OAK RIDGE NATIONAL LABORATORY *Annual Report* · 1967

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Annual Report • 1967

OAK RIDGE NATIONAL LABORATORY

OPERATED BY UNION CARBIDE CORPORATION • FOR THE U.S. ATOMIC ENERGY COMMISSION

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INTRODUCTION

The pace and momentum of the past few years at Oak Ridge National Laboratory have not diminished during 1967. In each of our major areas of interest, striking new results and applications have been achieved.

To single out specific achievements could be misleading, since there is so much of great interest in this report. Indeed the report, limited as it is to fewer than 100 pages, can hardly do justice to all that went on at ORNL during 1967. Yet some results are so important as to warrant special recognition. These include the commercial production of flu vaccine purified by means of the Oak Ridge zonal centrifuges; the demonstration that the dipole moment of the neutron, if it exists at all, is much smaller than had been expected on the basis of experiments on time-reversal invariance; the continued successful operation of the Molten-Salt Reactor Experiment; and the opening of the University of Tennessee–Oak Ridge Graduate School of Biomedical Sciences.

These and many other achievements are recorded in the pages that follow. In presenting this account of 1967, we at ORNL are justifiably proud of, and possibly a little astonished at, all that has happened. We hope that this report conveys to its readers some of the excitement that pervades Oak Ridge and that sustains us in our efforts to use science for the benefit of our nation and the world.

Alvin M. Weinberg

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View of that portion of Oak Ridge National Laboratory located at the X-10 site.

Research, Development, and Engineering

LIFE SCIENCES

Biological science today is undergoing dramatic growth, with new fundamental knowledge being developed at a rate similar to that experienced in physics during the early decades of this century. This trend is reflected in the Laboratory's research in the life sciences, which now receives support from the Atomic Energy Commission, the National Institutes of Health, and other federal agencies. This biological research, basic and applied, has been greatly facilitated and strengthened by direct interaction of the Laboratory's life scientists with engineers, chemists, and physicists in efforts to develop the tools and techniques necessary for understanding how living things function.

Oak Ridge National Laboratory's work in biology and health physics began with emphasis on radiation as a biomedical hazard; this required an understanding of how radiation influences life processes, how to prevent damage to cells or to treat already damaged cells, and how to protect man and his environment from unwarranted radiation exposure. The facilities and techniques that were developed in the course of these studies have now proven to be well suited for the study of other threats to the public health and for the investigation of basic biological processes. The study of these biohazards and of fundamental biology now involves methods ranging from x-ray diffraction to pathology, from macromolecular chemistry to analysis of the food chain in a typical forest environment.

The MAN Program

To mount a successful attack upon many human diseases it is necessary that they be understood at the molecular level. Isolating and cataloging the molecular constituents of human cells are necessary groundwork for attempts to bring the powerful tools of molecular biology to bear on human pathological states; to provide this groundwork is the aim of the Laboratory's MAN (molecular anatomy) program. But this enormous task is beyond the techniques now available, and accordingly the first steps taken have been toward the development of applicable separation methods and analytical techniques.

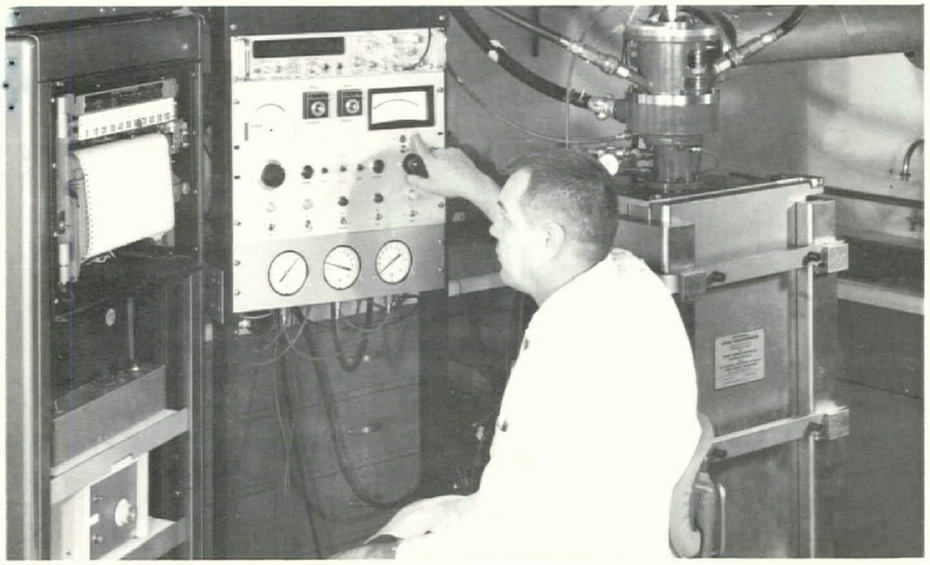
Centrifugal separation has been the method of choice for fractionating cells and isolating subcellular components such as nuclei, mitochondria, and ribosomes. Collaborating with specialists in centrifugal separations from the Oak Ridge Gaseous Diffusion Plant, Laboratory biologists have developed a new family of zonal rotors and centrifuges especially designed for rapid fractionation of large volumes of cellular constituents. These devices use a new technique that exploits differences in both sedimentation rate and density to achieve purification. It was quickly realized that the

In the foreground the zonal rotor of the K-II centrifuge is being dismantled. In use the rotor spins within the shielded compartment shown opened on the right.

equipment is uniquely capable of isolating not only normal subcellular components but also abnormal inclusions—viruses. If a virus can be isolated, a vaccine can be produced to protect against infection with that virus. Further, the centrifugal method yields isolated viruses that are virtually free of the other constituents of the cells in which they are grown, and thereby permits the production of "clean" vaccines without the undesirable side effects brought on by cellular contaminants.

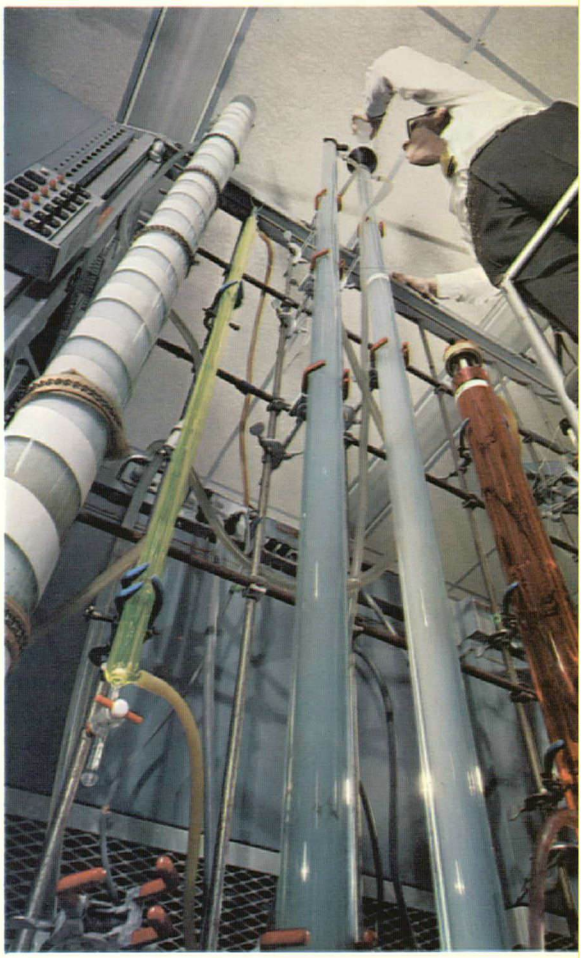
Development of the K-II centrifuge, a large-capacity machine designed for vaccine preparation, was completed during 1967. These units were employed to prepare the improved influenza vaccine distributed by pharmaceutical firms in 1967, providing a particularly appropriate example of "spin-off" of technological development into unforeseen applications. Several pharmaceutical and government laboratories are now making arrangements to use the K-II centrifuge to isolate and purify other disease-causing agents to produce new or improved vaccines. Commercial firms are now manufacturing the rotors (B-XIV and B-XV) that were developed earlier in this program's cell fractionation studies. Since these rotors were designed to be used in currently available centrifuge equipment, the zonal centrifugation technique is being quickly adopted in biological research laboratories around the world.

Equipment to perform automated chromatographic analysis of carbohydrates and of nucleic acid derivatives has also been developed and will soon be produced commercially. Further refinement of this type of device is under way, aimed at developing instruments capable of an automated determination of the sequence of amino acids in proteins and of the nucleotides in nucleic acids. In collaboration with analytical chemists, a high-pressure anion exchange chromatography system has been developed for qualitatively and quantitatively determining the more than 100 ultraviolet-absorbing constituents of urine for use in diagnosing diseases. High-resolution electron microscopy is also being investigated in part of the MAN program; if the resolution of this instrument could be pushed close to its theoretical limit, the determination of sequence in biological polymers would no longer slow the pace of advance in molecular biology.



The K-II ultracentrifuge is capable of passing up to 10 liters/h of virus-containing fluids through the zonal rotor, which spins at 27,000 rpm within the shielded compartment on the right. Operation of the centrifuge is monitored spectrophotometrically and controlled by the electronic equipment facing the investigator.

Laboratory biochemists, chemical engineers, and analytical chemists have joined forces to develop methods for isolation of individual species of transfer RNA (tRNA) in quantities large enough to permit determination of the structure and function of each species. The last step of this process is reversed-phase chromatography, the apparatus for which is shown in the photograph below. In 1967, 1 g of phenylalanine-specific tRNA was prepared from more than ½ ton of bacterial cells and distributed to qualified investigators by the National Institutes of Health, which supports this program.

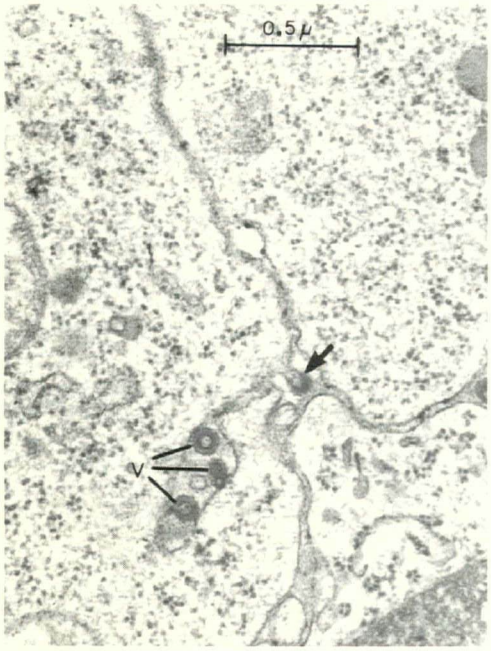


Virus Nucleic Acids as Carriers of Genetic Information

Rapid advances in molecular genetics indicate that the genetic constitution of an individual may be alterable, rather than irretrievably fixed at conception as was previously supposed. Thus diseases arising from genetic deficiency (such as phenylketonuria, certain anemias, and albinism) could be "cured" if the missing genetic information were supplied in a usable form. Previous studies at the Laboratory indicated that operational genetic information can be introduced into animals – including man – by means of apparently harmless viruses. If the virus nucleic acids could be modified to include the genetic information that is known to be missing in a deficiency disease, infection with the modified virus would effect a cure. The announcement late in 1967 that laboratory synthesis of genetically active DNA has been achieved at Stanford University, together with an earlier report of synthesis of active RNA at the University of Illinois, lends further impetus to the exploration of this concept.

To test the feasibility of using viruses as carriers, pilot studies are being carried out with the tobacco mosaic virus. This virus infects an organized multicellular plant, but its nucleic acid (in this case RNA) is in the simple single-stranded form, facilitating experimental manipulation. With the purified enzyme polynucleotide phosphorylase as catalyst, repetitive sequences of either purine or pyrimidine nucleotides were added to the end of virus RNA chains. This modification did not prevent the RNA from infecting tobacco plants. Knowing which amino acids are coded by a given nucleotide sequence, it is possible to predict the resulting change in proteins if the synthetic nucleotide sequences are read in the tobacco cell. A search for polymers of lysine is being made after infection with RNA modified by addition of multiple adenylic acid residues to determine if the appropriate relationships hold. If these experiments are successful, the next step will be to add nucleotide sequences providing information for biologically active peptides to find if these, too, can be specifically induced.

While the current results offer much promise, it is clear that a great deal of exploratory work in this and other experimental systems will be required before these procedures can be considered for application to humans.



An electron microscopic view of portions of spleen cells shows particles that are virtually identical to leukemia viruses at *V*; one of these (arrow) appears to be forming at the cell membrane.

Germinal Centers of Lymphatic Tissue

With the widely heralded introduction in 1967 of heart transplantations into clinical practice, much attention has been focused on the unsolved problem of "rejection" of foreign tissues or proteins (antigens) from the body. This rejection mechanism consists in the production by the lymphatic system (spleen, lymph nodes, bone marrow) of cells that synthesize antibody directed against the antigen and is called the immune response. Since the cells of this vital system undergo a continuous renewal process, they are highly sensitive to radiation. Thus an understanding of the immune response at both the cellular and molecular levels has long been a major aspect of the Laboratory's efforts in biology.

Recently, interest has been focused on unique structures in the lymphatic tissues, the germinal centers. The parenchymal cells of these structures undergo a rapid turnover, and they proliferate in response to antigen. This is in accord with suggestions that these cells may be a source of antibody-producing cells. During the course of the immune reaction, a small amount of antigen, rather than being degraded, is concentrated in the germinal centers. Upon examination of this phenomenon with the electron microscope, it was observed that a large number of virus particles were localized in the germinal centers of normal (i.e., not experimentally treated) mice. The virus particles, strongly resembling viruses associated with leukemia in mice, can be seen to be budding from the plasma membrane of immunologically competent cells in the centers, signifying that the viruses are undergoing replication at that site. Further studies in mice injected with leukemia virus confirmed that the viruses are quickly localized in germinal centers, perhaps reflecting their antigenic nature. Such virus particles also replicate in the parenchymal cells of the centers.

These findings are consistent with the concept of the central role of germinal centers in the immune response. Perhaps of more immediate importance, they implicate a specific type of lymphatic cell as a target cell for some types of leukemia virus.

Aging and the Immune System

In both mice and men the immune system achieves a maximum in functional capacity during early adulthood and thereafter declines steadily with advancing age. Various observations have implicated the failure of the immune system in senescence and death. There are sound theoretical reasons to believe that replenishment of the immune system with competent progenitor cells, capable of extensive proliferation to yield antibody-producing cells and other blood cell types, might substantially prolong life.

Recent attempts at the Laboratory to extend the life-span of certain inbred strains of mice have been encouraging. These studies have also revealed several possible reasons for depletion of immunologically competent cells in the aging animal. Of major interest is the discovery in the spleens of aged mice of a toxic factor which, when transferred to other middle-aged mice, substantially reduces remaining life expectancy. The magnitude of this effect is strictly correlated with the age of the donor. These results suggested that surgical removal of the spleens from mice of advanced age might extend their life-span, and this was found to be the case. When spleens were removed from mice 100 weeks old (about three-fourths of their normal life-span), their remaining life expectancy was ex-

tended from approximately 30 weeks to about 53 weeks. It is anticipated that even more dramatic results can be obtained by combining procedures, for example, splenectomy followed by total repopulation of the blood-cell-forming system with cells from juvenile donors.

Development of Leukemia in Germfree Mice

There is increasing evidence that the development of cancer involves a complex interaction of various host factors such as age, sex, strain, and genetic susceptibility with environmental factors such as radiation, chemical pollutants of the environment, and micro-organisms. Tumor-inducing viruses constitute one of the more important environmental factors in mice, and perhaps in humans as well. Both tumor-inducing viruses and nontumorigenic "helper" viruses have been described in laboratory mice, but their role is not clearly understood. A better understanding of the part played by such viruses in the induction of cancer can be obtained by studying animals in an environment in which all factors influencing development of the disease are controlled. With the introduction of germfree techniques, animals adequately defined from the standpoint of microbial flora and fauna have become available for such studies. Germfree mice of several strains are being raised at the Laboratory and are being studied with respect to the development of spontaneous and radiation-induced leukemia.

Results with one strain have shown that germfree RFM mice have a lower incidence of leukemia than their conventional counterparts, whether they are irradiated or not. Separate evaluation of each of the three types of leukemia (lymphoma, myeloid leukemia, and reticulum-cell sarcoma) demonstrates that germfree mice have a higher incidence of radiation-induced lymphoma, but a lower incidence of radiation-induced myeloid leukemia, than mice raised in conventional surroundings. Reticulum-cell sarcoma also occurs with less frequency in germfree mice than in conventional mice.

Alteration of type and incidence of mouse leukemias by the germfree state points out the importance of regulating the microbial flora in laboratory animals used for cancer research. Additional study of these alterations may help to clarify both the role of tumor viruses in neoplasia and the mechanism by which "nontumorigenic" microbial agents affect the development of cancer.

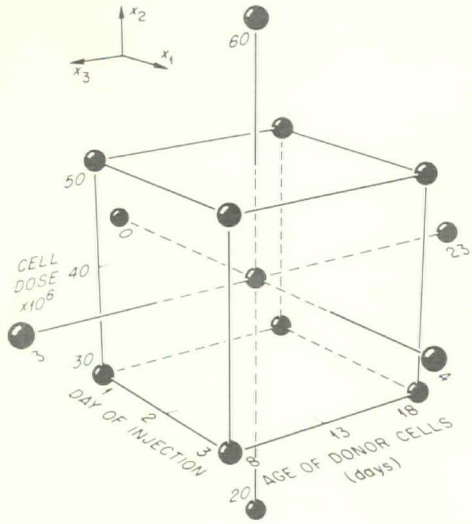
Lung tumors *(L)* and tumors of the hemangioma type in the liver *(H)* are found in a mouse fed the carcinogen dimethylnitrosamine in experiments designed to study the process of chemical carcinogensis.

The Theory of Experiment Design

Research in the theory of experimental design is continuing and has proven its value in a variety of ways. A recent result provides a simple method of choosing additional runs for an experiment after the first phase has been completed. This allows the experimenter to repair weak spots found at this point. Other research has to do with the construction of large fractional factorial designs, which are used to study the effects of a large number of variables on the outcome of an experiment. New designs have been constructed to determine, as economically as possible, all main effects and two-factor interactions of up to 23 variables.

The use of statistically designed experiments continues to be successful in various applications. For example, a central composite design has been used to deduce minimum mortality in mice which have been irradiated and

given transplants of rat bone marrow. Even though the "optimum" has not yet been obtained, the use of the technique of experimental design has cut the overall mortality in half.



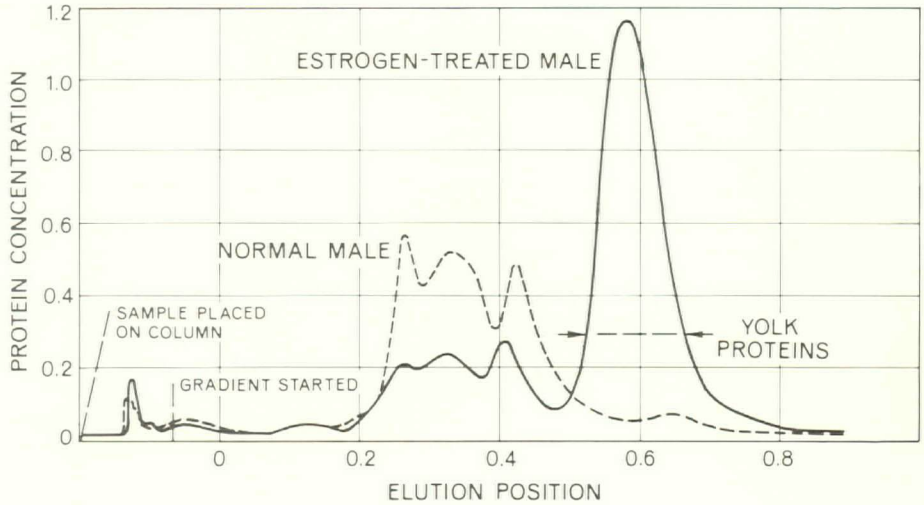
This "central composite design" was used to specify the levels of the variables in an experiment to find the treatment which gives the lowest mortality from secondary disease in irradiated mice with rat bone marrow transplants. A four-dimensional surface was fitted to the mortality data taken at these points, and regions of low mortality were found.

Developmental Biology

Differentiation is often called the central problem of biology, and a great deal of basic research is necessary to bring about an understanding of the largely mysterious processes by which a single cell can give rise to such diverse structures as muscle, bone, brain, etc. Biologists and biochemists at the Laboratory are studying a wide variety of experimental systems to analyze the mechanisms involved in differentiation.

The eggs that most nonmammalian vertebrates produce are being studied; they contain huge amounts of a simple mixture of yolk proteins, often in a crystalline form. The regulation of the synthesis of these proteins and the ways in which they are transported and accumulated in the developing egg are being studied in amphibians. It was found that the level of circulating estrogen controls the synthesis of yolk protein in the liver and that this protein is rapidly released into the blood stream. In females the yolk protein is then selectively adsorbed to the surface of the developing egg cell or oocyte and becomes incorporated into it by the formation of surface pockets that pinch off and fuse within the cell. If males are treated with estrogen, the hormone induces synthesis of yolk protein in their

The serum proteins of normal male toads and males treated several days earlier with estrogen are separated by chromatography. The large peak of protein present only after estrogen treatment was identified as yolk protein by various chemical criteria.



livers, also. However, there being no egg-production facility, the yolk protein is not removed from the circulation but accumulates there in large quantities that can readily be detected by chromatography.

Another investigation in progress concerns messenger RNA, the code-carrying species in the readout of genetic information; the types of mRNA present in a cell determine to a large extent what kind of proteins can be synthesized in that cell. The role of mRNA components is being analyzed during the differentiation process that involves the conversion of epithelial cells into the highly specialized cells of the eye's crystalline lens. In the developing calf embryo, the mRNA's of the fully differentiated lens fiber cell are stable, permitting continued synthesis of the unique lens proteins even when new RNA synthesis is completely blocked. In contrast, in the epithelial cells that are destined to become lens fiber cells, the mRNA population is largely labile, and protein synthesis stops when continual renewal of mRNA's is experimentally prevented. Thus the terminal stages of differentiation, yielding a cell type required to synthesize only a few specialized proteins, are associated with stabilization of the mRNA's coding for those proteins. While the evolutionary value of this arrangement is obvious, the molecular alterations involved are far from clear and are being studied further.

Biosatellite II

In September 1967 the Biosatellite II mission made a 30-orbit flight carrying a variety of living organisms, including spores of the common bread mold *Neurospora crassa* and adult males and females of the parasitic wasp *Habrobracon* from the Biology Division of the Laboratory. These organisms were part of an experiment carried out at the request of the National Aeronautics and Space Administration to study the genetic effects of radiation under conditions of weightlessness. Increased sensitivity of several biological parameters to radiation in the weightless state has been reported from previous American missions, but the data from these missions and from Soviet space flights did not conclusively confirm this. In an attempt to clarify this situation, a range of organisms ranging from bacteria to a flowering plant were chosen to make a coordinated evaluation of radiation exposure under weightlessness. An on-board strontium-85 gamma source was selected to deliver during the weightless phase of the mission a series of exposures in doses at which the different genetic effects could be readily and reliably detected and measured. Both of the ORNL experiments were flown in specially designed hardware that was installed a few hours prior to launch. Identical equipment and specimens were placed in the spacecraft and in a duplicate vehicle on the ground to provide control data.

A wide range of genetic effects on both the mold spores and the parasitic wasps is being studied. In the dormant spores of the bread mold, no effect of weightlessness was found on radiation-induced cell killing or on mutation. The wasp experiment, however, showed a variety of effects of weightlessness. Precursors to egg cells were killed less readily when irradiated in the weightless state, but the frequency of mutation in finished egg cells was greater at zero *g*. Mutation frequency in the sperm from irradiated males was not changed. The data from these two experiments, as well as those from other experiments flown on the Biosatellite mission, clearly indicate that the weightless state affects radiation-induced mutation rates in rapidly dividing and metabolically active cells, but that no

The Biosatellite II vehicle returning to earth off the coast of Hawaii after 30 orbits in space.

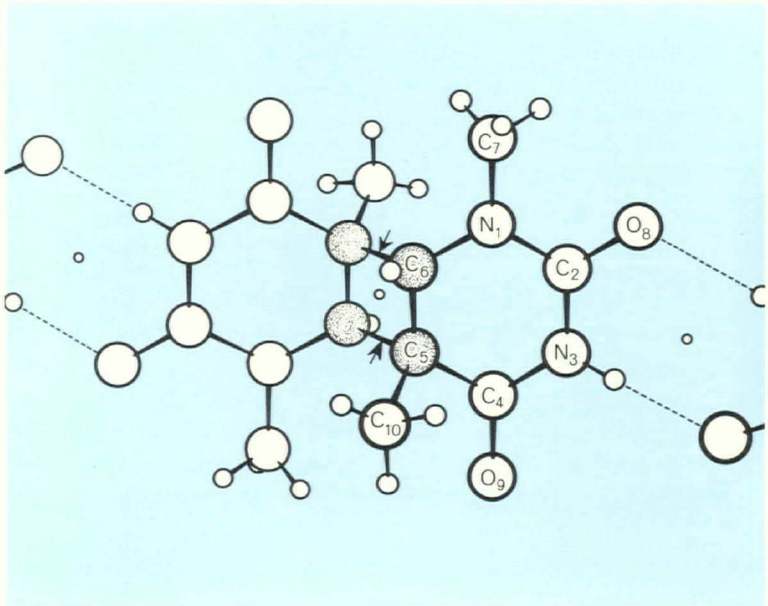
effect is found on cells that are metabolically inactive and do not undergo division. An additional Biosatellite experiment is being planned to confirm and extend these observations.

Mutation caused by methanesulfonate derivatives causes early embryonic death. In this instance, one normal embryo has survived treatment of the male parent with the chemical mutagen; the four others present died early in development and will slowly be resorbed.

Chemical Mutagenesis in Mammals

Although microbiological methods can be used to screen chemicals thought to be capable of causing mutation and to work out the mechanisms of mutagenesis, those chemicals found to be mutagenic in microbial systems must ultimately be tested in mammals. The Laboratory's large mouse genetics program is being used in tests to determine whether compounds with known mutagenic action in micro-organisms will effect the same kinds of genetic change in mice. The compounds tested were all alkylating agents known to cause chromosome aberrations in microbial systems. Chromosome aberrations in male mice would be expected to be dominant lethal mutations causing early embryonic death in the offspring. Using this as a criterion, it was found that there is a close correlation between the degree of dominant lethal mutations in mice and the extent of chromosome aberrations.

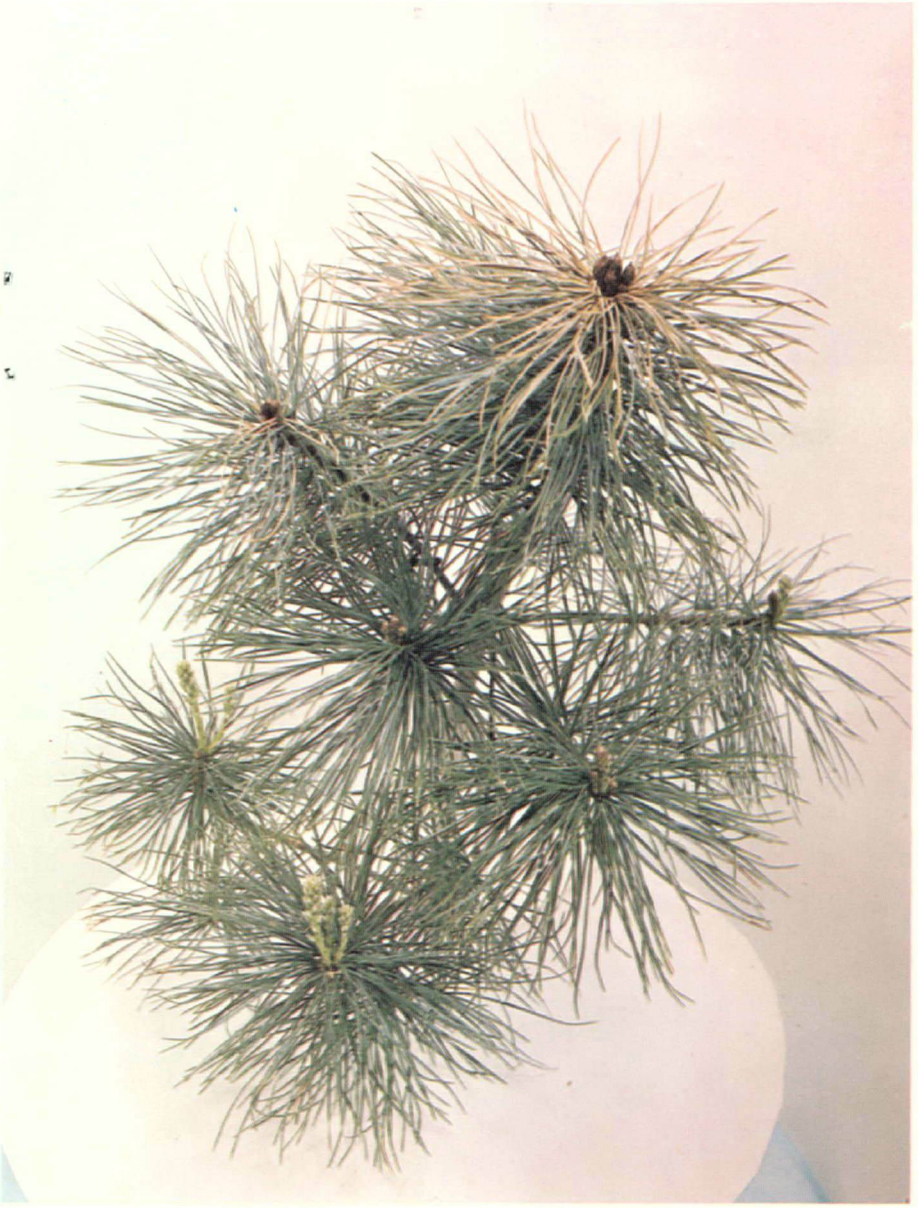
In extending these observations, the investigators found that closely related chemical compounds can have markedly different patterns of mutagenic effects in mice. Isopropyl methanesulfonate and *n*-propyl methanesulfonate differ only in the arrangement of carbon atoms in the esterified alkyl group. The *n*-propyl compound was found to induce a high frequency of mutations in sperm cells and their immediate precursors, but not in more remote precursors. In contrast, the isopropyl compound was most effective in inducing mutations in spermatocytes, remote precursor cells that appeared to be insensitive to the *n*-propyl compound; genetic damage to these cells can, however, be repaired. These observations suggest that the mechanisms by which genetic damage can be repaired may be rendered ineffective by small changes in the structure of the chemical doing the damage.



In earlier biophysical studies at the Laboratory it was found that much of the genetic damage caused by ultraviolet radiation could be ascribed to the formation of dimers between adjacent pyrimidines in DNA. The most common dimer is formed between two thymine molecules, linked together by the formation of a cyclobutane ring. Formation of this unnatural ring distorts the structure of DNA and prevents its normal replication. In 1967, Laboratory biophysicists determined the complete molecular structure of the *trans-anti* isomer of 1-methylthymine photodimer, using x-ray crystallography. In the drawing one complete dimer molecule and parts of two neighboring molecules in the crystal are shown, the smallest circles represent centers of symmetry in the crystal, and the next smallest unlabeled circles represent hydrogen atoms. Hydrogen bonding between neighboring molecules in the crystal is indicated by broken lines. The carbon atoms forming the cyclobutane ring are shaded, and the bonds formed in the dimerization are denoted with arrows.

Ecological Studies with Microcosms

The Laboratory's experiments on the transfer of radioactive tracers between various ecological compartments in nature—soil, vegetation, animals, and micro-organisms—are leading to a better understanding of the factors involved in the spread of contamination of the environment by radioactivity or other noxious agents. However, some mutual interactions in natural biological communities are too complex to be analyzed by current techniques. Small-scale simplified ecological systems (microcosms) consisting of a limited number of interacting components provide a means for insight into natural processes that cannot be obtained in the usual laboratory approach; here attention is focused on the effects of only one or two variables. Laboratory ecologists are developing various kinds of micro-



In part of a Civil Defense project in the Laboratory's Ecology Program, particles containing strontium-90 were applied to the terminal bud clusters of white pines to simulate fallout exposure. The topmost buds, which received the particles, exhibit no growth, and "beta burns" of surrounding foliage can be seen. New shoot growth increased with increasing distance from the contaminated buds; dose rates were estimated as 350 rads/h to the contaminated buds and 150 millirads/h to those producing new shoots at the bottom of the picture.

cosms and are using ionizing radiation, isotopic tracers, and other techniques to unravel some of the processes in the environment not amenable to field study, such as soil respiration cycles, radionuclide uptake, and reaction to radiation stress.

Rates of CO_2 evolution from soils long have been used as a measure of metabolic activity of the soil biota. This rate of evolution depends not only on biological activity but also on the physical condition in and above the soil. Since annual cycles of CO_2 from forest floor litter have been correlated with the annual temperature cycles, it has been hypothesized that there is a daily cycle of CO_2 evolution from the soil following the daily temperature cycle. In a series of microcosm experiments, Laboratory ecologists now have shown that the daily cycle of CO_2 evolution from litter parallels the temperature cycle; however, the evolution of CO_2 from the entire profile may correlate positively or negatively to temperature. The negative correlation occurs when the surface temperature is lower than the soil temperature at night and higher during the day. Presumably, convection of CO_2 from the soil's atmosphere at night results in low CO_2 concentrations in soil and a high rate of evolution at the surface. During the day, high surface temperatures presumably enhance CO_2 production and accumulation in the litter and consequently impede CO_2 diffusion from the soil to the surface.

A two-year study on laboratory aquatic microcosms has shown how the complexity of an ecosystem affects the cycling of mineral elements and the response to ionizing radiation. Small aquatic ecosystems containing various combinations of plant and animal species, but constant physical conditions, were used to test the effects of ecosystem complexity (number of biological connections) on the cycling rates and biological accumulation of cesium-137 and cobalt-60 introduced into the system. After rates and pathways of radionuclide movement were delineated for systems of varying complexity, additional systems were irradiated with fast neutrons at the Health Physics Research Reactor. Following irradiation the cycling parameters were measured as an index of ecosystem response to sublethal radiation stresses.

The effect of increasing biological complexity on cycling differed for the two radionuclides. For example, increasing system complexity decreased the time to steady-state accumulation of cobalt-60 in biological components but increased the time needed in the case of cesium-137. Functional roles of microcosm components were not always identical for these two radionuclides even in microcosms with the same degree of complexity. Snails, for example, served as grazing animals, and this could effect transfers of both elements from vegetation to water and soil. But their role in stirring up soil, a system reservoir, particularly affected transfer rates of cesium-137 from biotic and water components to soil.

The relationship between ecosystem complexity and response to radiation stress was measured in terms of changes in steady states (damage) and time required for return to steady state (recovery). Systems with few biological components showed less perturbation following a low-magnitude stress of 100 rads than systems with many components. Following a stress of 1000 rads, the more-complex systems were better able to maintain stability. The larger number of biological connections in the more-complex systems offered alternative pathways of element transport and thus a greater buffering reaction to a large stress. This study is among the first in which ecosystem responses to radiation and degree of system resiliency have been demonstrated quantitatively.

With closed ecological microcosms consisting of producer (grass), consumer (grasshoppers), decomposer (bacteria, molds, etc.), and soil compartments, the infrared gas analyzer and gas stream selector in the foreground are used to monitor CO_2 evolution under various constant conditions of light, temperature, and moisture.

Operation HENRE

During the last decade a nationwide study has been conducted of methods to predict the various components of radiation fields at large distances from intense radiation sources. Several groups at the Laboratory have contributed to this program through experiment and theory; the most recent field experiment was Operation HENRE (High Energy Neutron Reactions Experiment), which was completed in September 1967. This program utilized the world's most intense 14-MeV neutron generator, which was designed and fabricated at ORNL.

Preliminary results of this experiment indicate that much progress has been made in calculational techniques. For example, measurements of neutron and gamma-ray absorbed doses as functions of distance from the source and height above the air-ground interface have yielded a series of experimentally determined boundary correction factors. Consequently, a physicist may now calculate absorbed dose near the earth's surface by multiplying his computed value for absorbed dose in an infinite air medium by the appropriate boundary correction factor.

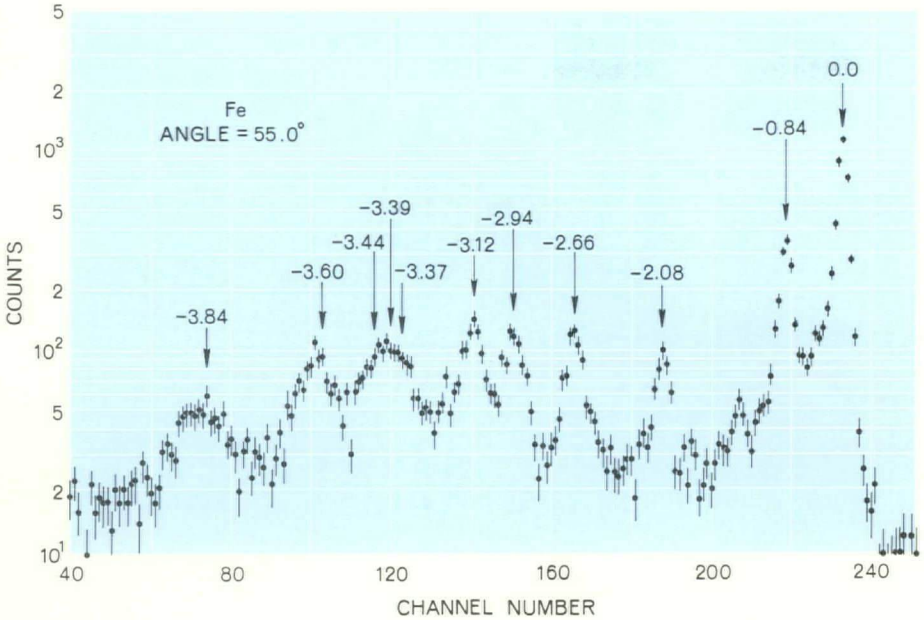
PHYSICAL RESEARCH

The prosperity and diversity of research in the physical sciences performed at Oak Ridge National Laboratory during 1967 should be apparent from the samples presented here. The prosperity results from the careful choosing of the most meaningful problems for attack, those that will most clearly shine new light on a significant research area. The diversity results from a tradition of freedom in the pursuit of knowledge. Given a mandate by the Atomic Energy Commission in 1954 to perform the basic research needed to maintain a superior weapons technology and to engender and sustain a safe and effective nuclear power generating industry, the research programs of the Laboratory immediately enveloped a wide selection of basic physical science disciplines. More recently, the capabilities of the staff and facilities have been made available to satisfy the research needs of other federal agencies. But the research efforts have always been distinguished by two characteristics. First, there is a great deal of activity in problems that involve several scientific and engineering specialties. Second, and this reflects the major thrust of work at ORNL, a large fraction of the research is related to understanding nuclear structure, the effects of nuclear radiation on molecules and solids, the processing of irradiated materials, the chemistry of reactor fuels, and the interaction of radiation with nuclei and atoms.

