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ON THE COVER: Cathode ray tube graph of contour lines representing a one-dimensional ion distribution function: a part of the Thermonuclear Division's plasma research.

Editor, Barbara Lyon
Consulting Editor, A. H. Snell

Oak Ridge National Laboratory Annual Report 1969

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

FOREWORD

The year 1969 was the year of the environment. With concern for the environment becoming a great political issue, it was natural for the nuclear energy laboratories to be drawn, visibly and explicitly, into the quest for a better environment. ORNL, as well as the other AEC national laboratories, has always had strong interests in these matters. Our current broadened involvement with the environment is sanctioned by the 1967 amendment to the Atomic Energy Act, which authorizes and directs the Atomic Energy Commission to "conduct, through its own facilities, research and development or training activities for others, relating to the protection of the public health and safety." In this Annual Report one section is devoted to several representative activities connected with the environment.

But it would be wrong to conclude that we have allowed the environment to divert us from our primary goals in nuclear energy. In this report we again present vignettes that display the breadth and virtuosity of our nuclear work. We touch upon breeders of both the fission and fusion variety; on nuclear safety; and on research that ranges from time-reversal in elementary particle reactions to aging in mice, from non-destructive testing to heavy elements, to space, and to urban studies. The essays are necessarily brief and hardly do justice to the many dedicated ORNL people who were responsible for the work reported here, let alone the very many whose work is unreported.

Above all, the report again shows how productive is an appropriate mixture of pure science and technology, carried on in a serene atmosphere. This is the Oak Ridge style. It is a style that all of us at ORNL can be proud of and that we intend to preserve and improve.

Alvin M. Weinberg

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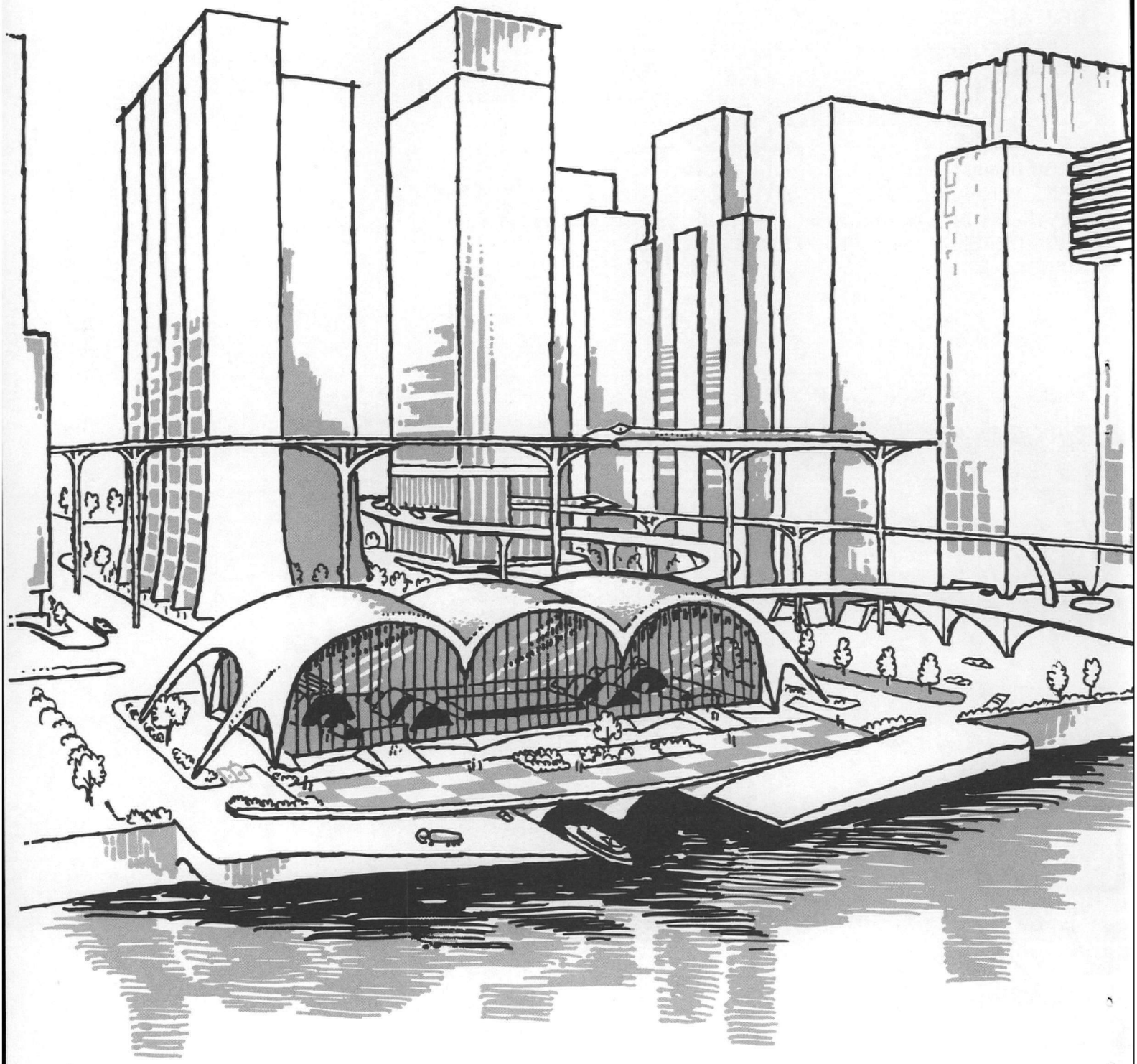
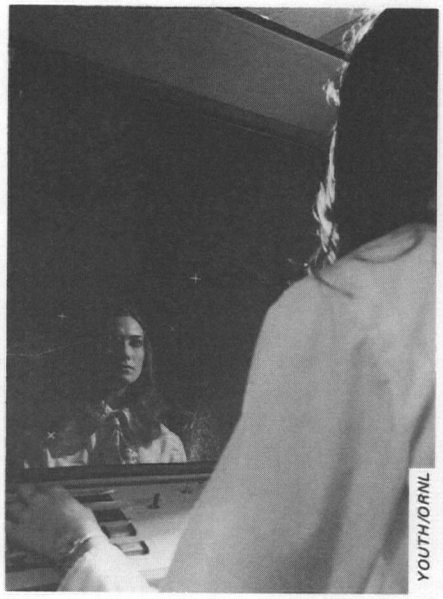
Youth at Oak Ridge National Laboratory

ORNL 1969 Nuclear Energy



Reactor Development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The development of a safe and economical breeder reactor has been called the primary task of the nuclear energy community. In contrast with today's reactors, which can use only 1 to 2% of the uranium that is mined, breeder reactors can achieve almost complete utilization. (They can also convert thorium to fissionable uranium-233.) Thus the cost of electric power from breeder reactors need not rise significantly when low-cost uranium ores are exhausted.

The ability of this nation to prevent erosion of the "quality of life" and to provide the possibility for long-term survival is seen by many to depend upon its ability to produce large amounts of energy reliably and safely at low cost; to exploit our nuclear and other natural resources more efficiently; to introduce new products based on the use of abundant, low-cost energy; and to improve and maintain the quality of our environment. These requirements form the basis for the principal objectives of the Atomic Energy Commission's breeder reactor program. The realization of these objectives on a proper time scale will have momentous national and international implications. Low-cost, abundant energy is basic to raising the living standards of all people; the impact of nuclear energy on the energy-starved areas of the world is yet to be felt.

Oak Ridge National Laboratory continues to be responsive to the worldwide needs cited above. The major portion of our work in this connection (more than one-third of our total reactor development program) has been with the high-priority liquid-metal-cooled fast breeder reactor (LMFBR) program. In this concept, fertile and abundant uranium-238, upon capturing a neutron, becomes fissile plutonium-239. Additional support has been provided in a program for the molten-salt breeder reactor, a thermal breeder concept, in which fissile uranium-233 is produced from fertile thorium-232. In an ancillary program, irradiation tests have been conducted by ORNL of fuel elements for a gas-cooled fast breeder reactor concept.

Following are descriptions of some of the developmental work in nuclear breeder reactors performed at the Laboratory in 1969.

Liquid-Metal Fast Breeder

We have brought a variety of our established talents to bear on high-priority LMFBR problems, with efforts in fuels and materials, fuel recycle, neutron physics, instrumentation and controls, high-temperature structural design methods for components, sodium technology, and safety.

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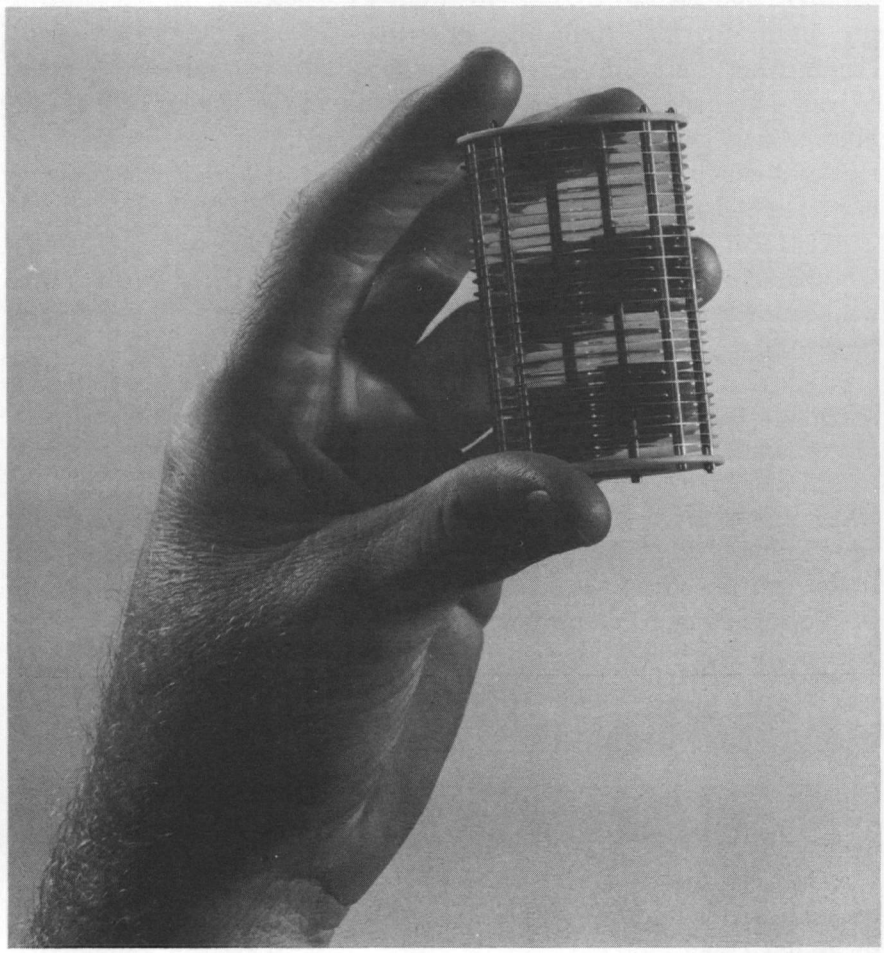
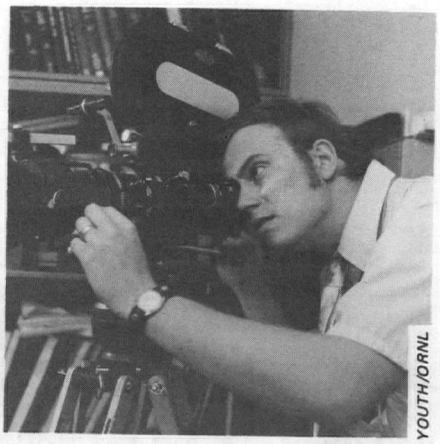
The principal key to technological success of any breeder reactor is an economical fuel cycle. The fuel cycle includes preparation of the nuclear fuel and fabrication of the metal-clad fuel elements, performance and lifetime (burnup) in the reactor, processing of the "spent" fuel to recover the valuable fissile material that has been produced, and remote refabrication of fuel elements for timely reinsertion in the reactor. In connection with fuel preparation and fabrication we are exploiting the ORNL-developed sol-gel process (which has received broad acceptance in the nuclear industry) for LMFBR fuels, because of its simplicity, versatility, and ready adaptability to remote operation. The sol-gel process deals exclusively with fluid streams that are easily transferred and controlled, and it accepts directly nitrate solutions from essentially conventional aqueous chemical reprocessing systems. In the sol-gel process, the fuel product (black uranium-plutonium oxide, for example) takes the form of tiny spheres, from two to four times the size of granulated sugar particles, which are simply poured along with much finer particles into the $\frac{1}{4}$-in.-diam stainless steel tubes to form, after moderate shaking, an adequately dense fuel pin. The feasibility of this process has been established, and good performance has been demonstrated in high-burnup irradiation tests.



