future possible wars. Among other problems under consideration are the effects of radiation (both alone and combined with other insults) on the ecosystem of man and his environment; problems of nuclear proliferation and means of curtailing it; the relationships between arms control, ballistic missile defense, and civil defense; and agricultural production, surpluses, and needs for reserves in national disasters. This study group is not trying to solve all these problems, but it recognizes the necessity to gain an appreciation of the entire problem in order to effectively tackle a few component parts.

An example of one study being performed is the problem of the defense of Manhattan Island. This area is a particularly inviting target in case of nuclear war or "blackmail"; the population density is high (several hundred thousand people per square mile in Midtown), and the real estate is valuable. No monetarily acceptable and effective plan has yet been devised to solve the problem of Manhattan's defense. A new approach investigated by the Laboratory's study group was the possibility of partially solving Manhattan's traffic and parking problems while simultaneously providing an effective shelter for about 1.8 million people. The basic idea partially stems from an observation made several years ago by Hoffman of the Rand Corporation that the cost of urban highway construction was *increasing* with time, mostly because of the increasing value of land, and was approaching the costs of tunneling underground. Hence, even if one ignores the real aesthetic value of putting highways underground, it was apparent that tunneling might soon be a practical economic alternative. Under the Laboratory plan a large tunnel would be built across Manhattan connecting the existing Queens-Midtown and Lincoln tunnels, thus allowing crosstown traffic to "bypass" the city. In addition, underground parking spaces for 30,000 cars would be excavated on both sides of the main tunnel. Such a facility, sorely needed in peace, could also be extremely valuable in case of any sort of nuclear emergency.

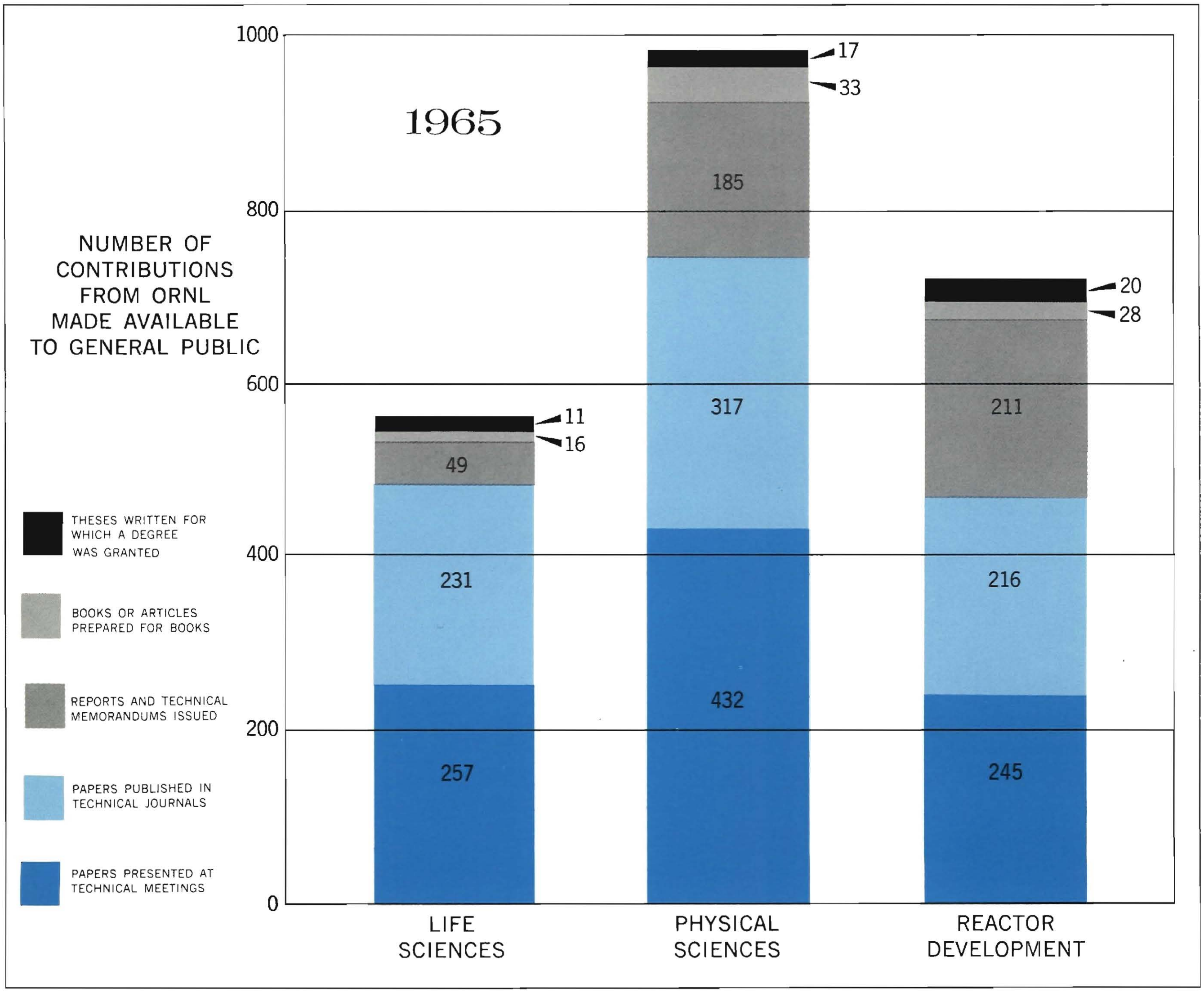
A second example of the diverse but interrelated studies by this group is the following: Agricultural research revealed that our nation's previous fortunate possession of large surplus stocks of food has nearly ended. For five consecutive years the total of domestic consumption plus export has exceeded wheat production. In addition, dairy surpluses such as butter, cheese, and powdered milk have virtually disappeared, and the nation has become a large importer of livestock. Studies are under way on the validity of projecting these trends and on their possible impact on the reserves required in case of a national catastrophe.