Since there are nearly 700 doctoral-level researchers at the Laboratory supported by several times that number of highly trained personnel, we cannot, in these few pages, do justice in reporting their work. We can only present some selections as a representation of the sort of work they do. As beauty resides in the eye of the beholder, the relative interest of these choices must lie in the background and tastes of the reader.

Neutron Cross-Section Studies

The work of at least one neutron cross-section group at ORNL is tailored to respond directly to the requests of designers for cross sections that describe neutron reactions in specific materials used as radiation shields or as structural components. The most urgent requests are for cross sections that describe the energies and directions of neutrons that are inelastically scattered against various nuclei. These cross sections are obtained from the energy spectra of the scattered neutrons measured at several angles from an incident neutron beam, and although such measurements have been under way for some time, it has only been since an on-line computer was acquired in October 1966 that the spectral data could be obtained in any appreciable quantity.

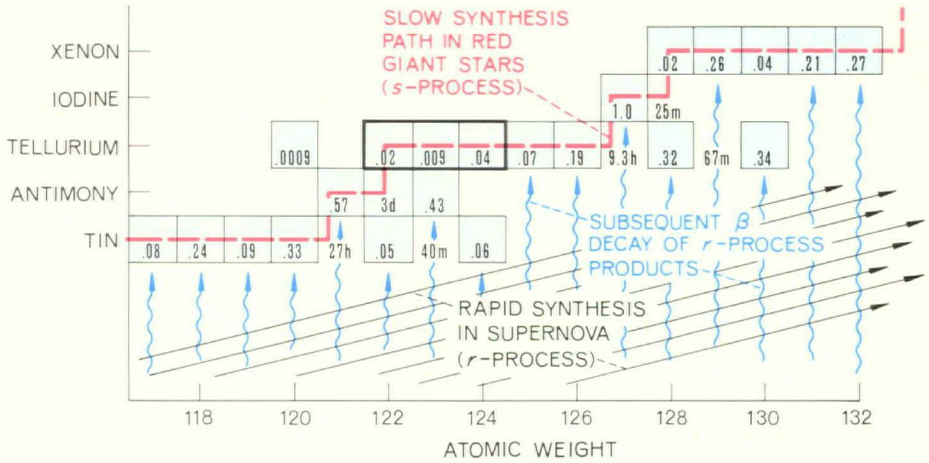


Energy spectrum of neutrons scattered from an iron-56 target. Neutron interaction cross sections are deduced from energy spectra such as the one given here. This spectrum shows how 5.0-MeV neutrons are knocked down in energy as they scatter inelastically from iron-56 nuclei at an angle of 55°, the numbers identifying the peaks showing the specific energy losses in MeV. The channel numbers correspond to a decreasing linear time scale, with the highest-energy neutrons being detected in the largest channels. The highest peak at the right represents elastically scattered neutrons, and the unnumbered peak (third from the right) represents neutrons scattered inelastically from the iron-54 isotope, which comprised 6% of the target.

The (n, n') measurements cover a relatively wide energy range; this is made possible by using the Laboratory's three electrostatic accelerators, the 3-, the 5.5-, and the tandem 7.5-MV Van de Graaffs. With these machines, measurements have been made for a variety of elements at incident neutron energies between 4.5 and 11 MeV. These energies penetrate well into the region between approximately 6 and 14 MeV that has in the past represented a hiatus in neutron cross-section technology. Furthermore, background problems have been reduced to the extent that the continuum regions, in which the energies of the scattered neutrons form a continuous energy spectrum, existing at the higher excitation energies can be covered in the experiments. The energies of the scattered neutrons are deduced from the time interval between the production of the incident neutron and the detection of the scattered neutron.

In addition to the inelastic-scattering data, requests have been received for cross sections that describe the energies and directions of gamma rays emitted by nuclei promoted to excited states by neutron interactions. Gamma-ray spectra are inherently more difficult to measure than neutron spectra, principally because of a high intensity of background gamma rays produced in the vicinity of the detector by neutrons from the source. Also, until recently the gamma-ray energy resolution of available detection systems was insufficient for complex spectra. Solid-state detectors, present-day electronics, and the availability of an on-line computer have made it possible to handle the background problem. Since prompt gamma rays from the target arrive at the detector sooner than most background gamma rays, the time interval between the production of an incident neutron and the detection of the gamma ray can be used to discriminate between the two. As information is received, the computer is used to determine the origin of each gamma-ray event, the background is screened out, and the background-free data are immediately available. Spectra of neutron-induced gamma rays have been obtained for targets of carbon, nitrogen, and oxygen for incident energies up to 8.5 MeV.

In this schematic diagram of the two major nucleosynthesis processes responsible for heavy-element production, the dashed line traces the path of the *s* process, which occurs in stars during their helium-burning phase and involves neutron capture on a slow time scale. The rapid neutron-capture process presumably occurs in supernovae. The shaded boxes are stable isotopes, with isotopic abundances indicated; half-lives of important radioisotopes are also given. Three tellurium isotopes (heavy lines) are shielded from any *r*-process contribution and therefore provide a test for the *s*-process theory.



Neutron Capture and the Origin of the Solar-System Elements

The most favored model of heavy-element synthesis assumes that two separate neutron-capture processes are responsible for the production of almost all nuclides heavier than iron. The first, the rapid or *r* process, is believed to have produced many neutron-rich isotopes and to be responsible for all element production beyond bismuth. This process involves capture of many neutrons by a seed nucleus in a fraction of a second. It is very difficult to "test" this theory, since it corresponds to the extreme physical conditions found in supernova explosions.

The other main production process is the slow or *s* process, and this involves neutron capture under considerably different conditions. In this theory a typical seed nucleus captures a neutron once every thousand years or so. Because of the slow pace of the *s* process, nuclei produced in this manner lie along the valley of stability against beta decay. Given the theoretical model of element formation, one can trace the separate paths of the two processes from iron to uranium and can consequently make specific predictions that, in the case of *s*-process nuclei, can be tested in the laboratory. The prediction is an inverse correlation between abundance and capture cross section for neutrons whose energy corresponds to stellar temperatures.

The relative abundances of isotopes have been found remarkably uniform for both terrestrial and meteoritic material. The other laboratory measurements required to test the theory are neutron-capture cross sections averaged over a neutron energy distribution appropriate to stellar interiors. Laboratory personnel have been making such measurements with small samples of separated stable isotopes. With theoretical guidance, particularly from colleagues at the California Institute of Technology, the isotope lists have been combed for those cases in which the most precise predictions of cross-section ratio can be made.

The most recent, and probably the most sensitive, test involved a triplet of rare isotopes of tellurium. According to the stellar nucleosynthesis theory, the isotopes tellurium-122, tellurium-123, and tellurium-124 were shielded by tin-122, tin-123, and tin-124 from any *r*-process contribution and thus had to be produced solely by the *s* process, therefore permitting a quantitative and unambiguous test of the theory. The cap-

ture measurements show cross sections for the three isotopes that vary up to a factor of 5, but the product of cross section times isotopic abundance is constant, within experimental error. These results, together with earlier tests of other *s*-process isotopes, give strong confirmation to the theory. In addition, they enable one to much more accurately determine the abundance distribution of *r*-process products, a most important clue in developing *r*-process models.

The *s*-process correlations give an almost unique insight into the element abundances just before the condensation of solar-system material into solid bodies. It is important to know this primitive abundance in order to understand the chemical and physical processes that have since occurred in the earth, moon, meteorites, and other bodies of our solar system.

Neutron-Scattering Facilities at the HFIR

Computer-controlled neutron spectrometers, among the most advanced available today, were installed at three of the four horizontal beam ports of the High Flux Isotope Reactor during the past year. These facilities, with their very high-intensity neutron beams, offer excellent opportunities for experiments in neutron spectrometry and diffractometry on magnetic and nonmagnetic materials, in critical neutron scattering associated with chemical or magnetic phase transitions, in polarized neutron scattering, and in small-angle neutron scattering.

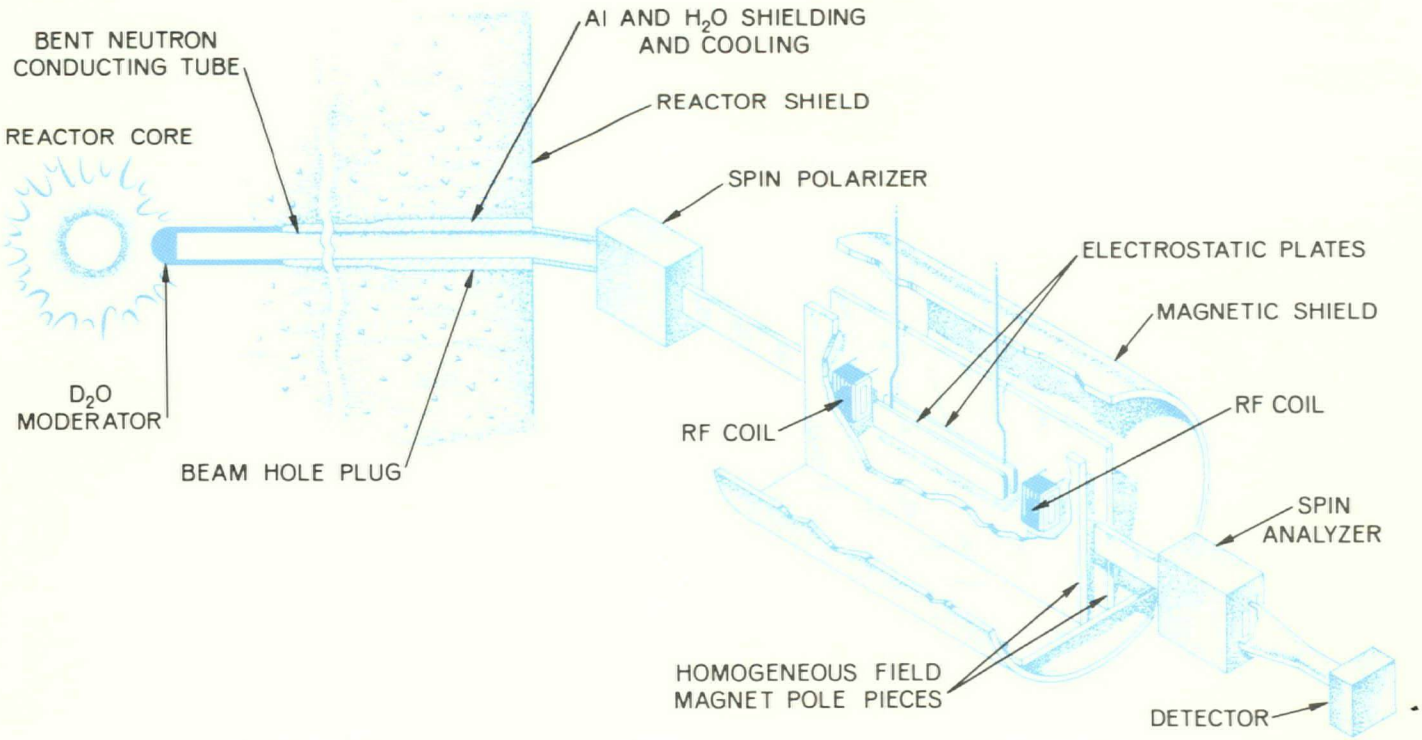
With the very high-intensity neutron beams provided by the High Flux Isotope Reactor, investigations can be conducted that have not been possible previously, and associated equipment adds to the facility's versatility in neutron-diffraction experiments. Both a polarizing and a nonpolarizing crystal can be placed in the monochromator cavity, and the investigator can select and position the proper crystal quickly and accurately by external controls. The neutron energy can be varied continuously and automatically through scattering angles up to 120°. Neutron-beam collimators, Soller slits, neutron filters, and neutron-velocity selectors can all be installed in the beam-hole cavity. A computer directly controls each spectrometer through pulsed motors that drive up to six spectrometer axes. The advantages of this system lie in the flexibility of control afforded by programs stored on magnetic tape.

Two of the facilities have triple-axis spectrometers and are in use by solid-state physicists concerned primarily with the lattice dynamics of crystals and with the magnetic properties of materials. The third facility, a four-circle diffractometer, is used by chemists for experiments in crystal-structure analysis, primarily on materials of biological interest.

Among the investigations that have been initiated at the HFIR are inelastic neutron scattering experiments that provide information on the forces that hold solids together. Many physical properties of solids are strongly dependent on the nature of these forces, and neutron scattering is the only technique capable of giving certain types of information directly. One of the first studies was made on copper crystals containing small amounts of aluminum in an attempt to understand the influence of substitutional impurities on the vibrations of atoms in a crystal. Measurements have revealed the existence of localized vibrational modes in these alloys. These modes correspond to the high-frequency vibrations of the light aluminum atoms in the heavier copper lattice. This is the first observation of localized modes by coherent inelastic neutron scattering, and this technique has the unique advantage of providing information on the degree of spatial localization of the mode in the crystal. Theoretical work is being directed toward relating the experimental results to the microscopic structure of the alloy and to the interaction of defect atoms with atoms of the host crystal.

Electric Dipole Moment of the Neutron

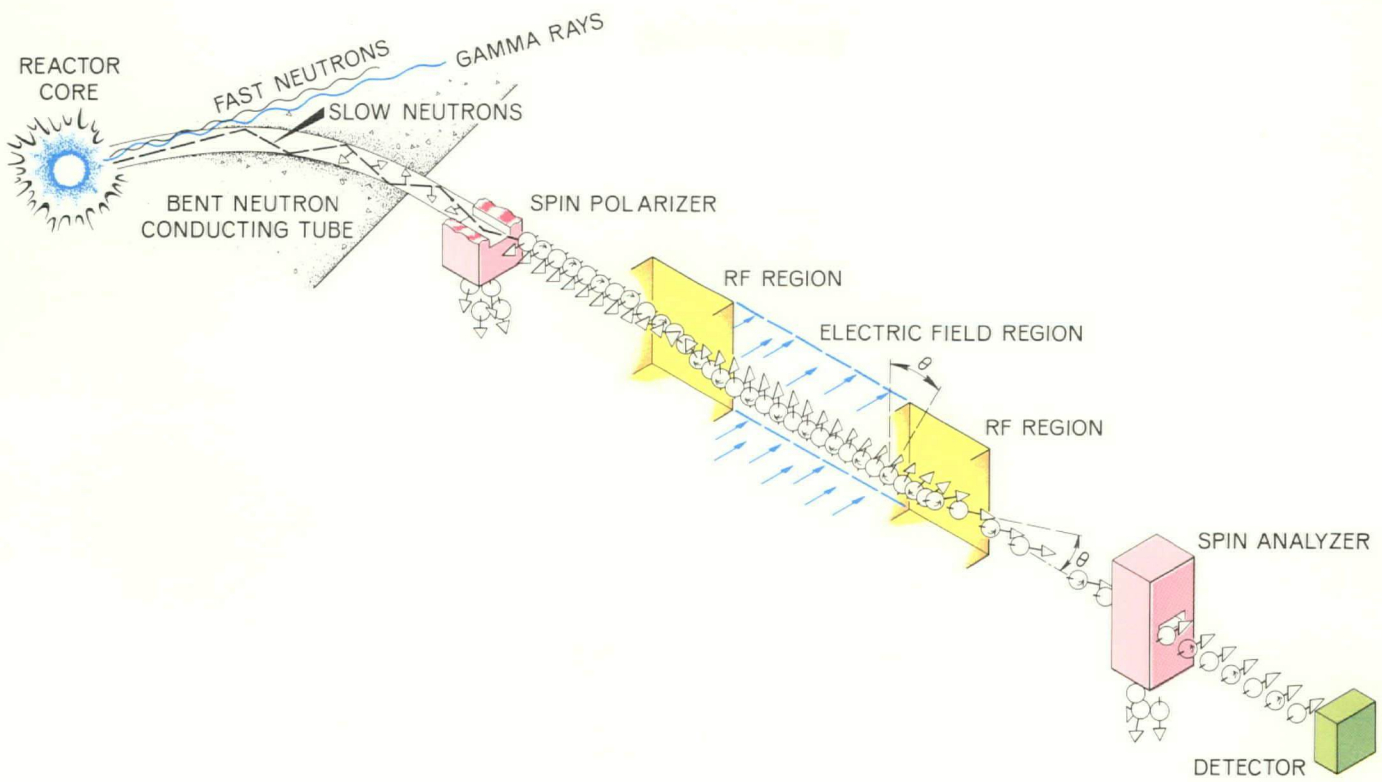
Nearly two decades ago, Oak Ridge National Laboratory was host to physicists from Harvard University who investigated the possibility that the neutron possesses a measurable electric dipole moment. They were able to show that p/e is less than 5×10^{-20} cm, where p is the possible



In measuring the electric dipole moment of the neutron, a beam of slow neutrons is extracted from a reactor, polarized, and passed into a spectrometer that provides parallel electric and magnetic fields along the beam path. Radio-frequency coils at both ends of the combined-field region induce spin-flip transitions in the neutron beam. The polarization of the emerging beam, as measured with a detector in conjunction with an analyzing mirror, tells what happened to the neutrons in the spectrometer. Obviously, the longer the neutrons are subjected to the electric field, the more they are precessed by it; so the velocity of the neutrons and the length of the combined-field region directly affect the sensitivity of the experiment.

electric dipole moment of the neutron and e is the electronic charge. The existence of a nonzero value of p/e would indicate that parity-inversion and time-reversal invariance, which assume that physical phenomena on a microscopic scale show no preference of right-handedness over left-handedness or as to the direction of time flow, are not precise laws of nature. Investigators from Princeton University recently observed at Brookhaven National Laboratory that the K_2^0 meson occasionally decays into two pions instead of the usual three. This rare decay mode is strictly forbidden by the so-called CPT theorem if time-reversal invariance is not violated. In order to establish the universal nature of this implied symmetry violation, it has become necessary to look with higher precision for an electric dipole moment of the neutron.

In the apparatus to measure the electric dipole moment of the neutron, slow neutrons are totally *externally* reflected at the nickel wall of the neutron-conducting tube and thus are able to navigate the bend in the tube, whereas gamma rays, fission neutrons, and the faster thermal neutrons pass through the walls and are absorbed in the shielding. The arrows emerging from the polarizer indicate the beam of polarized slow neutrons. The first radio-frequency (rf) coil tips the spin at 90° to the original direction. In the combined-field region, the electric field (acting on a presumed electric dipole moment) causes the spin vector to tip forward at an angle depending on the time spent in the electric field. If no tipping occurs, the second rf coil will realign the neutron spins in their original direction, and none will be lost in the analyzer. However, if tipping does occur, the neutrons will not be lined up in their original direction, and the number reaching the detector will decrease. Thus the change in counting rate upon reversing the electric field provides a determination of the amount of tipping and therefore the size of the electric dipole moment.



Consequently, physicists from ORNL and Harvard have undertaken this task. They have made use of recently developed techniques for obtaining an intense beam of very slow neutrons by using bent neutron-conducting tubes that are similar in principle to the light pipe. Although the sensitivity of the neutron magnetic resonance spectrometer used in the previous measurement of 1950 was about $1\frac{1}{2}$ times that of the preliminary apparatus used in the 1967 experiment, the slow neutrons provided by the velocity-selection and containment properties of the neutron-conducting tubes improved the overall sensitivity by about 200 times.

Polarization of the slow neutrons is accomplished by reflection from a magnetized cobalt-iron mirror. Spin-flip transitions are induced in the neutron beam when the frequency of the applied oscillating magnetic field in the rf coils equals the average Larmor frequency of the neutrons in the fixed magnetic field between the two coils. One observes the resulting change in polarization of the beam by reflection from a second magnetic mirror that reflects only those neutrons whose spins are unchanged. The technique employed to measure the electric dipole moment is to apply a strong electric field parallel or antiparallel to the fixed magnetic field. If there were an electric dipole moment of the neutron, the Larmor precession frequency of the neutrons would be changed because of the additional torque of the electric field. This change in the frequency of precession would change the polarization of the neutron beam. Thus the presence of an electric dipole moment would result in a change in the counting rate as the electric field is switched from parallel to antiparallel.

Even though the 1967 experiment was very sensitive, no neutron electric dipole moment has yet been found. The upper limit established at ORNL in October shows that p/e must be less than 3×10^{-22} cm. A group of theoretical estimates lying in the range of 3 to about 0.3×10^{-22} cm will become subject to experimental test during 1968 using a new, longer spectrometer, which should improve the present sensitivity by another factor of 10.

Proton-Proton Bremsstrahlung

At present, some nuclear structure information is extracted, without experimental verification, mostly from potentials that have been developed to reproduce only elastic scattering data. Moreover, the problem has been not merely the lack of experimental verification, but also an embarrassment of potentials of vastly different types – hard core, soft core, no core – all of which furnish equally good fits to the elastic data.

Proton-proton bremsstrahlung, literally "slowing down radiation," is an inelastic nucleon-nucleon interaction in which one of the protons slows down while in the force field of the other and in which the excess energy is emitted as a gamma ray. The total kinetic energy of the two protons after the collision is smaller than the initial energy by the amount that the photon carries off. This process is amenable to rather precise theoretical calculations because the only nonnuclear force, the electromagnetic field, is well understood and is weak relative to the nuclear force. The calculations are by no means trivial, however, and there have been serious disagreements among theorists.

Recently, the theoretical situation has been substantially cleared up by measurements using the Oak Ridge Isochronous Cyclotron. The experiments are extraordinarily difficult because bremsstrahlung events

are very rare. In the arrangement used at ORNL, a typical counting rate of five genuine events per hour must be electronically discriminated among 5000 false events per second. Innovations in the ORNL experiment make it possible to register more true events with less background and with better angular resolution than was ever before achieved at similar bombarding energies.

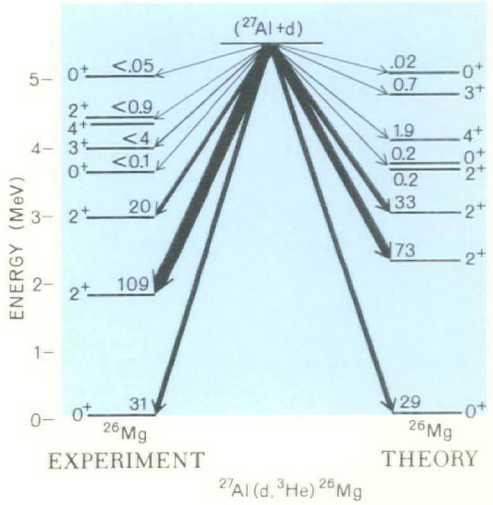
The inelastic interaction cross-section and angular-distribution results indicate that some of the existing nucleon-nucleon potentials fail to agree with experimental data. With further refinements and extensions of this experiment, it may be possible to select the best potential among the several that fit elastic data equally well.

Nuclear Shells: Theory and Experiment for Complex Nuclei

Theory and experiment have been combined in a study of the energy levels and wave functions describing nuclei between oxygen and silicon. The experiments consisted in measuring the helium yield as a function of emission angle for the $(d, {}^3\mathrm{He})$ reaction on targets of sodium-23, aluminum-27, and silicon-28 on the Oak Ridge Isochronous Cyclotron. The experimental data were analyzed to yield the values of the orbital angular momentum transferred in the reactions. Conservation laws then permit assignments of, or restrictions on, the total angular momentum and parity for the nuclear states involved. The analysis reduced the intensities for each of the individual transitions to intrinsic strengths, the so-called spectroscopic factors, which in turn are intimately related to the detailed structure of the nuclear states involved. For instance, if the nuclear state $(A+1)_i$ resembles nuclear state $(A)_j$ plus a simple orbital state of quantum numbers (n, l, j), then the spectroscopic factor for transfer of a particle with characteristics (n, l, j) between the states is large. Thus the experimental data yield the energy spacings and quantum numbers of nuclear states, but moreover provide very specific information about the internal nuclear structure.

The theoretical calculations make use of computer codes that incorporate new advances in the formal theory of the shell model. With these improvements, and by utilizing to the fullest the memory and speed of the ORNL computers, very extensive shell-model calculations become possible.

The nuclei of mass $16 \leqq A \leqq 28$ were assumed to be composed of an inert oxygen-16 core and particles in orbits characterized by quantum numbers $(n, l, j) = (1, 2, 5/2)$ and $(2, 0, 1/2)$. The nuclear interaction for this model is completely specified by 18 numbers. The values of these numbers were fixed by minimizing the differences between 80 experimental and calculated binding energies of nuclear states in this mass region. The calculations thus yield energy-level locations for each nucleus and also the wave function, or structural formula, for each energy level. These wave functions are then used to calculate values for the spectroscopic factors between states $(A+1)_i$ and $(A)_j$. A comparison of these calculated values with the corresponding experimental results shows that the nuclear model closely resembles the actual situation. The agreement between the experimental measurements and theoretical calculations typified by the results for magnesium-26 indicates that the present approach offers a unified and comprehensive theory for this interesting and complex group of nuclei.



The shell model is remarkably successful in predicting level locations, spins, and even the spectroscopic factors (transition strengths), as is seen here for the level structure of magnesium-26 as measured by ^{27}Al$(d, {}^3\mathrm{He})$ reaction studies (left) and as calculated using the nuclear shell model (right).

High-Energy Radiation Shielding Studies

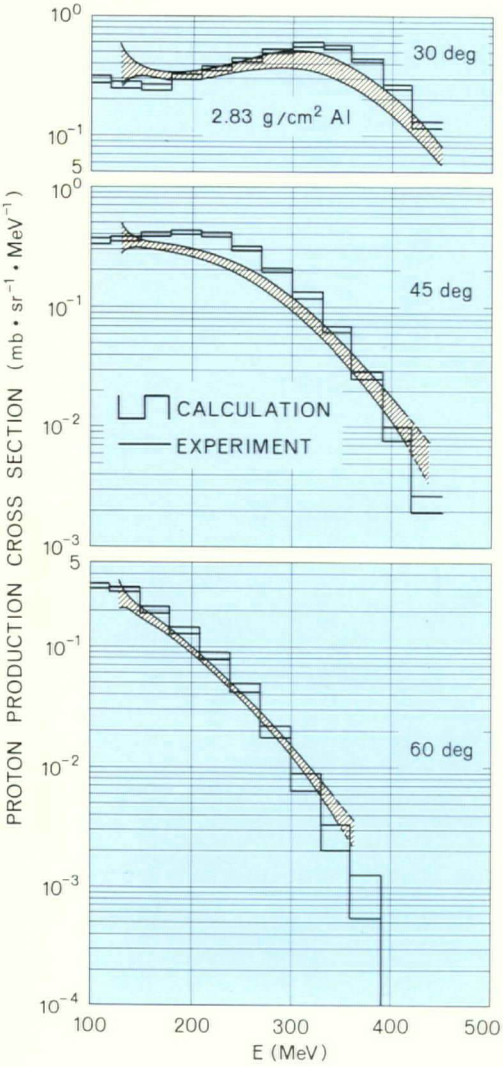
The design of shields to protect against the radiation encountered by manned spacecraft and against that produced by high-energy accelerators must at the same time be effective and economic. In both cases the initial radiations are protons and electrons. The production of secondary radiation (neutrons, protons, mesons, and gammas) in the shields complicates the problem, especially in the thick shields around accelerators. Because there is an insufficient understanding of the detailed mechanism of particle production from nucleon-nucleus or pion-nucleus collisions, much of the current High-Energy Radiation Shielding program is devoted to empirically investigating the frequency of occurrence, the angles of emission, and the energies of the various secondary particles and to developing radiation-transport calculations describing and predicting the findings of these investigations.

The energy spectra of gamma rays produced by 160-, 56-, 34-, and 16-MeV protons incident on a variety of elements have been measured; these data represent the only information on which secondary gamma-ray dose levels in spacecraft can be based. Secondary radiations pose no problem in the relatively thin shield required to reduce incident radiation doses to acceptable levels in, say, the Apollo moon missions. The next step is to assess the importance of secondaries on manned interplanetary missions, which will involve longer exposures and therefore require thicker shields.

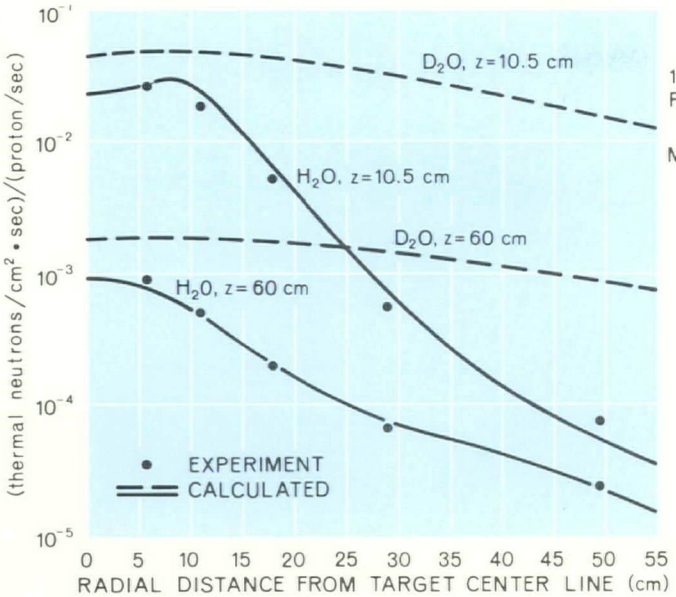
Calculations of the cross sections for secondary particle production by nucleons incident on a number of elements have been completed for energies up to 400 MeV. Laboratory measurements of secondary protons and neutrons from a variety of elements exposed to 160- and 450-MeV protons are in reasonable agreement with the calculations. The calculational technique has been extended up to 3 GeV.

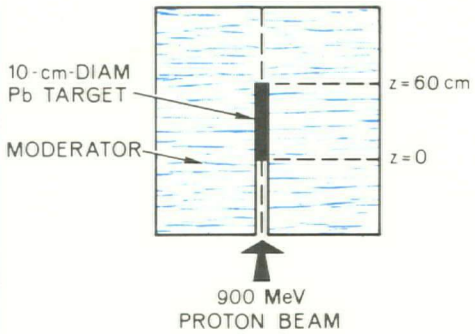
Values obtained at the Princeton-Pennsylvania Accelerator for the production of secondary protons by 2.9-GeV protons incident on platinum are in substantial agreement with the calculations, as are values measured by a Russian group for the production of secondary protons by 600-MeV protons incident on several elements. In another test the calculated cross sections were used in a Monte Carlo transport calculation simulating an experiment performed at the Brookhaven National Laboratory Cosmotron. In this experiment 900-MeV protons struck a thick lead target surrounded by a water bath; secondary neutrons produced in the lead were thermalized in the surrounding moderator. The thermal-neutron fluxes measured in the experiment were correctly predicted by the calculation.

Two experiments recently performed at the Oak Ridge Isochronous Cyclotron provided data on the low-energy limits of the cross-section calculations. The first experiment greatly increased the amount of available data on secondary neutron production for relatively low-energy (14- and 18-MeV) protons incident on a variety of elements ranging in mass from beryllium to lead. The second experiment yielded information on the production of charged particles in targets of bismuth, iron, oxygen, and carbon exposed to 60-MeV protons. The relatively small divergence between the experimental and predicted results has led to increased optimism that the calculational techniques, originally intended for application only above 100 MeV, can be extended to lower energies.

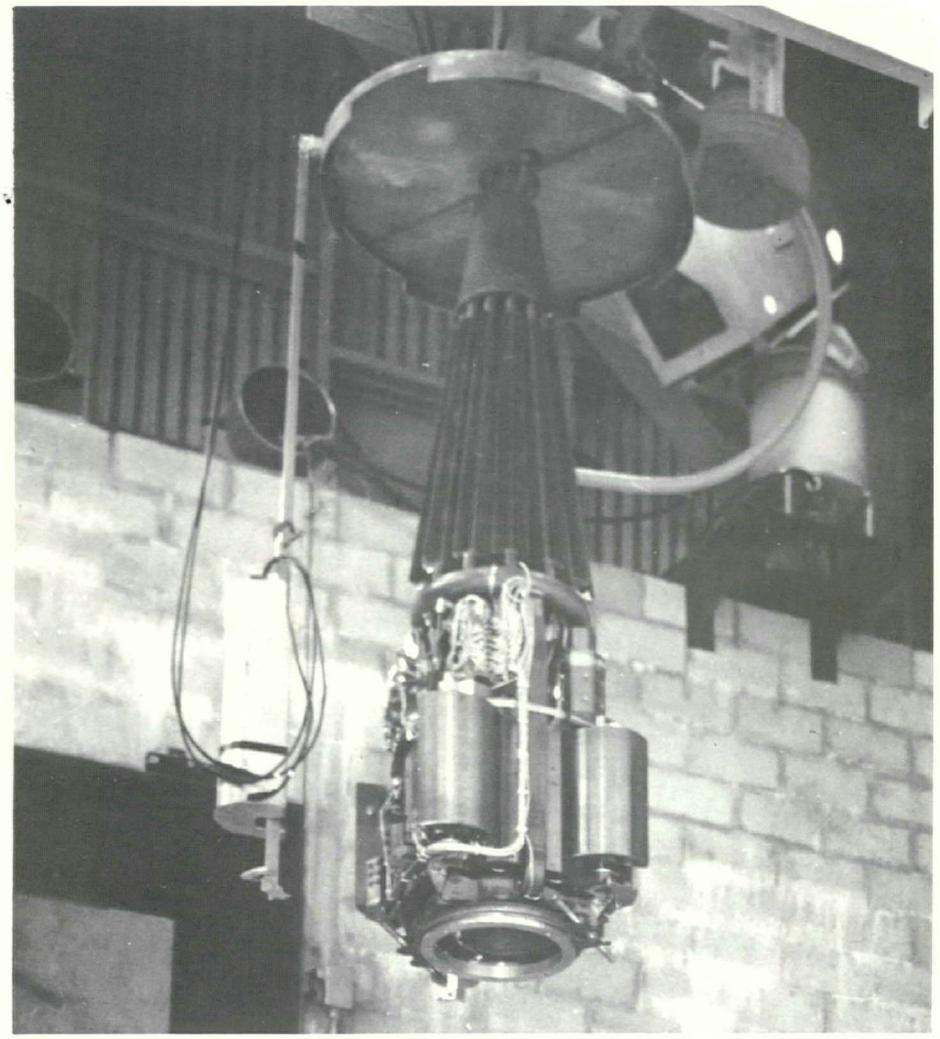


The results of the technique for calculating the cross sections that describe the production of secondary particles in materials exposed to high-energy radiation are in close agreement with the experimental results for the production of secondary protons in aluminum by primary protons having an incident energy of 450 MeV. The angles indicated on the figure are angles of emission of the secondary protons, and *E* gives their energy. The calculations are in histogram form because they were performed for energy intervals rather than for discrete energies.





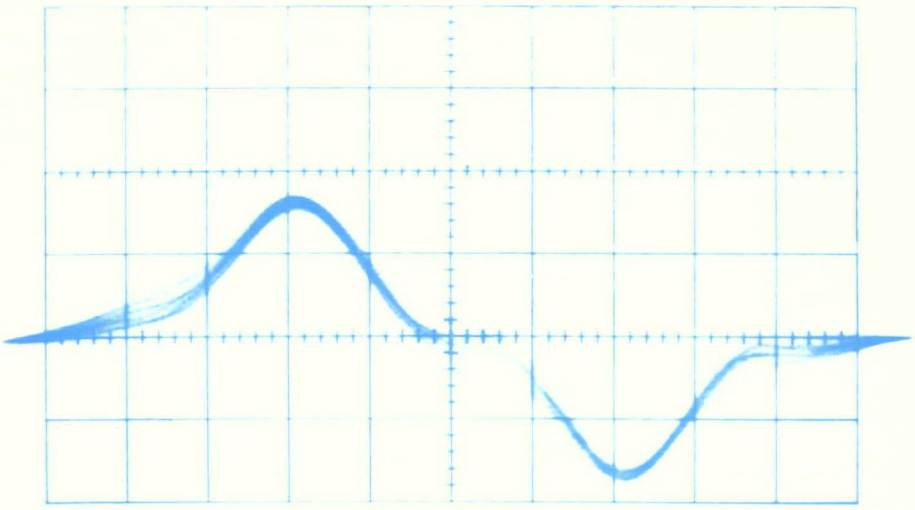
A cooperative experiment performed at the Brookhaven National Laboratory Cosmotron by Chalk River and Oak Ridge National Laboratory personnel to measure the thermal-neutron fluxes produced in a water moderator surrounding a lead target hit by 900-MeV protons gave excellent agreement with calculated fluxes. The validated calculational technique was then used to calculate the higher-intensity fluxes that could be obtained with a D_2O moderator.



The SNAP-TSF Reactor, a reactor similar in design to those proposed as auxiliary electrical power systems in spacecraft and in manned orbiting laboratories, has been installed at the Tower Shielding Facility for a series of measurements that will aid in the design of shields to protect the crew and instrumentation from the reactor radiations.