Model of a highly sensitive neutron detector developed at ORNL. The operative instrument is fabricated of 32 plates of titanium coated with enriched uranium-235 and is placed in a container of argon gas inside the reactor. Neutron events, producing emission of charged particles from the fissionable coating, can be counted with unprecedented accuracy.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Because processing costs for LMFBR fuels are strongly influenced by plant capacity, large central processing plants are economically attractive. We have designed and constructed and are testing a full-scale mockup of shipping-cask internals to demonstrate convective heat transport by sodium within the fuel element cavity for safe shipment (by rail or truck) of the very radioactive spent fuel elements containing valuable plutonium-239 to such plants. In addition, we are developing, with very encouraging results, chemical scrubbing and trapping techniques for removal of gaseous fission products – principally iodine – released during shearing and dissolution of the spent fuel elements. These techniques will be immediately applicable to processing plants of the type currently used for "cooler" light-water reactor fuels. (It is important to process the fuel after only 20 to 30 days of decay time, because the cost penalty, i.e., plutonium inventory charge, for allowing the fuel to decay for a year is approximately three times the cost of processing it.)

In regard to long-life cladding performance, we have modified the composition of an otherwise conventional stainless steel by adding small quantities of titanium for increased resistance to irradiation-induced embrittlement. Fuel tubes of this new composition are being fabricated by industry for ultimate evaluation in a fast-neutron environment.

The LMFBR program in physics involves basic measurements of cross sections and capture-to-fission ratios, using the Oak Ridge Electron Linear Accelerator (see page 36), and shielding calculations and measurements necessary for fast breeder reactor cores. The shielding measurements are conducted at the Laboratory's Tower Shielding Facility.

We are developing a monitoring system to measure the level of subcriticality of LMFBR's. Such a monitor is desirable from considerations of both safety and economics. Of particular concern from the standpoint of plant safety is the possibility of accidental approaches to criticality (a situation of sustained chain reaction) during reactor shutdown, especially during refueling operations. For the subcriticality monitoring system, a neutron sensor in the form of a fission counter must be situated in the reactor and provide reliable information while operating in the very intense gamma-ray fields which exist in that environment. We developed a fission counter and pulse amplifier assembly for this application that can detect neutrons in the presence of high gamma radiation fields nearly ten times as well as existing sensors.

Molten-Salt Breeder Reactor

The Oak Ridge National Laboratory has pursued for some years the development of a breeder reactor in which the nuclear fuel is dissolved in molten salt. December 1969 saw the completion of a major phase in the development of molten-salt power reactors: the successful conclusion of over four years' operation of the Molten-Salt

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Reactor Experiment. The MSRE was conceived, designed, built, and operated by ORNL to prove the practicality of the molten-salt reactor concept. This goal was achieved.

For Those Who Came In Late

The key to the attractiveness of the molten-salt breeder is its promise of low electric power generation costs because of an unusually low-cost fuel cycle. In conventional power reactors the fuel, uranium dioxide, is canned in corrosion-resistant jackets and arranged so that a fission chain reaction can be sustained at a controlled rate. The carefully made (and expensive) fuel elements must be periodically replaced and reprocessed to separate the unconsumed fissile material from the "ashes" of the fission reaction. The heat from the fission reaction is transferred out of the fuel elements to a coolant which circulates through the core and through an external heat exchange system to produce steam to drive a turbo-generator.

The molten-salt reactor is radically different in that the fissile material is simply dissolved in the circulating coolant. Gaseous fission products can be removed continuously by a simple physical separation, and a chemical "kidney" can be used to remove other fission products from the circulating fuel. The elimination of fuel element fabrication and the simplification of processing open the way to low fuel costs.

Mixtures of certain fluoride salts have properties that make them remarkably well suited for reactor use: high heat capacity, reasonable viscosity (like kerosine), immunity to radiation damage, and a very low vapor pressure at high temperature (less than 0.001 psi at 1200°F). But they freeze at temperatures around 800°F. The practicality of working with such a fluid, containing highly radioactive fission products, has now been demonstrated by the ultimate test: the long-term operation of a molten-salt reactor.

In the MSRE the fuel salt is a mixture of ^{7}LiF, BeF_2, and ZrF_4 containing about 0.2 mole % UF_4. This salt is circulated by a centrifugal pump at 1200 gpm through the reactor core and a heat exchanger. The fission heat (up to 8000 kW) is taken from the circulating fuel by a secondary coolant solution, a salt similar to the fuel but without uranium, and dissipated through an air-cooled heat exchanger. Although the salt loops operate at the bright-red temperature of 1200°F, the pressure of the helium blanket gas in the loops is only 5 psig.

Design of the MSRE started in 1960, and salt was first circulated in January 1965. Uranium (enriched to 33% uranium-235) was added to the carrier salt, and on June 1, 1965, low-power nuclear operation began. Completion of some containment features and difficulties with the radioactive gas stripping system delayed high-power operation until the spring of 1966. By the end of 1966 the kind of startup difficulties attending any new system had been conquered, and thenceforth the MSRE attained a service record that is exceptional among experimental reactors. Over the next 15 months, despite four weeks spent in the scheduled replacement of metal and graphite specimens in the core, the reactor was critical for 80% of the time. There was no interruption for refueling; the small amounts of uranium-235 required to compensate for burnup were added to the fuel salt during operation at full power. Capping the demonstration of reliable operation was a six-month run that ended as scheduled in March 1968.

Although the original goal of the MSRE had been attained, another major experiment lay ahead. This was the on-site recovery and decontamination of the uranium from the fuel salt and its replacement with uranium-233. The MSRE was the world's first reactor to be fueled with this man-made isotope, and there was keen interest because of its different nuclear characteristics. The original uranium was recovered, as clean UF_6, by simply bubbling fluorine gas through the fuel salt in a tank in the reactor building. Then uranium-233, in a highly concentrated salt, was added to the stripped carrier. The new nuclear characteristics, determined in several months of low-power operation late in 1968, turned out as predicted.

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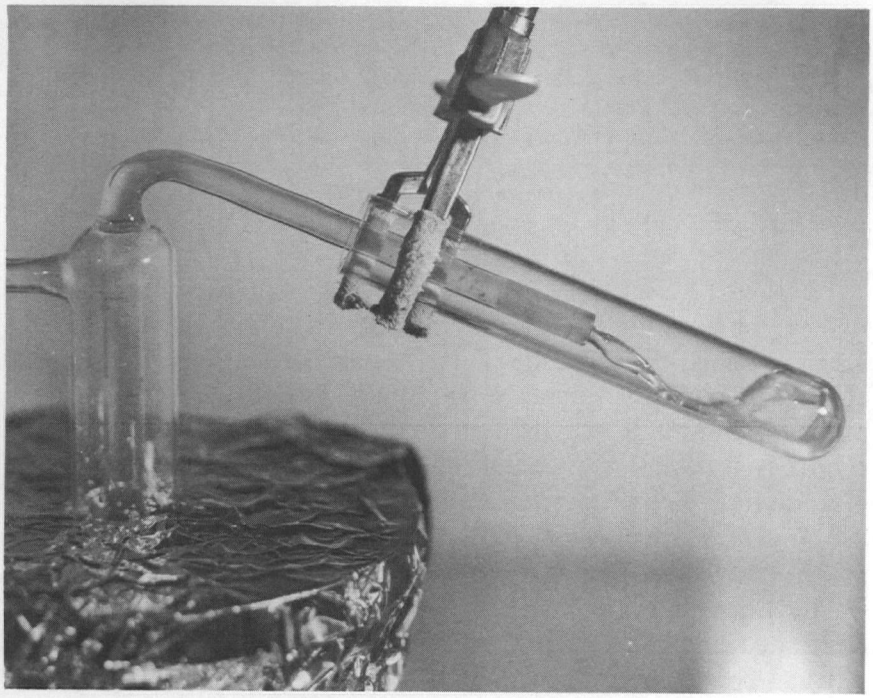


This picture is remarkable only when one learns that this liquid is at 1200°F and the test tube is open to the air. The liquid is molten salt like that used as the fuel medium in the MSRE.

Maintenance of the primary systems of nuclear reactors is complicated by fission product contamination and radiation. This was recognized in the design and layout of MSRE components, with the result that the MSRE proved practical to maintain with simple long-handled tools through this portable maintenance shield.