Information, Education, and Industrial Cooperation

It has been said that the principal product of a scientific research laboratory is its technical information. For this information to be of greatest benefit it must be disseminated promptly and effectively. This is done through journal articles, speeches at technical meetings, laboratory progress and topical reports, releases to news media, lectures at universities, conferences with representatives of industry, laboratory seminars, periodic information meetings, and other similar means of communication.

To accomplish these communication objectives the Oak Ridge National Laboratory has designated offices and staffs of personnel who are responsible for technical information, public information, education and university relations, and industrial cooperation. In addition, the Laboratory has established technical information centers in various areas of research and development where technical specialists originate, collect, organize, evaluate, and disseminate information of interest to other workers in these particular fields.

The accompanying chart shows the various kinds of open-literature publications which the Laboratory made available in 1965. These publications are shown in the three broad areas of life sciences, physical sciences, and reactor development. In addition to these data, the office of public information has provided a large number of news releases to newspapers, magazines, radio, and television.



TECHNICAL INFORMATION

The Laboratory's technical information services provide editing, composition, makeup, illustrating, photography, and reproduction for much of the technical and nontechnical literature originating at the Laboratory. Improvement programs in technical writing and in the design of technical reports are vigorously pursued. Excellent technical libraries and extensive report files are maintained for reference and circulation. Other services provided by the libraries include interlibrary loans, literature searching, and preparation of bibliographies.

The demand for technical information services has increased steadily through the years, and 1965 was no exception. The libraries increased their efficiency in handling a larger volume of reference materials by greater use of computers and by automating the circulation system for books. All new books carry punched cards which are used for circulation purposes and for establishing a book catalog. The handling of all records associated with the 3000 journal subscriptions is also now being automated.

Another trend in scientific information handling is in the rapidly increasing use of microfiche * for research and development reports. Over 15,000 reports were received during the year in microfiche format. Several information centers store their holdings on microfiche. Microfiche readers and reader-printers were distributed throughout the Laboratory for individual use, and equipment was centrally installed for making duplicate microfiche and for producing microfiche from full-size copy. Also, equipment was designed and built by the Graphic Arts Department for enlarging microfiche to full-size copy.

*Microfiche is the term widely adopted for a small sheet of photographic film which contains reduced images of the customary full-sized printed page. The standard microfiche is 105 mm high and 148 mm wide and can contain a maximum of six rows of images, 12 images per row. Thus up to 72 pages of a typical report can be contained on a single microfiche. A few images are usually sacrificed to provide legible headings. Federal standards have been established by the Federal Council on Scientific and Technical Information and are now in use by the Atomic Energy Commission, the National Aeronautics and Space Administration, the Department of Defense, and the Department of Commerce.

INFORMATION CENTERS

In the publication *Science, Government, and Information,* a Report of the President's Science Advisory Committee, January 10, 1963, it is stated: "We believe that the specialized information center, backed by large central depositories, might well become a dominant means for transfer of technical information. . . .

"Specialized information centers, to be fully effective, must be operated in closest contact with working scientists and engineers in the field. The activities of the most successful centers are an intrinsic part of science and technology. . . ."

Consistent with this philosophy the Oak Ridge National Laboratory has a number of information centers in fields of research where the need is clearly justified.

During 1965, Laboratory specialized information centers have worked toward the consolidation of their activities, the improvement of relations with generators and potential users of the information, and a closer cooperation among centers here and elsewhere. The centers benefit from being in a large multipurpose laboratory where scientific work of interest to the centers is continuously in progress and specialists are conveniently available for consultation. In addition, summer participants, university faculty members, and international visitors contribute to the centers and utilize them.