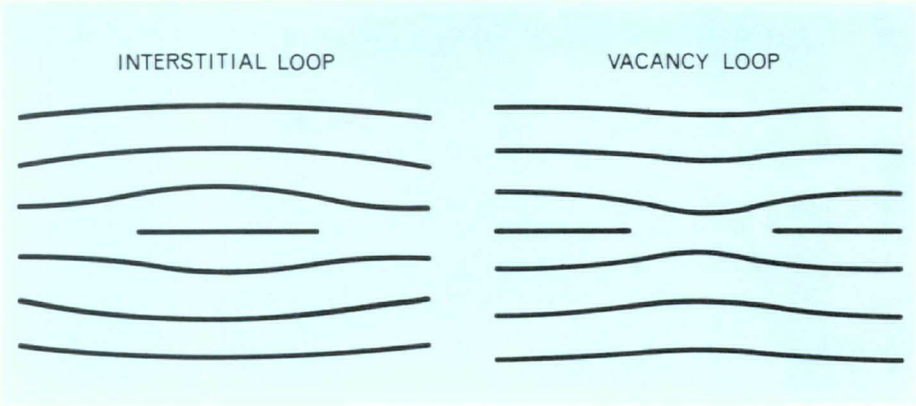
The experiments consist in energy and angular-distribution measurements of leakage spectra, that is, determinations of the energy and angle of emergence of neutrons and gamma rays emitted from the reactor core. The results will be compared with leakage spectra calculated by radiation transport techniques utilizing the best available cross sections for interactions within the core. If the calculated and measured spectra agree, then it can be assumed that the transport methods are reliable and that the interaction cross sections used for the materials in the core are correct. The methods can then be applied with confidence to other proposed core configurations.

Shown here is a photograph indicating the improvement in waveform from a pulse amplifier using a new electronic technique called a time-variant filter. Until now the best signal-to-noise ratios were obtained with unipolar pulse-shaping systems. However, such systems exhibit a count-rate-dependent energy-calibration shift that broadens the spectral line if the radiation source strength decays appreciably while the spectrum is being taken. During the past year theoretical and experimental studies were made of both unipolar and bipolar pulse-shaping systems, each consisting of a linear gate in cascade with an arbitrarily chosen linear filter. In the bipolar pulse-shaping systems, which have no count-rate-dependent energy-calibration shift, a method of operation was discovered that produces "quiet spots" on a bipolar pulse and allows the signal-to-noise ratio to be as high as that of the best realizable nongated unipolar system. By use of this technique a 41% improvement in the resolution of americium-241 spectral lines was observed for bipolar pulse shaping; this is within 7% of the theoretical maximum.



Observations of Defect Clusters with Transmission Electron Microscopy

Some of the lattice defects produced by irradiation of metal crystals with energetic particles, such as fast neutrons or fission fragments, cluster both during the irradiation and during subsequent annealing of the crystals. The detailed nature of the defect clusters is of great interest in understanding the properties of lattice defects, since some properties of the metals are markedly altered by their presence. During 1967, transmission electron microscopy was used to investigate defect clusters produced in copper, gold, and niobium. The number of clusters produced by fast-neutron irradiation of copper at room temperature increased monotonically with, but not proportionally to, the dose; there was a distribution in cluster size, but the peak in the distribution remained constant at a diameter of about 60 Å. From the details in the electron micrographs it was determined that the clusters were vacancy in character. An investigation of

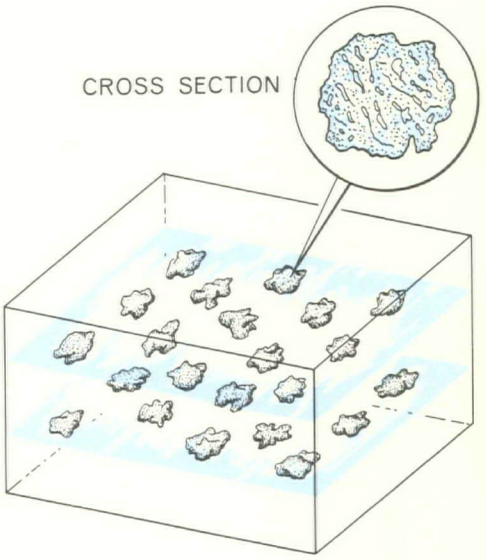


Interstitial loops in crystal structures result from platelets of interstitial atoms in the crystal lattice causing a bulging in adjacent planes. Vacancy loops result from the absence of some part of a plane; the closest planes then collapse inward to fill this platelet of vacancies. These effects are less and less noticeable in successive planes away from the abnormality.

the clusters produced in gold films by irradiation with 60-MeV iodine ions showed that the formation of clusters was decreased when the ions were directed along certain "channeling" directions in the gold. Good agreement was found between experimental observations and collision spectra obtained from Monte Carlo calculations of the successive two-body interactions occurring as an ion moves through the crystal. Defect clusters were observed in niobium crystals irradiated at room temperature; 5×10^{15} clusters per cubic centimeter, with the peak in the size distribution at about 80 Å, were observed after irradiation with 2×10^{18} fast neutrons/cm^2. In contrast with the observations on copper, these defect clusters were predominantly interstitial in character.

High-Temperature Radiation Damage in Copper

It is well known that the defects produced by the irradiation of copper at room temperature with fast neutrons can be removed completely by annealing at about 400°C. It was found that copper crystals irradiated at about 400°C contained defect clusters and dislocation loops generally larger than those produced by room-temperature irradiation. But instead of being distributed homogeneously through the crystal, which is the usual manner, they were aggregated into discrete regions, "defect regions," separated by regions of perfect crystal. These regions were observed as a specific type of etch pit and by x-ray topography and electron microscopy. While the total concentration of point defects aggregated in these defect regions was but a small fraction of those produced by the irradiation, their peculiar arrangement resulted in marked effects on the crystal properties. Annealing of these defect regions occurred between 500 and 800°C; defect regions near "as-grown" dislocations appeared to be most stable against anneal. This type of radiation damage was totally unexpected and has important practical implications for materials used in a high-temperature enviroment, such as advanced-design reactors.



Defect regions in a copper crystal result from neutron irradiation at high temperatures. Each region contains dislocation loops, defect clusters, and dislocation tangles.

Stabilization of Plasmas Within Toroidal Geometries

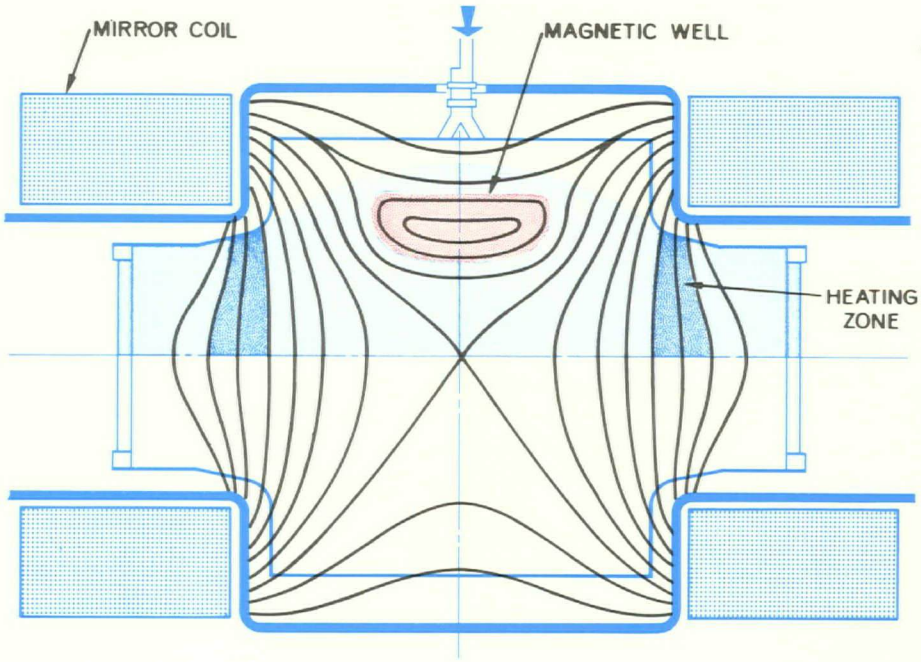
Probably the most appealing magnetic "bottle" for containing a plasma is one that has no ends, so that any loss of plasma must cross the field rather than flow along field lines. Usual toroidal configurations have, nonetheless, anomalously lost plasma across the magnetic field at close to the maximum possible rate. Recently, these inefficient conventional toroidal devices have been modified by introducing current-carrying rings internal to the plasma. This change created a magnetic field that was small in the plasma region but larger in the directions in which plasma normally tried to escape. The result of this magnetic well was to reduce these anomalous losses dramatically. There remained, however, plasma losses to the leads and supports that supplied the current to these internal rings, since these leads necessarily passed through the regions in which plasma was circulating.

Experiments were undertaken at ORNL to eliminate these support losses by levitating the internal conductors by electromagnetic induction. The experiments showed that the plasma loss was greatly reduced both by the shape of the magnetic field and by the elimination of conducting supports. Direct measurements revealed that the lifetime of the plasma was at least 30 times as long in the improved toroidal configurations.

Magnetic-Field Modifications Caused by Dense Plasmas

Dense plasmas that have particle pressures approaching the magnetic-field pressures holding the plasma together are called high-β plasmas, since β is the ratio between the pressure generated by the hot plasma and that exerted by the confining magnetic field. Because dense plasma appreciably modifies the magnetic configuration and because the stability of all plasmas depends critically upon the interaction between magnetic fields and plasmas, it is very important to understand the complex interaction between plasma and magnetic field. There are three incentives to do so. Dense plasmas can create in their interiors a stable configuration, a magnetic well in which the magnetic field increases in all directions. High-β plasmas can more effectively utilize the magnetic volume created at considerable energy expense by external coils. Finally, the reaction rate of a fusion plasma increases in proportion to β^2, so the higher the density, the more economically attractive these systems appear.

In the Laboratory's ELMO facility, high-β plasmas have been created by heating electrons to high energies at high densities. Although the reasons are as yet not totally clear, these plasmas have remained stable to at least 60% of the maximum β allowed by the magnetic field. The experimental demonstration of such stability supplies added incentive to develop the formal theoretical framework.



Dense plasmas can substantially modify the magnetic field in which they are created and produce an improved stability combination. The magnetic field in the ORNL ELMO facility is depicted without the dense plasma in the lower portion of the figure, while the plasma-modified field is shown in the upper portion. Improved stability for the plasma interior is a result of the magnetically shielded well that the plasma had made in the field produced by the external coils.

Atomic and Molecular Radiation Physics

The scattering of slow electrons, including thermal electrons, by polar molecules is predominantly influenced by the permanent electric dipole moment μ of the molecules. Experimental and theoretical work has shown that there exists a critical value, $\mu = 1.625$ Debye units, below which binding of an electron to a dipole is not possible. This critical value of μ lies intermediate in the range of dipole moments of many molecules studied in physics, chemistry, and biology; the dipole moment of water, for example, is 1.82 Debye units.

The effect of the existence of bound states, which have large binding energies, above the critical dipole moment has been observed as an enhancement in the elastic-scattering cross section.

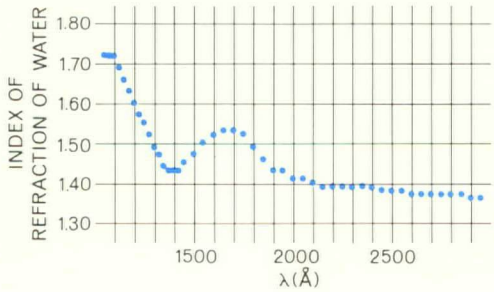
In electron attachment to the higher aromatic molecules, including anthracene and 1,2-benzanthracene, zero-energy electrons are captured with high efficiency to form parent negative ions, and the probability of electron attachment has been found to be a strong function of the molecular electronic structure. Low-energy electron interactions with the diatomic molecules HX and DX (X = halogen) revealed new electron-attachment processes and aided in the development of a comprehensive picture of electron-attachment processes that lead to molecular fragmentation. Electron capture in chlorinated linear hydrocarbons provided interesting results, which form at present the basis of an attempt to relate electron capture with the toxic action of these molecules.

When a neutral molecule cannot bind an extra electron, a short-lived compound negative-ion state can be formed with a lifetime as short as 10^{-16} sec. Such negative-ion resonances have been discovered in benzene, seven benzene derivatives, and naphthalene. In addition, electronic excitation by electron impact has been studied at the threshold of excitation processes. Important results have been obtained for temporary negative-ion resonances and triplet-state excitation of aromatic hydrocarbons.

Finally, it has been found that the emission of light from organic liquids excited by electron impact is completely due to excimers—transient dimeric species that exist only when in an excited state. The characteristic emission from single molecules observed under ultraviolet and x-ray excitation was completely absent under intense electron bombardment. Ion recombination is believed to be the origin of the excimer emission, while strong ionization quenching of excited monomer molecules is believed to be responsible for the absence of monomer emission. The investigation of excimers as luminescent species and as intermediates in energy transfer processes has led to their use in improving organic scintillators.

Radiation Interactions with Liquids

Despite the prevalence and importance of water, very little is known about its electronic properties that determine how liquid water responds to light and how it behaves in biological systems. A knowledge of the electron transport properties of water will also be useful in understanding electron transfer in biological processes. The only electronic property of water that is known and has been studied to any degree is the generation by ionizing radiation of polarons or hydrated electrons. There may, however, be two other important electron energies in liquid water: ionization of



Reflectance measurements at 20, 45, and 70° indicate an increase in reflectance with decrease in wavelength below 2000 Å. The reflectance has a maximum at about 1725 Å and increases with decreasing wavelength below 1400 Å. These reflectance data also have shown that there is a marked change in the index of refraction around 1500 Å. Such optical behavior is typical of insulators and indicates an exciton level at this wavelength. Below this wavelength the index of refraction increases rapidly and approaches unity in the x-ray region.

individual molecules in liquid water and plasmon generation, the absorption of energy by many electrons acting together.

To determine the optical and electronic properties of liquid water in the spectral region below 2000 Å, the reflectances of the liquid have been measured as functions of wavelength and angle of incidence. These reflectances can then be used to evaluate the dielectric constants of water and, subsequently, to decide which electronic energies are excited by ionizing radiation.

In the experimental setup, light from a monochromator horizontally enters a cell where water in an open dish is in equilibrium with its vapor near 0°C. Incident light reflects downward from a mirror onto either the water or a reference gold surface of known optical properties. The light is then reflected onto a photomultiplier. By minimizing the vapor pressure and path length, it is possible for light of sufficient intensity to reach the photomultiplier at wavelengths corresponding to minimum absorption by the vapor. Comparison of the spectral reflectance from the water surface with that of the reference gold surface gives the reflectance of liquid water.

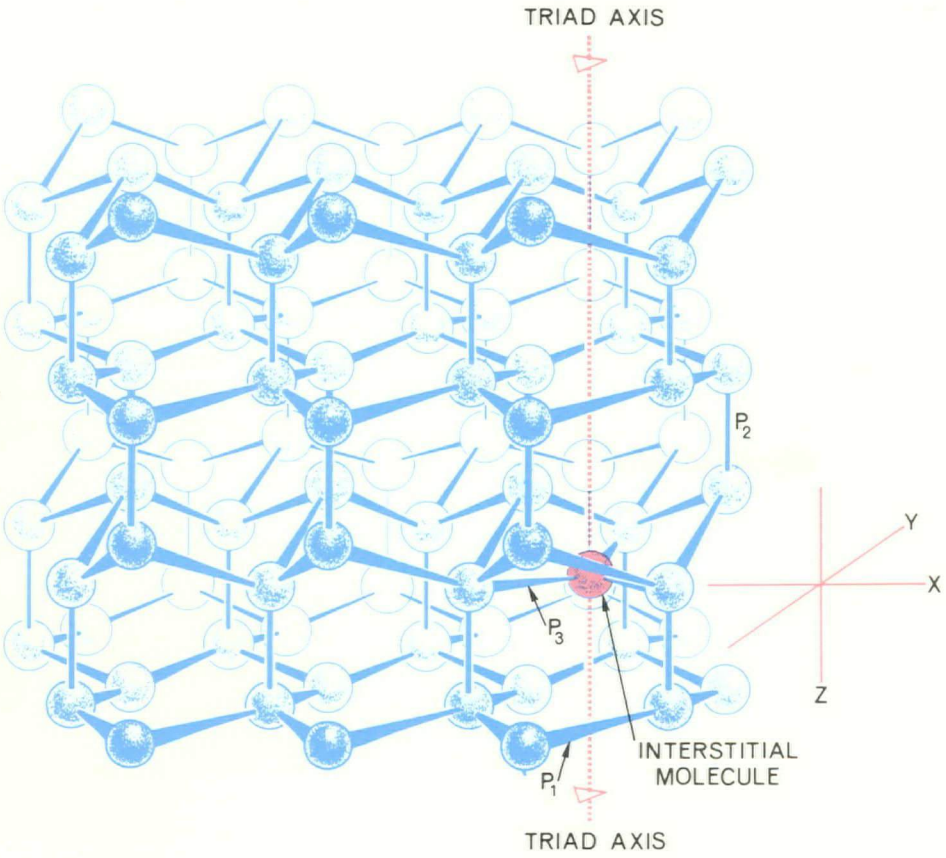
Structure of Liquid Water and Ammonia

A crystal is characterized by an extremely precise repetition of a geometrical pattern throughout its entire volume. Consequently, the location of every atom in that crystal, no matter how far distant, can be specified once a single atom is chosen as the origin. In a liquid the molecules nearest the origin show a definite but less predictable structure than that of a crystal. Molecules in the next layer are more nearly randomly arranged; and, farther away, the orientation of the molecules shows no correlation with the position of the origin molecule. This fading away of the predictable arrangement of the molecules can be seen in the results of x-ray diffraction from a quiet surface of a liquid.

A method of interpreting x-ray diffraction data for water and other liquids was carried further during 1967. This method uses a localized crystal structure as a model for calculating the probability of occurrence of the intermolecular distances. The "structure" of a liquid can then be described by giving the average number of molecules per unit volume as a function of distance from an origin molecule. The x-ray diffraction from water has been measured over a wide range of temperature, and concentration effects have been measured for ammonia solutions ranging from liquid ammonia to liquid water.

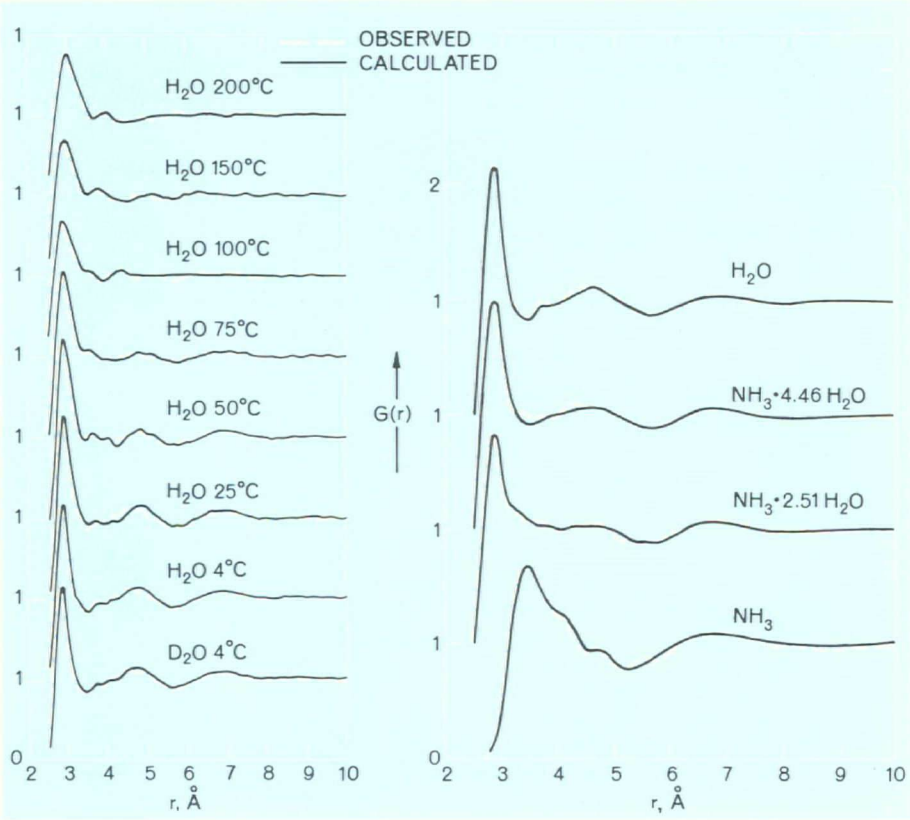
In this work the localized crystal structure used in the model was that of ordinary ice. Because liquid water has a higher density than ice, the

model permitted single molecules of water to occupy cavities in the open structure characteristic of ice; the degree of filling of these cavities was taken as one of the parameters to be adjusted in fitting the data. The specific structure that was in best agreement with the data was a modified ice structure in which the lattice was expanded along different axes and in which about half the cavities were filled with extra water molecules. Such a model, with slightly varying parameters, explains the observed x-ray diffraction pattern of the liquid from 4 to 200°C. This same model explains what happens when ammonia is added to water: the larger ammonia molecules increase the distance between nearest neighbors, and the cavities in the icelike network of the model are filled with more and more extra molecules. Considerable credence can be given to the model structure, since the calculated and observed patterns are in good agreement, particularly the data for higher scattering angles, which were not previously available with good precision.

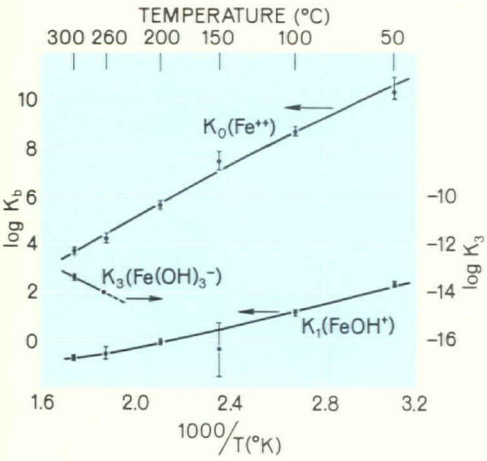


The Oak Ridge model for liquid water and ammonia has been developed on a theoretical basis by computers and on an experimental basis by x-ray diffraction. In the figure, the balls represent water or ammonia molecules, and the sticks should be thought of as hydrogen bonds. The "interstitial molecules" spheres represent extra molecules not present in ice, which occupy about half the cavities of the icelike structure in water and almost all of them in liquid ammonia.

This graph compares the observed radial distribution of molecules in liquid water and ammonia with those values calculated from the Oak Ridge model. The model explains the structural changes that occur in water when the temperature is raised from 4°C to 200°C and when ammonia is added to water at 4°C.



Magnetite, the stable iron oxide phase formed in pressurized-water reactors by corrosion of iron-bearing alloys, is transported throughout the reactor system and deposited on all surfaces to varying extents. The chemical reactions responsible for this transport, although very important, are difficult to elucidate because they involve the solubility and hydrolysis of various iron species such as Fe^{2+}, $FeOH^{+}$, $Fe(OH)_3^{-}$, $Fe(OH)_4^{2-}$, or combinations of these. The concentration of iron in high-temperature aqueous solutions is at any instant very low. During 1967 extremely difficult measurements were completed in which magnetite was equilibrated with solutions containing known amounts of dissolved hydrogen and KOH or HCl; the iron in solution was then determined by chemical analysis. The results have been used to derive the solubility constants for the three species listed in the figure. Fundamental information such as this can provide a basis for understanding how corrosion products and related fission products behave in a reactor environment and how this behavior can be controlled to minimize corrosion and contamination.



Complete Aqueous Electrolyte Equilibrium Constants

A remarkable simplification in the representation of aqueous electrolyte equilibria has come from studies of the chemistry of aqueous systems at high temperatures and pressures (as high as 800°C and 4000 bars). Although water is an essential component of the equilibrium, interacting with dissolved solutes to form hydrated ions, its concentration had not been specifically included by other workers in arriving at the conventional equilibrium constants for the dissociation into ions. This was not an obvious error, because aqueous solutions that had been studied at lower temperatures show very little variation in density or in the volume concentration of water. Under supercritical conditions, however, the density of the system can vary widely with pressure, and the volume concentration of water can consequently change markedly. This wide variation in water concentration with pressure gives data that permit the testing of a complete equilibrium constant, one that includes the concentration of the water as well as the concentrations of the other species involved in the equilibrium. These complete equilibrium constants, calculated for a variety of electrolytes and for many different temperatures, appear to be truly constant over the entire range of experimental conditions.

The concept holds also for low-temperature studies in which the concentration of water was varied by using solvents such as dioxane as diluents. The complete equilibrium constants for the water-dioxane system show very little variation with changes in the composition of the solvent. A point of considerable theoretical interest is that these constants do not change, even when the macroscopic dielectric constants of the solutions

change markedly. The simplifying concept is also applicable to solvating species other than water.

It seems clear that previous theories of the hydrolytic dissociation equilibrium must be altered in some way to conform to the tremendous predictive power of the mathematical representation afforded by the complete equilibrium constants.

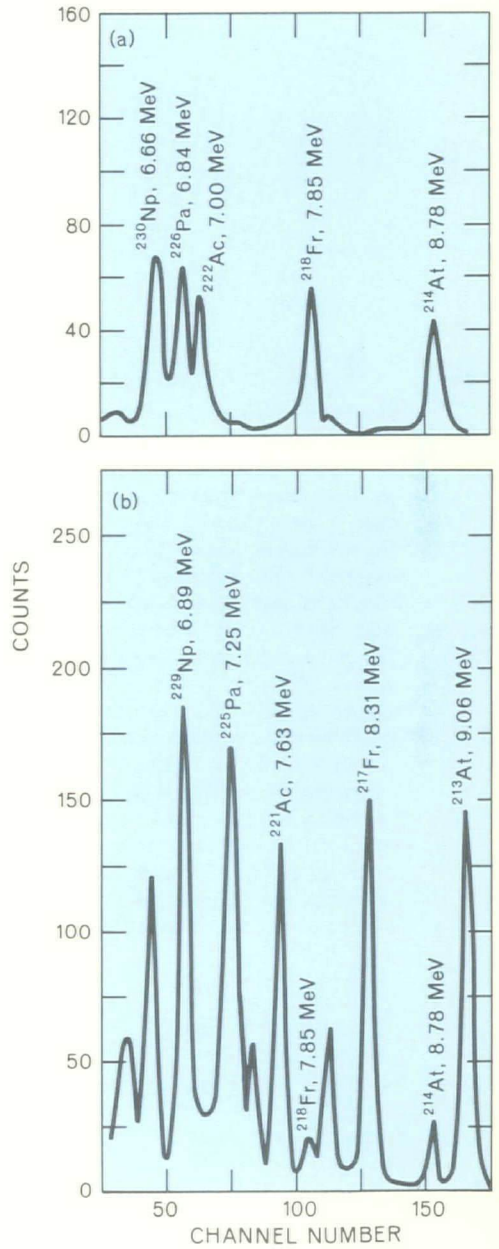
Discovery of Two New Transuranium Isotopes

Although the element neptunium has already been rather thoroughly explored, two new isotopes of it were identified at Oak Ridge National Laboratory during 1967. These two comprise the first isotopes of a transuranium element to be discovered at ORNL.

Highly enriched uranium-233 was bombarded with protons in the Oak Ridge Isochronous Cyclotron, and nuclei formed by the nuclear reactions between protons and uranium-233 were caught as they were ejected from the target. The foil on which they were caught was assayed for alpha-particle radioactivity and showed, among other groups of alpha particles, a previously unknown activity with an energy of 6.66 MeV that decayed with a half-life of 5.5 ± 1.0 min. Other groups in the assay correspond in energy to already-identified alpha particles emitted from protactinium-226, actinium-222, francium-218, and astatine-214. Since these all decayed with the same 5.5-min half-life as the 6.66-MeV peak, the isotopes responsible must arise from the decay of the isotope giving the 6.66-MeV peak. This identified one of the new isotopes as neptunium-230, the only isotope with the right mass and charge to give protactinium-226 by loss of an alpha particle.

Another new alpha-particle peak was observed at 6.89 MeV in a separate experiment; the isotope giving rise to that peak decayed with a half-life of 4.0 ± 0.5 min. This new 6.89-MeV peak was accompanied by the members of the decay chain protactinium-225, actinium-221, francium-217, and astatine-213, all of which decayed with the characteristic 4.0-min half-life. The protactinium-225 chain thus arose from the decay of the other new isotope, neptunium-229.

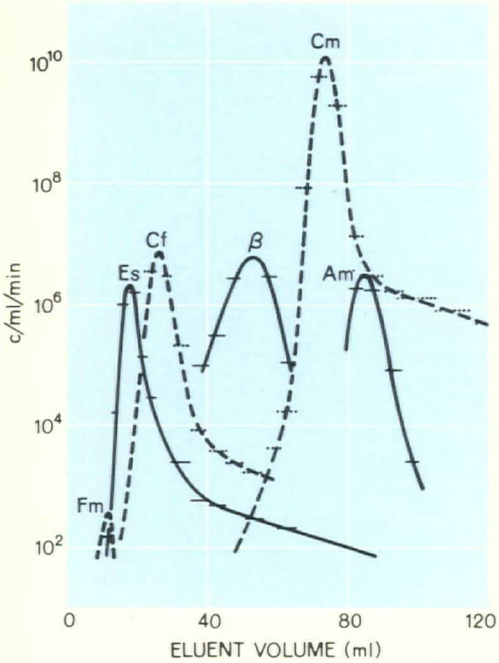
Since there are plans to devote considerable effort to the nuclear physics of the transuranium elements, it is encouraging to find new nuclei to study in such a thoroughly examined element.



In spectrum *a* are seen the 6.66-MeV alpha peak ascribed to the new isotope neptunium-230 and the peaks from the daughter nuclei that are formed by its alpha decay. Spectrum *b* shows the 6.89-MeV peak of the new isotope neptunium-229 and the peaks from its daughter nuclei. Small peaks from francium-218 and astatine-214, which are daughters of neptunium-230, are also visible.

Actinide Element Separation Using High-Pressure Ion Exchange

Chromatographic elution from ion exchange resin still provides the best method for accomplishing the more difficult separations of actinide and



Quantitative separation of the heavy actinide elements from an HFIR target, achieved with a high-pressure ion exchange system, is shown in this elution curve. Dowex 50-X12 ion exchange resin, 10 to 20 μ in diameter, was loaded with the actinides and eluted at 80°C with 0.25 and 0.32 *M* α-hydroxyisobutyrate (50 ml and 80 ml in sequence) at a flow rate of 24 ml cm^{-2} min^{-1}. The curve labeled "β" represents both berkelium and contaminant europium, which are not separated from each other in this process. A characteristic of this chemical system is the tailing of each elution band across subsequent ones. Curium and the heavier actinides are nonetheless obtained in high purity and yield.

lanthanide elements. These separations generally require at least several hours and may take days. With solutions of the highly radioactive actinide elements, special problems arise because of radiation damage to both the resin and the actinide solution. In extreme cases this damage may prevent elution from the resin; it always produces gas bubbles that cause channeling and mixing of the resin bed, producing poor separations.

An ion exchange system that operates with unusually finely divided resin with 10- to 20-μ beads under a pressure of 1500 to 2000 psi has now been developed, and it is being used routinely for the rapid separation and purification of the heavier actinide elements. The fine resin provides improved column resolution. High pressure is used to obtain relatively high flow rates, thus diminishing exposure of the ion exchange resin to radiation and effectively eliminating problems from gas bubble formation.

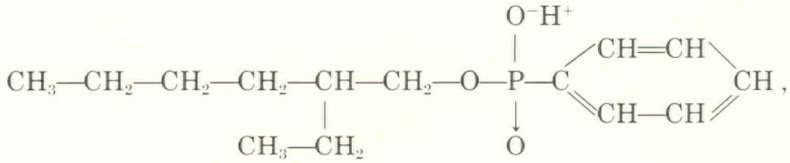
In addition to their application to highly radioactive actinides, these rapid separations are expected to be useful for the isolation and purification of many short-lived isotopes, such as the rare earths resulting from cyclotron bombardments. Good chromatographic separations on the laboratory scale have been achieved in 5 min, and it is hoped to reduce this time to 1 min or less.

In initial work, rare-earth elements were separated in amounts of several hundred milligrams; such amounts would correspond to full-scale operation for future separations of the heavy actinides. Some actinide elements have now been separated in milligram amounts, and each of the elements americium, curium, berkelium, californium, einsteinium, and fermium was obtained in high purity. These laboratory-scale separations usually required about half an hour.

During the past year, high-pressure ion exchange columns were used for final purification of all californium and heavier-element products from the Transuranium Plant. The products have included milligram quantities of californium and microgram quantities of einsteinium, amounts many times those ever before available.

Two-Metal Synergism in Extraction by Organophosphorus Acids

Solvent extraction continues to be a preeminent separations method and as such is a fruitful field for work in both process development and fundamental studies. A noteworthy recent finding is a two-metal synergism in extractions by several organophosphorus acid esters; more specifically stated, the extraction of certain metal ions is enhanced by the presence of even a small amount of zirconium. For example, with 2-ethylhexyl phenylphosphonic acid,

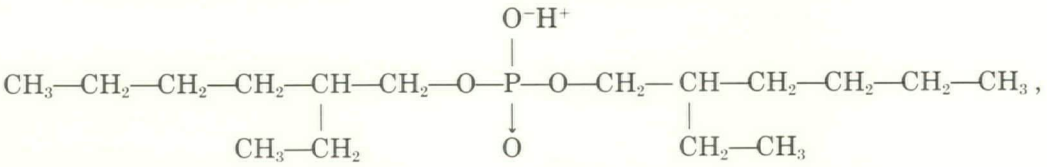


dissolved in such diluents as kerosene at a 0.5 *M* concentration, extraction coefficients from 1 *M* nitric acid solutions are increased up to a factor of 11,000 by the addition of 0.05 *M* zirconium:

Ion	*Without Zr*	*With Zr*	*Enhancement Factor*
Calcium(II)	0.02	250	11,000
Cerium(III)	1.3	800	600
Europium(III)	19	980	50
Americium(III)	1.2	520	430

In extracting some other metals, such as beryllium(II), zinc(II), scandium(II), and iron(III), there is little effect under similar conditions.

The zirconium synergism is of immediate, and unfortunate, importance in extractions of transplutonium actinides by 2-ethylhexyl phenylphosphonic acid, since the (otherwise) least extractable members of the series are enhanced most. This impairs the selectivity between members that is available in the absence of zirconium, and as little as 100 ppm of corrosion-product zirconium in a Transuranium Plant process solution can destroy the expected utility of this extraction in transplutonium separations. On the other hand, zirconium synergism has not impaired transplutonium separations by extraction with di(2-ethylhexyl)phosphoric acid,



under any conditions so far used, which is in itself surprising, since there is so much similarity in structure of the two acids.

Similar synergism has been observed with the use of hafnium and to a slight extent with titanium(IV), but not with thorium, vanadyl, uranyl, or tin(IV). Fundamental studies in progress suggest that the zirconium synergism may involve formation of a complex zirconic acid, which in turn is a new and powerful extractant for the second metal.

Theory for the Separation of the Isotopes of Boron by Chemical Exchange

The individual boron isotopes have strikingly different nuclear properties. Boron-11, making up 81% of naturally occurring boron, has the very low absorption cross section for thermal neutrons of less than 0.05 b, while boron-10, making up the other 19%, has a cross section of 4000 b. Because of this, the separated isotopes have important uses in the Nation's nuclear-energy program.

The principal method of separating these isotopes is a chemical exchange reaction in which BF_3 gas and one of its liquid molecular addition compounds, donor·BF_3, are equilibrated in a packed column:

$$\text{donor} \cdot {}^{11}BF_3\ (l) + {}^{10}BF_3\ (g) = \text{donor} \cdot {}^{10}BF_3\ (l) + {}^{11}BF_3\ (g).$$

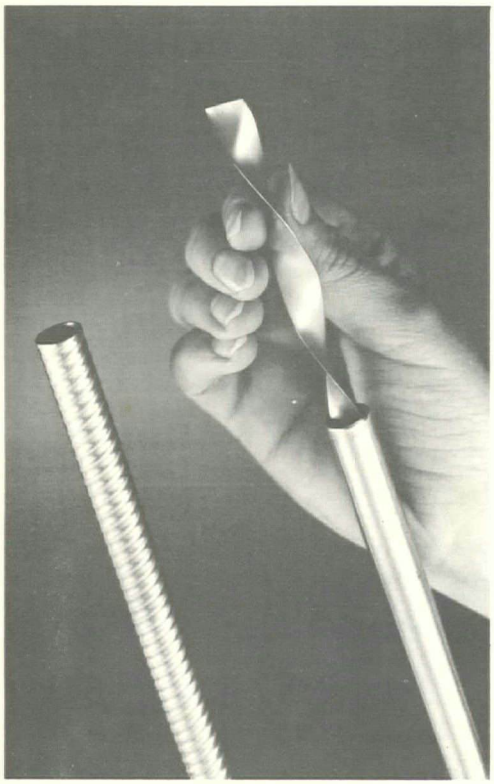
The equilibrium is such that there is a slight enrichment of ^{11}B in the gas phase. Although this reaction was first studied in 1943, the mechanism by which boron-11 was concentrated in the gas phase was obscure. In fact, according to the ordinary simple theory for such equilibria, the fractionation should have been in the reverse direction.

Recent work at ORNL has resulted in a theoretical explanation for the chemical exchange process by which isotopic fractionation occurs.

The reason lies in the unique electronic characteristics of the boron and fluorine atoms that make up the BF_3 molecule. Contrary to expectations, the boron is actually more strongly bonded in the BF_3 gaseous species than when it is in the donor·BF_3 liquid species, and thus the general rule is upheld that the heavier isotope concentrates in the more strongly bonded species.

The revised theory based on this explanation correctly predicts the chemical species in which each boron isotope will concentrate, the size of the isotopic separation factor that will result when the donor of a given complex is replaced by other suitable Lewis donors, and the maximum separation factor that may be attained at a given temperature under ideal conditions. The theory also predicts the isotopic behavior of other boron trihalides when these are substituted for boron trifluoride in the exchange reaction.

It would have been extremely valuable to have such a theory 25 years ago when large-scale separation of the boron isotopes was first undertaken, but it is satisfying to have at last a single explanation for the behavior of all the systems that have been studied in the meantime. If the need for separated boron isotopes grows sufficiently to justify the capital investment for a more efficient plant, the theory will be of great practical use, for it predicts that a reduction by more than 50% could be made in the cost of separated boron isotopes.