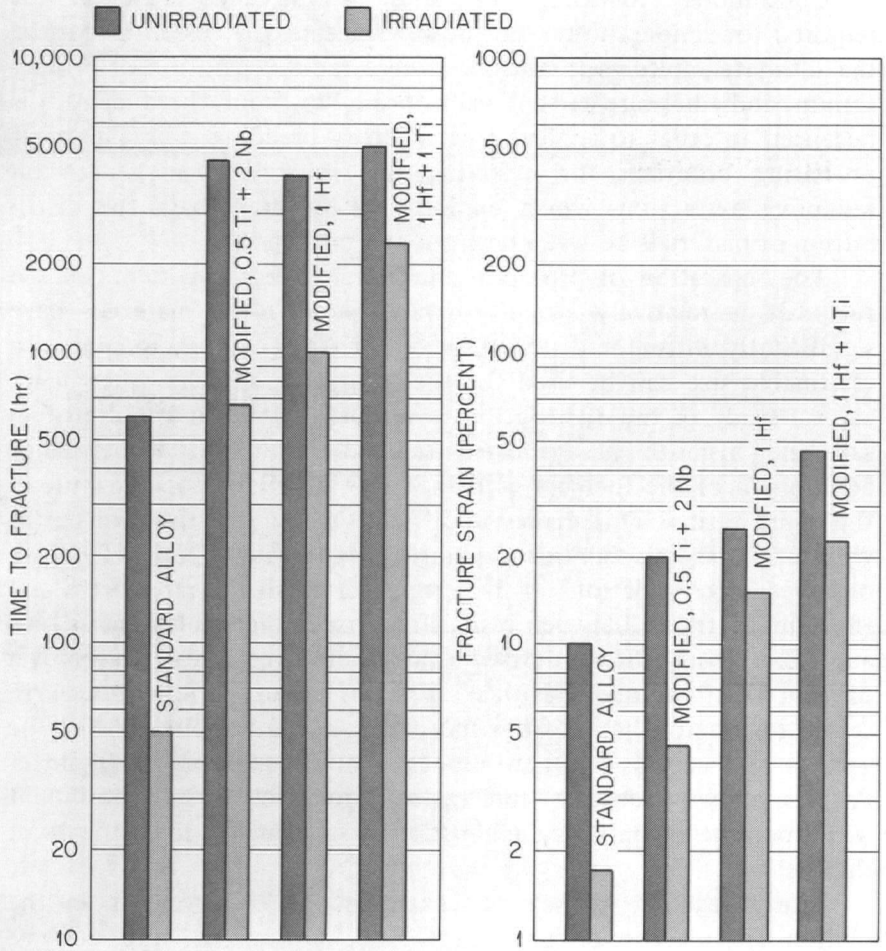
Transmission electron micrograph of a modified Hastelloy N containing 0.7% Hf. The fine precipitates are carbides of the MC type, where M designates a metal (molybdenum, chromium, and hafnium in this alloy). Although these are basically carbides, small amounts of boron are associated with each precipitate and are then dispersed throughout the metal. The lines are dislocations caused by the dimensional changes as the precipitates are formed. Magnification 6000X.

During 1969 the reactor operated at high power much of the time to observe the behavior of fission products in the salt and the long-term changes in the new fuel. When it became necessary to start adding more fissile material to compensate for that consumed, instead of uranium we used plutonium (which, like uranium and thorium, is quite soluble in the fluoride salts). The addition of plutonium-239 reaffirmed the ability of the molten-salt reactor to use any kind of fissile material and to shift readily from one to another.

In December 1969 the experimentation with the MSRE was concluded and the reactor was shut down. By the final shutdown, salt had been circulated in the fuel system for 21,788 hr, the reactor

had been critical for 17,655 hr, and the nuclear heat production amounted to 13,172 equivalent full-power hours. The long operation had revealed no basic flaw in the molten-salt concept. Corrosion was negligible, the nuclear reactivity had behaved as predicted, the key equipment such as the salt pumps had proved reliable, and the necessary maintenance had been handled safely. In short, the MSRE had fulfilled its designers' aims and had proved the technical feasibility of a molten-salt reactor.

What has been the impact of the MSRE? Although a molten-salt power reactor promises some important advantages, it is probable, in view of the strong trend toward the concentration of development efforts on fewer kinds of reactors, that the survival of the molten-salt concept hinged on the experience with the MSRE. Now, from the success of the MSRE, the molten-salt reactor is emerging not only as an attractive route to the breeding that will ultimately be essential for long-term cheap power, but also as a possibility for lowering power costs in the nearer future using the technology already demonstrated. Indeed, the vision of a scaled-up MSRE with a very simple fuel cycle producing low-cost electricity has taken on enough reality that utilities are beginning to invest in studies to explore this possibility seriously.



Comparison of the creep properties of standard Hastelloy N and several modified alloys in the unirradiated and irradiated conditions. The samples were irradiated at 760° C and were tested at a stress of 35,000 psi at 650° C.

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Meanwhile ORNL is proceeding with the developments that are necessary for any large molten-salt power reactor, including the breeder.

The Hastelloy N used for containment of the salts in the MSRE proved highly satisfactory in this reactor, but it revealed one shortcoming that would be a problem in large power reactors: it is embrittled by long exposure to neutrons. Research showed that this embrittlement is due to helium, produced mostly by transmutation of the boron in the metal. In standard Hastelloy N the boron segregates in the grain boundaries, where the neutron-produced helium can have a large influence on the fracture characteristics. We felt that the key factor in making material more resistant to embrittlement was more uniform dispersion of the boron (and hence the helium). Addition of elements such as hafnium, titanium, and niobium that form compounds with boron obtained the desired dispersion, and irradiation and testing of the modified alloys showed strength and ductility much improved over standard Hastelloy N. Thus a satisfactory container material for future molten-salt power reactors seems assured.

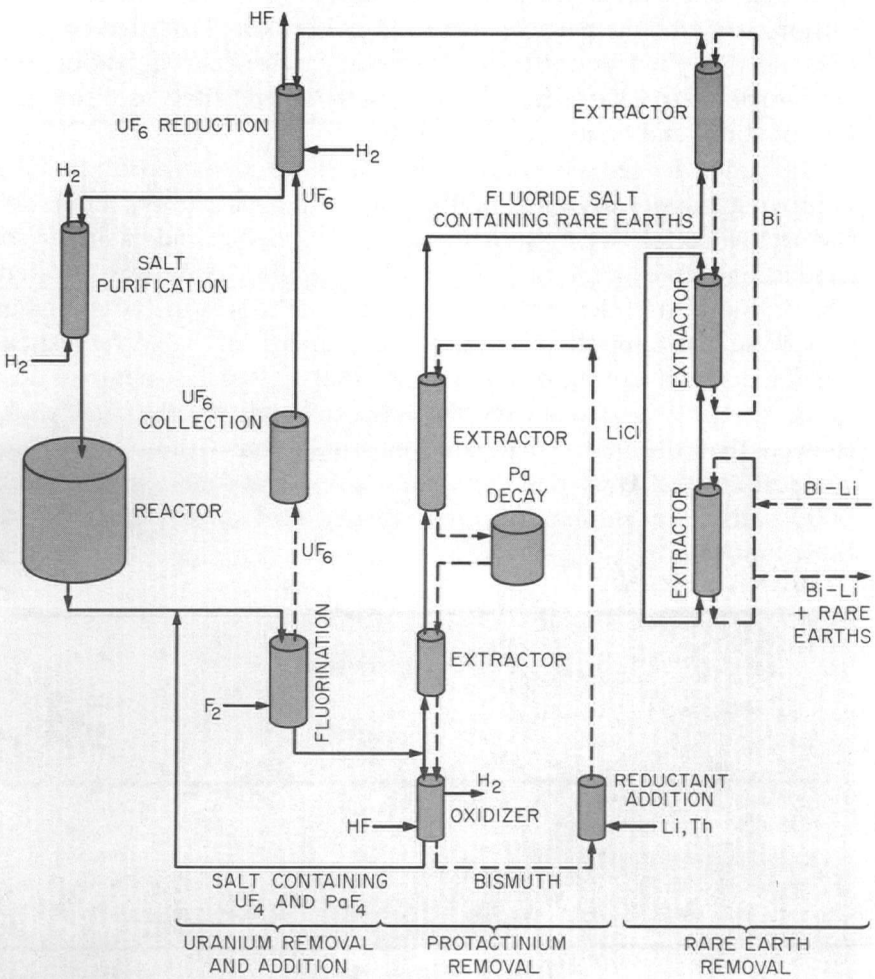
On-Site Processing

Continuous processing of molten salt streams, although not required for simple molten-salt power reactors, is an essential part of the ultimate molten-salt breeder, where rapid separation of protactinium and the rare-earth fission products from the fuel salt is necessary in order to achieve a satisfactory breeding gain. The most promising processes for effecting this separation are based on reductive extraction, which exploits the differences in the distribution of materials between bismuth and molten salt.

The separation of protactinium from other components of the fuel salt is relatively straightforward, since these materials have significantly different distribution coefficients, and equipment of a reasonable size can be used for the separation. On the other hand, careful study of the distribution of rare earths between molten fuel salt and bismuth has revealed that thorium fluoride, a major component of the fuel salt, and the rare-earth fluorides distribute in the same ratios. This makes it difficult to remove the rare earths without discarding significant quantities of thorium. During 1969 we observed large variations in the extent to which the rare earths and thorium distribute between bismuth and such molten halides as LiCl and LiBr. From this we devised a vastly improved rare-earth removal process that exploits this fact. The effective thorium–rare-earth separation factors range from more than 10^4 to about 10^8 for the various rare earths. The new process, known as the Metal Transfer Process, allows removal of rare earths in relatively simple equipment while permitting only negligible discard of valuable constituents of the fuel salt.

The foregoing are selected examples of the progress in the molten-salt reactor program at ORNL. Optimized core designs,

longer-lived graphite for high-performance cores, analytical chemistry for on-line use in a breeder power plant, larger pumps and other components – all are coming along. Much remains to be done before molten-salt power reactors share the load of man's energy needs. It has become evident, however, that success does not hinge on any revolutionary breakthrough. Through the success of the MSRE and the other dedicated efforts at ORNL, the bright dream of inexhaustible, cheap power, while not yet in hand, now appears to be an attainable goal.

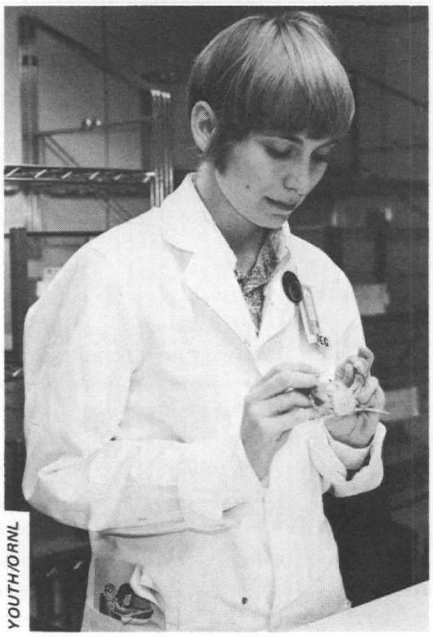


The metal transport process. A simplified flowsheet showing proposed method for removing protactinium and the rare earths from a molten-salt breeder. Salt leaving the reactor is fed to a fluorinator, where most of the uranium is removed as UF_6. After fluorination, most of the salt is fed to an extractor, where the remaining uranium is extracted into a downflowing bismuth stream. The protactinium is then removed from the salt in a second extractor and is held for decay to uranium-233 in a tank through which the bismuth flows. Finally, the uranium and protactinium are removed, by hydrofluorination in the presence of about 10% of the salt leaving the fluorinator, from the bismuth stream exiting from the lower contactor; the resulting salt is recycled to the fluorinator. Lithium and thorium are added to the bismuth leaving the hydrofluorinator to provide the metal stream that is fed to the upper extractor.