The *Charged Particle Cross Section Information Center* published its second compilation, covering the charged-particle reactions of nickel and copper. Future compilations will be published in the journal *Nuclear Data.*

The *Information Center for Internal Exposure* continued its work in accumulating information and making interpretative studies on internal emitters for the use of the International Commission on Radiological Protection and the National Council on Radiation Protection and Measurements in revising their recommendations. In particular, a tentative list of recommended maximum permissible concentration values covering certain isotopes of carbon, iodine, thorium, and uranium was prepared.

In 1965 the *Nuclear Data Project* realized one of its goals by the establishment of a new journal, *Nuclear Data,* devoted to the presentation of compilations and evaluations of both experimental and theoretical results. In the past much of this material has appeared only in reports or other limited publications. The new journal has already published, or has in hand, manuscripts from Dutch, German, Russian, and Japanese as well as from United States scientists. Academic Press, the publisher, is promoting the publication vigorously. The journal is being issued in two sections: Section A for general compilations and Section B for the "Nuclear Data Sheets" only.

The *Criticality Data Center* publishes compilations with complete bibliographic reference in the field of criticality experiments. It is collecting values of variables encountered in chemical and metallurgical processes in order to provide guidance to designers and operators of facilities in which special nuclear materials are handled.

The *Nuclear Safety Information Center* developed its new computer code, which makes it possible to prepare bibliographies and perform retrospective searches by means of a weighted combination of key words. As an indication of the flexibility of the various search strategies, retrieval may be based on (1) author(s), (2) installation(s), (3) date, (4) content evaluation, (5) category, and (6) weighted combinations of key words. Searches may be structured combinations of any of the six, and negation may be permitted on any of the six.

State-of-the-art reports have been published on the "Behavior of Iodine in Reactor Containment Systems" and "U.S. Reactor Containment Technology." Some 2500 document references are listed in the four indexes and bibliographies issued during the year. *Nuclear Safety,* a journal in the Technical Progress Reviews series of the Atomic Energy Commission, is published quarterly by this center.

The *Isotopes Information Center* includes an estimated 80% of the world's current isotopes literature; the foreign-language literature is now more carefully covered. The Termatrex System, a random-access visual system based on a plastic-card memory, is used to retrieve documents. To avoid duplication, cooperative relations have been established with similar organizations in Australia, France, Great Britain, and Belgium and with Euratom. The journal *Isotopes and Radiation Technology,* one of the Technical Progress Reviews, is published quarterly by this center.

The *Research Materials Information Center* has found that requesters are more interested in data and techniques than in availability of materials. Special emphasis was laid on the establishment of direct contact with working scientists. Graduate students use the services of this center in preparing theses.

The *Radiation Shielding Information Center* has been broadened to include shielding from radiation in the environment of high-energy accelerators and in space. The Center has assembled and disseminated about 60 complete computer code packages. Three state-of-the-art review papers were issued during the year. The Center has become a link of cooperation between the United States Atomic Energy Commission and the European Nuclear Energy Agency through an agreement to exchange and standardize computer code packages.

The *Nuclear Fuel Technology Information Center* was organized during the year by the Metals and Ceramics Division to cover the technical and economic aspects of fuel fabrication. Reviewers were appointed, a thesaurus of key words was compiled, and a limited "selective dissemination of information" service was started, using a specially adapted computer program which serves also for information retrieval.

In addition to these centers several others, including the Accelerator Information Center, the Atomic and Molecular Processes Information Center, the Engineering Data Collection, the Molten-Salt Information Center, the Space Materials Information Center, and the Water Desalination Collection, are actively serving workers in these areas.

EDUCATION AND UNIVERSITY RELATIONS

Through its research program, the Oak Ridge National Laboratory is extremely active in the field of education in appropriate disciplines. The Office of University Relations develops and conducts educational programs of mutual benefit and interest to the Commission, to the Laboratory, and to universities. A close working relationship exists with Oak Ridge Associated Universities.

The Faculty Research Participation Program and the Traveling Lecture Program were established in 1950 to assist universities in expanding the scope of training offered to undergraduate and graduate students and to stimulate research in universities which is of interest to the atomic energy program. Fifty-five faculty members represented 36 universities in the Research Participation Program during 1965; under the Traveling Lecture Program, 84 staff members of the Laboratory visited 104 institutions and presented 221 lectures.

Eighty undergraduate (junior and senior) and 70 graduate students spent the summer in the research divisions of the Laboratory. Research was conducted on a full-time basis by 42 Graduate Fellows. Some of them and other graduate students completed 21 doctoral dissertations and 27 master's theses. Six AEC Postdoctoral Fellows were in residence during the year, and several others held equivalent, temporary appointments. In addition to those supported by the Atomic Energy Commission, there were other Fellows at the Laboratory who were supported by other agencies and organizations. On the average there were at any given time 70 noncitizens who had come for periods of time ranging from a few months to three years to learn by participating in the Laboratory's research.

The Research Participation Program, the Traveling Lecture Program, the Oak Ridge Graduate Fellowships, the AEC Postdoctoral Fellowships, and the ORAU Traineeships (which account for about half of the 80 undergraduates alluded to) were conducted in cooperation with the Oak Ridge Associated Universities. This association is a link of growing importance between 40 Southeastern universities and the Laboratory.