Tubes with spirally corrugated walls or internal full-length twisted tapes, having corrugations of various spacing and depth and tapes of various twist tightness, are mounted between electrodes so that the tube wall can be heated by the passage of electric current. Thermocouples attached to the outside surface of the tubes and located in the inlet and exit gas streams provide information needed in determining the best heat transfer coefficient. Small holes through the tube wall at the inlet and exit permit simultaneous measurement of the pressure loss as the gas flows through the test section.

Gaseous Heat Transfer Enhancement

Although gases have many physical and chemical characteristics that make them attractive as reactor coolants, they are relatively poor heat transfer agents. Consequently, a gas-cooled reactor must be operated at a lower power density than a liquid-cooled reactor of comparable total power. Enhanced heat transfer would permit the design of gas-cooled reactors of smaller size and of increased efficiency.

Two techniques for increasing the heat transfer for gases flowing inside tubes are being investigated: corrugation of the tube surface and modification of the flow by inserting a twisted tape into the tube. The spirally corrugated tubes provide improved heat transfer without significant increase in pressure drop (pumping power) and perform best at high flow rates. The tubes with full-diameter, full-length twisted tapes increase heat transfer at all flow rates; however, particularly for the tightly twisted tapes that improve heat transfer the most, a disproportionate increase in pressure drop accompanies this increase.

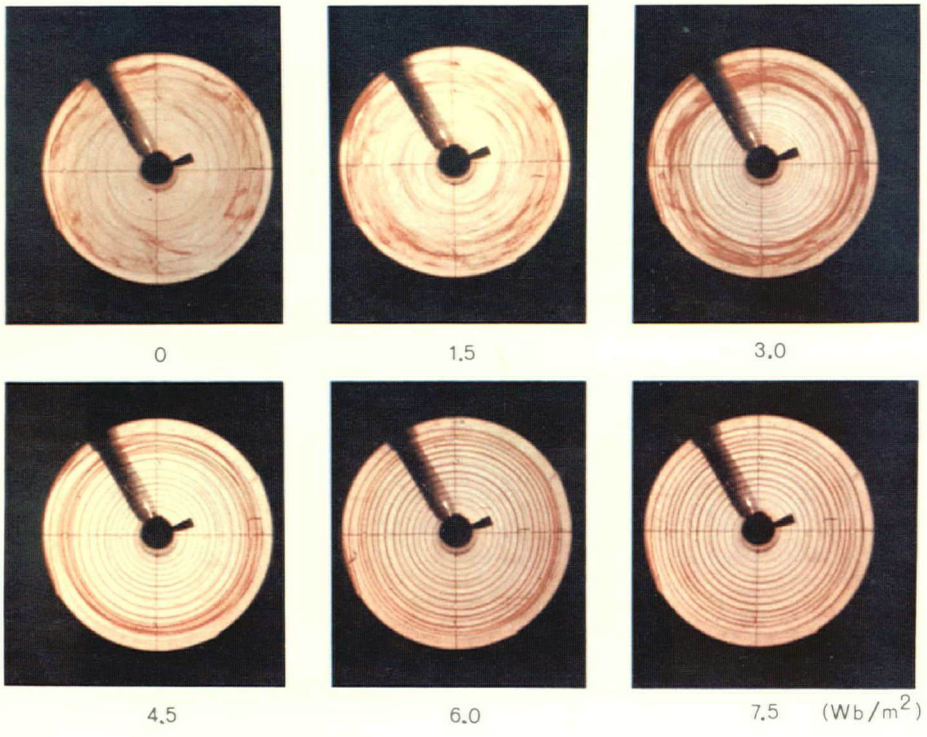
Hydromagnetic Stabilization Research

For many years cyclone separators for solids and liquids in gases and hydroclone separators for immiscible liquids have employed vortex-like flows driven by tangential jets of fluid. The Laboratory has considered the applicability of such flows to separation of gases on a molecular scale for possible use with an ultrahigh-temperature nuclear reactor in which the fuel would exist as a vapor. The fuel may, in principle, attain a critical mass in an annular region within the vortex cavity by the balancing of

the inward force resulting from diffusion of a low-molecular-weight coolant gas through the fuel against the centrifugal force resulting from rotation. Cyclone and hydroclone separators operate successfully in the turbulent flow regime because the density differences between the materials to be separated are relatively large and because there is no requirement for diffusive flow. Molecular separation of gases for the reactor application requires, on the other hand, that turbulence and associated eddy mixing be minimized to permit adequate fuel retention.

Since the fuel-zone temperature will be high enough to produce ionization and therefore an electrically conducting plasma, the application of a sufficiently high magnetic field parallel to the axis of the vortex tube might stabilize the flow against turbulent breakdown, by inhibiting fluid motion across the magnetic field.

A relatively simple experiment investigated the possibility of magnetically stabilizing jet-driven vortex flow of an electrically conducting liquid. Four full-length tangential slits fed a vortex tube 4 in. in diameter and 16 in. in length. The working fluid, a concentrated aqueous solution of ammonium chloride, entered through the feed slits, spiraled radially inward, and exited at the center of one end of the tube. These experiments, which were performed in the ORNL Magnet Laboratory, revealed that the tangential velocity at transition to an unstable flow that ultimately became turbulent increased approximately linearly with the magnetic flux density above 1.7 Wb/m^2. As a matter of fact, the tangential Reynolds number at transition increased from about 1000 to about 10,000 upon application of the full axial magnetic field, 7.5 Wb/m^2. Since theory suggests that the stabilizing effect of the field should increase with increasing electrical conductivity and decreasing absolute viscosity of the fluid, a gas-fueled reactor might realize an even greater gain in stabilization.

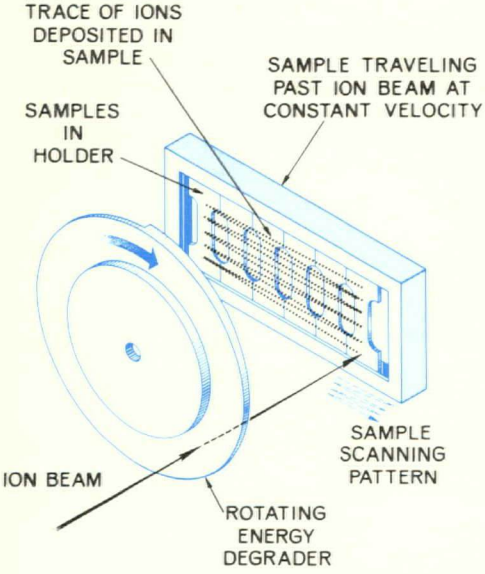


Vortex-like flow of an electrolytic conductor injected through tangential feed slits at 8, 11, 2, and 5 o'clock positions undergoes stabilization by an axial magnetic field. The tangential Reynolds number is 9500. Dye injected at the midplane of the vortex tube through one of the feed slits and observed in the axial direction through transparent end walls makes the flow path visible. Unstable, turbulent flow characterized by gross mixing prevails when there is no magnetic field. Stabilization with increasing magnetic field is evident: the dye trace follows the spiral laminar streamlines as the fluid exits at the center of one end of the tube. Note that the flow is laminar all the way to the wall under the influence of the full magnetic field.

MATERIALS RESEARCH

Many activities in materials research and development at the Laboratory have come to fruition recently, and several are highlights in the accomplishments of 1967. A deepened understanding of the damaging effects of energetic nuclear radiations on cladding, structural, and containment materials used in advanced research, test, and power reactors has been achieved. The discovery of submicroscopic cavities and bubbles produced in metals and alloys such as aluminum, stainless steels, Hastelloy N, and vanadium when they are exposed to neutron fluences exceeding 10^{22} neutrons/cm^2 has constituted a breakthrough in radiation metallurgy. This phenomenon, which is accompanied by swelling and changes in strength of the affected metal, has profound implications for the use of these metals at high temperatures in intense radiation fields. Important progress has also been made in theoretical calculations of the properties of materials. For example, the utility of a quantum-mechanical theory of the motion of electrons in solids, known as band theory, has been extended and applied to estimations of the Fermi surface of copper by means of a highly practicable computational method developed by scientists at the Laboratory. A unique portable metal-testing instrument to identify metals and alloys, to detect flaws in metals, and to determine the thickness of metal coatings was brought to full development.

Thus the following reports represent the broad scope of materials work at ORNL, from basic research to the development of a utilizable product; but the full dimensions of the materials-science effort are hardly alluded to.



Helium ions bombard a sample evenly because the zigzag motion of the sample holder gives uniformity across and along the specimen. Since the penetration depth of alpha particles depends on the particle energy, a rotating wheel of varying thickness intersects the beam to vary the energy and thus to distribute the resulting ions uniformly through the thickness of the specimen.

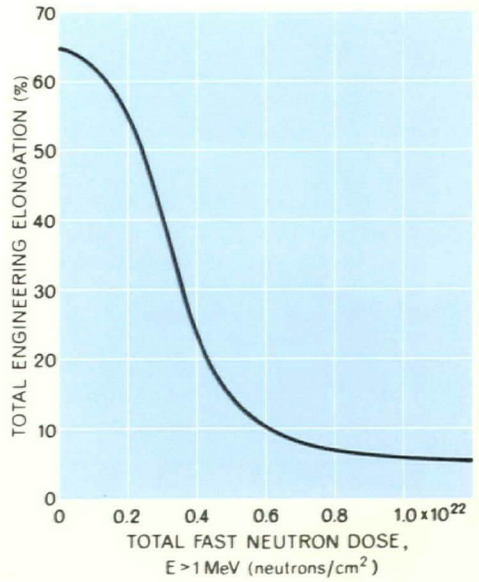
Use of Cyclotrons for Testing Reactor Materials

Materials scientists at Oak Ridge National Laboratory have found that high-temperature reactor irradiation damage can be simulated by cyclotron bombardment. A beam of high-energy alpha particles from a cyclotron is used to inject helium into a metal. A special ORNL test rig distributes this helium uniformly through the specimen, simulating the helium distribution resulting from the (n,α) reactions that would occur in the material if it were exposed to the fast neutrons in a reactor environment. The high-temperature mechanical properties of materials containing cyclotron-injected helium agree well with those of reactor-irradiated materials containing similar amounts of neutron-generated helium. This directly confirms the role of helium in damaging material properties. Since the cyclotron can inject more helium into a specimen in a few hours than is produced by a year of neutron irradiation in existing fast reactors, simulation of some of the effects of prolonged neutron irradiation can be accomplished in a very short time.

Neutron Irradiation Damage in Aluminum

Aluminum alloys are used as fuel cladding and structural members in several types of reactors. Until recently, there had been no evidence that neutron irradiation caused any significant changes in the physical and mechanical properties of aluminum alloys, at least from the standpoint of reactor design. However, when aluminum target-rod cladding cracked in the High Flux Isotope Reactor and aluminum components warped in the Oak Ridge Research Reactor, ensuing investigations demonstrated that the ductility of several aluminum alloys decreased severely when the alloys were tested between 100 and 700°F after irradiation to approximately 10^{22} neutrons/cm^2. The strength of the alloy doubles as the dose increases from 10^{21} to 10^{22} neutrons/cm^2. The ductility was restored by heating at approximately 1000°F, but this annealing treatment caused the growth of large voids or bubbles and consequent swelling.

The observed irradiation effects may result from one or more of these possibilities: the generation of hydrogen and helium gas within the metal, the production of silicon by transmutation, and the displacement of atoms by colliding neutrons giving voids in the metal. Doses of approximately 10^{22} neutrons/cm^2 can generate in the alloy approximately 1 atom of helium per million atoms, 100 atoms of hydrogen per million, and 1% silicon.



Effect of neutron irradiation on the elongation of aluminum at 400°F. The ordinate shows the percentage that the metal stretched before breaking in a standard test of strength, and the abscissa measures dose of high-energy neutrons. This dose corresponds to a year in common high-intensity test reactors at the steep portion of the graph.

Calculation of Fermi Surfaces

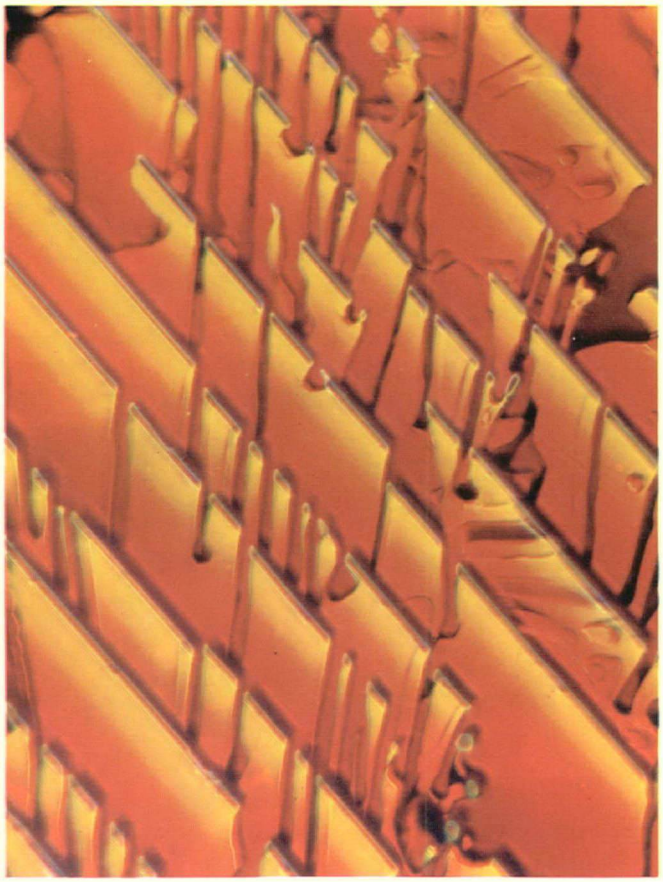
Theoretical metallurgists at the Laboratory have developed a new tool for calculating the Fermi surface of a material, which constitutes a geometrical description in reciprocal space of electron energies in a solid. The Fermi surface is directly related to the electrical properties and is important to the understanding of mechanical, thermodynamic, and transport properties. Using special computer-programming techniques, surfaces are calculated for 26,066 points, rather than just a few points for key directions only, without prohibitive use of computer time.

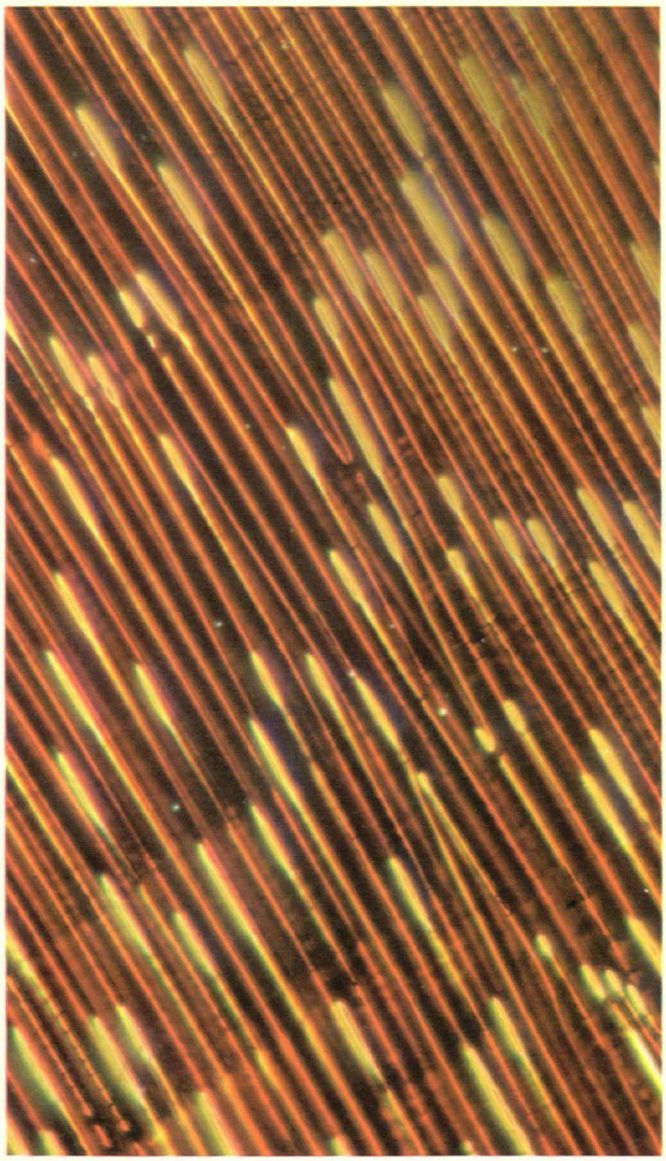
The first application of the method resulted in the description of the Fermi surface of copper in unprecedented detail and its variation with hydrostatic pressure. These results have agreed with experimental results, where available, and have aided in the interpretation of experimental work. The method is being expanded to treat more complex properties and to permit use with materials having more than one kind of atom.

Controlled Growth of Uranium Dioxide–Tungsten Composite

Ordered composites of the ceramic uranium dioxide and the metal tungsten were grown at the Laboratory during 1967 by controlled solidification of the eutectic composition from a melt. The composite is basically a single crystal of uranium dioxide containing a highly ordered array of very fine rod- or plate-shaped crystals of tungsten. Such materials have shown double the compressive strength of pure single-crystal uranium dioxide and, in the direction of the tungsten rodlets, 30% greater thermal conductivity. Thus these composites might be useful for special nuclear fuel where more rapid heat extraction or increased strength is needed.

Uranium dioxide crystal grown with tungsten lamellae nearly parallel to the sectioned surface. During controlled solidification of the tungsten-UO_2 eutectic, parallel thin plates of tungsten grew in a single crystal of UO_2. The dark stripes are the protruding edges of the lamellae; the color of the sides deepens with increase in the thickness of the UO_2 through which they are viewed.





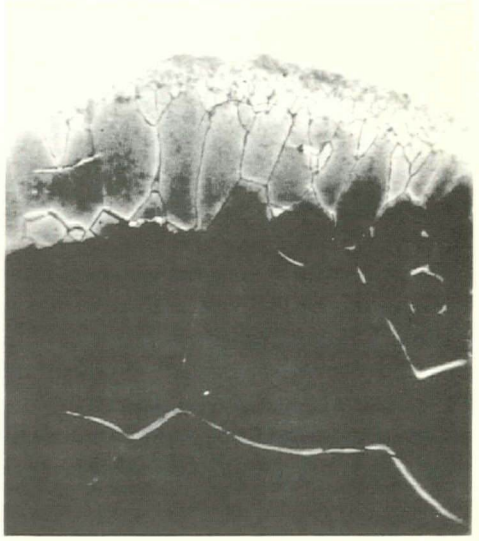
Uranium dioxide crystal with tungsten rods nearly parallel to the sectioned surface. During controlled solidification of the tungsten-UO_2 eutectic, parallel rods of tungsten grew in a single crystal of UO_2. The bright loops outline the protruding ends of the rods; the trailing lines deepen in color as the rods are seen through increasing thicknesses of uranium oxide.

The crystalline composite is produced by a method developed at ORNL for growing large uranium dioxide crystals with high perfection. A bar compacted from a mixed powder of UO_2 and tungsten is lowered slowly through an induction heating coil and rotated. The electrical and thermal properties of uranium dioxide are such that the interior melts within a solid outer crust. The rotation centrifugally casts the melt against the solid wall; this shapes the interface favorably for crystal growth. The tungsten rods in the eutectic structure are typically 1 to 2 μ in diameter and about 1 mm long. Lamellae are 2/3 μ thick, 10 to 100 μ wide, and longer than 1 mm.

Diffusion in Uranium Dioxide

Penetration of uranium-233 into a single crystal of uranium dioxide could not be detected after five days at 1400°C. Coarse-grained material cut from the same ingot as the single crystal showed penetration that increased as the density of grain boundaries increased, confirming that, at the temperature range used, uranium atoms can move in the oxide only along imperfections.

Previous measurements of diffusion in uranium dioxide had been made on polycrystalline material but had been interpreted as diffusion through the crystals. According to the recent ORNL result, volume diffusion coefficients reported in the literature are at least 100 times too high. The knowledge of diffusion gained from this work permits better understanding of consolidation by heating of pressed powders, deformation under prolonged load, reactivity, and migration of fission products.

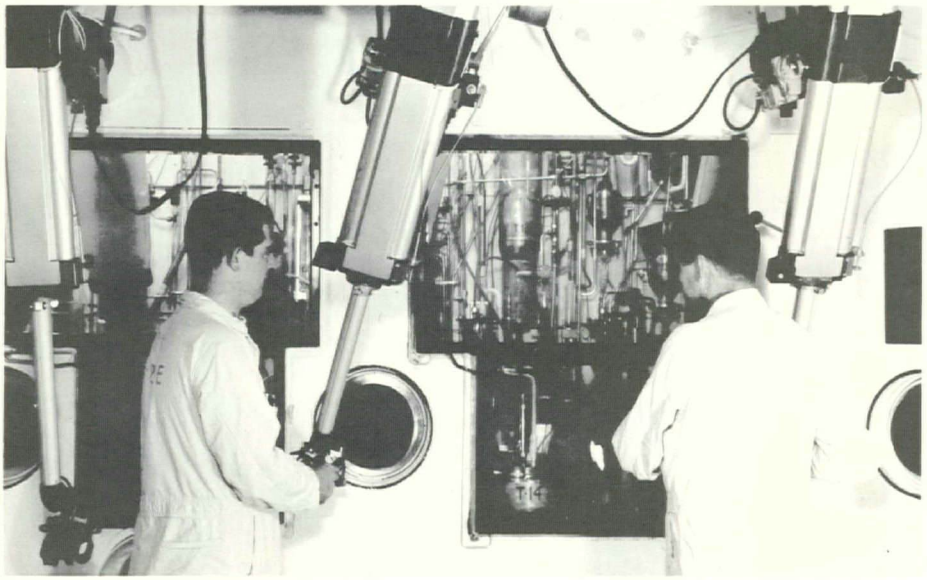


This autoradiograph of a uranium dioxide specimen was obtained by depositing a thin layer of uranium-233 on the specimen and then heating it to allow the tracer to diffuse into it. When the specimen was laid in contact with photographic film, radiation from the active uranium remaining on the surface blackened the film. The pattern of white shows that penetration occurred along the grain boundaries. That penetration occurs only along the grain boundaries was proved when a single crystal cut from the same ingot next to this specimen showed no measurable penetration.

Sol-Gel Preparation of Heat-Source Materials

The continuing development of the sol-gel process technology has led to the successful preparation of microspheres of the oxides of plutonium-238 and curium-244. These microspheres are attractive for use as fuels in safe, compact power sources for application in the oceanographic and space programs. Because of its low gamma and neutron emanation, the plutonium-238 is also uniquely applicable in power units for heart pacers.

The microsphere preparation process consists in precipitating a hydrous oxide from a nitrate solution, peptizing to form a hydrosol, forming gel microspheres by dispersing the sol in an organic solvent that extracts water, thus solidifying the sol droplets, and finally calcining the gel to produce strong, dense oxide microspheres. This procedure was used in laboratory experiments to prepare several sol batches, each of which contained 10 g of plutonium-238. These sols were formed into gel microspheres, which were calcined in air at 1150°C. The product microspheres had high density, good surface characteristics (high gloss and no surface imperfec-



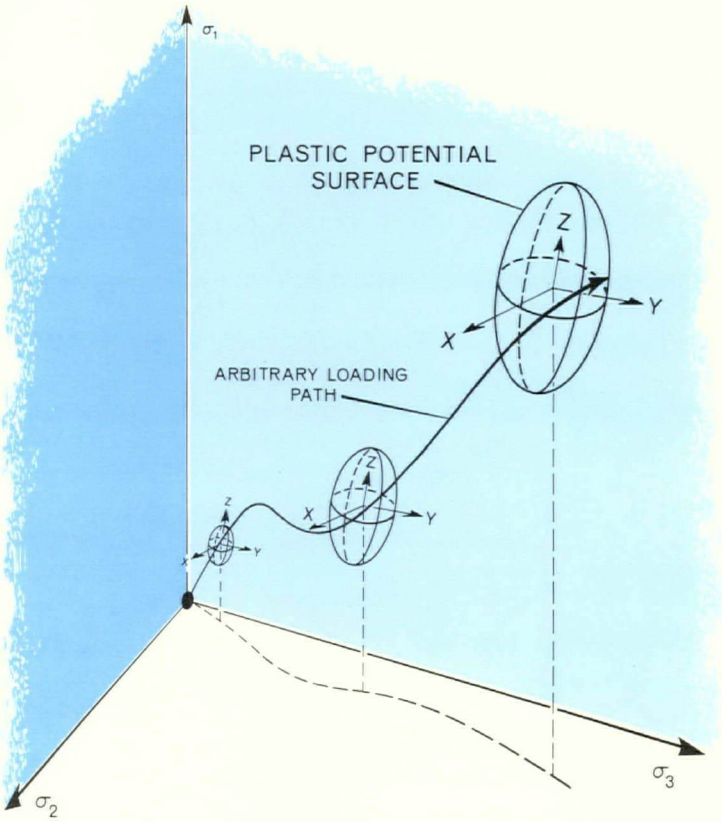
Technicians performing maintenance on the remotely operated PuO_2 sol-gel pilot plant system at Oak Ridge National Laboratory.

tions), and excellent crushing strength. The spheres can be washed free of virtually all leachable radioactivity.

Since a low neutron emission rate is desired for heart-pacer application, the product PuO_2 is enriched in oxygen-16, while the oxygen-17 and oxygen-18 contents are decreased. Experiments indicate that this can be readily accomplished by use of isotopic exchange reactions.

Development of the plutonium-238 sol-gel process has advanced from laboratory to engineering scale. The Laboratory has successfully operated a pilot plant that is capable of producing plutonia microspheres or mixed oxides such as UO_2-PuO_2. Because of the personnel exposure problems associated with the handling of plutonium-238 prior to oxygen exchange, this pilot plant is shielded and operated remotely. The demonstration of the remote operability of this plant is expected to have a direct bearing on the design of fast-reactor fuel fabrication facilities, where this type of operation will be mandatory.

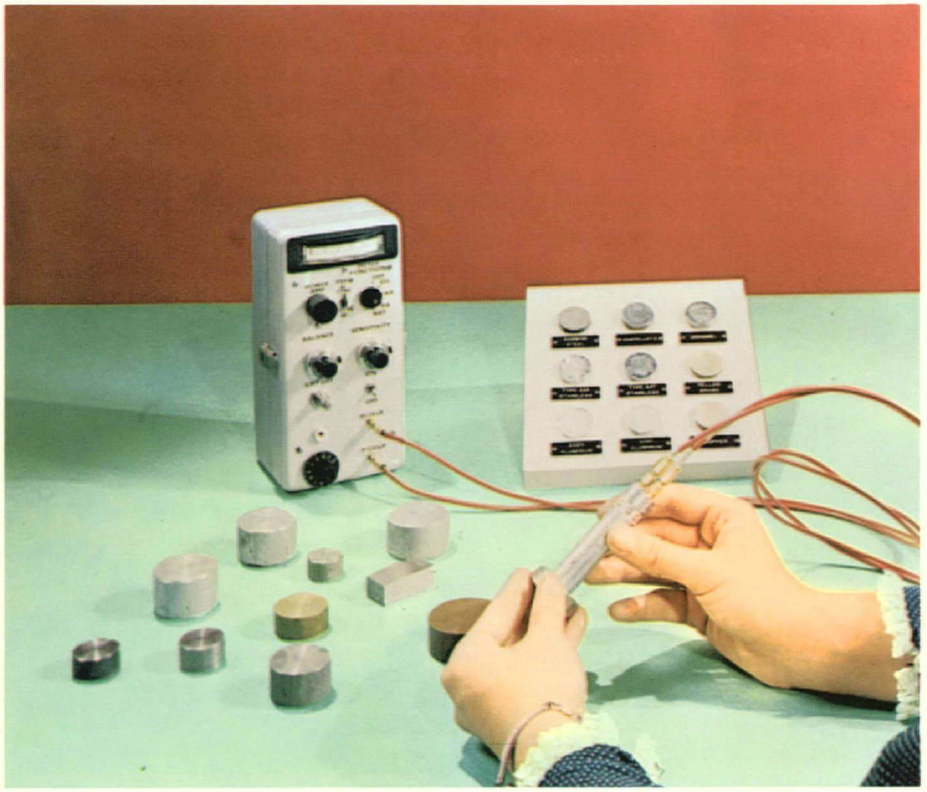
As an outgrowth of the pilot plant, a full-scale (150-g/day) plutonium-238 microsphere system was fabricated at ORNL and shipped to Mound Laboratory. This system gives considerable advantage in equipment size, process simplicity, high process yield, and decreased personnel exposure compared with other methods for producing microspheres.



Graphite, an important material in the design of nuclear reactors, is unlike metals in that, in general, no discernible regions of reversible or elastic response are detectable from simple tension or compression tests. In addition, specimens exhibit both permanent (or plastic) elongation and volume change when loaded and unloaded. A mathematical theory describing this complex behavior for combined stresses as well as for simple test conditions has been developed. The room-temperature behavior is described by an elastic-plastic model of time-independent behavior. The plastic strains are given in terms of a potential function representing a surface in stress space that both moves and grows as the stress state changes. This surface differs from that used in the ordinary mathematical theory of plasticity in that it does not enclose a region of purely reversible response. This novel mathematical analog of the stress-strain behavior for graphite represents an important advance in the general field of solid mechanics that will find immediate application in the design of nuclear reactors.

Portable Phase-Sensitive Eddy-Current Instrument

A unique portable metal-testing instrument has been developed at the Laboratory to measure thickness, detect flaws, and identify or sort metals and alloys. A probe coil attached to the instrument sends a radio signal into the specimen to be tested. This signal induces in the specimen an



The probe of this portable metal-testing device induces a radio-frequency eddy current in a metal specimen and measures how much this current lags behind the original signal; this lag depends on the properties of the metal. For identifying metals and alloys the instrument can be used with a set of known specimens, as shown on the right of the instrument.

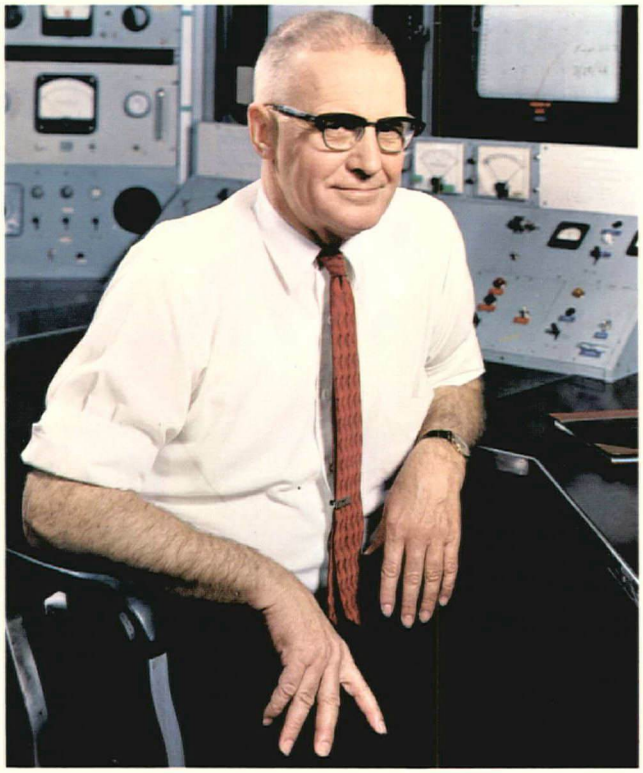
eddy current, which lags behind the current in the coil by an amount that depends on the properties of the metallic specimen. The instrument measures lags in the induced current as small as 10^{-9} sec; with appropriately chosen standards, the lag can be related to the property measured. Thus the problems of previous eddy-current instruments, which measured the amplitude of the induced current and were therefore very sensitive to and often obscured by variations in the coil-to-specimen distance, are avoided.

The portable instrument weighs only 4 lb and operates on alternating current or its own rechargeable batteries and has measured the thickness of 0.010-in.-thick stainless steel sheet to closer than 0.00005 in.

Evaluation of Protective Coatings

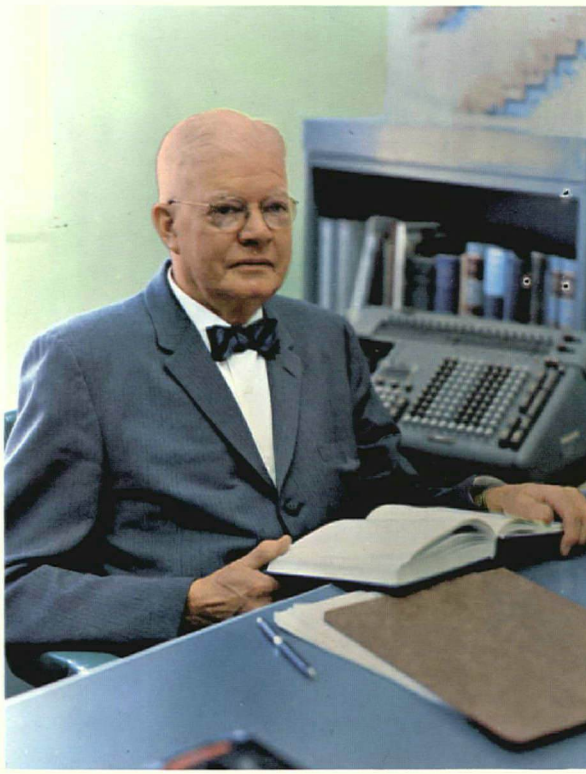
During the past several years a testing and evaluation program has been conducted at Oak Ridge National Laboratory on the specialized protective coatings used extensively in the nuclear industry to protect the surfaces of facilities and equipment from corrosion and from contamination by radioactive materials. Under the auspices of the American Standards Institute, standards were set up that offer a common basis on which to define and specify conditions to which coatings will be exposed. Incorporated into the standards are specific tests for radiation tolerance, decontaminability, chemical resistance, and physical properties of coatings. Specific methods of surface preparation for shop and field applications and of inspecting coatings during and following application are also included.

AWARDS



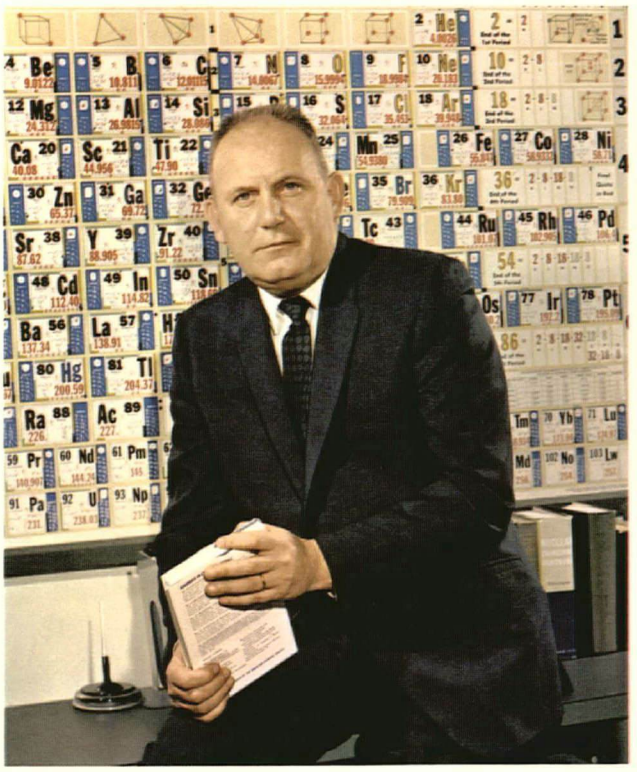
A. Dixon Callihan, Associate Director of the Neutron Physics Division, was presented the American Nuclear Society's David V. P. Williams Memorial Award in recognition of his leadership in the field of critical experimentation and the significance of his activities as editor of *Nuclear Science and Engineering*.

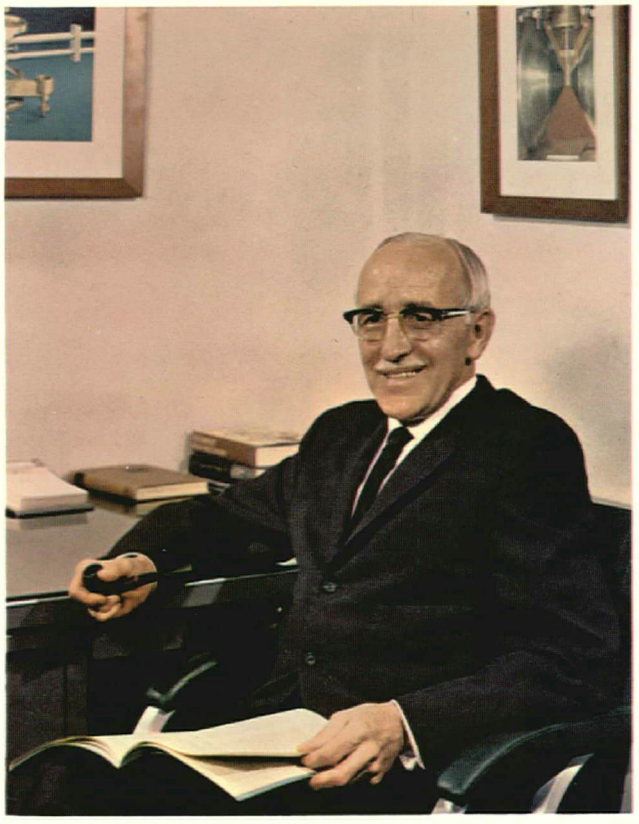
Groves H. Cartledge, a consultant to the Laboratory's Chemistry Division, was awarded the Herty Medal by the Georgia Section of the American Chemical Society for his outstanding work in the field of corrosion chemistry.



Harold H. Abee, who directs the Health Physics Division's Environmental Monitoring and Bioassay programs, received the Elda E. Anderson Award, the Health Physics Society's highest honor, in appreciation for his long record of contributions to the field of health physics, the many assignments he has completed for the Society, and his aid in organizing the International Radiation Protection Association.

Warren R. Grimes, Director of the Reactor Chemistry Division, was a recipient of the 1967 Special American Nuclear Society Award in recognition of the importance of his contributions to the field of the chemistry of reactors.