The salt leaving the upper extractor, which is essentially free of uranium and protactinium, is fed to the rare-earth removal system, where a fraction of each of the rare earths and thorium is extracted into a downflowing bismuth stream. Contact of the bismuth stream with molten LiCl in a second contactor results in the preferential transfer of the rare earths to the LiCl. In the final step of the rare-earth removal process, the rare earths are extracted from the LiCl by contact with bismuth containing a relatively high concentration of lithium. The fuel salt is reconstituted by reducing the UF_6 (produced by fluorination) to UF_4 in the presence of the fuel carrier salt leaving the rare-earth removal system.

High-Temperature Gas-Cooled Reactor

Two high-temperature gas-cooled reactors in the United States and two abroad have now been operating satisfactorily with potential high power availability for from six months to over four years, and larger prototypes are under construction. In January 1969 an important remaining problem was the design of graphite structures to hold the fuel which could withstand damage by fast neutrons at the levels required for large power stations.



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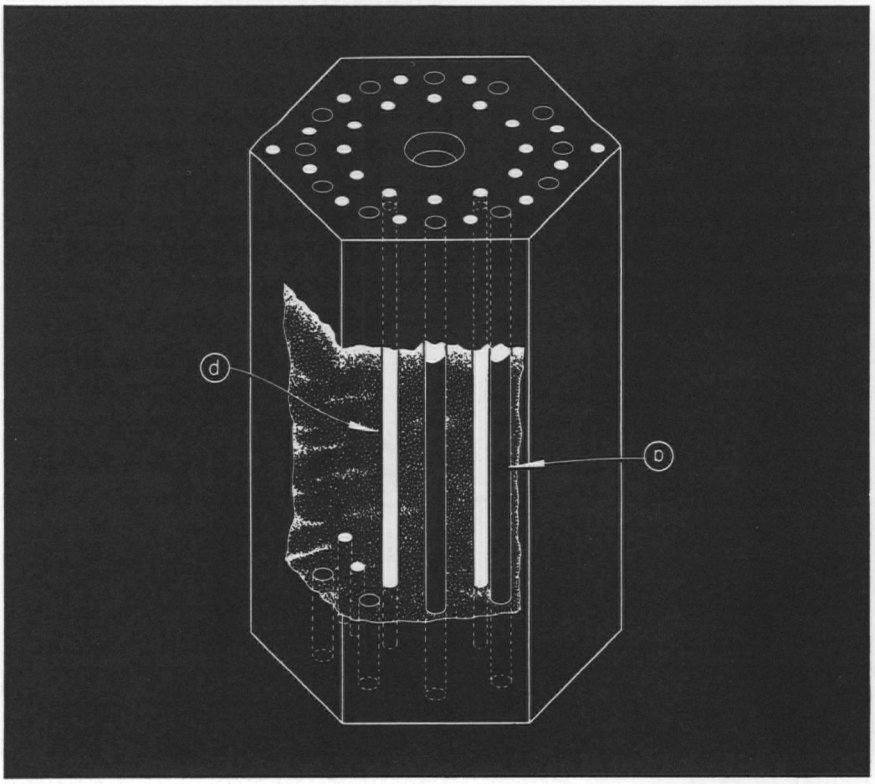
Fuel elements proposed for advanced HTGR's consist of hexagonal blocks of graphite with parallel fuel and coolant channels. The fuel channels are loaded with carbon-coated particles of fissile and fertile materials with the particles bonded together into sticks. The bond holds the fuel in place during handling, minimizes release if the block is damaged, and improves the transfer of heat.

During the past two years successful methods for bonding coated fuel particles into sticks have been developed.

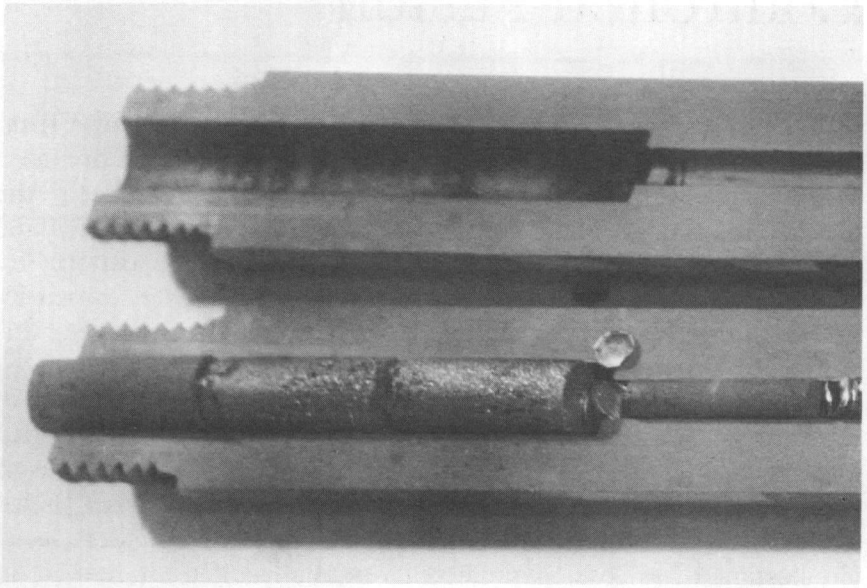
Earlier we had concentrated on fabricating densely packed particles into sticks as long as 15 in. by injecting a resin binder. However, when the bonded stick was heated to convert the binder to carbon, some of the particle coatings were broken. Modified coatings that did not bond as tightly to the resin survived carbonization, but additional matrix shrinkage during irradiation resulted in disintegration of sticks and breakage of coatings.

In order to reduce the matrix shrinkage we concentrated on improving the density and stability of the matrix carbon. Pitch and furfuryl alcohol were substituted as binders, and a filler of irradiation-stable graphite powder (Poco grade AXM) was selected. The amounts of filler material (40 wt % or more) in these binders also were substantially increased. Specimens of such fuel sticks remained intact during irradiation at 1000°C to a fast-neutron dose of 8×10^{21} neutrons/cm^2. Polished sections of the fuel sticks showed that the matrix had survived irradiation without significant physical change. Only one damaged coating was found among about 2000 particles examined in four irradiated fuel sticks prepared with these binders.

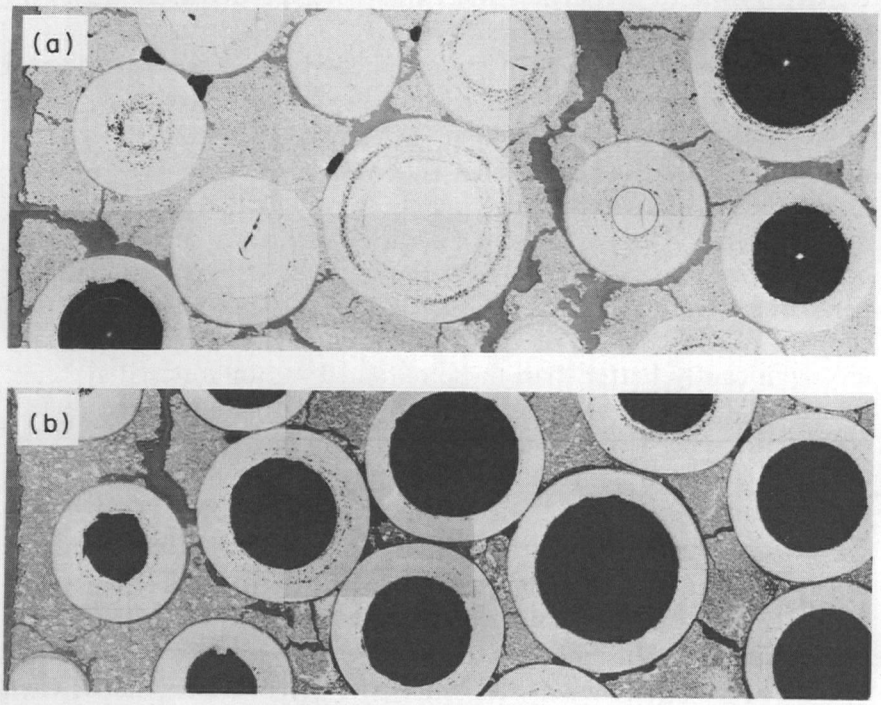


High-Temperature Gas-Cooled Reactor fuel element, in the form of a hexagonal graphite block. The coolant channels, a, *surround the fuel rods,* b.

Bonded beds of coated particles irradiated at 750°C to an accumulated fast-neutron dose of 5×10^{21} neutrons/cm^2 in HFIR. This photograph taken through a periscope in the hot cell shows that the bonded fuel sticks are still intact. The fuel sticks are 13 mm long and 6.5 mm in diameter.



Polished sections of bed of coated particles bonded with a mixture of 29 wt % carbon black, 29 wt % Poco graphite powder, and 42% pitch. (a) *Unirradiated.* (b) *Irradiated at 1050°C to a fast-neutron dose of 8×10^{21} neutrons/cm^2. Shrinkage of the particle kernels due to irradiation loosened them from the coatings, causing them to fall out of the specimen during polishing.*



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Controlled Fusion

One of the most likely paths to obtaining controlled power from the nuclear fusion process has involved the general method of closed confinement. In this method magnetic field lines confining the plasma are arranged in such a way that they do not leave the volume in which the plasma is contained, so that particles can be lost only by crossing magnetic field lines. Anomalous losses, however, caused by an unknown physical process, have repeatedly hampered this approach.

It was therefore very reassuring when the Russians announced in 1969 that in a particular configuration called TOKAMAK they had made substantial advances in quenching these losses and as a result had produced a plasma having very impressive characteristics. It also seemed true from their results that the loss rates were, under special circumstances, as low as predicted for simple diffusion and in all cases much less than the anomalous loss rates previously observed. In addition, several empirical scaling laws, though not unique in describing the plasma performance, strongly suggested the proper ways to go for improvement of these results. These basic findings were later confirmed by a British research team visiting in the Soviet Union. The results gave reinforced hope in the validity of this approach and led to the designation of ORNL as a prime site in the USAEC effort to investigate and exploit this particular approach to closed confinement geometries.

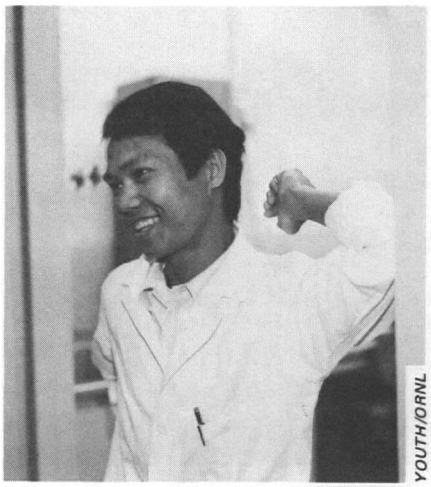
Therefore there began, in the summer of 1969, the construction of a new facility at ORNL called the ORMAK (or Oak Ridge TOKAMAK) with several unique features that should extend the plasma parameters of the Russian TOKAMAK's.