Since 1963 about 30 members of the Laboratory's senior staff have spent part of their time on a regular and continuing basis as professors at the University of Tennessee.

A school to educate biomedical scientists capable of original research in biology and fundamental medical sciences is being designed jointly by the Oak Ridge National Laboratory and the University of Tennessee. Based on a report prepared after a five-month study by a committee appointed by the University and the Laboratory, a plan to establish the Oak Ridge Graduate School of Biomedical Sciences was unanimously approved by the University of Tennessee's Board of Trustees on November 5, 1965. The committee recommended that the proposed educational unit be classified as a School and be authorized to offer a program of study and research, on the completion of which the University will grant its Ph.D. degree. A Director has been appointed and a faculty (many of whom will be Biology Division investigators who will teach on a part-time basis) is to be selected. The first students will probably enroll in September 1967.

INDUSTRIAL COOPERATION

The Office of Industrial Cooperation was established in November 1962 to carry out the Laboratory's responsibilities related to the prompt transfer of newly developed technology and its utilization in private industry. This office is industry's point of contact for obtaining information concerning technical developments at the Laboratory. When required, it serves to establish communication between Laboratory staff members and companies desiring technological details. All information and assistance are made available to industrial firms on a nonpreferential basis.

Significant advances in technology connected with Laboratory programmatic work are traditionally presented to the public at professional society meetings, in technical journals, and in official reports. This method of dissemination is well established; the Office of Industrial Cooperation is devoted primarily to making available specific details of programmatic developments which might be applicable in industry.

For firms not in touch with technical developments at the Laboratory, the general news release and the Industrial Cooperation Conference have been employed to provide a means of acquainting the industrial community with innovations, devices, techniques, processes, and other technology which could possibly be utilized in private industry.

When a firm becomes interested in the application of Laboratory technology in its own operations, the Office of Industrial Cooperation arranges for conferences with qualified Laboratory staff members. Following this, consulting and other services or training of personnel through work experience may be arranged, as required, to assist in the application of the technology or adoption of a Laboratory innovation.

During 1965, more than 2000 visitors to the Laboratory were identified as representatives of industry. In addition, an undetermined but large number of industrial firms wrote to the Laboratory for technical information, which was supplied to them by mail. Among the developments publicized through news releases were an improved design for a laboratory arc melting furnace and a method for fabricating radiation-resistant manipulator gauntlets. Private industrial firms were provided with 191 man-days of consulting assistance, and 11 representatives from industry were assigned to work with Laboratory personnel, for periods of from two months to two years, to gain on-the-job experience of value to their parent organizations.

A chemical firm, which has recently completed this country's first privately owned plant for reprocessing fuel for nuclear reactors, was assisted in evaluating various head-end treatments, by which the fuel elements are prepared for processing. Consulting and advisory services were also provided by the Laboratory in the general design of the plant and during startup.

Operations and Services

The Oak Ridge National Laboratory provides very complete assistance to its professional staff with skilled specialists, technicians, and craftsmen, who operate one of the most advanced physical plants for research and development to be found anywhere in the world. The professional research man may devote most of his attention to the scientific aspects of his work while auxiliary needs, ranging from operating the reactors used by the researcher to the care of his health, are handled by the services staff. Sixteen divisions, departments, and staff offices devote their efforts primarily to service and operations work;* four research and development divisions also provide special services; † many services are available from the Y-12 Plant for divisions of the Laboratory located in that area. In addition to these services, the Central Services departments of Union Carbide Nuclear Division provide accounting, purchasing, general administration, and personnel services; the special skills and equipment of the Union Carbide Nuclear production plants are also available to support research work and operations.

The work of the service and operating groups is an integral part of all Laboratory activities; it is so large and diverse that only brief mention of it can be made in a report devoted primarily to the year's scientific highlights.

The Oak Ridge Research Reactor (ORR), operating at 30,000 kW, continued as the mainstay for research programs using reactor neutrons. In 1965 the reactor operated 84.8% of the time, providing a maximum flux of 2×10^{14} neutrons cm^{-2} sec^{-1}, at a cost of less than $1 million (including maintenance, overhead, materials, and fuel). The cost of ORR operations was reduced during the past year by the development of a 240-g fuel element which gives a burnup of about 100 g, rather than the 60 g burnup obtainable with the formerly used 200-g elements. Remote controls make it possible to operate two smaller reactors, the Low Intensity Test Reactor and the Bulk Shielding Reactor, from the ORR main control area.

Management of radioactive waste liquids, gases, and solids attained very high levels of efficiency during the year. A central control room was put into operation, where a 24-h watch is kept on all of these activities. Millions of gallons of contaminated wastes and large volumes of contaminated air and gases were thoroughly cleaned before release from the Laboratory; discharge of radioactivity to the environment for the year was less than 1% of the permissible amount.