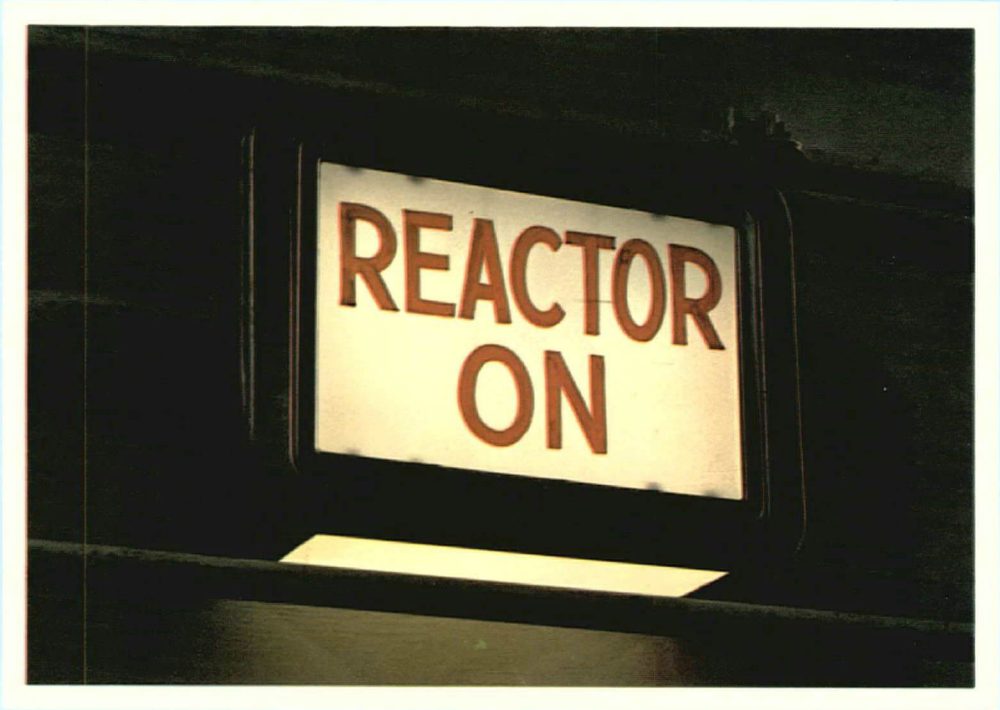




Ernest O. Wollan, a member of the Laboratory's Directors Division, received the John Price Wetherill Medal of the Franklin Institute for his early work in developing the equipment and techniques for study of neutron diffraction and for his many investigations that resulted in the discovery of the magnetic structure of solids.

A radioisotope light source for photometric analysis, invented by Harley H. Ross of the Analytical Chemistry Division, was selected by *Industrial Research* magazine as one of the 100 most significant new technical products of the year.

Projects



Important national needs for economic development and for enhancement of the quality of living are given comprehensive attention at Oak Ridge National Laboratory by assigning them project status. Such projects seek to identify key problems and to develop the technology needed to provide solutions. In treating these problems, a strong interdisciplinary character is achieved by structuring the program organization so that it cuts across divisional lines, and close coordination of the projects enables them to interact effectively with each other and with the basic research groups of the Laboratory.

Most of the projects at ORNL remain oriented to the principal civilian purposes of the Atomic Energy Commission, such as the development of nuclear power sources and the production and use of isotopes. The heavy responsibility engendered by the increasingly widespread use of nuclear power plants by private electric power companies requires continued research and development on subjects such as nuclear safety, fuel handling, and radioactive waste disposal. Furthermore, the low utilization of nuclear fuel achieved by present reactors makes them only an interim solution to the energy problem; the development of the breeder reactor will constitute an essentially permanent solution. To this end, the Laboratory is not only developing the very promising thermal breeding cycle, but also making an important contribution to the development of fast breeder reactors.

In recent years the Laboratory has started projects that have broader social implications, such as civil defense research, the application of cheap energy sources to the recovery of desalted water from the sea, the development of economically feasible methods of pollution control, the production of additional food for the world's increasing population, and the use of low-cost electricity in producing industrial products. As these projects develop, social and other nontechnical aspects come to bear on the subject, and this has resulted in the recent trend to supplement our strong physical science capabilities with social science talent.

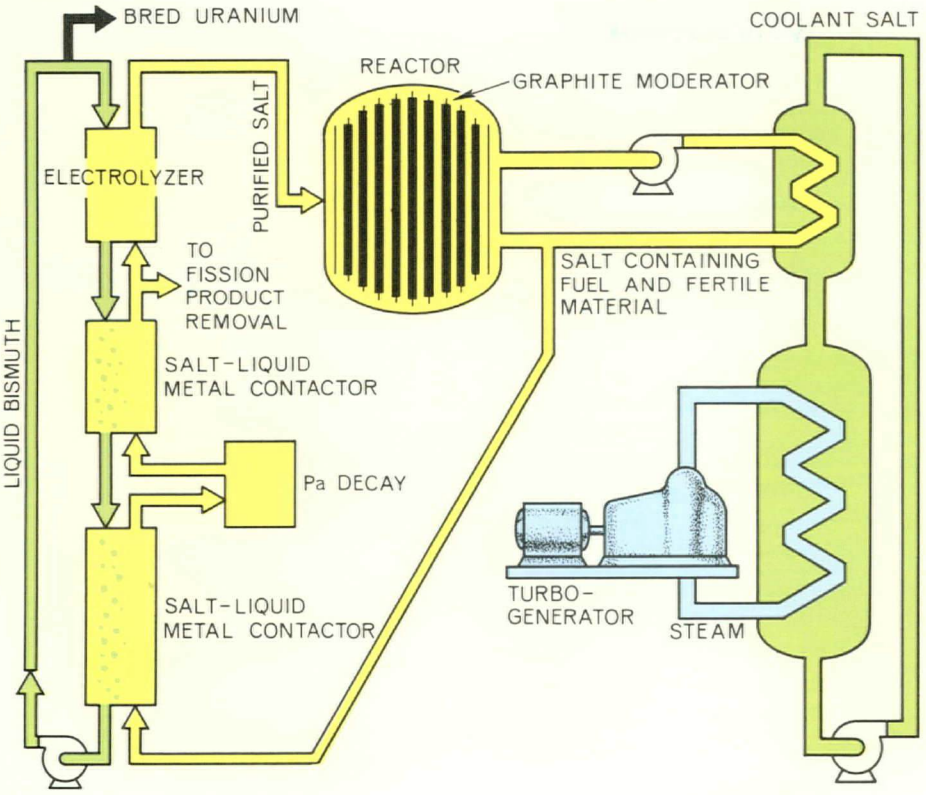
The paragraphs that follow describe a few of our most recent advances in a number of typical projects.

MOLTEN-SALT REACTOR PROGRAM

During 1967, utilities filed applications with the AEC to construct and operate boiling-water and pressurized-water reactors with a total designed electrical output of 24,287 MW. Since these reactors can extract energy from less than 1% of the uranium mined, the development of breeder reactors that conserve our limited resources of low-cost uranium-235 is urgent.

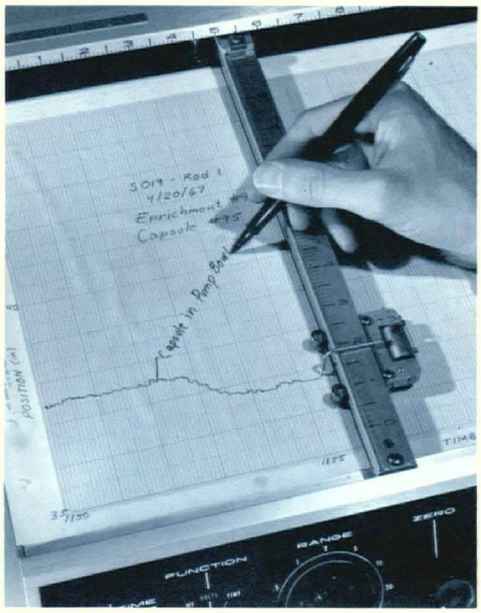
Oak Ridge National Laboratory has been convinced for several years that a safe and economic breeder can best be attained through molten-salt reactors that convert thorium into uranium-233. Two major accomplishments in 1967 make us even more confident that this view is correct: the extraordinary success of the Molten-Salt Reactor Experiment (MSRE) and inventions in reprocessing chemistry and reactor core design that allow a single salt to serve as both fuel and fertile blanket for a breeder.

The basic technical feasibility of molten-salt reactors was demonstrated by the experience with the MSRE. On October 7, 1967, the MSRE passed the milestone of 6000 equivalent full-power hours, the point that



A major advance of 1967 was the invention of the one-fluid molten-salt breeder reactor, which has a high ratio of graphite to salt in the core and a low ratio of graphite to salt in the blanket. Thus in the core, neutrons are quickly slowed down to thermal energies and produce fission of uranium, but they remain at higher energies longer in the blanket, where they are readily captured by thorium.

Even with this design, however, protactinium-233 must be continuously removed from the salt so that it does not capture any neutrons before decaying to uranium-233. In the process that was developed for removing protactinium from the salt, uranium is transferred from the salt to molten bismuth at the bottom of a liquid-liquid extraction column, protactinium is trapped in salt in a decay tank in the middle of the column, and the uranium is returned to the salt at the top of the column. The protactinium is held up in the tank until it decays to uranium and returns to the reactor.



The fissile uranium in the MSRE fuel salt was replenished periodically during power operation. Here the position of the control rod used to compensate for the added uranium-235 shows the effect of a capsule of enriching salt melting quickly and blending into the circulating stream.

had been set in advance as that at which success could be judged. A total of 7600 equivalent full-power hours were achieved by the end of the year. During 1967 the reactor was critical 74% of the time, and, allowing credit for the time spent in removing experimental specimens from the core, it was available for operation 82% of the time, a remarkable record for an experimental reactor.

The MSRE was refueled twice during the year at full power, and the fuel salt was sampled more than 100 times. A second array of metal and graphite specimens was removed from the center of the core and, like one removed the preceding year, was found to be completely undamaged by exposure to the salt. The fuel off-gas system had given trouble in earlier operation, but corrective measures were effective, and no difficulty was encountered in 1967. More than 80% of the xenon-135, the most important fission product, was removed continuously from the reactor and swept into the off-gas charcoal traps. There were no malfunctions of the primary system, and for more than 13,000 h the salt pumps have now run flawlessly except for a small, correctable leakage of oil into the pump bowl. Several minor components of auxiliary systems were replaced with the use of remote maintenance techniques.

The experience with the MSRE in 1967 demonstrated that molten-fluoride reactors can be operated at temperatures above 1200°F without corrosive attack on either the metal or graphite parts of the system; reactor equipment can operate satisfactorily at these conditions; and, when necessary, the radioactive equipment can be repaired or replaced.

The MSRE has not, however, tested one important feature of the breeder-reactor designs to which the Laboratory has devoted the most attention during the past several years: the use of graphite in the core to separate uranium-bearing fuel salt from thorium-bearing blanket salt. Separate fuel and blanket salts are necessary for a breeder if there is no process for continuous removal of protactinium. Requiring graphite to serve essentially as a plumbing material while exposed to very large neutron doses is a major disadvantage of the two-fluid system. To prove that graphite can adequately serve in that way would require a number of years of exposure in a prototype reactor. Moreover, the entire core would have to be replaced when any graphite element reached its radiation limit. As a consequence, a one-fluid breeder reactor in which graphite serves only as a moderator has been a much-sought goal.

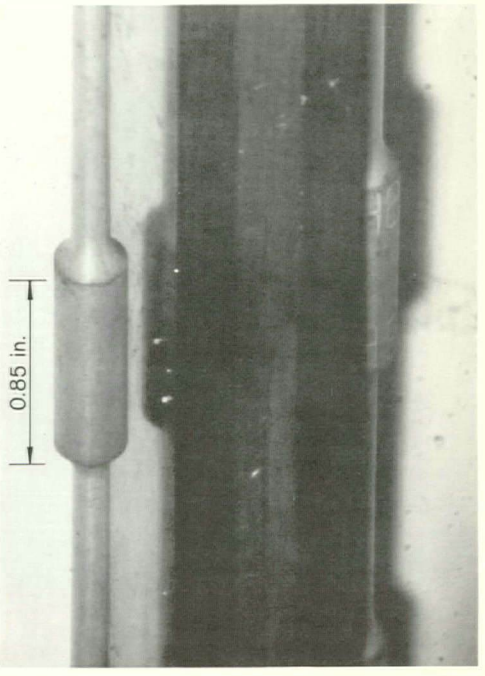
The feasibility of such a one-fluid breeder has been promoted during the past year by the establishment of the chemical steps in liquid-liquid extraction processes for the removal of protactinium, uranium, and fission products from fluoride salts. The process exchanges thorium and lithium metals dissolved in molten bismuth for the constituents to be removed from the salt. Hopefully, this extraction process can be carried out rapidly and continuously with relatively small process equipment.

Our studies have shown that protactinium and uranium can be satisfactorily removed by direct extraction from the molten salt mixture characteristic of a one-fluid breeder reactor; our calculations indicate that we can do so on a processing cycle of only five days. An experimental program now in progress will reveal whether the rare-earth fission product poisons can be extracted directly from salt that is free of uranium and protactinium. Only a 100-day cycle is required for rare-earth removal, and if direct extraction does not prove feasible, there are other processes that can be adapted for this longer cycle time.

A second achievement that makes a one-fluid breeder seem feasible is the recognition that a fertile blanket can be obtained with a salt that contains uranium as well as thorium. This is accomplished by removing some of the graphite moderator from the outer part of the reactor. The outer region is then undermoderated, and thorium captures most of the neutrons before they are slowed down to energies at which uranium absorbs them. Although this design has been under consideration for some time, only after it was known that protactinium could be removed were the optimization calculations completed. The calculations show that dimensions and volume fractions can be selected that will keep the inventory of uranium in the outer region from being excessive and that a single-fluid, two-region molten-salt breeder reactor can be built that has fuel utilization equal to the two-fluid design, and probably better economics.

Characteristics of One-Fluid, Two-Region Molten-Salt Breeder Reactors

Fuel and fertile salt	72 mole % LiF, 16% BeF_2, 12% ThF_4, 0.3% UF_4; melting point, 930°F
Moderator	Graphite (bare)
Salt volume fractions: core, blanket	15%, 40%
Core inlet, outlet temperatures	1050°F, 1300°F
Reactor power	1000–2000 MW (electrical)
Reactor diameter	14–18 ft
Steam system	3500 psia, 1000°F, 44% net cycle efficiency
Breeding ratio	1.05–1.07
Specific fissile fuel inventory	1.0 kg/MW (electrical)
Doubling time (compound interest)	13–18 years
Fuel cycle cost	0.3–0.5 mill/kWh



Even after 103 consecutive days of exposure at 1200°F to radiation and flowing molten salt inside the MSRE, metal and graphite test specimens were essentially unaltered. The metal tensile specimen on the left can be seen reflected on the smooth surface of the graphite. The bright surfaces of the metal specimens were only dulled slightly.

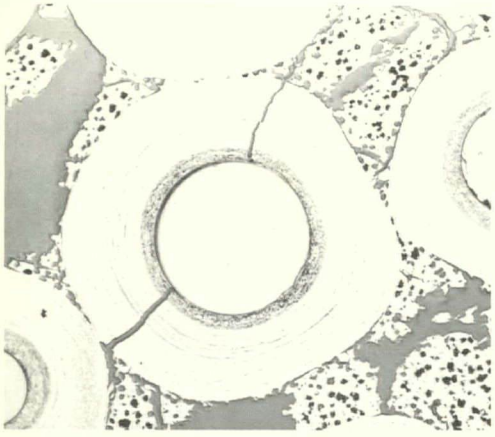
The favorable experience with the MSRE and the significant developments of the past year might be followed by the construction of a Molten-Salt Breeder Experiment. Such an experiment would be designed to demonstrate all the basic features of a one-fluid breeder, including an integral processing plant. Construction of this new reactor appears straightforward, since, in its basic features, it is mainly a scaled-up MSRE. If it is as successful as the MSRE, economic molten-salt reactors with good fuel utilization characteristics could have an earlier impact on the ore conservation problem than has been visualized up to now.

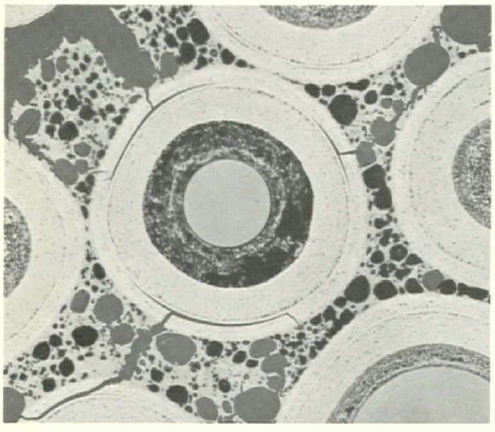
GAS-COOLED REACTOR RESEARCH

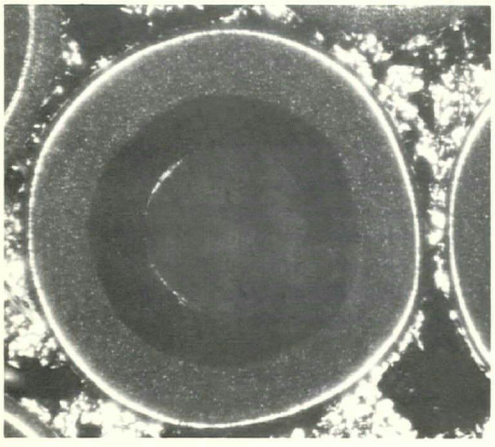
The high-temperature gas-cooled reactor (HTGR) concept promises economical power production and effective utilization of thorium and uranium resources. The Laboratory's program on fuel development for advanced HTGR's is concerned with demonstrating remote manufacture of recycle fuel. This fuel will contain uranium-233 recovered from irradiated thorium and is an important economic feature of the reactor. Equipment and techniques are being developed for blending and bonding two sizes of coated particles for loading into holes in the hexagonal graphite fuel elements. Injection of a phenolic resin catalyzed by maleic anhydride bonds the fuel into sticks.

To prepare sol-gel-derived thorium-uranium oxide fuel particles, a high-density isotropic layer of carbon is deposited pyrolytically at low temperatures (1250°C) and high deposition rates from propane or propylene. This method gives excellent stability to the fuel upon irradiation to high uranium burnup. In early experiments the carbon coatings sometimes cracked after bonding into fuel sticks. Surface porosity (0.1-μ pore size) of the isotropic coatings apparently enables a strong bond to develop between the resin and the coating, which enables shrinkage cracks to propagate from the matrix through the coatings on some particles.

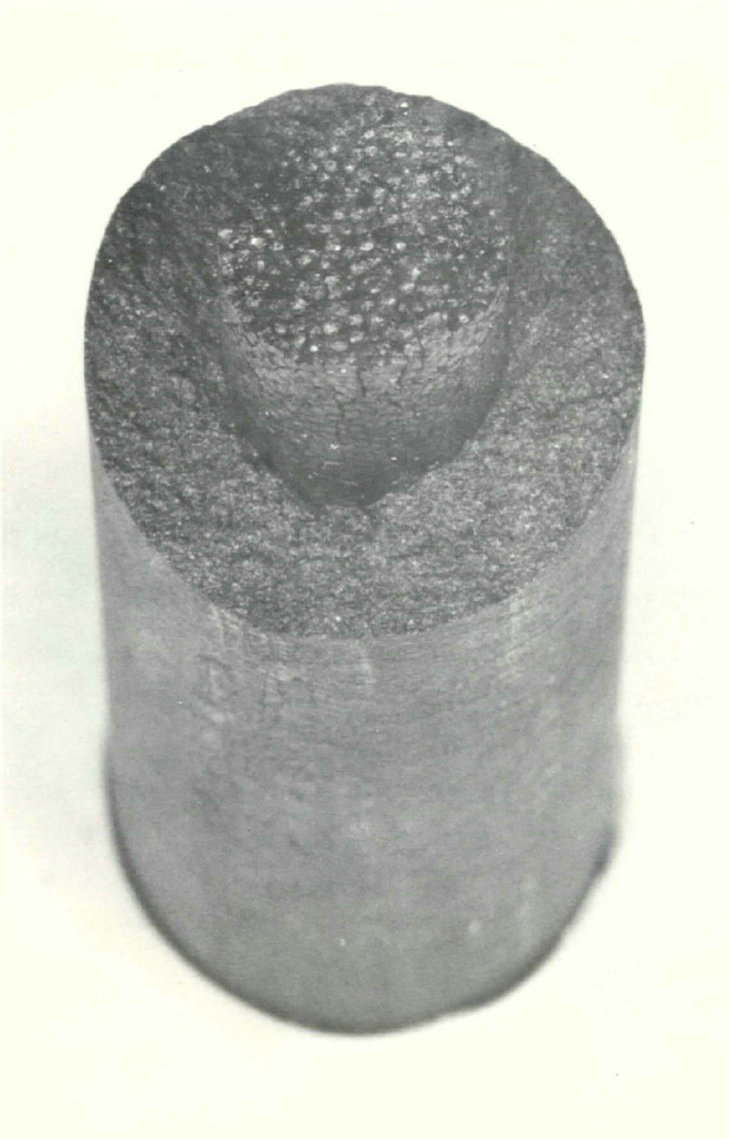
However, resin does not bond to dense anisotropic carbon coatings deposited at lower rates and having little, if any, open porosity. Accordingly, a thin nonbonding anisotropic layer was deposited on the surface of the isotropic coating, and over this a sacrificial outer layer that bonds tightly to the resin but cracks without affecting the coating underneath. Particles coated in this manner were bonded into two fuel sticks that gave good performance in a sweep-capsule irradiation experiment at 1300°C to a fuel burnup exceeding 25%.



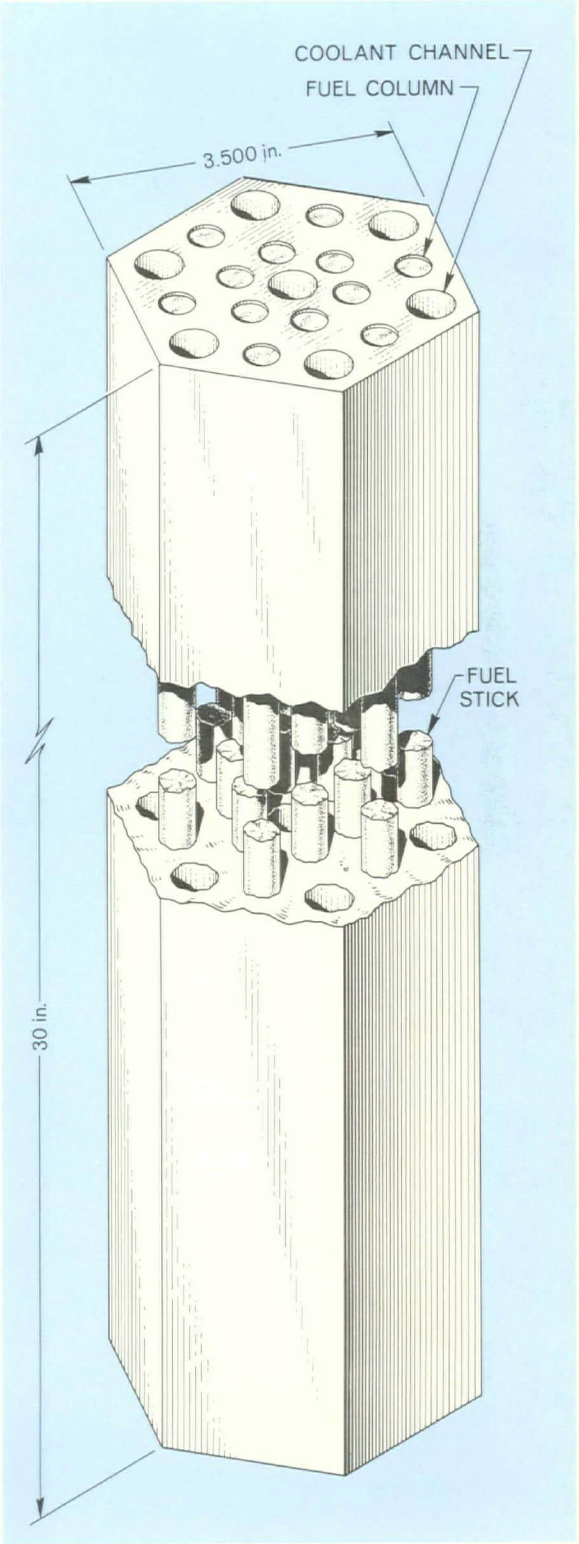




Polished sections of bonded fuel sticks show the various layers of the fuel particles and the cracks that appear in them. The top photomicrograph shows how cracks originating in the matrix as a result of severe shrinkage of the resin-base bonding material during carbonization propagate through two-layer coatings. In the middle photograph the addition of nonbonding and sacrificial layers prevents cracking of the base coatings. The bottom photograph, taken with polarized light, shows the thin nonbonding (bright) and sacrificial layers on particles used in a successful irradiation experiment.



The closely packed coated particles can be seen in this experimental HTGR fuel stick, broken and partially ejected from its graphite support tube.



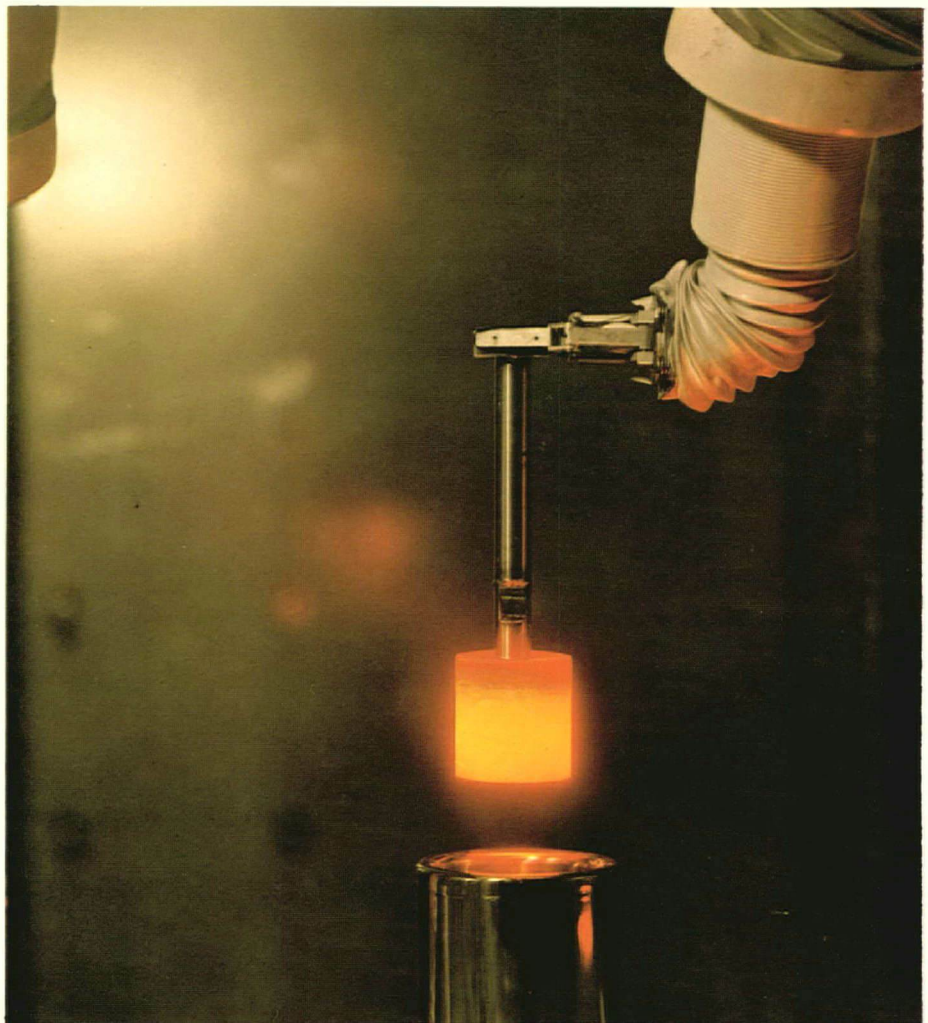
Fuel sticks are shown here loaded in the graphite matrix of the fuel element designed by Gulf General Atomic and specified for testing in the Peach Bottom Reactor.

ISOTOPES DEVELOPMENT CENTER

Isotopic Power

Research and development on the use of radioisotopes in devices to produce small amounts of electric power, for long periods of time, continue to be major activities of the Laboratory's Isotopes Development Center. Radioisotope fuel fabrication and encapsulation techniques were developed for an advanced-design thermoelectric generator, SNAP-21, for undersea applications. The first prototype model of this generator was fueled with 28,000 curies of $^{90}SrTiO_3$ and tested at ORNL.

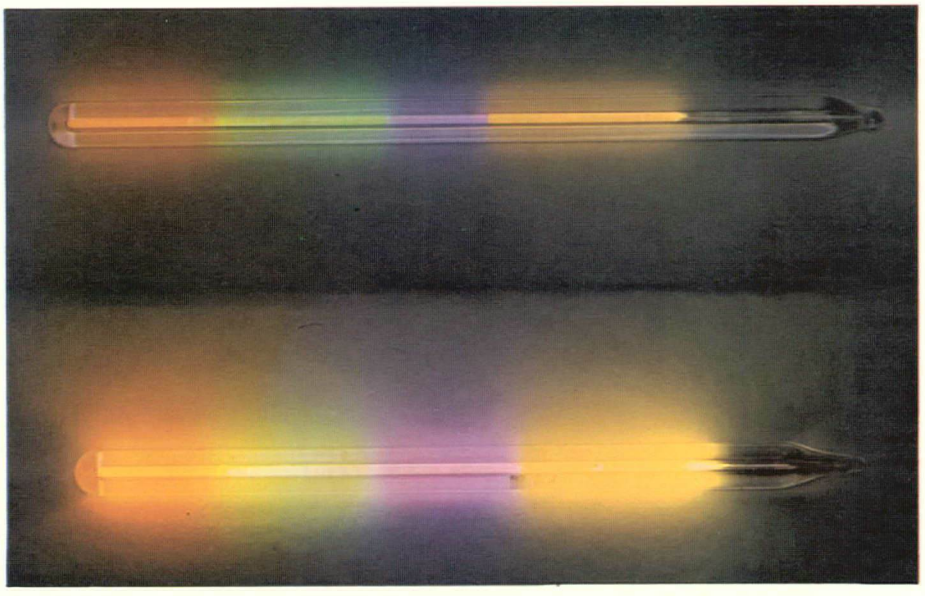
Work sponsored by the USAEC in this field of radioisotope applications has led to the manufacture and marketing of radioisotope power generators by private industry. During 1967, 160,000 curies of radioisotope fuel was prepared and encapsulated at ORNL for use in generators manufactured by domestic and foreign companies, and an additional 1,010,000 curies was on order by the beginning of the year 1968.



A prototype SNAP-21 source containing 28,000 curies of $^{90}SrTiO_3$ encapsulated in Hastelloy C.

Thermal-Diffusion Enrichment of Krypton-85

An experimental thermal-diffusion unit to investigate the technology and economics of enhancing the isotopic concentration of krypton-85 in fission-produced krypton was put into operation. Because of its comparatively low radiobiological hazard and its potential availability in very large quantities from power reactor fuel reprocessing operations, krypton-85 is an attractive radioisotope for use in beta gaging, in radiation-stimulated light sources, and as a tracer in gas systems. Operations of the experimental unit have been successful in increasing the isotopic abundance of krypton-85 from 3.6% to 28%.

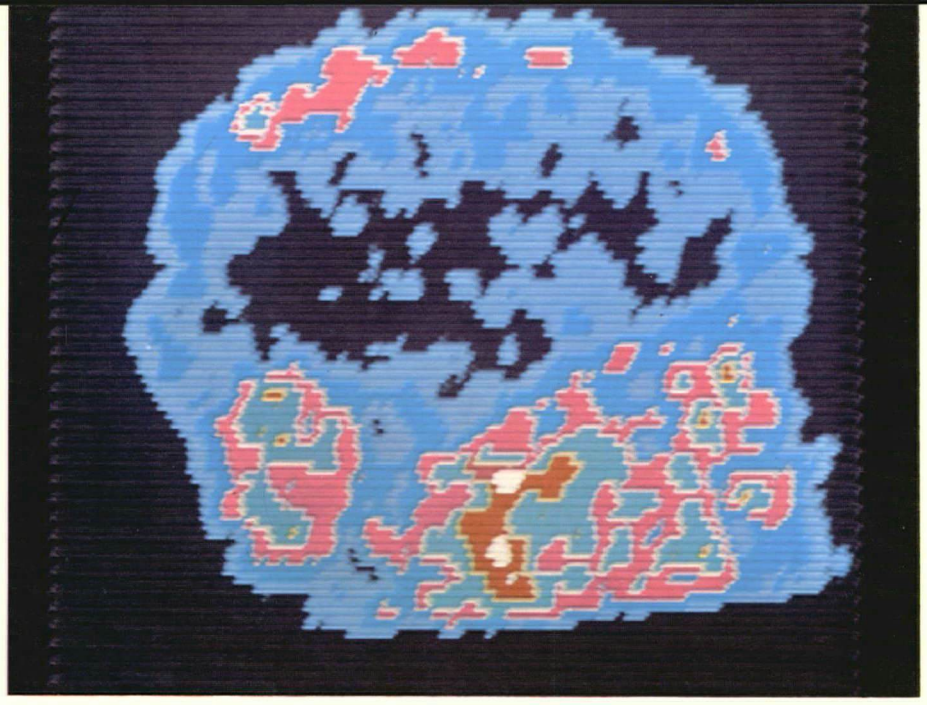


Krypton-85 stimulates emission by phosphors. The dimly lit ampul contains krypton with an isotopic abundance of 3.6% krypton-85. The brightly lit ampul contains krypton enriched approximately to 28%.

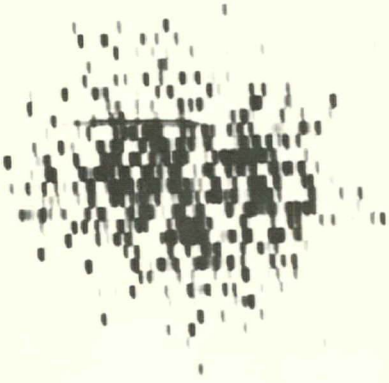
Radioisotopes for Medical Applications

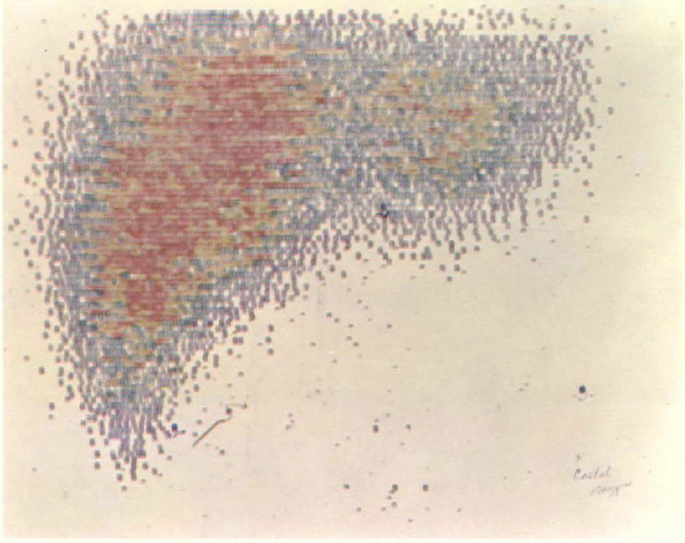
Oak Ridge National Laboratory prepares and supplies relatively uncommon radioisotopes that have properties desirable for specific medical applications. Medical researchers use these isotopes in cooperative programs to study the potential use of the radionuclides in clinical work, particularly diagnosis. Such a cooperative study was carried out with Walter Reed General Hospital. In this experiment, 14-h zinc-69*m* prepared at ORNL in the Oak Ridge Research Reactor was tested for take-up in tumor tissue in the prostate gland. A scan of the organ showing the radioactivity intensity reveals areas where radioactive material is deposited. If the take-up is quite selective in tumor tissue, it may prove to be an effective method for early detection of prostatic carcinoma. Zinc-69*m* is also useful for detecting abnormalities in liver tissue. Zinc-65 has been used for radioscanning the prostate glands of dogs and monkeys, but its relatively long half-life and high radiation energy make it undesirable for use in humans. The short half-life and lower radiation energy of zinc-69*m* produce a much lower internal radiation dose.

Rubidium-83 was produced at the Laboratory in the 86-Inch Cyclotron and supplied to medical investigators at the University of Utah College of Medicine for studying the metabolism of alkali metals (sodium, potassium, rubidium, and cesium) in children afflicted with muscular dystrophy.



The location of radionuclides in the body can be pinpointed by externally scanning the body with a suitable collimated radiation detector. Below is the first scan of a prostate gland in a human after administration of zinc-69*m*. The liver scan (bottom right) uses color to indicate the intensity of the radiation detected. The information from a brain scan (top right) has been electronically stored and displayed for analysis.





In this type of cooperative program, production variables and the medical benefits of a specific radionuclide are studied concurrently.

In a cooperative research effort with the Mayo Clinic, copper-67 is being used to compare the metabolism of copper in normal persons with that in patients with Wilson's disease. Copper-64 is generally used as a radioisotopic tracer of copper because it is easily produced from stable copper-63 by the (n,γ) reaction. In many applications, however, its usefulness is severely limited by its short half-life of 12.9 h. Copper-67, on the other hand, has a half-life about five times as long and is the longest-lived radioisotope of copper.

Iodine-123 was prepared by the proton bombardment of enriched tellurium-123 in the ORNL 86-Inch Cyclotron and supplied to a number of medical institutions for evaluation. One result of this effort was the first brain scan obtained with this isotope. Iodine-123 is more suitable for scanning than iodine-131 because of the lower internal radiation dose to the patient and better resolution of the 0.159-MeV gamma of iodine-123.

Research Materials

The custom fabrication of many kinds of materials, such as enriched separated stable isotopes, radioisotopes, and high-purity materials, into accelerator targets and other special forms continued to be one of the most rapidly growing services of the Laboratory's Isotopes Development Center. Very thin foils of uranium-233, uranium-235, uranium-236, uranium-238, plutonium-239, and plutonium-241 were prepared by cold rolling within stainless steel sandwiches. These foils were used in charged-particle interaction studies, cross-section measurements (fission chambers), filters, and other nuclear-physics applications. The minimum areal density achieved for each of these metals was 2.5 mg/cm^2 (0.00005-in. thickness). Since uranium and plutonium are extremely reactive, all cold-rolling operations were performed in a protective atmosphere of continuously purified argon.