In the Russians' large experiments they obtained plasmas having ion densities of 5×10^{13} cm^{-3}, ion temperatures of 500 eV, and confinement times of 30 msec. By the standard Lawson criteria these parameters are each a factor of 10 lower than those conditions thought necessary to break even in a fusion device. Nevertheless they are significantly better than those obtained in other closed systems. In addition, they indicate that large fat tori are even better containers and that symmetry is an important attribute. The ORMAK has been designed to extend the experimental conditions in these directions.

Less optimistically, there also appeared in their experiments an upper limit to the plasma pressure that the magnetic field could support. This pressure limit was substantially below the theoretical predictions. It also appeared that the heating method (turbulence) may not prove effective as the other parameters are extended. Then

of course there remains the very important consideration that we do not yet know what the the processes are that are responsible for the good results.

What then is this device and how does it work? A look at the ORMAK design itself will give some insight into how the plasmas are created and contained. Three magnetic fields are used to contain and control the plasma. The strongest is the main magnetic field which acts as a backbone to the plasma. It is created in ORMAK by current flowing in a single-turn toroidal magnetic field coil. By induction from a transformer running vertically through the center of the apparatus, a large plasma current is made to flow in a ring following this main magnetic field, thereby creating the second important magnetic field. (It also heats the electrons and thus the ions of the plasma to significant temperatures.) The combination of the applied main magnetic field and the field due to the induced intense current twists the resultant magnetic field, thus preventing the rapid escape of particles. Finally, the small but vital magnetic field perpendicular to the other two, provided by eight ring conductors close to the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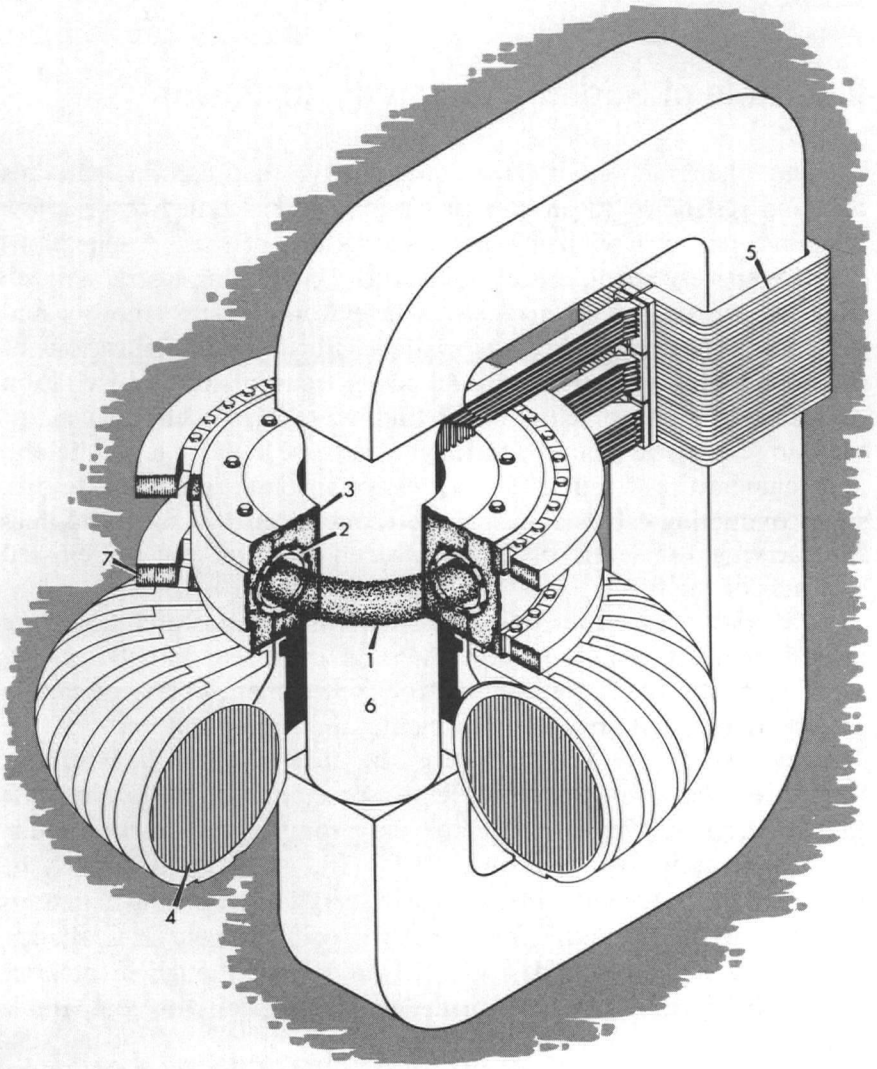
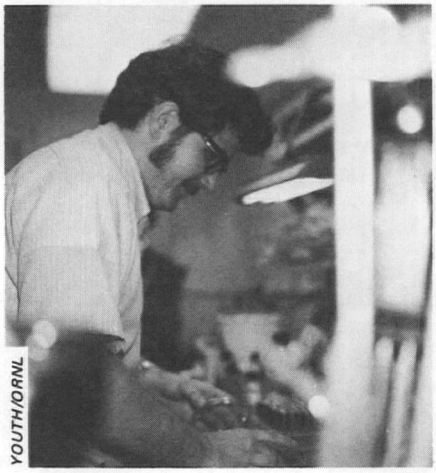


This is a schematic of ORMAK-I, the Oak Ridge TOKAMAK, as conceived in 1969 at ORNL. The main magnetic field is created by currents flowing in the replaceable single-turn coil (3), and the plasma current is created by induction through the transformer (5). The essential features of high symmetry and modular design for interchanging different types of plasma chambers, all at high magnetic fields, should allow an early determination of the requisite scaling for more fusion-like plasmas in larger TOKAMAK-geometry confinement devices of the future.

(1) Plasma current ring
(2) High vacuum liner
(3) Toroidal magnetic field coil
(4) Impedance matching transformer
(5) Plasma current driving winding
(6) Induction core for plasma current
(7) Torus holding bands and wedge jacks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plasma, serves to "fine tune" the plasma to a position best suited for stability.

The ORMAK device retains the essential features of the successful Russian experiment but with a higher degree of azimuthal symmetry and in a modular design that permits easy replacement of the plasma chamber. It should therefore allow free development of empirical scaling laws and physical knowledge necessary for the extension of this concept. Two ORMAK's are currently planned. ORMAK-I, now being built, is a highly symmetric high-magnetic-field version of the Russian TM-3 device, and ORMAK-II, planned for next year, is also a highly symmetric high-magnetic-field device but with a small aspect ratio, that is, the ratio of the large radius of the torus to the radius of the cross section of the plasma, which results in a short-and-fat experiment. Further modifications, like the one in ORMAK-II, will consist only of different configurations in the plasma section instead of the design of an entirely new experiment.

As the understanding and information of these devices come, it may be possible to design and build an experiment which truly tests the scientific feasibility of fusion based on the closed confinement scheme.

The Role of Superconductivity in Fusion

The phenomenon of superconductivity, that certain materials offer no resistance to an electric current when cooled to very low temperatures, is now being put to a variety of uses. Applications range from very small, extremely sensitive measuring instruments to large power users like magnets, accelerators, electric motors and generators, and energy storage systems. Further-off applications of superconductivity are underground power transmission and levitation of transportation vehicles. Superconductors have their drawbacks: they are expensive metals, and they need to be kept by liquid helium at a temperature within a few degrees of absolute zero. Despite this, superconducting cables appear more economical than overhead lines for carrying the levels of power needed to meet the anticipated demands of the future.

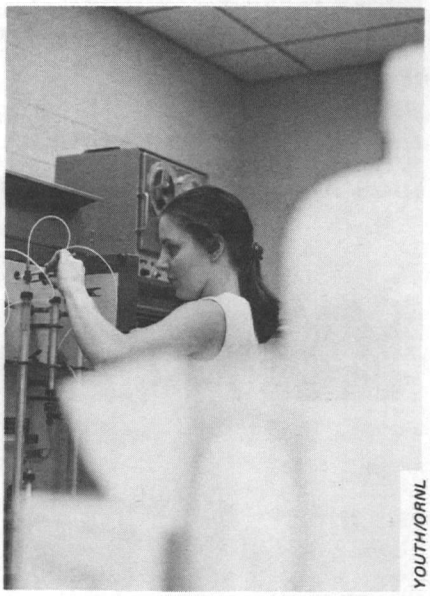
To those engaged in controlled thermonuclear research, there are both immediate and long-term interests in superconductivity. Because magnetic fields are essential for confinement of the plasma in an eventual fusion reactor, the capital and operating costs of the magnet systems are important for the success of such a reactor. Studies of the engineering problems associated with fusion indicate that superconducting coils are the only solution and also conclude that moderately high magnetic fields (50 to 100 kG) must be produced in superconducting coils with very large working diameters – about 30 ft. Structural restraints for coils in these sizes, shapes, and environment (around −454°F) are severe, though in practice substantial success has been made in building coils of comparable sizes.

Furthermore, there is very immediate short-range interest in superconducting coils for operating experiments. The advantages of compactness and low power demand – even magnet operation proper without any power supply – combine in a number of cases to offer the only practical solution to the magnetic field requirements demanded by plasma physics experiments. Thus in recent years we have seen a variety of devices employed at a number of laboratories which utilize these unique features, the first of which was the IMP (Injection into a Microwave Plasma) experiment at ORNL.

For the IMP experiment the previously mentioned requirements of compactness and steady operation, the necessity to produce high magnetic fields (up to 70 kG in some regions), and the advantage of cryogenic pumping for achieving low gas pressure recommended superconducting coils as the superior means for generating these fields. The first phase of the experiment, operation with mirror coils, began in August 1969. The coil conductors consisted of thin niobium-titanium superconducting filaments embedded in a rectangular copper matrix, and this conductor was wound into the required coil shape. Operation since that time has been trouble-free, and the coils have performed as designed. The second phase of operation, employing quadrupole coils in a Ioffe configuration and using a composite niobium-tin ribbon as the superconducting material, is being constructed for operation in late 1970.

Yet, even with the number of successful coils operating, the attainment of complex fields is hardly a simple task. For example, the results obtained with simple, small superconducting coils do not extrapolate to large coils, especially when these coils are part of complex magnet systems. Even short pieces of superconductors tested separately show instabilities of their own. Substantial advances have been made in creating "stabilized" conductors. For example, the use of thin, twisted niobium-titanium filaments embedded in a copper matrix or the employment of pure aluminum tape wound between niobium-tin ribbon remarkably improves the stability of superconducting windings.