Services provided by the Mathematics Division increased during the year. The Mathematics staff operate large digital computers, consult on mathematical problems, and do research primarily in numerical analysis and statistics. A Biometrics Section is becoming increasingly involved in applying mathematical methods in research carried out in the Biology Division.

Laboratory protection services are concerned with everything from maintaining document and personnel security to fire fighting and prevention. During 20 years of operations at the Oak Ridge National Laboratory, fire loss has averaged less than $1700 per year; in 1965, the total loss from 39 small fires was $512.

The Laboratory balances its vigorous personnel protection programs with a comprehensive medical program. Since the diseases which cause absenteeism, decreased productivity, and premature death are considered almost entirely nonoccupational in origin, a major effort is made to promote personal health maintenance. A program of early detection and prevention, combined with health education, emphasizes the confidential doctor-patient relationship and the role of the occupational physician in helping to maintain the employee's health. The Laboratory's health services were augmented by new clinical facilities during the year.

*Plant and Equipment; Operations; Laboratory Protection; Personnel; Health; Mathematics; Instrumentation and Controls; Technical Information; General Engineering and Construction; Inspection Engineering (Department); Special Services (Department); Staff Offices — Safety and Radiation Control, Public Information, Budget and Programming, Education and University Relations, and Industrial Cooperation.

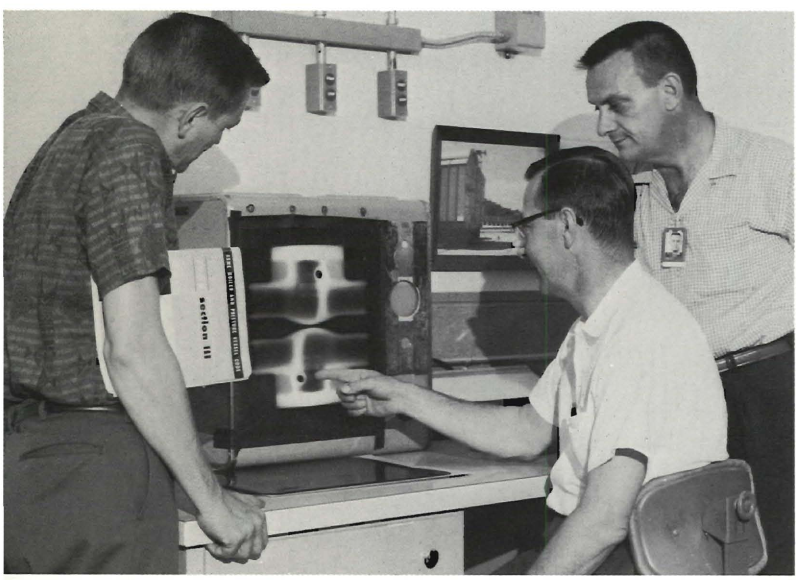
†Isotopes, Analytical Chemistry, Health Physics, and Metals and Ceramics.

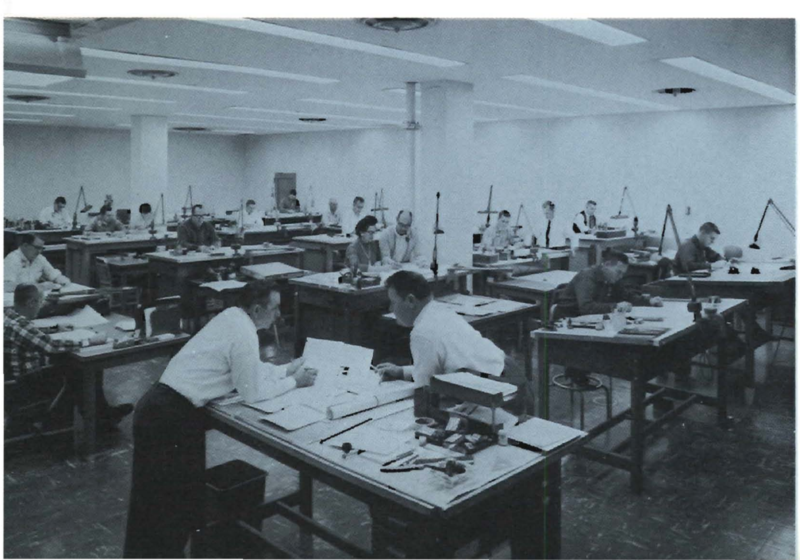
In the foreground is the IBM System/360 model 75 computer which was recently installed in the Laboratory's Mathematics Division. This system, one of the most modern and powerful available, is used in support of the Laboratory's diverse research program. In the background is the CDC 1604-A computer which has been in use at the Laboratory since early 1963.

A glass blower fabricates a boiling coil from quartz glass for use in the evaporation of curium-242 solution.