Quantities of up to 25 g of high-purity titanium and zirconium isotopes were prepared by a modified van Arkel – de Boer purification process. These metals were used to show how isotopic abundance influences the temperature at which normal electrical conductivity changes to superconductivity. By extruding a wire of the chemically purified zirconium-92 and using this as the substrate filament, a crystal bar was grown and subsequently zone refined into a homogeneous bar of 99.9+% pure material for use in the experiment.

Targets for High-Energy, High-Flux Neutron Production

As part of Project HENRE, Oak Ridge National Laboratory designed and fabricated several unusually large tritium targets. In the experiment, a special deuteron accelerator, a target, and auxiliary equipment were mounted at various heights on a 1527-ft-high tower at the Nevada test site, so that distance from the neutron source to the material being studied could be varied. Targets formed the end closure of the deuteron accelerator and produced more than 10^{13} neutrons/sec by the $^3H(d,n)^4He$ reaction while under continuous bombardment for 4 h with a nonpulsed 400-mA beam of 150-keV deuterons. During this period the neutron yield decreased, but some of the targets could be used for two such periods; one target was used for three exposures, producing an average yield of more than 10^{12} neutrons/sec during the final 4-h bombardment.

Each target substrate consisted of a 40-lb copper plate with cooling-water channels. A recessed area 14 in. in diameter on the face of the target substrate was coated with a thin layer of chromium, a heavier layer of erbium metal, and a protective coating of cadmium. Individual metal deposits were formed by condensing vapors of the respective metals successively on the substrate. Approximately 2000 curies of the tritium gas needed for neutron production was sorbed into the erbium layer.

Electromagnetic Separation of Isotopes

For the first time, a beta-emitting radioisotope has been separated in the Oak Ridge National Laboratory electromagnetic isotope-separation facility. Radioactive samarium-151 with a half-life of 90 years is produced in uranium fission: The feed material for this first separation was isolated by repeated ion exchange from the rare-earth fraction that is precipitated during fission product recovery. An 8.15-g sample of samarium containing

approximately 4% samarium-151 was processed in the calutron and provided 0.055 g of 94.59% samarium-151. This enriched sample will be used in studying the Mössbauer effect.

Another rare earth, gadolinium-160, which has an abundance of 21.90% in natural gadolinium, has a relatively low thermal-neutron cross section and would be suitable for neutron diffraction studies if the high-cross-section isotopes gadolinium-155 and gadolinium-157 were removed. A second-pass calutron separation of 300 g of 97.1% gadolinium-160 provided two samples: 8.6 g of 99.99+% gadolinium-160 containing less than 15 ppm of gadolinium-155 and gadolinium-157 combined and 50.17 g of 99.98+% gadolinium-160 containing less than 45 ppm of gadolinium-155 and gadolinium-157.

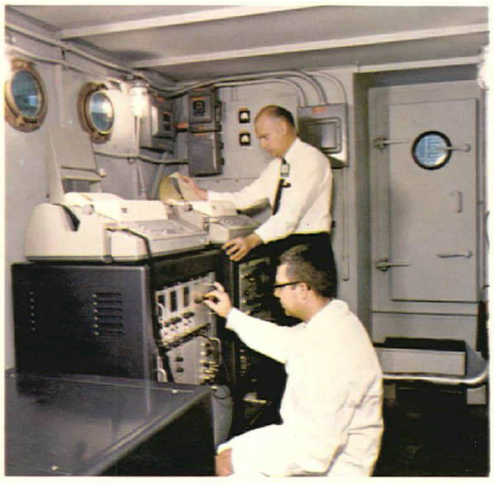
These two separations typify the Laboratory's potential for electromagnetically separating material of high isotopic purity for special uses.

Sand Transport Studies

Techniques and equipment have been developed at Oak Ridge National Laboratory for surveying the ocean floor and measuring littoral sediment transport. Three major tests of the system have been completed: one at Cape Kennedy, Florida, and two at Point Conception, California.

These studies tag sand indigenous to the test area with xenon-133 at high temperature and release the sand at a point in the ocean. Movement of the tagged sand is followed with cesium iodide detectors enclosed in a steel mesh sphere that is rolled along the ocean bottom. This ORNL survey system is towed through the release area behind a ship or an amphibious vehicle. Signals from the xenon-133-tagged sand are integrated with the position of the detectors and the vessel to produce maps showing sand movement over given time periods. The movements of the tagged sand parcel determine the direction and velocity of sediment transport. The results from this type of study are expected to provide basic information

The ORNL Underwater Survey System measures the diffusion of radioactively tagged sand moving on the ocean floor by means of shipboard instrumentation and an enclosed detector that is lowered over the side of an amphibious vehicle and rolled along the ocean bottom.



and engineering data that will be of economic importance in designing future marine structures to prevent disastrous erosion, for utilizing natural transport systems in a beneficial manner, and in determining maintenance requirements of artificial waterways before their construction.

Participants other than the AEC in this cooperative program include the U.S. Army Coastal Engineering Research Center; Los Angeles District, Corps of Engineers; U.S. Navy Pacific Missile Range; U.S. Air Force Western Test Range; U.S. Air Force First Strategic Aerospace Division; and the State of California.

Source Development

Encapsulated radiation sources must be safe and have accurately known energy characteristics before they can be used in process control or product inspection. A backscatter source using ruthenium-106 was developed at Oak Ridge National Laboratory for use in measuring eggshell strength. In this application the radioisotope was encapsulated to provide a highly collimated beam of 3.5-MeV radiation from the ruthenium-106 daughter. This source makes it possible to study the impact resistance of eggshells and to nondestructively determine the influence of various factors such as ambient temperature and humidity and hen's age, diet, and heredity on shell strength. Use of the device in research on egg production by the U.S. Department of Agriculture is expected to help reduce the national egg loss due to breakage, which amounted to $25 million in 1966.

Device for measuring eggshell strength. High-energy beta particles emitted from ruthenium-106 bombard a small area of eggshell, and a Geiger-Mueller tube determines the number of particles returned. The intensity of the backscattered particles increases as the shell thickness increases.

DESALINATION

Water Research Program

The Department of the Interior's Office of Saline Water, responsible for the Nation's program to produce fresh water from the sea and other briny sources, supports an extensive water research program at Oak Ridge National Laboratory. This effort has emphasized the study of the hyperfiltration process, which has shown much promise for removal of salts from water solutions.

In the Laboratory's hyperfiltration process, a thin membrane forms upon a porous support by deposition of special film-forming materials added to the solution passing over the support surface. Initial formation of the membrane requires a few hundred parts per million of such an additive, but subsequent maintenance of the membrane requires only a few parts per million in the feed. Most of the additives that have thus far yielded effective salt-rejecting membranes are substances that would be expected to form ion exchange layers. It should be possible to use the same dynamic methods to prepare neutral membranes analogous to cellulose acetate, but such membranes prove difficult to prepare. A new procedure, which met with some success in the past year, involves forming a membrane of a weakly ionized polyelectrolyte at an acidity that causes it to become charged and then changing the acidity to convert the film to the desired degree of neutral behavior. Particularly interesting films have been formed (though not always reproducibly) by this method with polyvinylpyridine. Salt rejection by a neutral membrane formed by this technique was frequently higher and not so dependent on concentration and composition of the feed. Although this is encouraging, for practical usefulness ways to raise the permeability will have to be found.

A bentonite–humic acid membrane filtered 77% of the neutral solute sucrose from a 5 wt % solution at a permeation rate of 17 gal day^{-1} ft^{-2} at 2000 psi. This rejection of organic solutes suggests that dynamically formed membranes may have applications in pollution control, and solutions generated in the washing of wood pulp after digestion in the sulfite process have been studied in hyperfiltration tests. It turned out that the waste forms its own membrane, and it is not necessary to put in an additive. With a fresh membrane, 94% of the solutes were rejected with a permeation rate of 230 gal day^{-1} ft^{-2} at 500 psi. Although the rate declined with time due to buildup of the membrane and residue, this result, along with the other observations, suggests that these membranes may be very useful in processing sulfite waste solutions when optimum conditions are found.

Since calcium salts precipitate from seawater at elevated temperatures and cause scale that interferes with the performance of seawater

Finned heat transfer surfaces designed at the Laboratory for use in desalination units considerably enhance the overall heat transfer coefficient. The original concept was a long cylinder with internal and external fins, as illustrated in the upper portion of the photograph. The achievement of maximum heat transfer within the limitations imposed by design practicability was the major criterion in choosing the initial configuration of the fins. A special flat heat transfer surface finned on both sides, as shown at the right, was used to study the effect of the fins, and the information gained from these studies formed the basis for the design and manufacture of the pilot-plant-scale brass surface shown at the lower left of the photograph.

distillation plants, measurements were made of the solubility of calcium sulfate and its hydrates in sea salt solutions to 200°C (392°F) and to salt concentrations about ten times those of normal seawater. The new data cover essentially the entire range of possible sea salt concentrations and temperatures that have been considered for desalting processes.

In the course of research on turbulence promotion and the boundary-layer phenomena that occur in distillation equipment, a spectacular increase in heat transfer occurred when longitudinal rectangular fins were loosely clamped to the outside and inside surfaces of vertical tubes. Twelve outside fins, 1/8 in. wide and 1/80 in. thick, were clamped to a 1/2-in.-OD vertical tube, and ten full-diameter fins were inserted in the interior. At a heat flux of 10^4 Btu hr^{-1} ft^{-2}, the overall heat transfer coefficient of the finned tube for condensation of steam by counterflowing subcooled water was approximately ten times that of the plain tube. The performance decreased with increase of heat flux, but even at a heat flux of 5×10^4 Btu hr^{-1} ft^{-2}, the overall heat transfer coefficient was four times that for a finless tube.

Nuclear Desalination Program

Studies performed under the AEC desalting program have confirmed the belief that reactors of very large size will produce power at lower unit costs. The evaporator design and development activities supported by the Office of Saline Water have consistently shown lower costs for large-size desalting plants also. Applying advanced technology, Oak Ridge National Laboratory designed a 250,000,000-gal/day nuclear desalting plant in which vertical evaporator tubes produce most of the distilled water and multistage flash evaporators distill some water while heating the incoming seawater. This reactor-powered plant would supply steam at 6¢ per 1,000,000 Btu and is estimated to produce distilled water at a cost of 12¢ per 1000 gal. The plant uses vertical tubes with fluted interior and exterior surfaces for good heat transfer. A pilot plant was built and tested at ORNL and moved to the OSW Test Station at Wrightsville Beach, North Carolina, where a subcontractor, Stearns-Roger Corporation, operates it for the Laboratory. In operation with seawater the five-effect vertical-tube evaporator has achieved the same high performance observed in the earlier tests. The pilot plant will be used to test other improved components and design features for performance and economy.

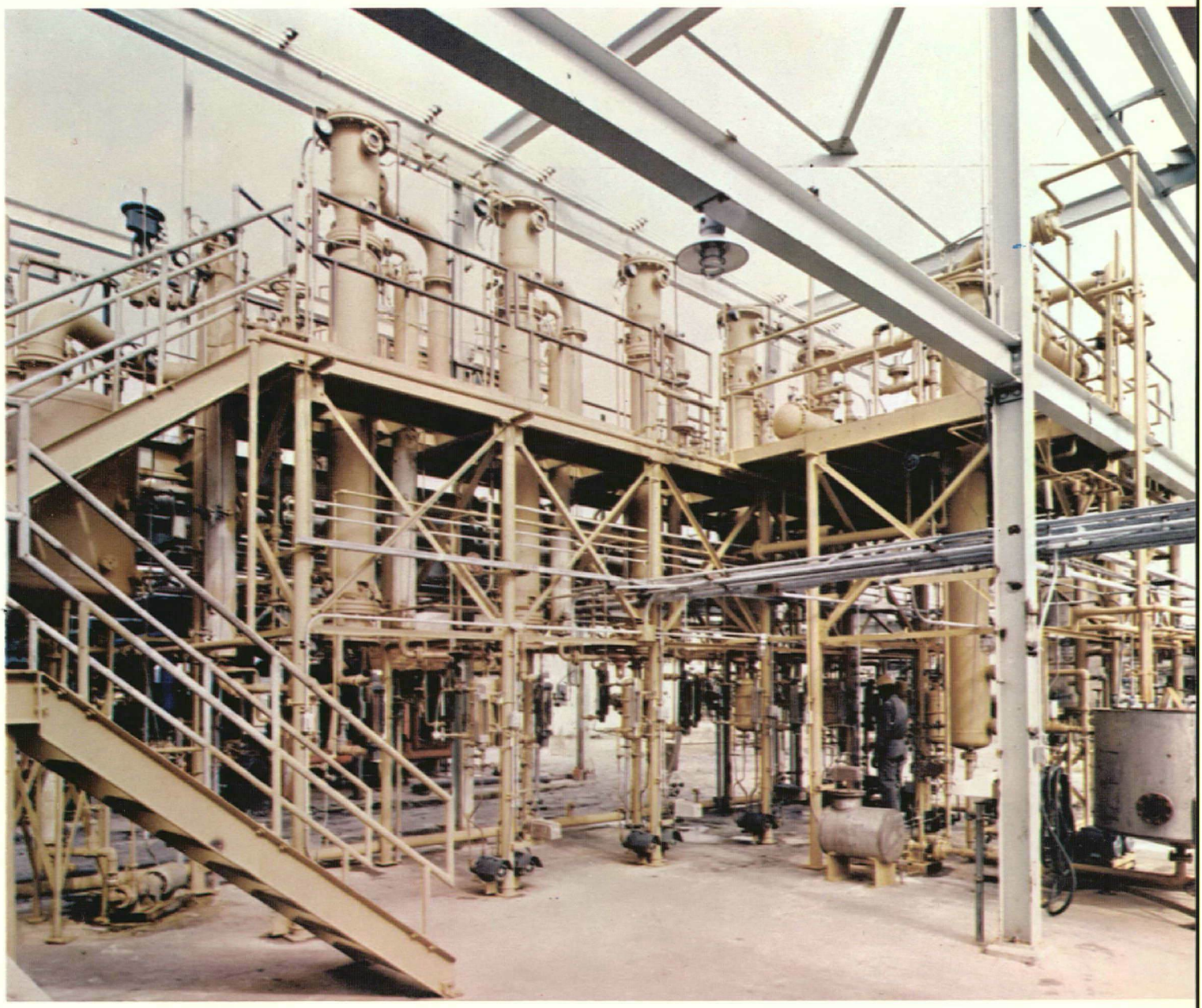
The comparatively low steam temperature required for a desalting plant suggests that a reactor operating at the lower temperatures typical of a sodium-cooled fast breeder might have some economic advantages when large quantities of power are not needed. Since thorium and uranium are not soluble or even subject to appreciable surface attack in oxygen-free sodium at these lower reactor temperatures, they could be employed as unclad metal fuels in a sodium coolant. Preliminary estimates indicate that if such an unclad metal fuel were developed successfully, fuel and fuel-cycle costs would be significantly reduced, breeding performance improved, and an economical heat source for nuclear desalination made available. Such sodium-cooled fast breeders or even large pressurized-water reactors might then produce low-cost steam that, after passing through turbogenerators to produce electric power, could run a desalting plant at costs as low as 5¢ per 1,000,000 Btu.

Agroindustrial Complexes

The futuristic idea of the agroindustrial complex centers around a large nuclear-powered dual-purpose plant that would produce water for intensive agriculture in a "food factory" and generate electricity and process heat for fertilizer plants and other industries located close by. Such complexes would be located on what are now barren coastal deserts primarily in the underdeveloped areas of the world.

To develop this concept more fully, Oak Ridge National Laboratory organized a summer study group of outstanding consultants to work with ORNL employees in considering all facets of the agroindustrial complex. Specific objectives were to evaluate the impact of low-cost electricity and process heat on the technology and economics of chemical and metallurgical industries and to evaluate the possibilities for use of desalted water for irrigation in an intensive agricultural production operation that would contribute to world food supplies.

The main conclusions were that a desalting plant capable of producing a billion gallons of fresh water daily could irrigate a 280,000-acre farm

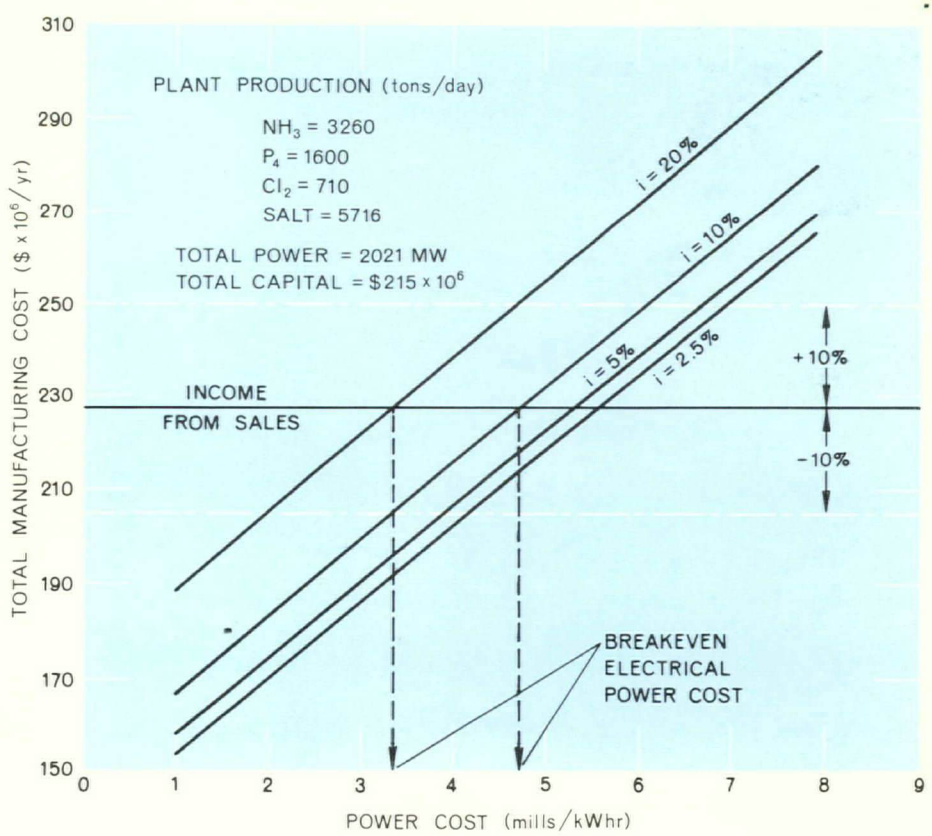


This five-effect vertical-tube evaporator pilot plant has been moved from ORNL to the OSW Test Station at Wrightsville Beach, North Carolina, where it is operating with seawater. Performance tests at higher operating temperatures, up to 325°F, are planned, as well as further tests of the performance of various types of vertical tubes.

that could, growing crops the year round, feed more than 5,000,000 people. Furthermore, the agricultural and industrial products of this food factory could be produced at costs competitive with today's world prices. For example, importing only phosphorus or phosphate rock, the complex could extract nitrogen from the air, obtain hydrogen and oxygen by electrolysis of water, and make ammonia and ammonium nitrate, which could be combined with phosphates in a variety of fertilizers at economically attractive costs. The studies showed that the plant could produce far more fertilizer than the food factory would need, and the surplus, used in conventional agriculture, could increase food production in other parts of the country to feed additional millions of people.

To operate the farm and to staff the industrial enterprises, a work force of about 9000 workers would be required. These employees, their families, and the people needed to supply supporting goods and services would make up a city of 60,000 or more, and the sociological problems of assembling and training these people were recognized but not assessed in this study.

Optimism for the development of nuclear-powered agroindustrial centers is based largely on (1) reduction in unit energy costs as nuclear reactors are made larger, (2) continued technological achievements in the reduction in unit costs of large-scale evaporator plants, and (3) reduction in water requirements with improved crop strains so that less than 200 gal/day used in farms operated the year round could provide sufficient food for a man. With all these advances, the agroindustrial complex could produce a high-calorie crop mix that would provide more than minimum protein requirements in a diet of 2500 Cal/day for a daily operating cost of



In developing countries, private investors often require an annual return of 20% on their investment. The estimated costs included in the graph show that industrial production operations based on high energy consumption can provide a 20% return annually if power costs are low enough—in these cases below 3.3 mills/kWh. The estimated annual returns are based on current world prices for these particular products.

only 3 or 4¢ per person fed. Although the initial capital investment would amount to about $160 per person, the initial study indicated that the whole agroindustrial complex might generate a sufficient return on investment to be attractive as a private enterprise.

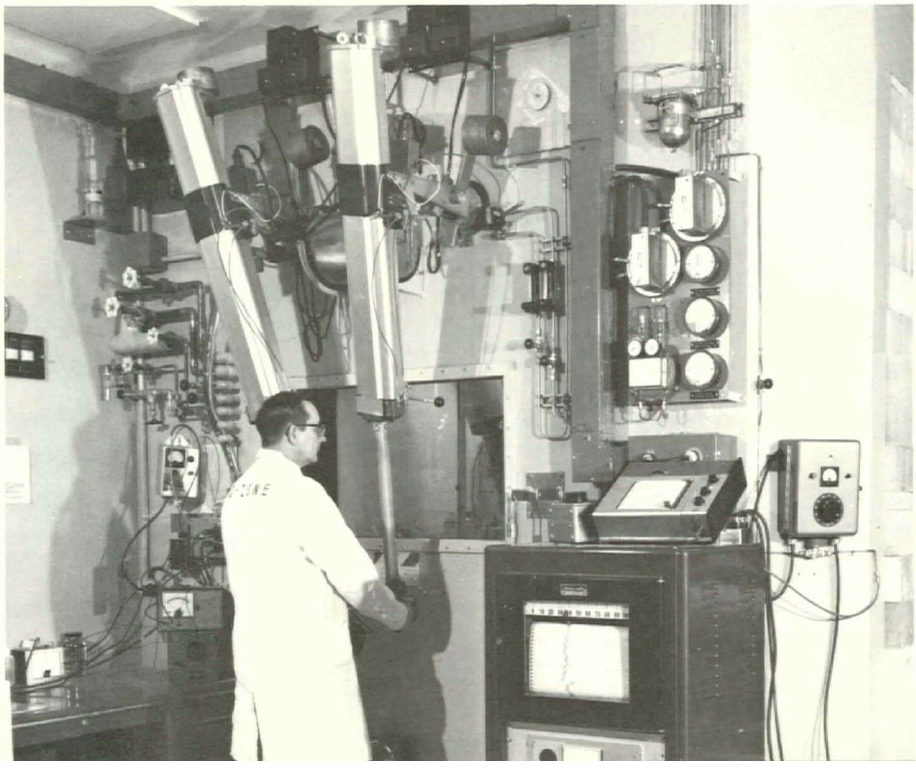
An agroindustrial complex uses low-cost electricity produced by a nuclear power plant to supply energy for desalination and industrial processes. Water from a desalting plant irrigates crops that are cultivated the year round. Such a complex produces food for several million people by intensive agricultural practices, which yield much more per acre per year than can be achieved even with advanced technology and equipment under less-controlled conditions.

The components of the agrcindustrial complex in the accompanying drawing are (1) reactors, (2) turbines, (3) evaporators, (4) seawater treatment ponds, (5) caustic chlorine plant, (6) electrolytic hydrogen plant, (7) aluminum smelting plant, (8) ammonia plant, (9) aluminum fabrication plant, (10) alumina plant, (11) railroad yards, (12) solar salt works, (13) bitterns pond, (14) food factory, (15) food export dock, (16) electric-furnace phosphorus plant, (17) phosphorus raw materials import–salt export dock, (18) chlorine, sodium hydroxide, ammonia, and aluminum dock, (19) bauxite import.

PRODUCTION OF TRANSURANIUM ELEMENTS

The High Flux Isotope Reactor (HFIR) and the Transuranium Processing Plant (TRU) have been in full-scale operation for a little more than a year. Already they have significantly increased the supply of several of the transplutonium isotopes, and these quantities have subsequently been used in various research programs. The Transuranium Element Program has been under way since 1959, when the irradiation of 10-kg quantities of plutonium-239 was started in Savannah River reactors to prepare a supply of heavier isotopes as target material for the HFIR. Since then, the HFIR has been built to irradiate these target materials at neutron fluxes up to 5×10^{15}, and the TRU has been built to fabricate targets for the HFIR and to isolate the heavy transplutonium elements from irradiated HFIR targets. The material produced in these facilities during the past year is just the beginning of the increased availability of transplutonium elements for research.

The products from main-line processing in the TRU were 85 g of plutonium-242, 37 g of americium-243, 143 g of curium-244, 500 μg of berkelium-249, 6 mg of californium-252, and 8 μg of einsteinium-253. These were recovered from 10 target rods of plutonium-242 irradiated in the reactors at Savannah River and from 17 other rods irradiated at Savannah River and then in the HFIR. The americium-243, berkelium-249, and einsteinium-253 products routinely have an isotopic purity greater than 99.8%. In addition to the main-line processing, a number of important special separations have been made. Aged californium product has been processed by ion exchange to yield a few micrograms of isotopically pure einsteinium-



Shielded facilities are required for handling purified californium product from irradiated HFIR targets. The small hot cell shown is shielded with 2 ft of concrete to attenuate the gamma rays and neutrons emitted from up to 0.5 mg of californium-252. Because of the high toxicity of the transplutonium elements, a sealed liner is also installed inside the cell to provide absolute containment of the californium. Californium product was reprocessed in this cell to isolate curium-248 and einsteinium-253, which are daughter products of californium isotopes.

Irradiated targets are transported in this 50-ton carrier from the HFIR to the TRU. The carrier is on a loading platform at the TRU with the HFIR building in the background. The carrier holds three targets such as the one being displayed by the technician, and its concrete shielding was designed to protect personnel from fast neutrons emitted from amounts of californium-252 of up to 1 g (2.4×10^{12} neutrons/sec).

253 and nearly 150 μg of 35 to 60% isotopically pure curium-248. The berkelium-249 product, which decays with a 290-day half-life by beta emission to californium-249, was stored for several months and then reprocessed by ion exchange to isolate 55 μg of californium-249. And plutonium-242 containing about 0.5% plutonium-244 has been processed with electromagnetic isotope separators to isolate 20 mg of 50 to 75% isotopically pure plutonium-244.

The transuranium products of the HFIR are divided primarily among Oak Ridge National Laboratory, Lawrence Radiation Laboratory at Berkeley, Lawrence Radiation Laboratory at Livermore, Argonne National Laboratory, and Los Alamos Scientific Laboratory. Scientists at Lawrence Radiation Laboratory have bombarded some of the einsteinium product with high-energy alpha particles to produce enough mendelevium-256 and mendelevium-258 for the first investigation of the solution chemistry of this element; mendelevium-258 is one of the heaviest isotopes ever produced. Scientists at the Los Alamos Scientific Laboratory have bombarded some of the plutonium-244 product with high-energy alpha particles to produce new heavier isotopes of americium. The 55 μg of californium-249 was specifically prepared for heavy-ion bombardment at Lawrence Radiation Laboratory at Berkeley to create new elements.

As the HFIR-TRU complex continues to function, large quantities of these and other transplutonium isotopes, prepared by special irradiation and processing, will become available, stimulating research and leading to an increased knowledge of the heavy elements.

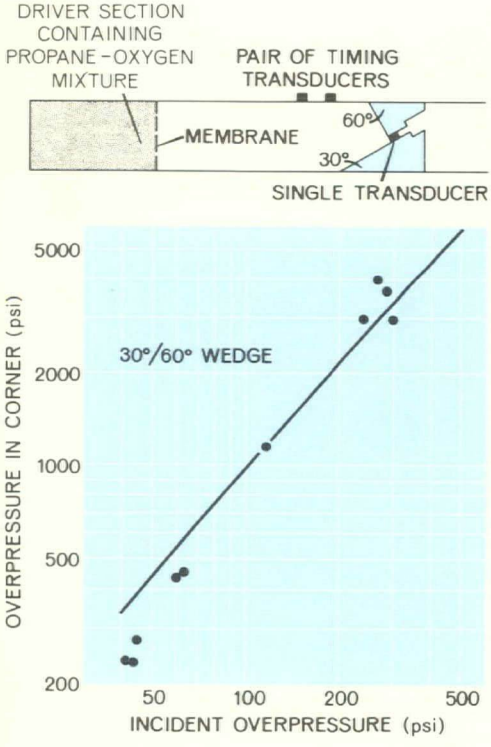
CIVIL DEFENSE RESEARCH

Shock-Tube Research

Providing blast protection for urban populations is one of the most important problems of civil defense and has been under study at Oak Ridge National Laboratory for the past several years. One of the concepts around which thought has centered is that of underground grids of interconnected tunnels. The shock waves produced by nuclear explosions need to be kept out of these tunnels, for example, by air locks or blast doors. Since blast doors and air locks are expensive and deny continuous access to the tunnels, finding other ways of protecting the interiors of long open tunnels from shock waves is desirable. Baffling the tunnel entrances with orifice plates or staggered segmental baffles is an effective way of doing this, as recent experiments carried out in a 4-in. shock tube have shown.

In these experiments, one part of the shock tube served as a "gun" to produce shock waves, while the rest acted as a scale model of the shelter tunnel. Detonation of an explosive mixture of propane and oxygen confined in one end of the shock tube created the shock waves, which propagated down the tube and struck the baffles. The experiments showed that, whereas strong shocks falling on open empty shelter tunnels propagate for miles before becoming harmless, the same shocks are attenuated to harmless levels in a few hundred feet when the tunnels are baffled.

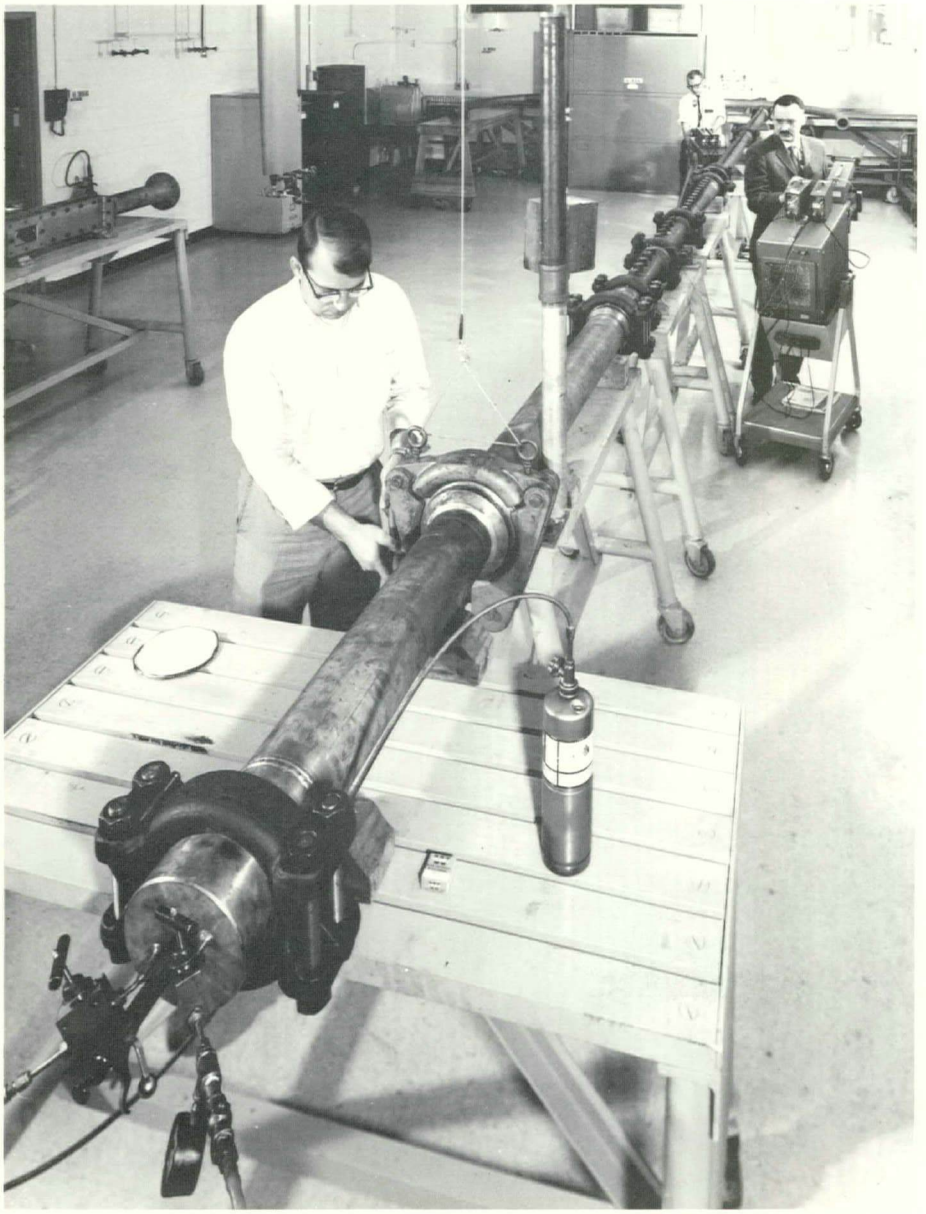
The shock waves produced in the shock tube have been used for other experiments besides those described above. In one such experiment, the attenuation of shock waves by close-packed arrays of cylindrical obstacles was studied. In another, the peak overpressure at the vertex of a reentrant right angle was measured as a function of the overpressure of the incident shock wave and its direction of incidence. Here, the experiment verified the great pressure amplification expected from theory.



Peak overpressure in the corner of a right-angle wedge is seen as a function of incident overpressure. The points are experimental, the line theoretical.

Defense-Policy Attitudes Among the American People

The survey data bank on national public opinions established by the Oak Ridge National Laboratory Civil Defense Research Project is recognized by many social scientists as the most comprehensive data collection of its kind in the United States. Consisting of more than 120 national-sample polls taken from 1945 to 1966, this data bank for the first time allows an analysis of the opinions of successive generations of the American public. This is done by a technique known as cohort analysis, a research method that measures generational groups at several points in time. Each generation grows up in a different environment influenced by the interaction of traditional beliefs and new events. Cohort analysis can separate the as-



The 4-in. shock tube can produce overpressures up to about 450 psi with explosive yields up to 100 g of TNT. With these overpressures and yields, it is possible to model the exposure of an 8-ft tunnel shelter to the shock waves from megaton-size explosions.

pects of human attitudes that are affected by aging from those aspects resulting from environmental influences specific for that generation.

Preliminary attitudinal analyses have focused on three distinct generational cohorts: the World War I, the Depression, and the Nuclear Era cohorts (so named because each group was approximately 21 years old during the beginning of these dramatic periods). Analysis of the attitudes of these three generations toward four foreign and national security policies shows that successive generations are becoming more aware of international crises and are attaching more importance to problems of foreign policy in general. There are concomitant generational increases in support for both foreign-aid policies and governmental policies that aim at extending American strategic resources to other parts of the world (both on bilateral and multilateral bases).

Linking such attitudinal trends to the processes of generational succession will help forecast future American attitude patterns.

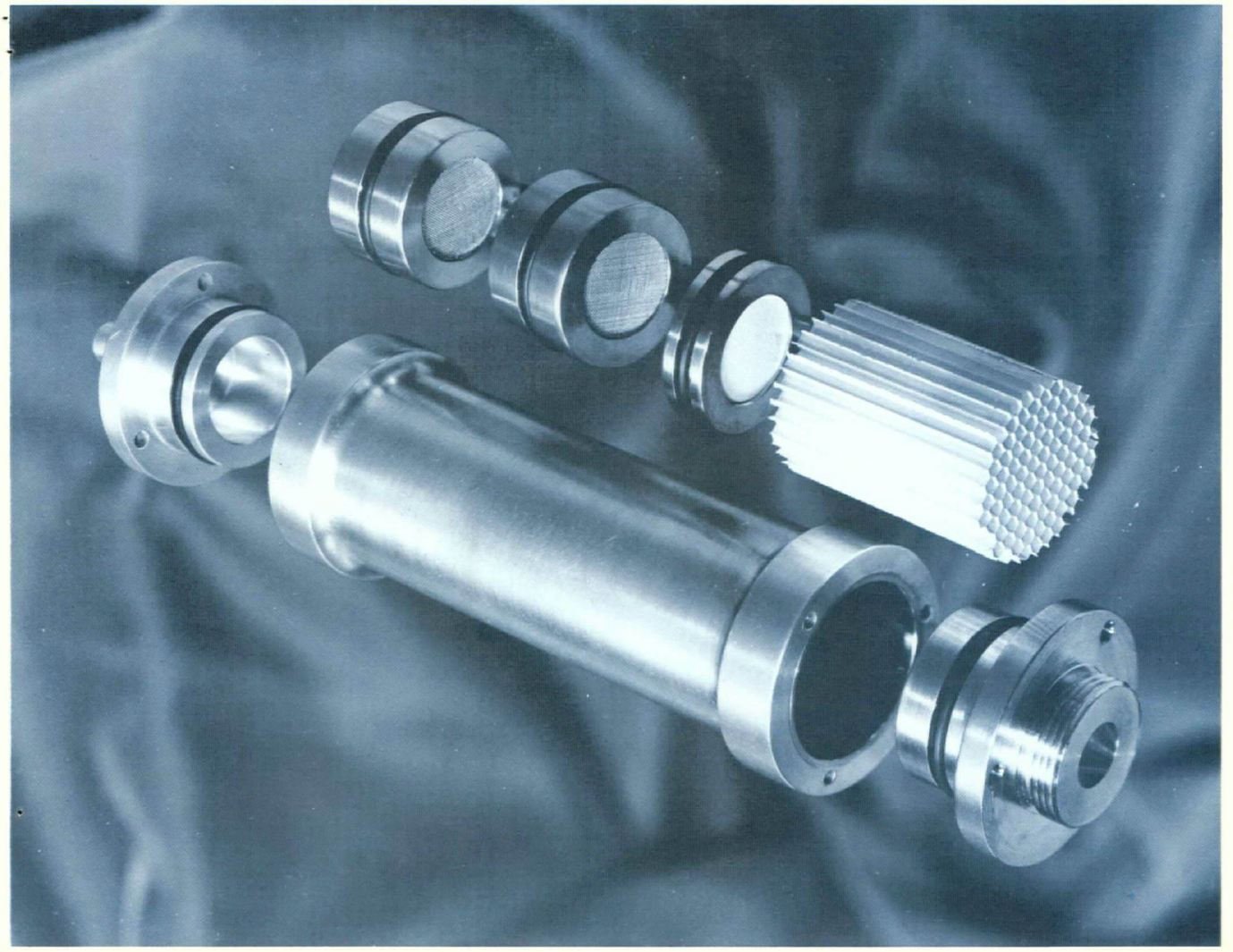
NUCLEAR SAFETY

Characterization of Accident-Released Fission Products

In a major reactor accident some fraction of the fission products in the fuel may be released. Furthermore, these elements may react with each other, with the fuel-element materials, or with the accident environment, so that the number of possible combinations of the chemical and physical forms in which the activity may appear is staggering. Fortunately, at the temperatures that exist beyond the immediate vicinity of the fuel, the noble gases, volatiles such as iodine, and nonvolatile activity associated with particulates are the only fission product species transported in significant quantity. Definitive information on the forms of iodine and on the size distribution of solid aerosols is an essential prerequisite to predicting, with confidence, their behavior toward engineering safeguards such as filter-adsorber systems and containment sprays. Consequently, Oak Ridge National Laboratory has been developing analytical samplers to measure the chemical form of radioiodine and the particle size of solid aerosols released in model containment structures.