Some of these magic recipes for superconductor stabilization have been developed at ORNL, and tests have been performed here with samples ranging from short wire pieces to large magnet coils. One of the outstanding test methods that has been developed here uses a cusp coil configuration which, in its moderate size, subjects the superconducting material to the same magnetic field shapes and mechanical stresses that occur in the most complex full-size magnet systems. Thus many of the specific conditions for actual coil design can be anticipated in moderate-size tests. In addition, a program in applied superconductivity is being carried out which investigates nonlinear flux flow and flux jump effects as well as other basic causes for instabilities and their propagation in coil systems. Through this broad applied research program, we intend to improve the design procedures for superconducting coils and to achieve the state of perfection now enjoyed by the conventional water-cooled copper coil design.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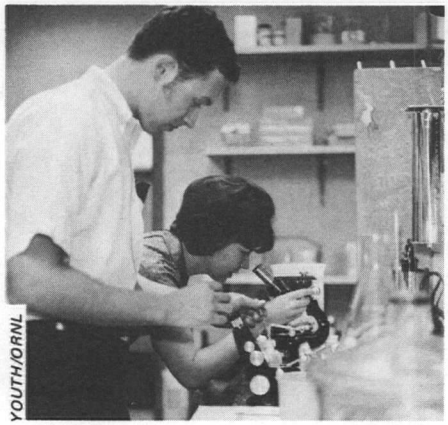
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Nuclear Desalting

In the original summer study of nuclear-powered agroindustrial complexes in 1967, "building block" data on various parts of the complex were developed by experts who served on the study team for short-term assignments. These units were incorporated into the agroindustrial complex but, in this preliminary feasibility study, were not optimized for greatest output at lowest cost. Since then, a continuing effort has been made to incorporate new technology as it becomes available and to develop refinements in the concept as indicated by new data or more detailed study.

Reevaluation of the water use technology and economics of intensive agriculture, as well as development of more sophisticated equipment, indicates that it is worth while to spend more dollars per acre to assure greater efficiency of water use. Recent studies show how ground surface evaporation losses can be greatly reduced, saving as much as half the water originally assumed to be applied. To eliminate these water losses, at least doubling the water use efficiency, expenditures for equipment can be economically attractive at levels two or three times as high as the estimates of the original study.

Crop yield increases of more than a factor of 2 above the original summer study estimates also appear attainable by using by-product CO_2 from the industrial segment to enrich the air surrounding the plants. Distribution of CO_2 to the fields, perhaps through the irrigation system, will increase the concentration of CO_2 in the air in contact with plant leaves and give higher yields for all crops. The quantity of by-product CO_2 available within the agroindustrial complex is more than enough to supply the entire 300,000 acres, but the method of distributing it has not been worked out. Tests will be required to show how efficiently the CO_2 can actually be utilized by the crops.

The overall effect of the attainable water savings and the increased crop yields is to make the cost of water much less important in the economics of intensive agriculture, so that expensive water can be used profitably, even for raising such low-priced basic food crops as rice and wheat.

Indian government studies of agroindustrial complexes are continuing with plans originally conceived by consultant Perry R. Stout of the University of California. ORNL is providing technical assistance by consulting with the Indian study group several times a year. The Laboratory is also working with the Puerto Rico Energy Center Study Committee, which is directing the study of a complex

to provide water and power for the water-short southern coast of Puerto Rico.

In distillation process development supported by the Office of Saline Water, U.S. Department of the Interior, Laboratory engineers have spearheaded the development of vertical-tube evaporators employing fluted or spirally grooved tubes. In single-tube heat transfer tests, the performance of these tubes has been far superior to the smooth tubes customarily used in vertical-tube evaporators. Most recent data indicate that conditions which promote foaming of the seawater as it flows through the vertical tubes will give even better heat transfer performance. Foaming flow in any type of vertical tube enhances the heat transfer rate and reduces fouling of the tube wall. The foam reduces the thickness of liquid layer on the tube surface, and as liquid evaporates from the film on the tube wall, the foam keeps the surface from drying.

ORNL, employing computer techniques and detailed scale models, has succeeded in designing large condenser bundles that minimize the possibility of collecting unwanted inert gas.

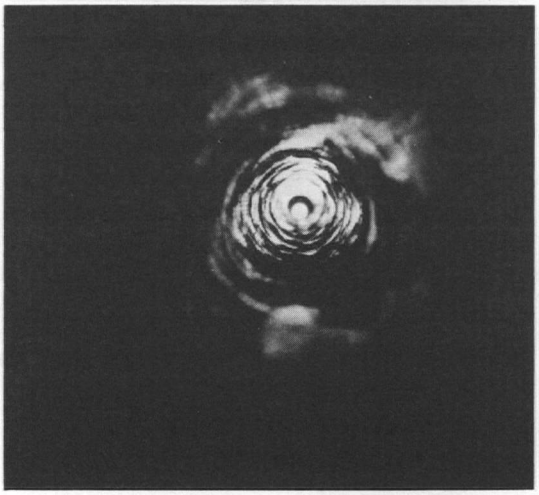
Based on the ORNL test data, a vertical-tube bundle with 10-ft fluted tubes was fabricated for the Office of Saline Water and installed in their million-gallon-per-day test bed plant at Freeport, Texas. Its heat transfer performance proved to be about two and a half times as good as the conventional 20-ft smooth-tube bundles in other vertical-tube effects of the Freeport plant. OSW has applied this information to the design of a two-effect module of a large vertical-tube evaporator called the VTE-X, which is being constructed at their West Coast Test Station at San Diego.

The horizontal tubes employed in flash evaporator stages and in feed heaters have also shown improved heat transfer performance as a result of new surface configurations. Tests showed that spiral grooves in the tube walls give enhanced heat transfer at a low increase in pumping power. A feed heater tube bundle, fabricated on the basis of ORNL design data and including spirally grooved horizontal tubes, was installed in the OSW's Freeport plant, where its performance was more than double the best of the original smooth-tube bundles in the plant.

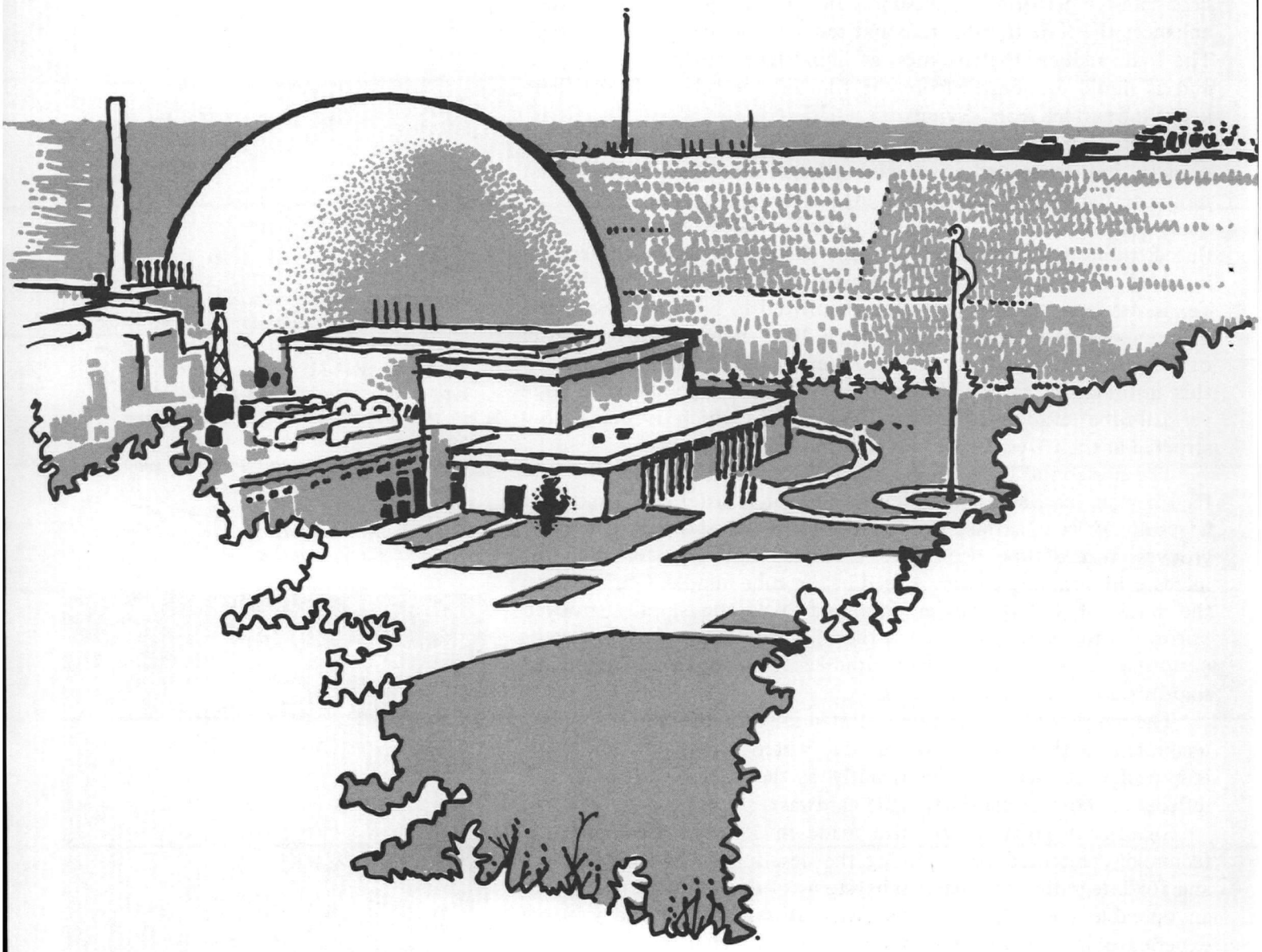
The net result of these demonstrated improvements in evaporator technology is that the cost of desalted water from distillation plants is expected to decrease significantly as the higher performance is reflected in commercially available hardware.

Significant progress was also made in 1969 in developing the technology required for coupling the desalting units with reactors and for integrating the many subsystems of dual-purpose plants into an operable unit. Test runs on evaporator plants yielded valuable experience in instrumentation techniques for large evaporators, as well as operating data that could be used on models in simulations.

View into a vertical evaporator tube. In a vertical-tube evaporator, salt water flows down the walls of a doubly fluted tube, leaving the center open for steam formed as the tube walls transmit heat to the film of water. The water flows down the tube wall in waves, which are clearly visible. The flutes of the tube wall can also be seen, perpendicular to the waves. When the water foams as it flows down the vertical tube, better heat transfer is obtained.



ORNL 1969 Nuclear Safety



Safety Research at ORNL

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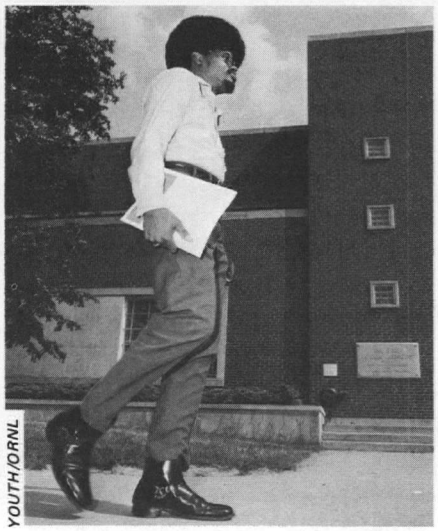
One of the vital tasks undertaken by the national laboratories has been to conduct studies and research through which the safety of nuclear power can be analyzed and established. The USAEC safety practices can be credited, in part, for the unparalleled safety record of the industry. Safety studies have become one of the largest programs at ORNL.