Top: *An x ray of a casting is interpreted by inspection engineers.*

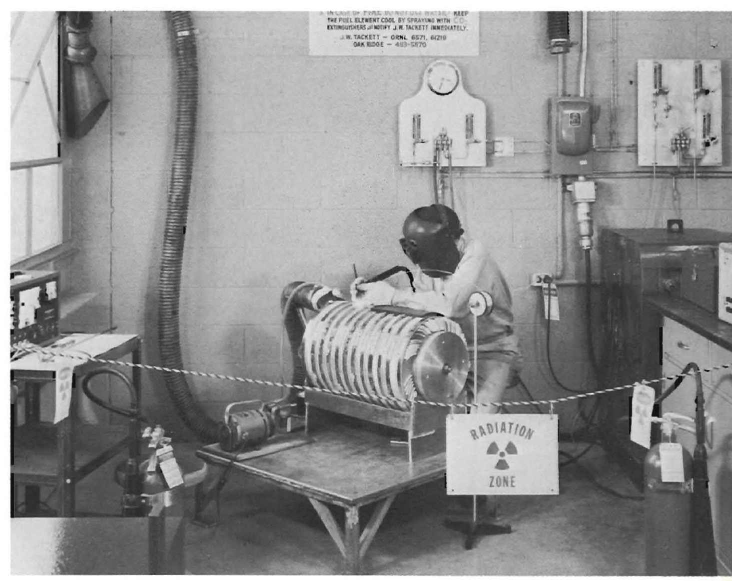
Bottom: *Technical illustrators in the Graphic Arts Department provide valuable assistance to researchers in preparing their results for publication.*

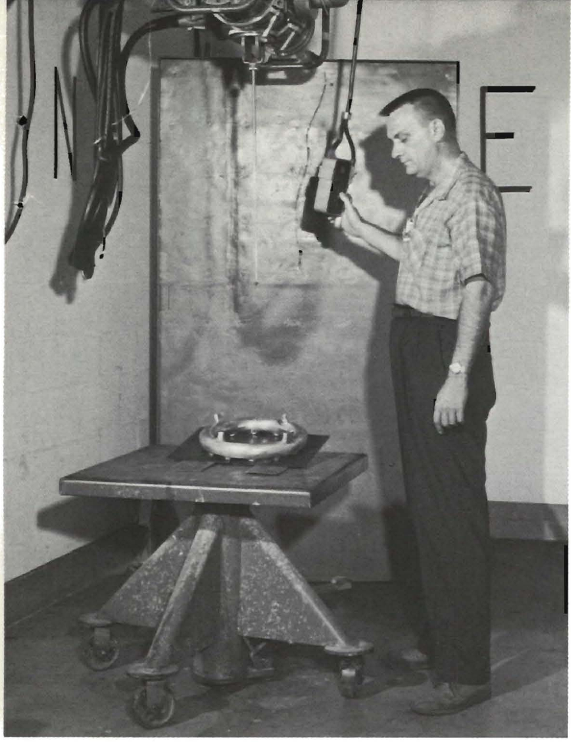




Top: *Unusual operations, such as welding on an HFIR fuel assembly, are carried out with special provisions for controlling the possible spread of uranium and with proper consideration for criticality problems.*

Bottom: *The ORNL Central Research Library contains one of the most complete collections in the Southeast.*