A new ORNL sampler for iodine, the so-called "honeycomb sampler," has a silver-plated aluminum honeycomb, high-efficiency filters, and charcoal traps arranged in series in a compact, relatively inexpensive package. As molecules of elemental iodine pass through the channels of the honeycomb, they are removed, as a consequence of their large diffusivity, by reaction with the silver surface. Aerosol particles have a much smaller diffusivity and therefore contact the silver surfaces less efficiently. The aerosol particles consequently pass through the honeycomb to be collected on the high-efficiency filters. Less reactive compounds of iodine, such as organic iodides, pass through both the honeycomb and the filters and are collected in the sections containing impregnated charcoal. Additional high-efficiency filters are included after the second charcoal bed to trap any eluted charcoal dust.

Improved cascade impactor samplers separate aerosols into size groups by utilizing the process of inertial impaction. This technique is normally limited to particles of a size larger than about 0.2 μ. But particles of this size, and smaller, are of interest in containment experiments, so an impactor model has been developed to operate at subatmospheric pressure and to characterize aerosol particles down to 0.001 μ.



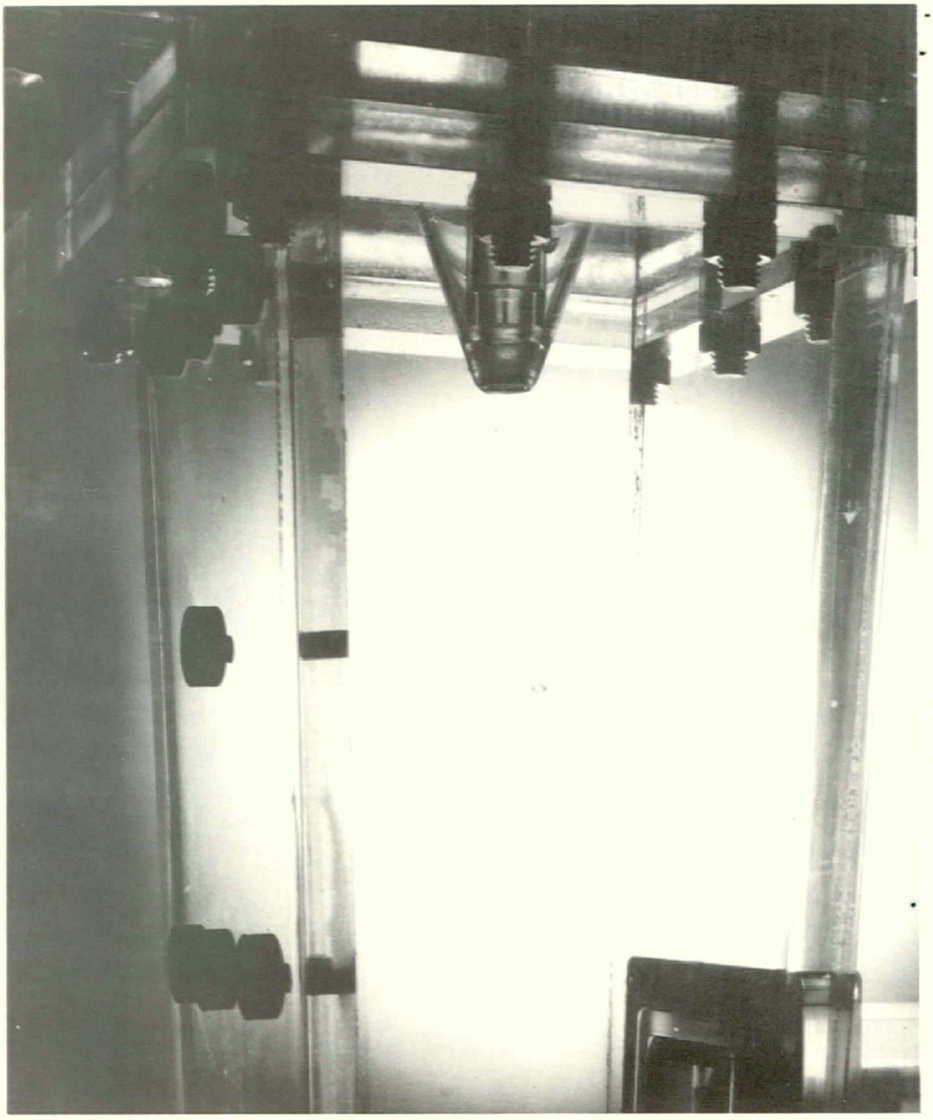
The "honeycomb sampler" has been developed at the Laboratory to characterize the chemical forms of radioiodine. In the photograph are shown the major collecting components of the sampler: the silver-plated honeycomb, a high-efficiency filter, the charcoal trap, and another charcoal trap with a high-efficiency filter incorporated into it at its downstream side.

Use of Aqueous Sprays on Fission Product Aerosols

The most likely accident visualized for water-cooled reactors, a failure of the primary pressure vessel, would result in the large-scale release of fission products and steam to the reactor containment building. In existing commercial reactors the pressure thus produced in the containment building would be reduced to near-preaccident values with an aqueous spray, thereby removing the driving force that could expel fission products into the environment. Although this pressure reduction by the use of sprays is now an accepted safety feature, the possibility of simultaneously removing contaminants from the building atmosphere has not yet gained wide acceptance.

It would be desirable to have the spray remove elemental iodine and organic iodides. However, while chemicals such as sodium hydroxide and sodium thiosulfate show very high removal efficiencies for elemental iodine, with removal half-times of the order of 1 min for typical geometries, organic iodides are removed less effectively. The Laboratory has undertaken an experimental program that includes laboratory screening of potentially promising solutions by determination of the mass transfer coef-

Since the effectiveness of a spray in removing contaminants from the atmosphere depends upon the properties of the individual droplets that comprise the spray, the behavior of individual drops was studied under closely controlled conditions. Here, single drops of solution are held in suspension in a wind tunnel by the upward flow of air, while their effectiveness in removing fission product iodine from the air is determined. The influences of pH, additive, concentration, relative humidity of the tunnel gas, light intensity, temperature, etc., are being explored in these experiments. Methyl iodide, formed from traces of various organic materials present in ordinary air, is an important radioactive iodine species, so the first study with the tunnel was of the uptake of methyl iodide by single drops of water and solutions of sodium thiosulfate. In the absence of light, the uptake of methyl iodide by the solution hardly occurs at all, suggesting that a surface photolysis of the methyl iodide is the primary step of the mass-transport process. This photolysis forms neutral iodine atoms, which are subsequently reduced by reaction with sodium thiosulfate within the drop.



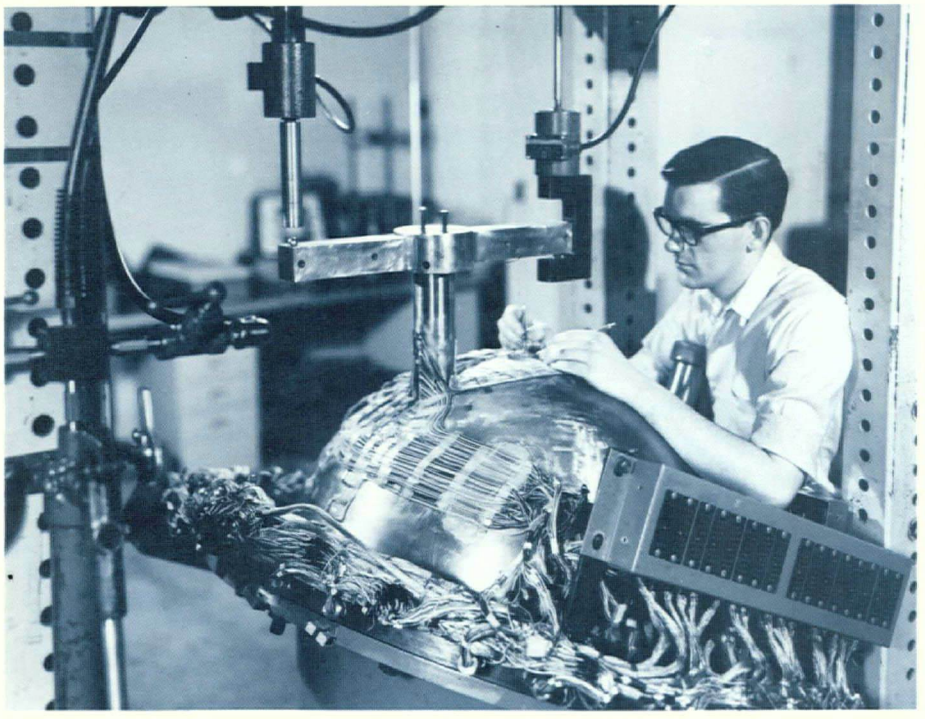
ficients of single drops suspended in a contaminated air stream; by measurements of the chemical, thermal, and radiation stability of the solutions; and by engineering tests of spray cleanup in large-scale facilities. While the removal times for iodine and even methyl iodide appear acceptable with a number of solutions, the expected radiation exposure (10^8 rads) will produce up to 1 mole of H_2 per mole of solution by radiolytic decomposition of water. Thus an optimum solution not only must remove I and CH_3I effectively, but also must meet many other stringent requirements.

Nuclear Pressure Vessels and Piping Systems

As the walls of pressure vessels become thicker (approaching 12 in.), we must explore new areas of metallurgy and engineering mechanics in order to better predict the performance of reactor vessels in commercial power plants. Furthermore, many nuclear piping system components, such as elbows, tees, valve bodies, and pump casings, have never been adequately stress analyzed. So the Laboratory has undertaken an exhaustive experi-

mental and theoretical research program to help improve the codes and standards governing the design and construction of nuclear power plants. During the past year, significant new work has been added to this effort, such as the development of stress charts and improved analytical methods for standards used in the design of such piping components.

In all this work, the Laboratory is cooperating with the Pressure Vessel Research Committee of the Welding Research Council, with various code-writing committees of the American Society of Mechanical Engineers and of the United States of America Standards Institute, with domestic and foreign universities, and with other research centers.



The primary pressure vessels of present-generation and future nuclear-reactor power plants contain numerous penetrations, which are potential locations for the development of high stresses. The Laboratory is sponsoring experimental and theoretical studies of the stresses in such regions at universities in the Southeast. Both steel and plastic models are extensively fitted with strain gages and loaded with internal pressure, as well as with external forces that duplicate conditions found in applications. Data obtained from these studies are used to develop safety criteria and improved analytical design techniques. The model shown here, under investigation at the University of Tennessee, is an oblique nozzle penetration in a hemispherical shell, which is typical of the design of pressure-vessel heads. Strain gages to provide data for stress analysis are seen placed at important points on the nozzle and the shell.

Prestressed Concrete Reactor Vessels

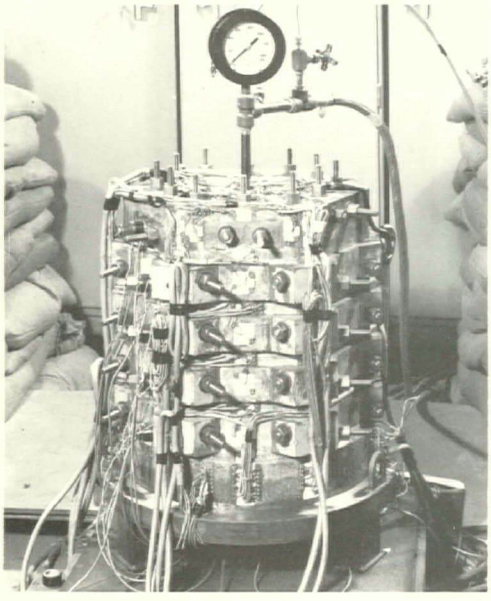
The Laboratory is studying the usefulness of small models of concrete vessels made of mortar or elastic material such as epoxy as part of a basic research and development program in support of the technology of prestressed concrete pressure vessels for nuclear-reactor applications. These models might be used, for example, to investigate the elastic-stress distributions, as well as the modes of cracking and ultimate failure, of pre-

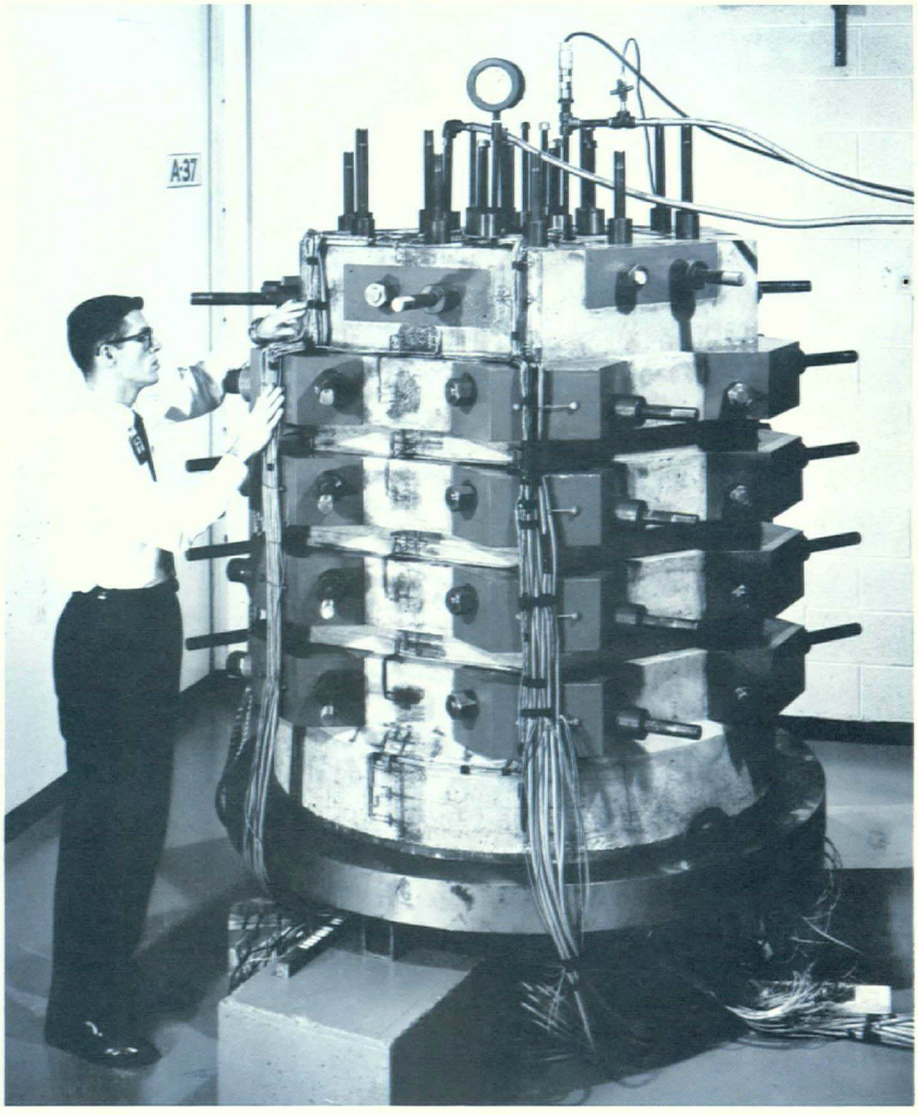
Prestressed concrete pressure vessels are receiving increasing attention for use with large power reactors. In the past, large, expensive structural models have been required to verify the predicted behavior of concrete vessels. Since small mortar models and small elastic models have gained acceptance in most other areas of structural concrete research, the Laboratory is investigating the use of such models for evaluating prestressed concrete vessels. A small concrete prototype, approximately one-tenth the size of an actual reactor vessel, and two models of the prototype are being utilized. The first model of the prototype is a 1/2.75-scale mortar model, and the second is a 1/5-scale prestressed epoxy model. The usefulness of the models is being established by comparing pressure-test results from the models with results from the prototype and with analytical predictions.

stressed concrete reactor vessels or of various components of concrete vessels such as the penetration and anchor regions.

A relatively small concrete prototype vessel, representing the top half of a cylindrical vessel with flat heads designed for an internal pressure of 500 psi, was tested hydraulically to failure. Two 1/2.75-scale mortar models of the prototype vessel were then tested to failure, the first pneumatically and the second hydraulically. A 1/5-scale prestressed epoxy model of the prototype has also been studied using electrical strain gages as well as three-dimensional photoelastic stress analysis with scattered light. The concrete prototype and the two mortar models were extensively instrumented with strain gages and tendon load transducers.

The behavior exhibited by the two mortar models was in excellent agreement with that of the prototype vessel. The mode of cracking and even the number and location of these cracks were essentially the same in models and prototype. In each case significant leakage from the structure began at a pressure equal to approximately twice the design pressure. The behavior of the two mortar models indicated that failure, whether caused by pneumatic pressure or hydraulic pressure, is gradual and not cata-

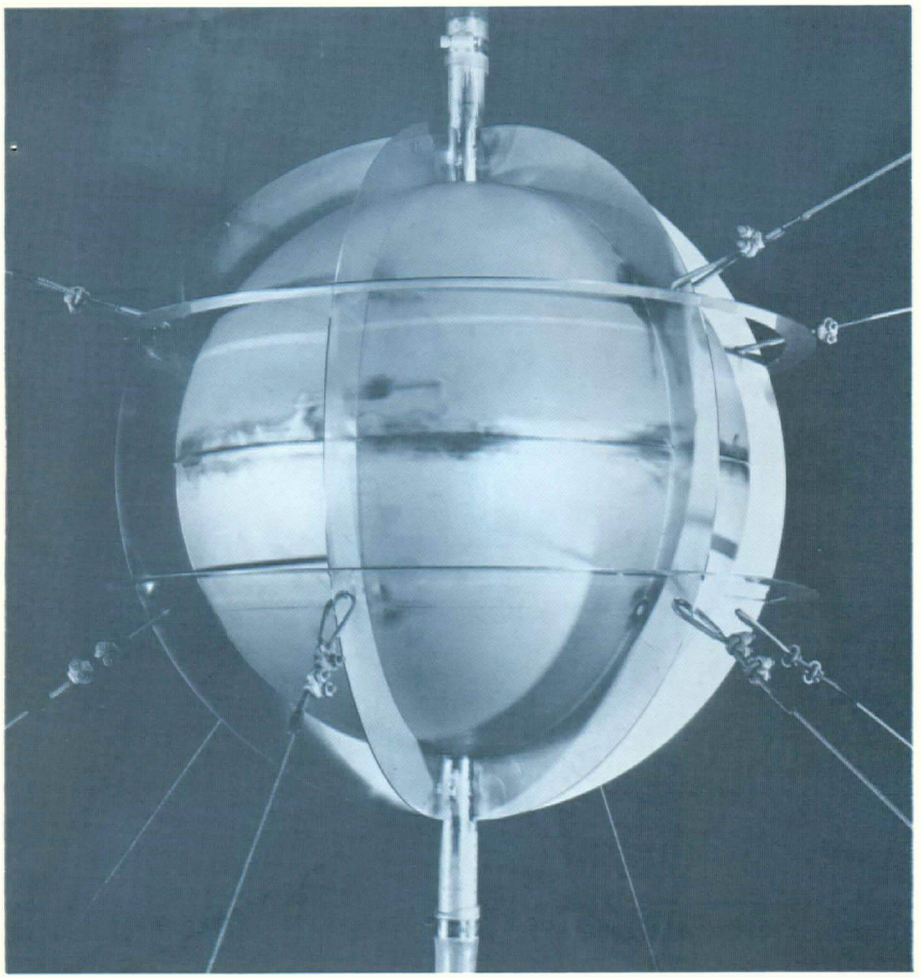




strophic in any sense of the word. Furthermore, analytical predictions of the behavior of the models were in good agreement with the experimental results, particularly in the elastic range. These predictions were based on the finite-element method of structural analysis, in which the structure is considered to be an assemblage of simple individual components or elements, interconnected at a finite number of nodal points. Such close agreement between prediction and experiment points up the effectiveness of this simplified method of analysis even for complex structures.

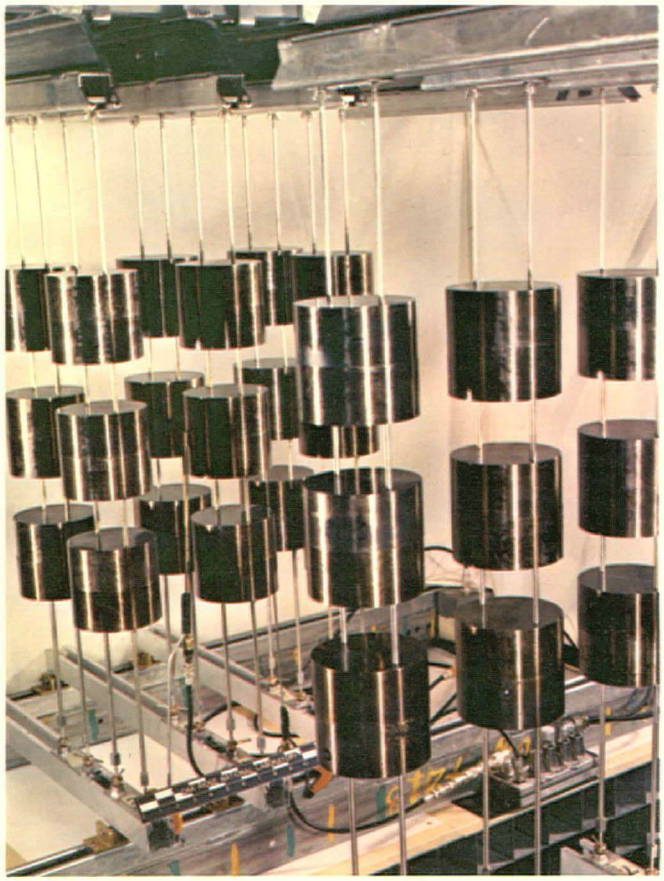
Nuclear Criticality Safety

Since 1946 the staff of the Oak Ridge Critical Experiments Facility has been determining values of the parameters of uranium enriched in uranium-235 and of uranium-233 necessary to establish neutron-chain-reacting conditions. These critical dimensions establish bases for specification of safe conditions for storage, transportation, and chemical and metallurgical processing of fissile materials. Most studies are made with common substances in simple geometry in order to yield data of general applicability. However, these measurements are supplemented, as required, with studies having more direct application to specific problems. The results are germane to specific nuclear criticality safety problems and, in addition, serve as background information for authenticating analytical and calculational methods describing neutron chain reactions.



Unusual measures were taken to perform a precise critical experiment with an aqueous solution of a salt of enriched uranium-235 in a single spherical vessel. Neutron reflection was reduced by using stainless steel only 0.5 mm thick in the vessel, by establishing the spherical form with thin circular bands mounted so that they displayed minimum area to the solution, and by suspending the sphere from cables. The UO_2F_2 solution contained in the 50.8-cm-ID sphere was critical at 19°C. The chemical concentration at this temperature was 910.18 g of uranium per liter; the uranium-235 content of the uranium was 4.98%. The small reactivity contribution by the container wall, the supporting members, and the column of solution in the filling connection was only 16.8 cents.

A critical array of 125 plastic cylinders containing uranium highly enriched in uranium-235 in aqueous solution was used in a study of the neutron interaction between subcritical units. The salt was $UO_2(NO_3)_2$ at a concentration of 415 g of uranium per liter and with a uranium-235 enrichment of 92.6%. The 5.0-liter containers were of a methacrylate plastic 0.64 cm thick and were of almost equal height and diameter. The array shown, without reflector, was critical when the separation between nearest surfaces in all three directions was 14.4 cm. Generalization of the resultant data provided guidance in the problem of storing fissile material.



Many studies have been carried out to determine safe conditions for handling fissile material in metallic form. In this experiment, twenty-seven 20.9-kg cylindrical masses of metallic uranium enriched to 93.2% in uranium-235, 11.5 cm in diameter and 10.8 cm high, were found to be critical without neutron moderator or reflector when their surfaces were separated 6.4 cm.

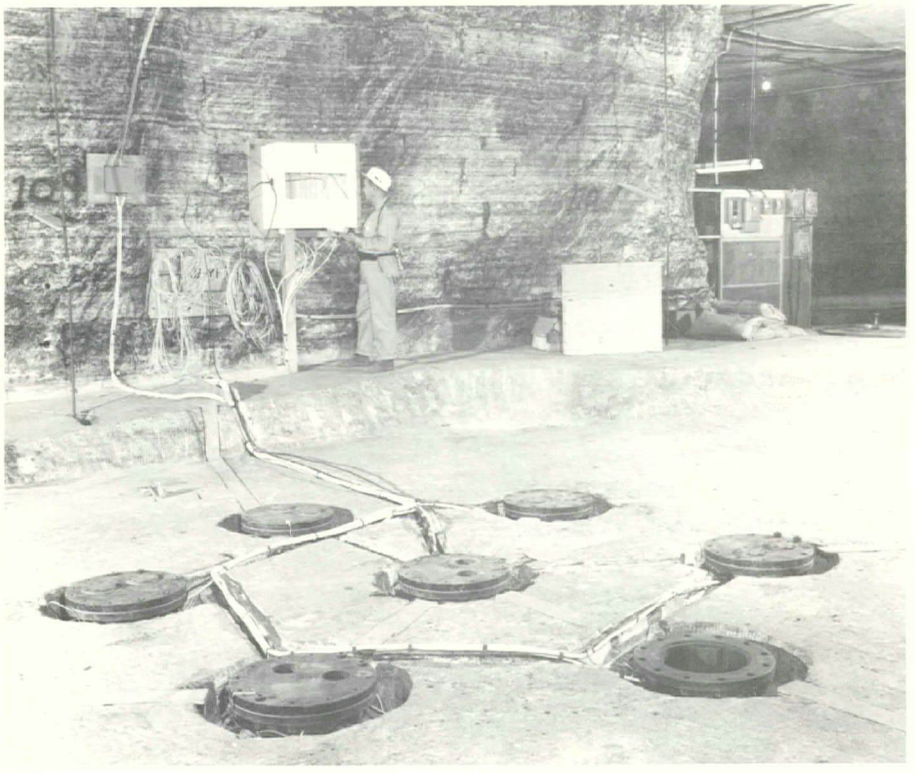
Initially the program emphasized simple measurements of single units such as slabs, individual cylinders, and spheres of both solutions and metallic uranium. These were extended to experiments with critical arrays of individually subcritical units of greater complexity. Analyses of such experiments by Monte Carlo calculations have advanced the application of statistical methods for describing the behavior of neutrons in complex arrays of fissile materials.

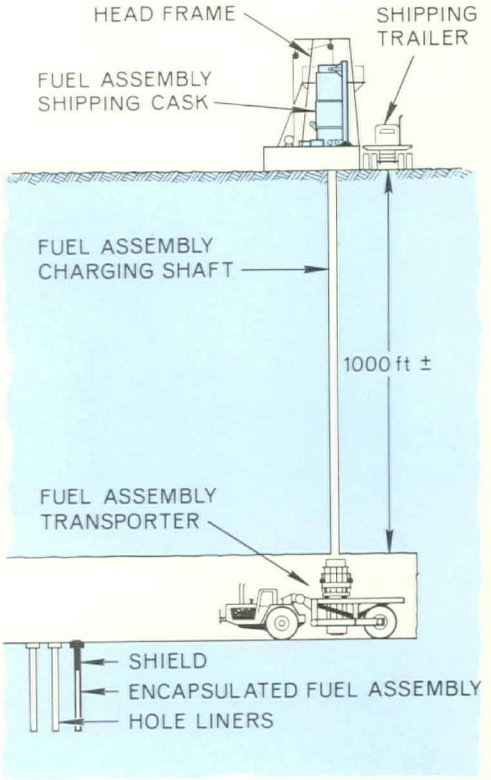
High-Level Waste Treatment and Disposal

The high-level radioactive wastes obtained as liquid residues from processing spent power-reactor fuels are extremely hazardous and must be isolated from man's environment. During the past few years Oak Ridge National Laboratory has developed a process to solidify these wastes by calcination in stainless steel pots. The pots would be sealed by welding and stored in a remote location, such as an abandoned salt mine. During the past year a cooperative program between ORNL and Battelle-Northwest Laboratory demonstrated the technical feasibility of the high-level waste-

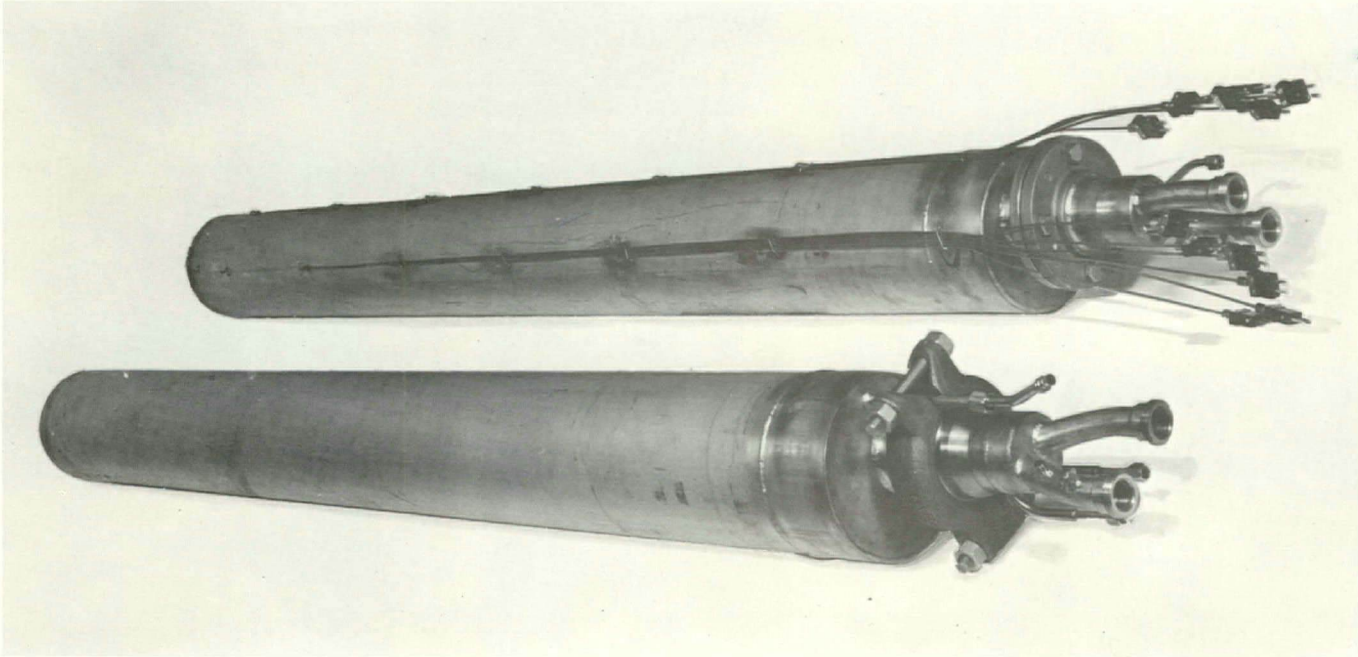
calcination process by solidifying wastes containing nearly 4,000,000 curies of radioactivity. Gaseous and liquid effluents from the process were so low in activity that they required little or no additional decontamination before release to the environment. One test converted an amount of waste equivalent to that from processing 1.2 tons of spent fuel and containing 1,300,000 curies of radioactivity to solids, sealing them in a pot 8 in. in diameter by 8 ft long. The 5100 W produced by radioactive decay resulted in a maximum internal temperature of 940°C when this pot was held in air. This demonstration processed more radioactivity than any other single known waste solidification experiment in the world. The tests showed that a single line of calcination equipment can handle the waste from the processing of about 1 ton of uranium per day; this is adequate to serve about 7000 MW of nuclear electrical capacity. Additional tests are planned to further establish operational reliability, safety, and economics.

The Laboratory successfully completed its study of the use of salt mines for the disposal of highly radioactive solid wastes during the past year. During the demonstration (November 1965 to June 1967), three sets of 14 irradiated ETR fuel assemblies in seven canisters, containing a total of about 4,000,000 curies of radioactivity, were stored for periods of six months each in holes in the mine floor. One measure of the success of the demonstration was that the highest dose received by any operator during the handling of these highly radioactive sources without benefit of hot-cell facilities was 200 mR to the hands. Radiation and heat from the radioactive material did not affect the salt in any way that compromised good mining practice. The seven holes in the floor of the main storage area are shown, together with the associated equipment for monitoring radiation doses, temperatures, and off-gases in the salt surrounding the array. A nearby identical room, with electrical heaters rather than radioactive material in the storage holes, was used as the control to identify and measure the effects of heat alone. These rooms were approximately 1000 ft below land surface.





In Project Salt Vault, simulated high-level-waste canisters were transferred from the shipping cask, which was at the surface, 1000 ft down into the mine and then into storage holes in the mine floor. These operations were carried out without hot cells.



This stainless steel pot for calcining and storing radioactive wastes is 8 in. in diameter by 8 ft long and has 1/2-in.-thick walls. After the pot was filled, the liquid-addition and gas-removal pipes and the thermocouples (at right) were removed and replaced with a stainless steel plate, which was welded to the top of the pot.

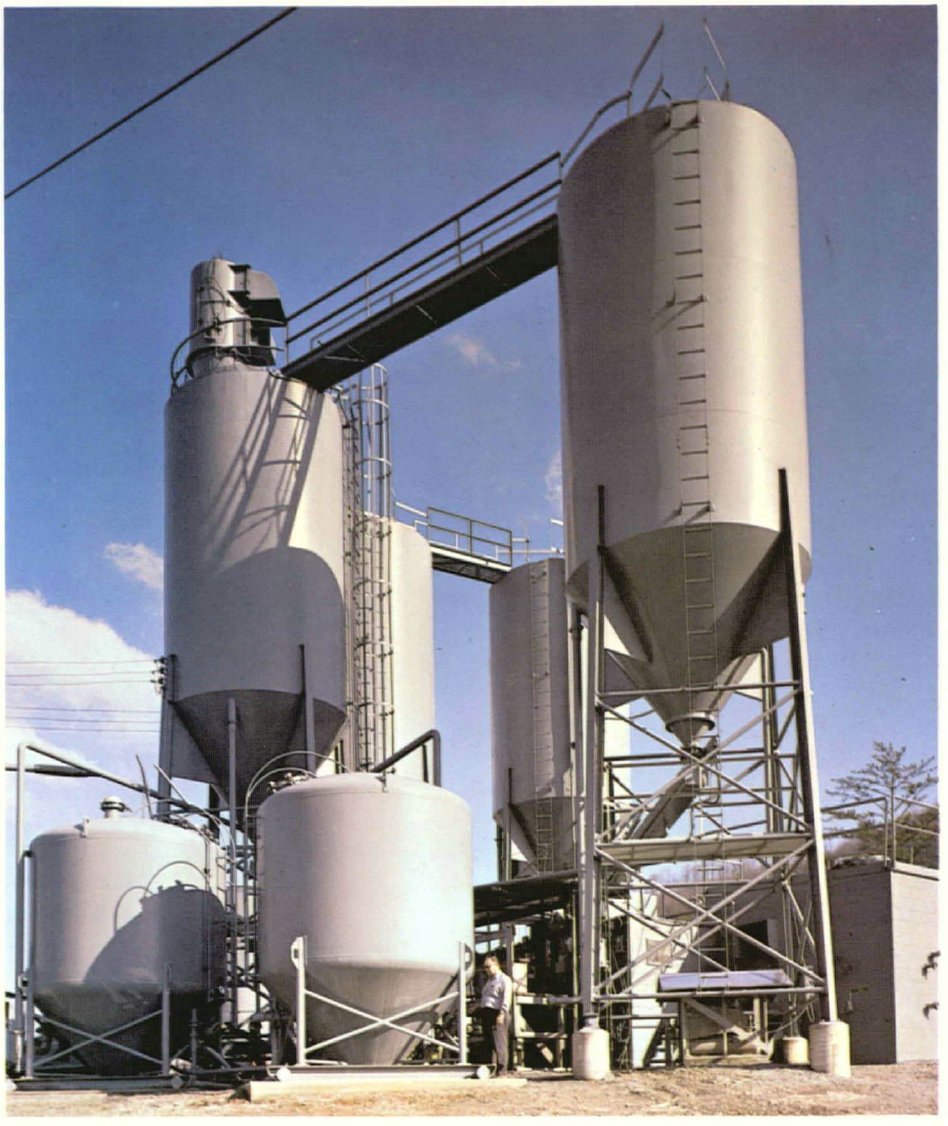
Incorporation of Intermediate-Level Wastes in Asphalt and Polyethylene

Oak Ridge National Laboratory is developing a process for concentrating and safely incorporating intermediate-level radioactive waste in asphalt or polyethylene. The solid that is produced effectively holds all radioactivity as a dispersion of dry solids in an asphalt or polyethylene matrix. Wastes are introduced into emulsified asphalt or polyethylene at any convenient temperature below the boiling point of the solution, and the aqueous or organic solvent is volatilized by heating. On reaching a temperature of about 160°C, the asphalt- or polyethylene-treated waste flows freely and solidifies on cooling in a suitable container. With aqueous waste, a purified stream of water is produced that is safe for disposal to the earth or to a river; with organic wastes, a purified stream of organic solvent is produced that may be reused in a processing plant. In both processes, noncondensable gases would be filtered to remove radioactive particles, and the gas would be discharged through a stack to the air. Burial or storage of the solidified waste in a concrete vault prevents the reentry of the hazardous radionuclides into man's environment.