All materials, devices, and systems have limits beyond which they are no longer able to perform service. One aspect of safety research is to seek the levels of temperature, stress, radiation damage, or chemical attack where failure can be expected. The work described below involves experimentation for components of present-day water-cooled reactors. From such work, a reactor operating level can be chosen that assures an acceptable margin of safety. For the cases under consideration, needless to say, these margins are deliberately kept large.

In addition to its necessary function, however, there are other benefits that derive from safety research. Testing to actual or near failure frequently reveals valuable information concerning the behavior of materials or designs under study. Experimenters, by searching out these limits, speed up the development processes significantly.

Waste Disposal

Radioactive wastes are produced as by-products of the fuel cycle for the production of nuclear power, wastes that are hazardous and must be isolated from man's environment. More than 99% of the radioactive products of nuclear fission appear in the liquid wastes produced at the nuclear fuel reprocessing plants. These wastes must be converted to a form suitable for disposal in isolated, stable geological formations. Disposal in the oceans is not desirable, and shooting the waste residues into space is impractical. From many experimental studies we have chosen solidification of the wastes in sealed stainless steel pots and permanent burial in deep bedded salt formations as probably the safest disposal method. Also, it is not prohibitively expensive. Salt formations have been studied intensively, and trial burial of simulated radioactive waste pots in salt has been successful.



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The first process for solidifying high-level wastes developed at ORNL was a calcination process which produced a highly fired friable oxide mixture in stainless steel pots. Recently a modification of this process has been developed which produces a solid with higher physical stability and a higher overall thermal conductivity. In this new dispersion-in-glass modification of the calcinating process, high-level wastes are solidified, and the solid is dispersed in a glassy matrix. A dispersion in glass is preferable to a single-phase glass system or to a crystalline product, having some of the desirable properties of each, namely, the lower solubility (in water) of the glassy continuous phase and the higher thermal conductivity of the dispersed crystalline phase. Since the waste solids are dispersed – not dissolved – in the glass matrix, the dispersion can accommodate a wide range of types and amounts of solids. Solids from simulated aqueous wastes resulting from the processing of fuels from light-water, fast breeder, and high-temperature gas-cooled reactors have been dispersed in glass. Up to 60 wt % solids have been dispersed in glass as compared with 25 to 35 wt % dissolved in glass or ceramic products. The thermal conductivity of the dispersion products is about four times that of the calcined product, twice that of the glassy product, and roughly equal to that of the ceramic product. Additionally, the borosilicate glass used as a matrix for the dispersion-in-glass process has a lower melting temperature (800 to 900°C) and is relatively noncorrosive to stainless steel. Thus the process eliminates the platinum melter used by other processes in making glassy products and operates at a lower temperature. The rate at which radionuclides are leached by water is low, being between that of a ceramic and that of a glass.

The previous calcination and glass-making processes have been successfully demonstrated in a pilot plant at AEC facilities using full levels of radioactive wastes. The dispersion-in-glass process is scheduled for pilot-plant tests in mid-1970. Thus we are confident that a safe and practical method for treatment and disposal of the radioactive wastes from the nuclear power industry will be ready when required.

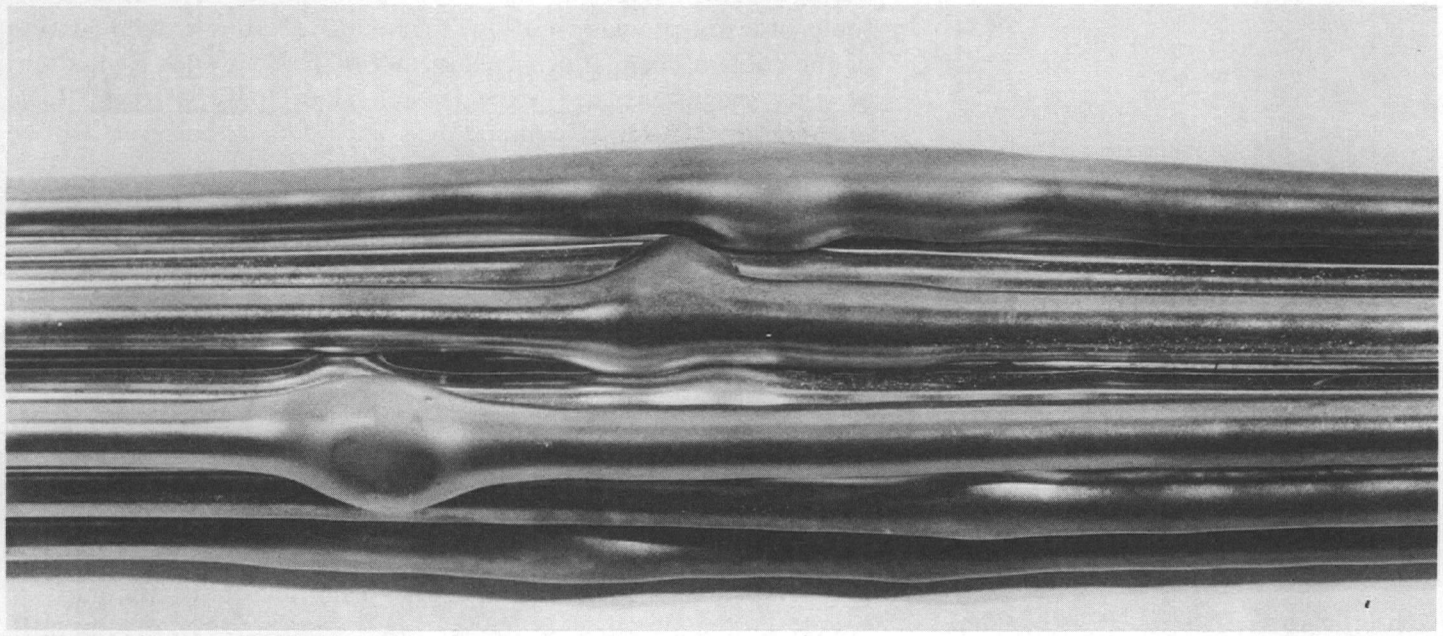
(a) (b)

The ORNL process for solidification of high-level radioactive wastes consists in evaporating and calcining the waste in a stainless steel pot 8 ft long and 8 in. in diameter. Either of two kinds of solid product can be produced – a calcine (a) *or a dispersion in glass* (b). *In the original calcination process, liquid waste was fed to a pot, concentrated, and then by continued heating, converted to calcine at 900°C. In the newer dispersion-in-glass process, the liquid waste is mixed with a borosilicate glass slurry, fed to the pot, concentrated, and calcined as before. In this case, the calcined particles are dispersed in molten borosilicate glass. The glass solidifies on cooling to form a mass which has low solubility in water and a high thermal conductivity. A stainless steel cap is then welded on the pot as a sealant and the pot transported to a final government disposal site.*

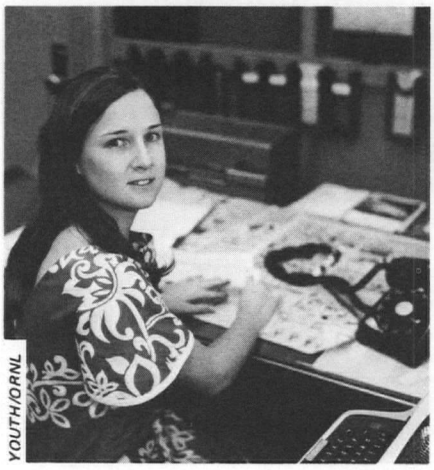
Fuel Rod Failure

The fuel of a modern light-water reactor is contained in about 40,000 long, thin zirconium alloy tubes which, in a bundle, constitute the core – the heat source – of the reactor. The radioactive fission products, both gaseous and solid, generated during power operation of the reactor are normally retained either within the fuel or inside the tubes. Further protection is provided by the pressure vessel surrounding the core and still further by the containment building with its associated fission product suppression systems.

At ORNL, a concerted effort is under way to assess the modes of failure of the fuel rod cladding in terms of accident conditions and reactor operating history, to learn how deformation and rupture may affect emergency cooling capability, and to ascertain what margin of safety exists relative to the above.



A bundle of tubes, simulating fuel rod cladding, that has been subjected to a very rapid rise in temperature (100°F/sec) with an internal pressure of 200 psig. All of the tubes ruptured between 1800 and 1850°F. In one post-test examination, no reduction of the coolant channel occurred greater than 60%.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In these studies, accident situations are postulated which result in the breach of one or more of the reactor's protective barriers. In one such contingency, the loss-of-coolant accident, the reactor's primary coolant vessel is considered to have been breached. In such a situation the cladding of the fuel rods could be heated rapidly to temperatures higher than the reactor's designed operational temperature range. This temperature rise would come from three sources: the stored energy in the fuel, the decay heat of the fission products, and the phenomenon that at temperatures above 2000°F a reaction between the zirconium alloy cladding and any water vapor present also produces heat.

Should such a surge of heat occur faster than the emergency cooling systems could go into effect, parts of the core could reach temperatures high enough to cause rupture of the fuel rod cladding, releasing gaseous and volatile fission products into the containment vessel, there to be dealt with by the fission product suppression system, an additional safety device.

A series of tests, multirod transient burst experiments, have been conducted at ORNL. Finding that cladding rupture is preceded by deformation, studies have been made to evaluate the effects of temperature excursions on coolant channels between the rods and the effects of rod interactions on failure behavior. In these tests the temperature starts at about 600°F, the nominal cladding temperature during reactor operation, and elevates until all rods have ruptured. In the post-test examination of one such multirod bundle, no reduction of the coolant channel occurred greater than about 60%. Reductions of this magnitude are expected to cause only a slight local temperature lag during cooling. This expectation, however, will be confirmed by further experiment.

Heavy Section Steel Program

One of the major safety research programs on light-water power reactors is the Heavy Section Steel Technology Program. The primary emphasis is on the structural behavior of reactor pressure vessels in the presence of flaws. The major research is currently focused on the transitional and tough behavior of thick-section ASTM A 533 grade B, class 1 steel. Tests of large 12-in.-thick specimens, in which they were subjected to drops of 25-ton weights from a height of 15 ft, demonstrated that the steel, when in thick section, significantly increases in toughness within a relatively short temperature range – between 150 and 200°F – indicating that the thickest reactor vessels planned will be tough enough to stand up under design conditions. Results from testing the tensile strength of

large flawed specimens further support the conclusion that significant plastic deformation will precede fracture at temperatures above the mentioned range. These tests provide valuable, although qualitative, experimental confirmation of the theory that thick pressure vessels have high resistance to crack propagation even when they contain large flaws.