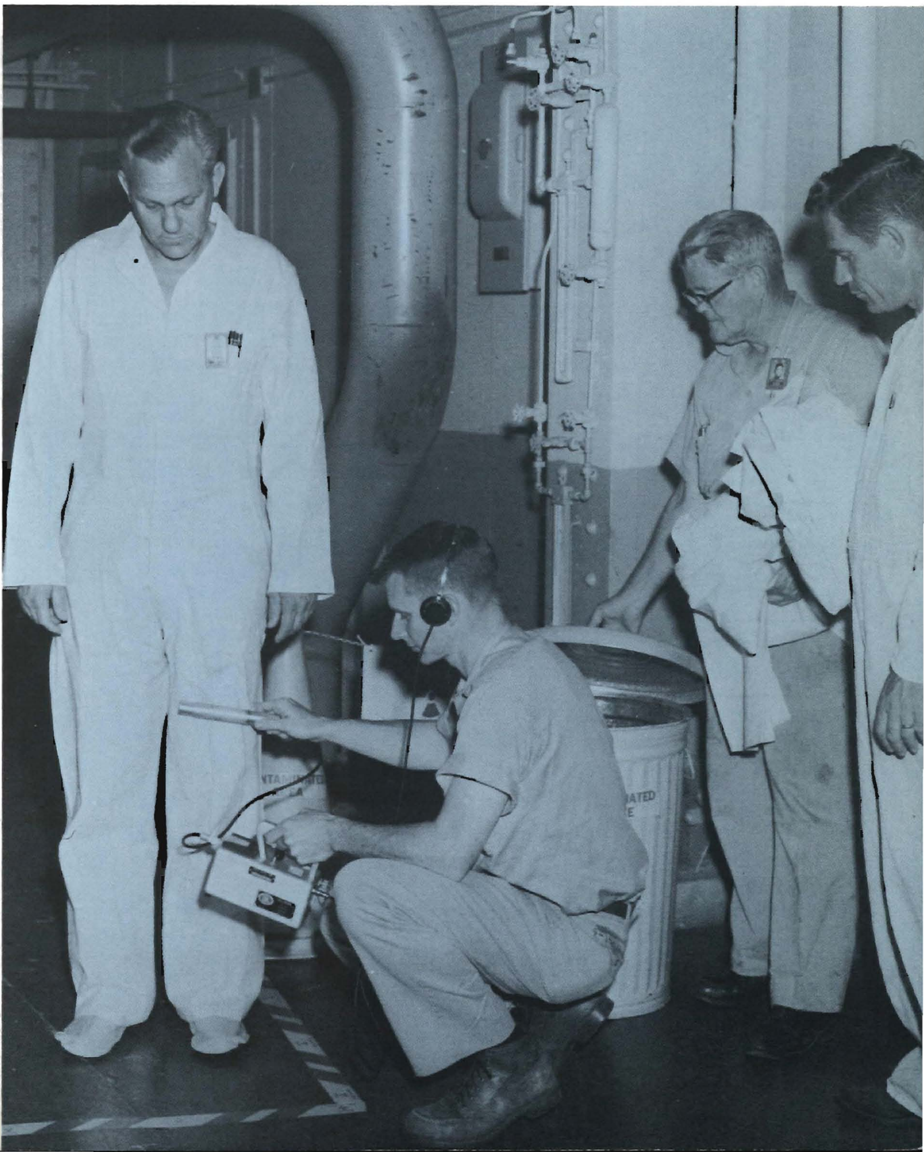


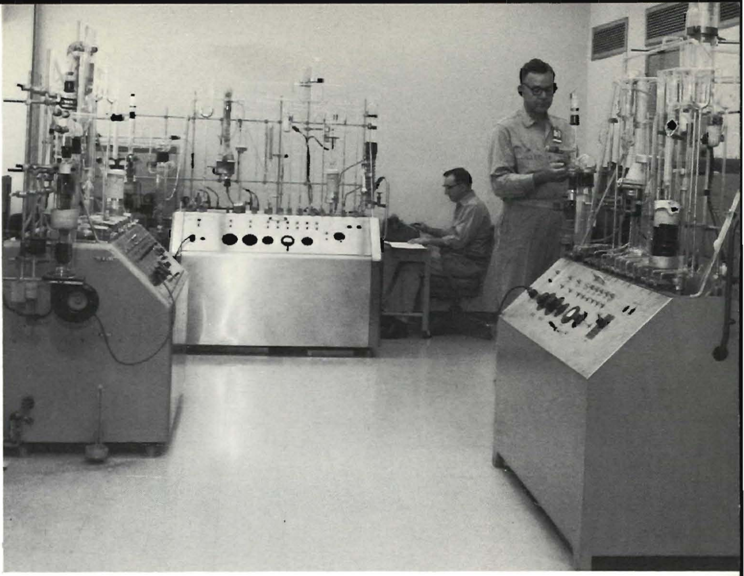


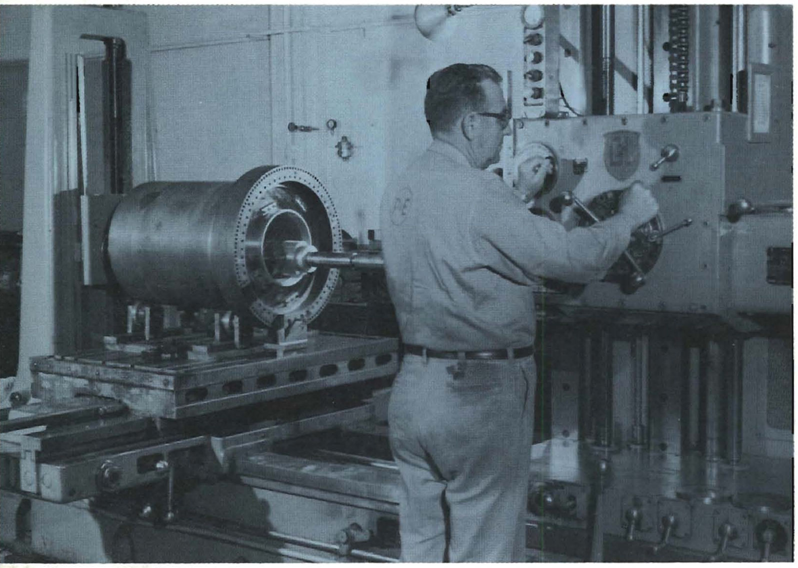
The integrity of equipment used in critical applications is assured by inspection engineers. Here, an x-ray machine is positioned in preparation for radiographing a welded part.