The asphalt-treated wastes are extremely insoluble in water, and the leaching rate of the radioactive materials is very low. No increase in leaching rates, swelling, or evolution of gas from the asphalt was observed over a one-year period with material containing up to 52 curies of mixed fission products per gallon and at absorbed doses of 7×10^7 rads.

The use of polyethylene instead of asphalt is a recent development that shows significant potential for increasing the safety of radioactive waste management. Polyethylene has several advantages in that it is less susceptible to radiation damage, can accommodate organic as well as aqueous residues, and is less flammable than asphalt. Furthermore, the cost of polyethylene is comparable with that of asphalt when it is used in large quantities.

Other Activities



The Shale Fracturing Waste Disposal Plant completed its first year as an operating facility for disposal of all intermediate-level liquid waste generated at ORNL. A total of 293,000 gal of waste, containing 110,000 curies of activity, was permanently disposed of, using the process developed at ORNL. This process consists in mixing the waste with cement, fly ash, and clays and injecting the grout, under high pressure, into horizontal fractures 900 ft below ground surface.

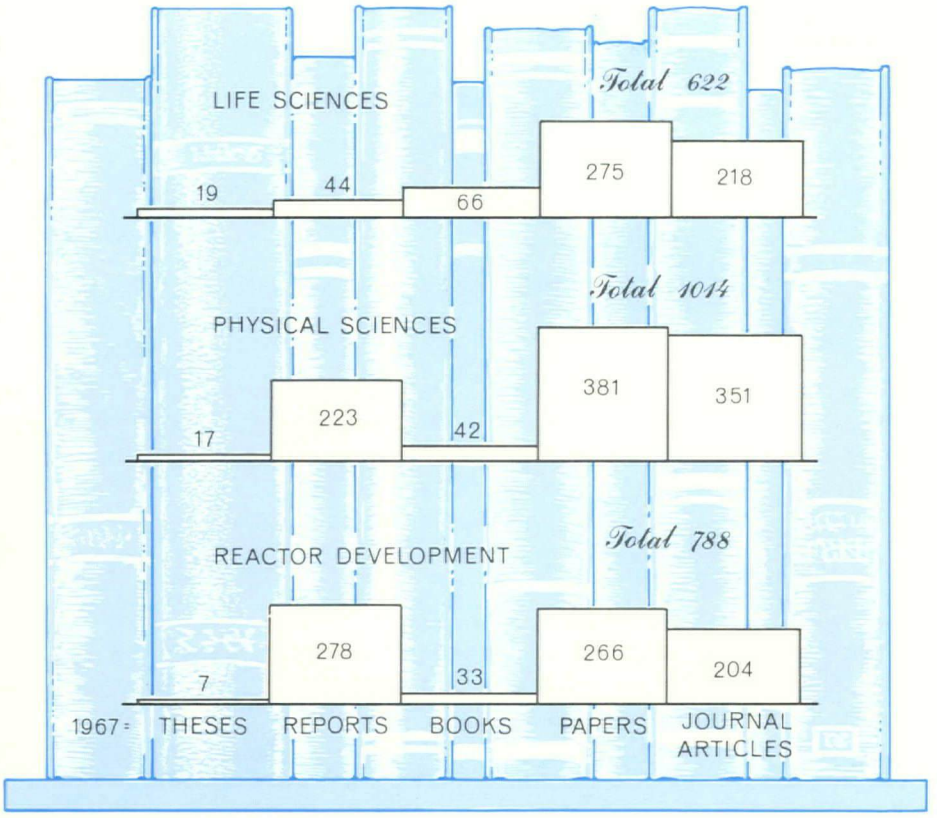
The photograph shows the two small tanks used for blending solids, the four large solid storage tanks, and the concrete cell that houses the wellhead.

TECHNICAL INFORMATION

The information tasks of the Laboratory fall into two categories: supplying the informational needs of the scientists working at the Laboratory to support them in their research, and then disseminating the knowledge that has been gained by this research. The first responsibility is primarily that of the libraries. According to statistics, the amount of periodical literature collected by the libraries is doubling every eight years. In order to maintain a sufficiently good collection of the literature and still keep the manpower expended in doing so within reasonable boundaries, the libraries have turned more and more to the use of computers in performing clerical functions. The ORNL book circulation control system has been converted to run on the faster, more economical data-processing machines now available, and there are now 12,000 volumes that can be readily processed in the mechanized circulation system. This constitutes only the libraries' acquisitions for the past four years, but it represents more than 70% of the libraries' book circulation.

The other half of the Laboratory's informational responsibilities, that of disseminating the knowledge gained from government-supported research, has continued to grow in the past year. A total of 1502 contributions to the open literature were published by Laboratory personnel during 1967. In addition, the Laboratory initiated publication of a new journal, the *Oak Ridge National Laboratory Review*, to give the scientific staff an opportunity to comment on the impact of the technology they are creating. In addition to the printed literature, participants from ORNL contributed heavily to the scientific meetings of leading professional societies. The Laboratory itself sponsored a number of significant meetings, such as the Eleventh Conference on Analytical Chemistry in Nuclear Technology, the Second International Conference on Cell Synchrony, the Sixth Rare Earth Research Conference, and the International Conference on Plasma Confined in Open-Ended Geometry.

The ORNL Central Research Library has acquired *Nuclear Science Abstracts* and *Chemical Abstracts* in microfilm cartridge form. With the associated equipment shown here, this allows anyone to quickly locate and, if necessary, reproduce any desired section of these publications. It is strongly felt that this method of storing and retrieving periodical literature will be extended to other journals in the future.



Now in its eighth year, the report ORNL-3300 annually lists the publications, reports, and papers generated at Oak Ridge National Laboratory. For 1967 it reported more contributions to the general body of scientific knowledge by ORNL personnel than in any previous year.

INDUSTRIAL COOPERATION

The Office of Industrial Cooperation, with the Analytical Chemistry Division, sponsored the Analytical Chemistry Instrument Demonstration Conference on October 16–17, 1967. This conference featured a group of ten outstanding instruments developed during the past few years, and these were individually demonstrated. This was the latest in a series of meetings organized to call attention to specific developments made by the Laboratory that are of particular interest to industry.

The Office of Industrial Cooperation served as host to more than 1500 industrial visitors who came to the Laboratory for technical discussions with various individual members of the Laboratory staff. In addition to technical information frequently supplied by direct communication, there were 58 technical news releases during the year. Finally, the Office of Industrial Cooperation acted as liaison for the Laboratory staff in providing consulting services to industry, including assistance in designing radioisotope sources and associated shielding, class instruction of customer personnel in the proper maintenance of master-slave manipulators, and aid in designing the ion source for a particle accelerator.

UT-OAK RIDGE GRADUATE SCHOOL OF BIOMEDICAL SCIENCES

The first class of the University of Tennessee–Oak Ridge Graduate School of Biomedical Sciences entered a formal program in September 1967. A small group of students from widely distributed parts of the United States is involved in this first venture of formal graduate education totally within a national laboratory.

The school is housed in rented quarters within the Biology Division of Oak Ridge National Laboratory. These accommodations consist of administrative offices, a student project laboratory, and student offices where privacy for study is assured. In addition to an informal class seminar room, a student lounge is available for relaxation, post-lecture discussions, and informal gatherings between Division members and the student body. A special building for graduate students, in close proximity to the Biology Division, is expected to be a reality by 1970.

The staff of the Biomedical Graduate School consists of three full-time faculty members; they are assisted by shared members of the Biology Division of the Laboratory, who make up the majority of the faculty and staff. This is in response to the concern expressed by various leading administrators, scientists, and educators that the talents of the staffs of large federal research establishments were not being used to the maximum possible degree in scientific education. The inauguration of the Biomedical Graduate School is the expression of a major and first effort to undertake such a mission.

The school's curriculum is designed to take advantage of the broad interdisciplinary talents of the total life sciences activities at Oak Ridge National Laboratory. In addition to the fields of cellular, molecular, genetic, and developmental biology, some of the broader national problems in both research and application, such as aging, bioengineering, and various aspects of carcinogenesis, will be emphasized in this new graduate school.

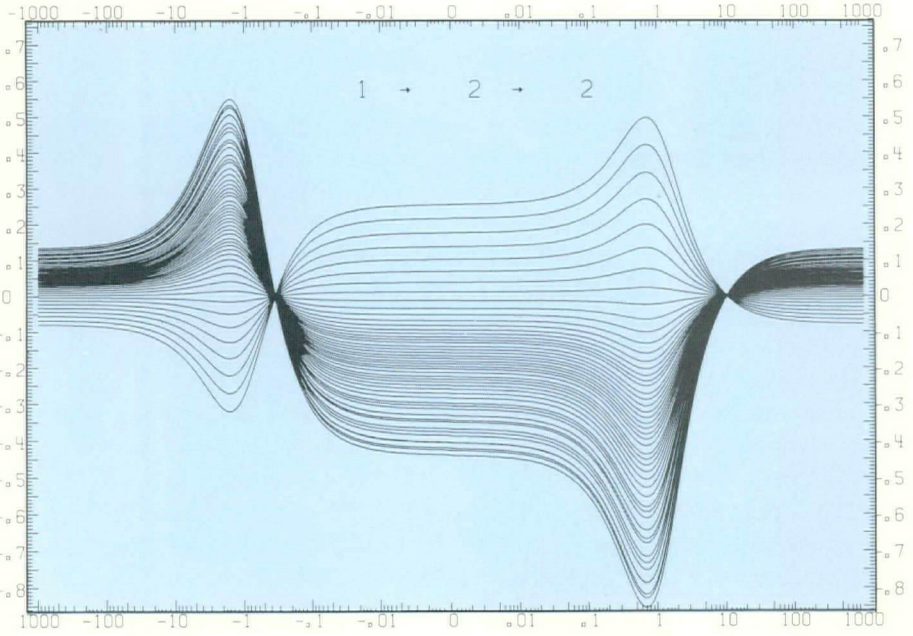
The University of Tennessee–Oak Ridge Graduate School of Biomedical Sciences draws upon the talent available within the Laboratory's staff for its instructors, making more effective use of the staff members' accumulated knowledge and allowing a more dynamic turnover of information from one generation of researchers to another.

INFORMATION CENTERS

During the past year, the *Nuclear Desalination Information Center* became operational, with abstracts and bibliographic information from several hundred articles stored on magnetic tape for a computer-based retrieval system. The Center published the results of a survey of United States technical groups that use computers for the design of distillation equipment for desalting processes and produced an abstracting and indexing guide for Desalination Project staff members, to be used by the Office of Saline Water and its contractors in preparing reports.

The *Nuclear Data Project* has completed the first phase of its conversion to a computer-based system with the machine storage and compilation of the Key Words and Numbers section of Recent References. The ultimate objective is to transfer all reference-type projects to automatic handling in order to speed up the publication of data, to make publication more economical, and to provide extra services in information retrieval. The computerization is primarily intended for the automatic organization of a continuous input of data in order to facilitate the use of the Nuclear Data Sheets.

The *Radiation Shielding Information Center* cosponsored a seminar-workshop with the Union Carbide Corporation Computing Technology Center August 14–16, 1967, to review the state of the art of the discrete



The Nuclear Data Group collates the massive amount of information generated by worldwide research on nuclear properties and publishes its findings in the journal *Nuclear Data*. To aid in predicting these properties, the Group has prepared several computer programs to graphically display the trends that the properties follow. Shown here are the predicted values of coefficients for an angular correlation function for the spin sequence $1 \rightarrow 2 \rightarrow 2$.

INFORMATION CENTERS AT OAK RIDGE NATIONAL LABORATORY

INFORMATION CENTER	DIRECTOR	SERVICES AND PUBLICATIONS
Accelerator Information Center	F. T. Howard	Inquiries and references
Atomic and Molecular Processes Information Center	C. F. Barnett	Inquiries, literature searches, state-of-the-art reports, and data compilations
Charged-Particle Cross Section Information Center	F. K. McGowan	Inquiries, literature searches, state-of-the-art reports, and data compilations
Criticality Data Center	A. D. Callihan	Data compilations and standards
Information Center for Internal Exposure	S. R. Bernard	Inquiries, literature searches, data compilations, and proposals for international standards
Isotopes Information Center	P. S. Baker	Inquiries, state-of-the-art reviews, and data compilations
Molten-Salt Chemistry Information Center	H. F. McDuffie	Inquiries
Nuclear Data Project	K. Way	Data compilations
Nuclear Desalination Information Center	K. O. Johnsson	Inquiries, state-of-the-art reports, and literature searches
Nuclear Safety Information Center	W. B. Cottrell	State-of-the-art reviews, SDI, and bibliographies
Radiation Shielding Information Center	D. K. Trubey	Literature searches, SDI, and state-of-the-art reports
Research Materials Information Center	T. F. Connolly	Inquiries, references, literature searches, and bibliographies
Nuclear Fuels Technology Information Center	W. H. Bridges	SDI, inquiries

ordinates method for radiation transport calculation and to conduct a workshop in the use of the ANISN radiation transport computer code.

The *Nuclear Safety Information Center* has started distributing its computer-generated "selective dissemination of information" (SDI) cards biweekly. The journal *Nuclear Safety* is now being published bimonthly after eight years of publication as a quarterly. To provide more efficient access to the central computer used by the Center, telecommunications equipment has been installed, and programming and testing to allow routine operation of the station is under way.

The *Accelerator Information Center* prepared a directory, *High Energy Accelerators—1967*, for distribution at the Sixth International Conference on High-Energy Accelerators. This booklet gave the chief characteristics of more than 40 major accelerator installations around the world, data sheets for each high-energy accelerator existing or under construction, and the characteristics of various injectors and storage rings.

The *Research Materials Information Center* has reorganized and indexed its microfilm collection and special bibliographies. This makes it possible, for example, to seek out recent work on the crystal growth of 88 materials in answer to an inquiry and to mail the answer back within a day of receipt.

SERVICES

The work of Oak Ridge National Laboratory scientists and engineers directly involved in research and development is dependent upon a great variety of services provided by others, including engineers, craftsmen, technicians, mathematicians, and administrators. The ratio of supporting service personnel to those engaged in research and development is approximately 2½ to 1.

The operation of six nuclear research reactors; the disposal of radioactive liquid, gaseous, and solid wastes; and the operation of a variety of hot cells for segmenting and examining radioactive material are some of

The Main Cafeteria serves 1000 people daily. Other food-service facilities available to employees include four canteens and a variety of vending machines.

the services that are closely integrated with the Laboratory's research programs. The volume of radioactive liquid waste generated at the Laboratory site is approximately 120,000,000 gal/year; the disposal of this waste alone is a major operation that draws on many technical skills, including those of chemists, health physicists, craftsmen, and chemical operators.

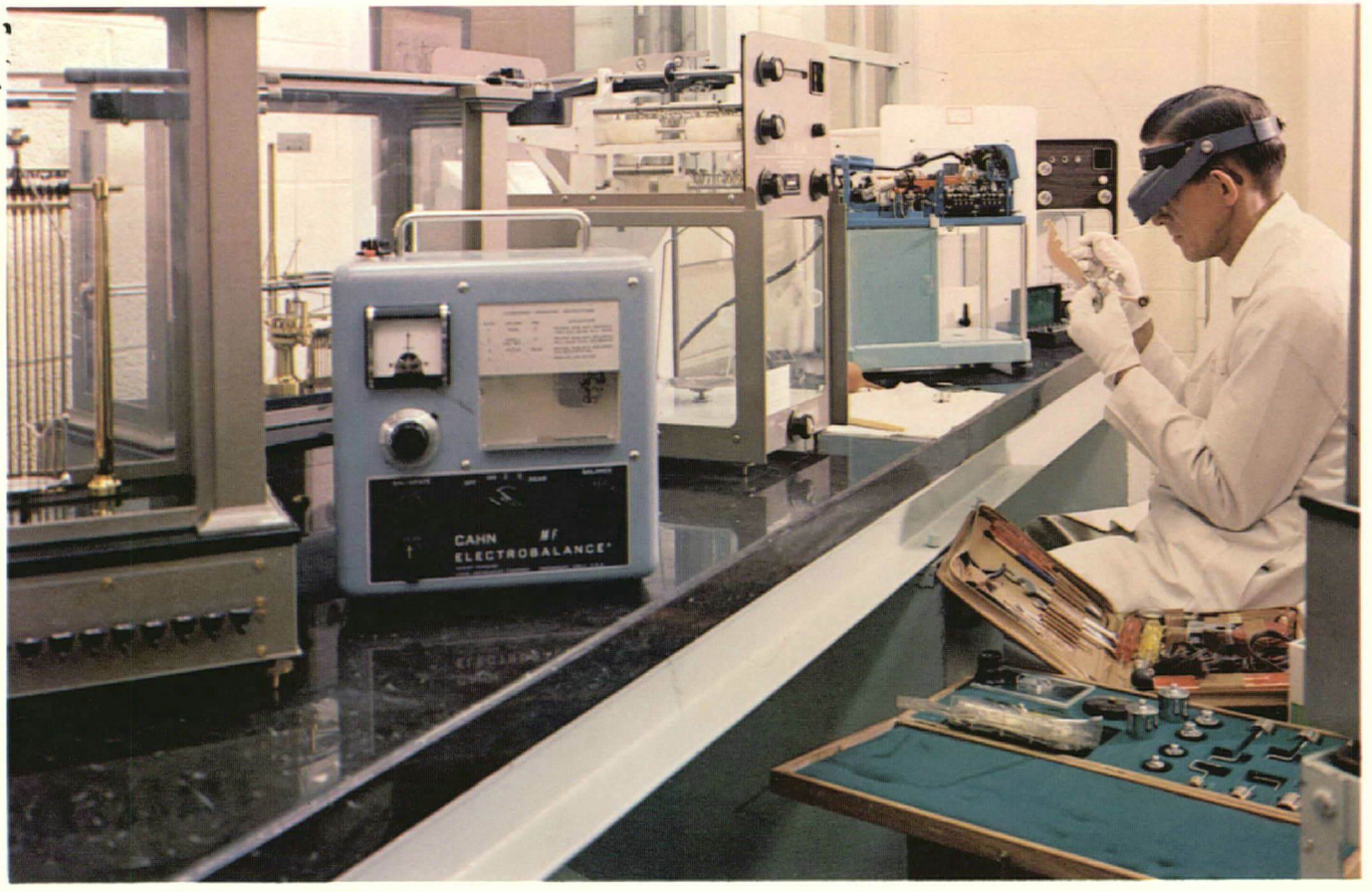
The magnitude of the industrial-type services that must be provided may be judged by the demand for utilities. The amounts of electric power, gas, and water used at ORNL would satisfy the demands of a city of 40,000 people. The distribution of these utilities to buildings spread over an area of 4 sq miles, the maintenance of the distribution systems, and the maintenance of the thousands of pieces of equipment that consume these utilities represent a large portion of the service work performed. The operation of a 300,000-lb/hr steam-generating plant to provide building and process heat, the maintenance of 210 buildings having a total area of 2,400,000 ft^2 of floor space, and the upkeep of 300 acres of grounds are some of the less noticeable but essential services on which the Laboratory depends.

The design, fabrication, and installation of equipment used by experimenters are among the most important of the services. They require approximately 600 people possessing a wide variety of engineering and craft skills. Included in the staff are 175 engineers and draftsmen and 155 machinists and mechanical instrument makers. The machinists and mechanical instrument makers make up the largest single group of craftsmen at the Laboratory.

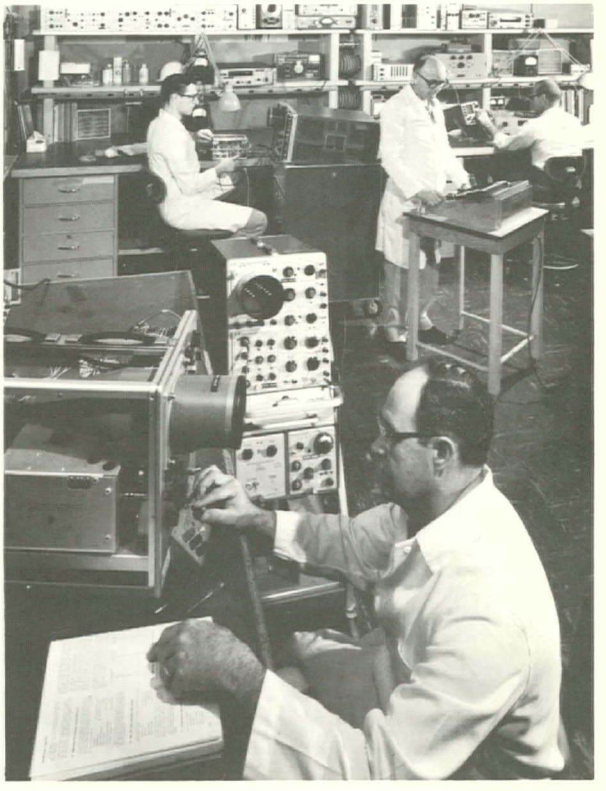
To maintain an adequate staff of craftsmen and technical support people, to improve their skills, and to encourage self-improvement, the Laboratory makes available to its employees a number of training and educational support programs. These programs include craft apprentice training, scientific refresher courses for support personnel, school tuition assistance, basic courses for the educationally underprivileged, and first-aid training. During the year 1967 approximately 1000 people participated in these educational programs.

Many other services, no less important than those already mentioned, are provided for the security of the plant and the health and safety of all Laboratory employees. The Laboratory employs a medical staff to minister to the day-to-day needs of the employees, to conduct periodic physical examinations, and to provide emergency medical service. Guards and firemen maintain the physical security of the plant. Health physicists and safety inspectors survey all work to be sure that the jobs are performed with the minimum exposure of the workers to radiation hazards and to see that conventional safety practices are followed.

A visitor receives a temporary pass to the Laboratory at the Laboratory Protection reception desk. During 1967, more than 30,000 people visited ORNL for exchange of scientific information and for business reasons. Included in the total were 1100 foreign nationals from all over the world and 9000 students.

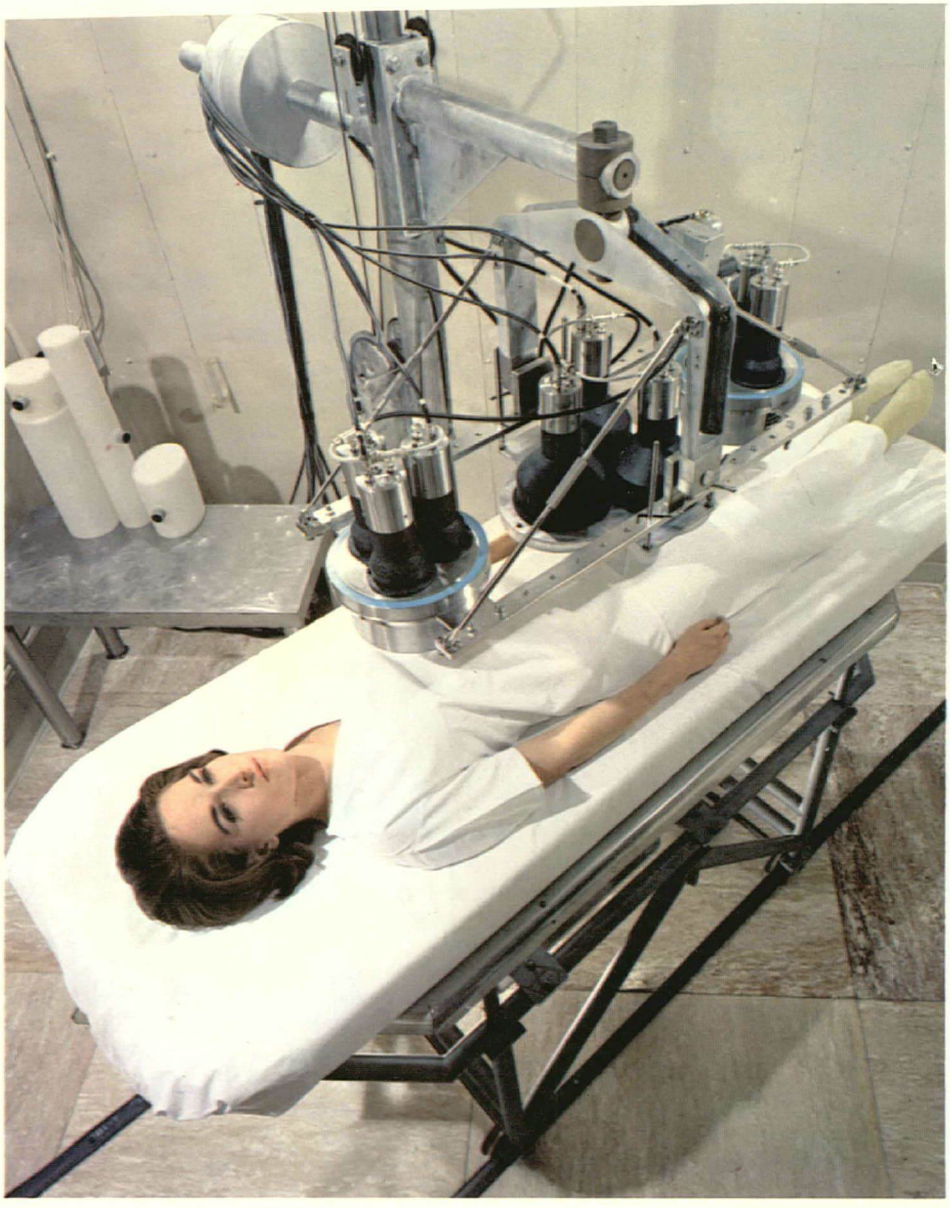


A machinist repairing one of 800 laboratory balances used at ORNL. Two craftsmen have been specially trained to repair and calibrate the balances and to modify them for unusual service, such as work in hot cells and glove boxes.



The repair and servicing of oscilloscopes as these men are doing is typical of the skilled and professional support provided by the Instrumentation and Controls Division in keeping about $30 million worth of instruments and control systems at ORNL in good working order. The Division also assists in design, development, fabrication, procurement, installation, and testing of new instruments and control systems.

A nurse applies a scratch test as part of the medical staff's study of the allergy to animal dander and sera. This allergy sometimes occurs among the biologists who work in an area where experimental animals are housed or used. The purpose of the study is to obtain new information on the natural history and prevalence of dander sensitivity and to develop a method for monitoring exposure levels.



An ORNL employee receives a routine whole-body gamma-ray count in the In Vivo Gamma Spectrometry Facility, to detect and identify any gamma-radioactive isotopes she may have assimilated during her work with radioactivity. The detection crystal, above the subject's chest in this photo, checks for radioactivity in the body from head to toe as the motor-driven bed rolls under the crystal assembly. The walls and ceiling of the room are made of 14 in. of steel and 1/8 in. of lead to eliminate natural background radiation.

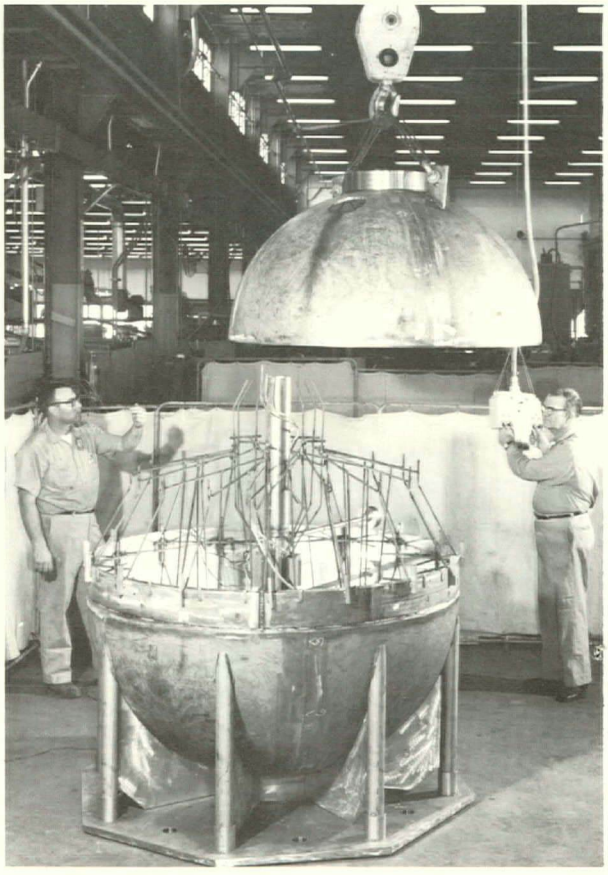
The ORNL Central Research Library now subscribes to Bell Telephone's TWX interlibrary exchange system. This device, shown here, allows employees of the Laboratory to draw upon the holdings of the more than 30 other libraries associated with the system.

One of seven radiation detection and stream sampling stations used to prevent pollution of surface streams. The Laboratory's discharges of radioactivity into the Clinch River in 1967 were maintained at less than 1% of the maximum permissible amount set by the International Commission on Radiological Protection.

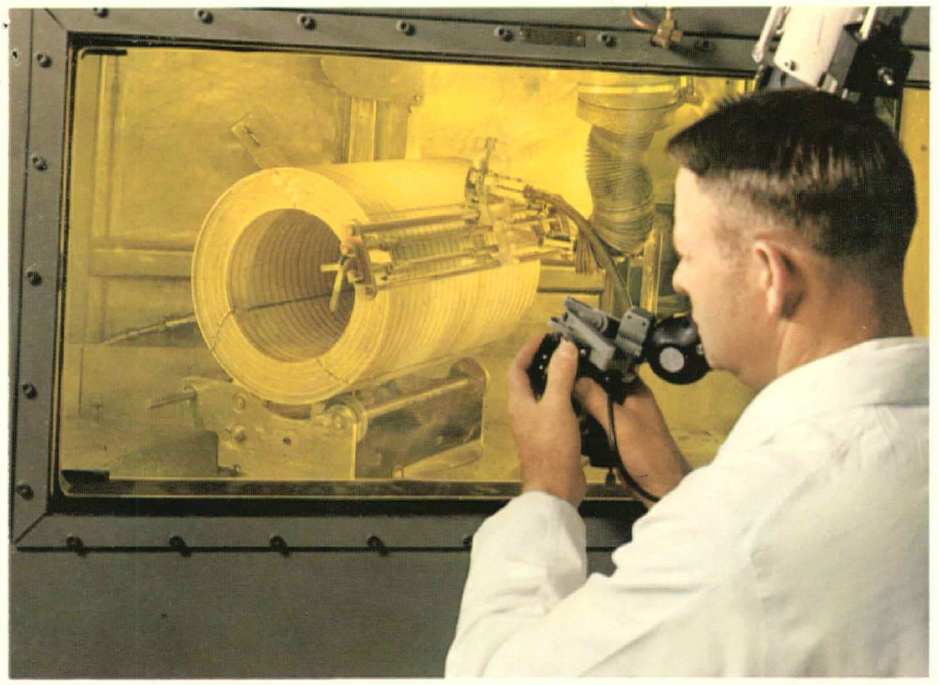
Spinning of aluminum containers that will enclose two 9-in.-diam sodium iodide crystal detectors to be used in a low-level gamma-ray spectrometer. The containers are being fabricated of virgin aluminum, which is essentially free of trace amounts of radioactivity normally found in metals. After spinning, the wall thickness of each container will be 0.015 in.

The spectrometer is being built at ORNL for the Lunar Receiving Laboratory, NASA Manned Spacecraft Center, Houston, for analyzing samples of materials that will be brought back from the moon.

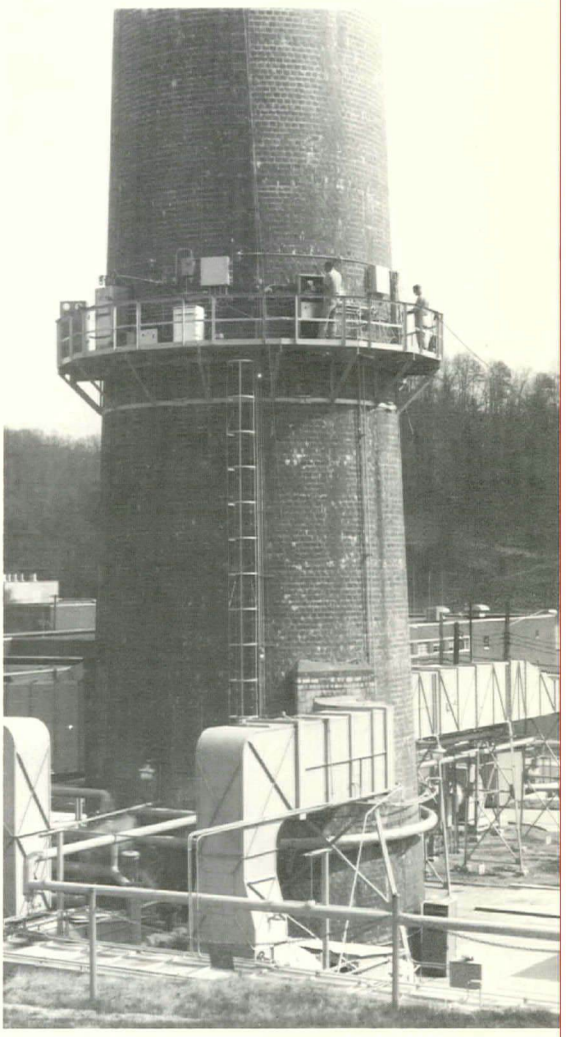
Craftsmen assembling the stainless steel shell of a container to be used for shipments of up to 10 mg of californium-252. After the two spherical halves of the shell are welded together, the space between the outer shell and the inner vertical tube, which will be the cavity of the finished container, will be filled with concrete radiation shielding. The finished container will weigh approximately 10 tons.



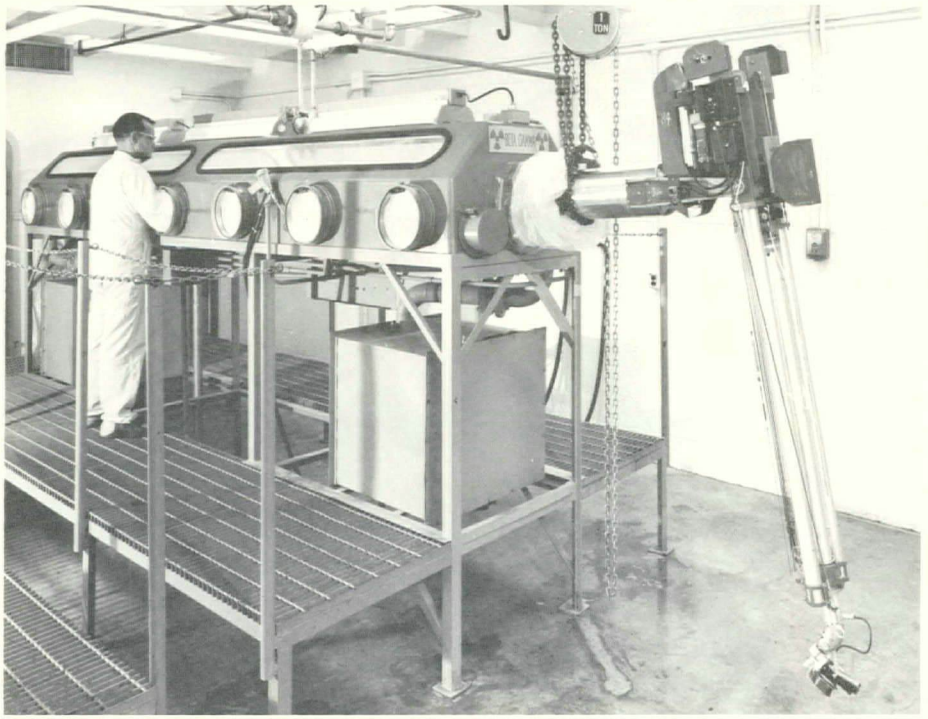
The ORNL Mail Center each month delivers about 600,000 pieces of plant and United States mail to, from, and among Laboratory employees. Besides this, they address 80,000 pieces monthly, meter postage, maintain internal and external distribution lists, address all intraplant bulletins, and mail 6000 copies of the *ORNL News* each week.



Remote cutting of a spent HFIR fuel element to determine possible damage of components after the reactor's first 20 days of operation at the design power of 100,000 kW. The photograph shows a circular saw cutting out a fuel plate for metallurgical examination after the end adapters and three other fuel plates had been removed.



Five stacks are used to discharge air from reactor buildings, hot cells, laboratory hoods, and other areas where air may become contaminated with radioactive materials. The balcony, at the 50-ft level of this 300-ft stack, supports an array of equipment that continuously monitors the air for radioactivity and continuously samples it for daily laboratory analyses. The information from the radiation monitors is telemetered to a Waste Control Center, where an operator initiates immediate corrective action whenever a significant release of activity is detected.



Millwright repairing the contaminated slave end of one of 294 master-slave manipulators used at the Laboratory for handling radioactive materials in hot cells. The repairs are being made in a sealed glove box to protect the craftsman against ingestion of the contamination and to prevent its spread into other shop working areas.

A technician in the Bioanalytical Service Laboratory is shown preparing samples for the determination of specific transfer ribonucleic acids (tRNA's) with a modified AutoAnalyzer that automatically takes a measured sample, mixes the proper amount of reagents, incubates the solution, and finally elutes the sample onto one of the filter paper disks shown on the left. The final determination is made by scintillation counting techniques. These analyses, made for the Macromolecular Separations Program, accounted for 68,000 of the total of 209,000 determinations performed in 1967 by the Analytical Chemistry Division in support of the research programs at the Laboratory.

The ORNL fire protection and prevention activities include many methods through which fire waste can be prevented. This year's efforts proved to be among the best in the 25-year history of the Laboratory, resulting in a fire loss of only $250.00.

The operation of the Laboratory is critically dependent on a reliable electrical power supply and distribution system. The annual consumption of electricity is 300,000,000 kWh.

Central
Research Library
Document Collection

OCT 8 - 1968