ORNL health physicists assist in maintaining control over the spread of radioactive materials by checking people leaving potentially contaminated areas.

The reception desk in the central research building provides the first contact of new employees at the Laboratory.

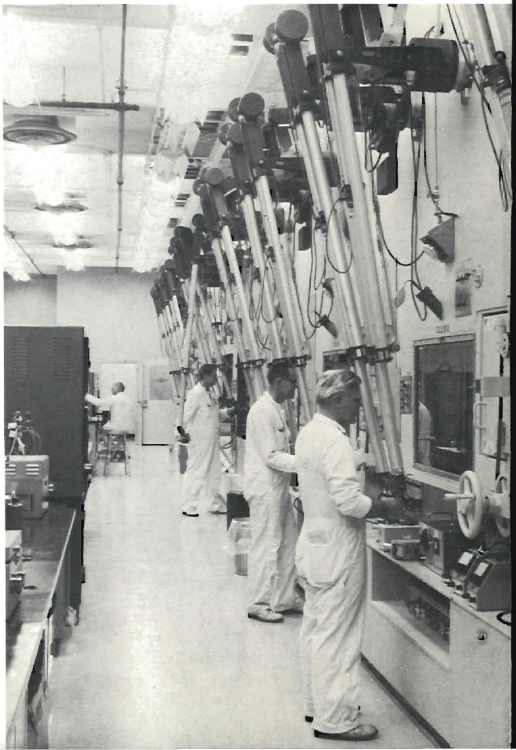






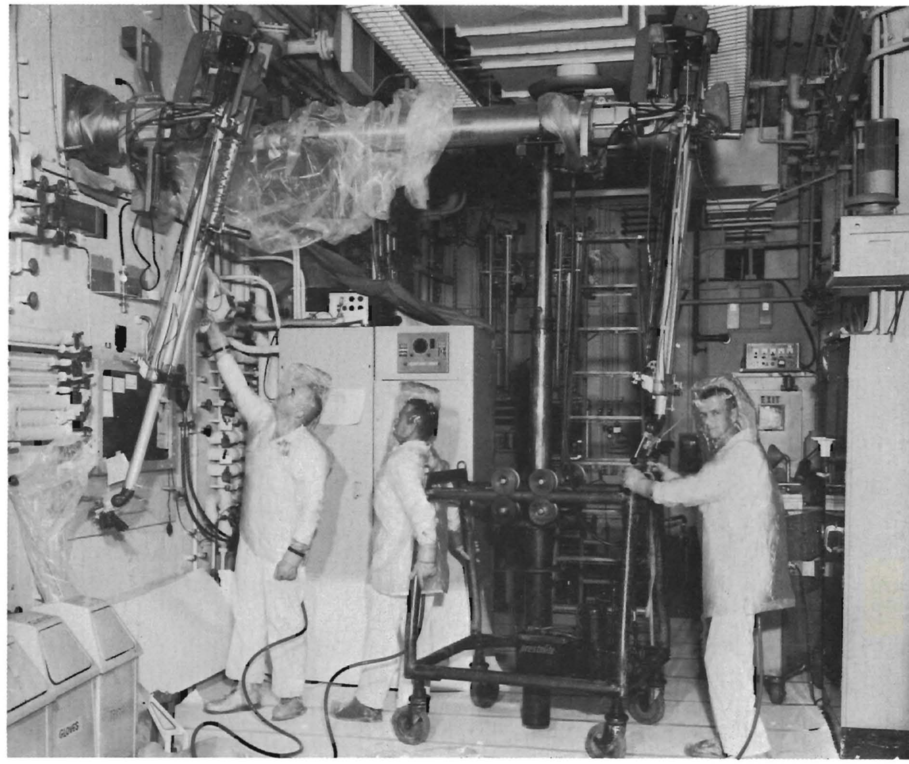
Top: *Liquid nitrogen, used in large quantities in the research program, is delivered by tank truck.*
Bottom: *The demanding requirements for high precision machining of the HFIR fuel element were met by ORNL craftsmen, using up-to-date equipment and techniques.*

Top: *Many high-vacuum furnaces, with associated equipment for gas chromatographic analyses, are used by the analytical chemists.*
Bottom: *Clinch River water and bottom sediment are sampled regularly to measure environmental contamination discharged from ORNL.*



The High Radiation Level Analytical Laboratory, which was commissioned in 1965, greatly increased ORNL's capability for analyzing highly radioactive materials.

Elaborate procedures are employed to prevent spread of contamination when manipulator arms must be removed from hot cells.



The medical staff offers advice to employees in a rehabilitation conference following personal illness.

Low-level wastes are treated by precipitation prior to discharge to the environment. The resulting sludge is then transported to a disposal area remote from the Laboratory.

The Union Carbide Recreation Park, located on Melton Hill Lake, is available to Carbide employees and their families. This park offers picnicking, fishing, boating, skiing, and camping facilities.