Further experiments are being designed for predicting fracture at any temperature and with various sizes of flaws.

Fracture surfaces of a heavy-section steel specimen containing a part-through flaw are examined following a tensile strength test. The test temperature was 215°F. The nature of the shear surfaces demonstrates the tough behavior. The maximum load reached on the specimen was 7,550,000 lb; the predicted load was between 7,350,000 and 7,575,000 lb.

ORNL 1969 Research and Development

Physics

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Neutron Polarization Analysis: A New Dimension in Neutron Diffraction

Neutron diffraction has long been an important and active area of research at Oak Ridge National Laboratory. The first experiments were carried out at the ORNL Graphite Reactor about 25 years ago and were intended to exploit what was then considered the high thermal-neutron flux (10^{12} neutrons cm^{-2} sec^{-1}) of the reactor for the study of solids. Applications were soon to be made to a wide variety of problems: among them were determining the crystal structures of hydrogen-containing compounds, magnetic structures of antiferromagnetic and ferrimagnetic materials, and the distribution of magnetic moment density in ferromagnetic alloys.

Those early experiments, as well as many being performed today, are what are called "elastic" neutron scattering experiments. They are typically performed on a double-axis instrument which holds a monochromating single crystal on its first axis of rotation. The reactor gives off a beam of neutrons of all energies, but when the beam hits the monochromator a narrow range of neutrons is selected by Bragg reflection from the crystal, resulting in a comparatively monoenergetic beam reaching the experimental sample on the second axis. The intensity of the scattered neutrons, proportional to the scattering cross section, is then measured as a function of the scattering angle.

Early in the ORNL experiments it was demonstrated that additional sensitivity was achieved for certain magnetic scattering experiments by using a polarized monochromatic beam, a technique that became more fully exploited as high-flux reactors were developed.

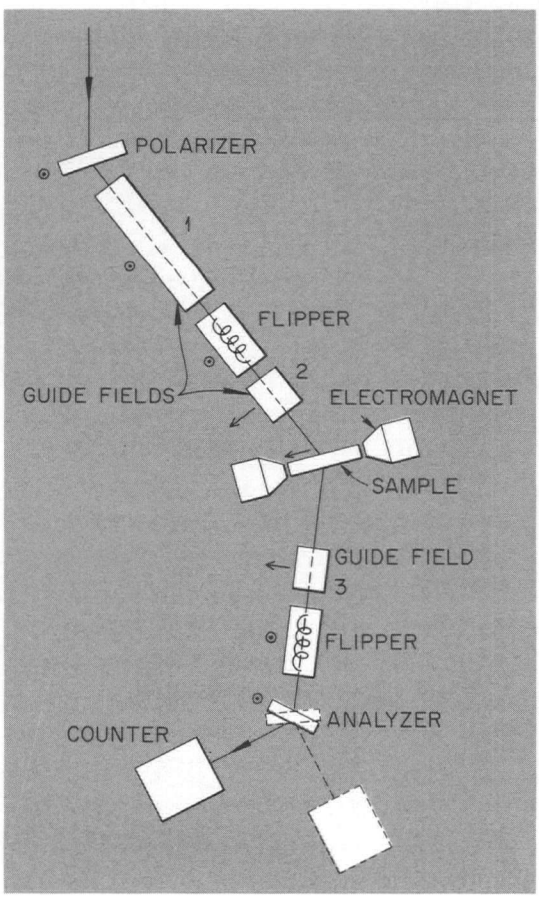
The usual polarized-beam instrument is a two-axis diffractometer using a polarization-sensitive crystal, typically a magnetized single crystal of an alloy of cobalt containing 8% iron.

Now an unpolarized beam, such as comes out of a reactor, may be considered to consist of two beams, one with neutron spin parallel to the direction of magnetization of the Co-Fe crystal and one antiparallel. The reflectivity of this crystal is very poor for neutrons with spins antiparallel to the magnetizing field; hence ideally only neutrons with spins parallel to it are diffracted by the monochromator.

In the usual polarized-beam experiment a "flipper" is introduced into the monochromatic beam which reverses the neutron polarization. Then the angular distribution of the scattering cross section of the sample is measured for neutrons of specified initial energy and spin regardless of the spin and energy after scattering. The scattering cross section is said to be averaged over the final spin and energy distributions. Information about the sample is lost in these averages.

With the advent of the second-generation reactors, with fluxes in the range of 10^{13} to 10^{14} neutrons cm^{-2} sec^{-1}, methods of inelastic neutron scattering came into being. One technique uses a triple-axis spectrometer in which a second crystal similar to the monochromating crystal is placed on the third axis, beyond the sample. This crystal then determines, by Bragg reflection, the energy of the scattered beam, just as the monochromator determined the energy of the incident beam. The technique is usually applied to the measurement of thermal vibrations in crystals, that is, lattice dynamics, or of the corresponding excitations in magnetically ordered systems. What is measured, in a typical case, is the distribution, in both angle and energy, of initially unpolarized monochromatic neutrons averaged over the final spin distributions.

A triple-axis spectrometer has been using the Oak Ridge Research Reactor's neutron flux of 6×10^{13} for the past five years. Because the three scattering processes take a heavy toll of the beam's intensity, the overall efficiency of such a device is low, requiring a high-intensity source. Thus the power of neutron spectrometry was not fully exploited at ORNL until a triple-axis instrument was put into operation at the High Flux Isotope Reactor, with its flux of 2×10^{15} neutrons cm^{-2} sec^{-1}.



The maximum information about a scatterer is contained in the partial cross sections for scattering of neutrons between well-defined states of momentum and spin. To measure such cross sections one needs to prepare a monochromatic polarized beam and to observe the distribution of scattered neutrons in angle, energy, and spin. Recently the new dimension of polarization analysis has been added to neutron diffraction at ORNL by the construction, at the HFIR, of a triple-axis spectrometer with polarization-sensitive crystals on the first and third axes.

The experimental arrangement is shown schematically in the accompanying drawing. A Co-Fe crystal mounted in the gap of a permanent magnet is used on the first axis for the production of a polarized monochromatic beam and on the third axis for analysis of the scattered neutrons in energy and spin. The sample is mounted in the gap of an electromagnet located on the table of the second axis. This electromagnet has a horizontal rotation axis, so that the field is easily changed from vertical to horizontal. Guide fields (1, 2, 3) are introduced to maintain the beam polarization in different parts of the instrument. Of these the fields 2 and 3 can be rotated so that the neutrons can be brought into or out of the field of the electromagnet in either a vertical or a horizontal orientation. Radio-frequency coils with a vertical guide field are used as flipping devices. Arrows

adjacent to the guide fields in the figure show the direction of the magnetic field sensed by the neutrons.

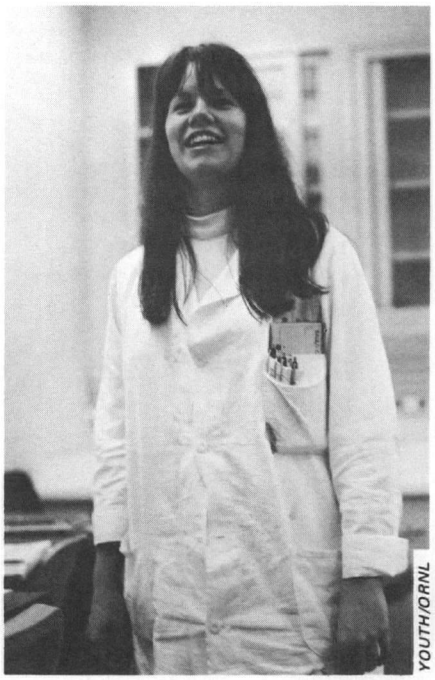
The overall efficiency of the system can be measured by rotating the analyzing crystal into the incident beam and measuring the ratio of neutrons reflected by the analyzer with the flipper "off" and "on." This flipping ratio varies with wavelength and beam size between 80 and 180. The performance in the horizontal field configuration is nearly identical to that in the vertical field configuration. A flipping ratio of 100 implies that the beam polarization and flipping efficiency are both in the range 0.98 to 1.0. Corrections to account for instrumental imperfections can be calculated, but for many experiments the instrument is good enough so that these corrections are negligible.

The operation of the instrument is most easily discussed in terms of idealized performance. The Co-Fe crystals are considered to be devices which have zero reflectivity for neutrons with spin polarization antiparallel to the field direction on the crystals. We refer to such neutrons as (–) spin neutrons. Those with spins parallel to the field are designated as (+) spin neutrons. The flippers are considered to be perfectly efficient in changing the neutron spin from (+) to (–) or conversely.

With both flippers off, the beam incident on the sample is in the (+) spin state. The analyzer will reflect only those neutrons incident upon it which are in the (+) spin state. Therefore only those neutrons which are scattered without change of spin state will be detected. Thus the partial cross section (++) for neutrons in (+) initial and final spin states is measured. With the first flipper activated, the incident beam is in the (–) state. In this case, only those neutrons which reverse their spins on scattering are reflected by the analyzer into the counter. Here the partial cross section (–+) is measured. Similarly, with the second flipper on, the cross section (+–) is measured, and with both circuits operative the (––) cross section is observed. It is convenient to talk of spin-flip scattering (+–) and (–+) and non-spin-flip scattering (++) and (––). Energy analysis is obtained as in any triple-axis instrument by variation of the angular positions of the analyzing crystal and counter. Thus the partial cross sections between well-defined neutron states mentioned above are in principle measurable with this instrument.

The most fruitful applications of polarization analysis are to problems in which spin-dependent scattering processes are to be identified. This is a result of the fact that components of the effective spin of the scatterer which are parallel to the neutron polarization produce non-spin-flip scattering, whereas components normal to the neutron polarization produce spin-flip scattering. Under the proper experimental conditions all magnetic scattering is the spin-flip type.

The areas of useful application of this technique include (1) separation of nuclear from magnetic Bragg scattering by antiferromagnets, (2) separation of magnon from phonon scattering by ferromagnets and antiferromagnets, (3) separation of paramagnetic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scattering from other types of incoherent scattering, and (4) separation of coherent from spin-incoherent nuclear scattering in solids and liquids. A wide variety of demonstration experiments on known samples have now been performed.

New information, not obtainable in other scattering experiments, has recently come to light as a result of this technique, information that elucidates the magnetic structures of the compounds Ti_2O_3 and V_2O_3, an example of application 1 above. For applications of type 3 the paramagnetic form factor of Gd^{3+} in the compound $^{160}Gd_2O_3$ has been measured. As an example of type 4 the ratio of coherent to incoherent proton scattering in a study of the vibrational spectrum of NH_4Cl has been deduced. Spin-wave measurements on gadolinium-160, an experiment of type 2, are in progress.

Unfortunately, even with the high neutron flux of the HFIR, serious intensity difficulties limit the present application of this technique. This is particularly true of impurity scattering experiments, for which this method is in principle ideally suited.

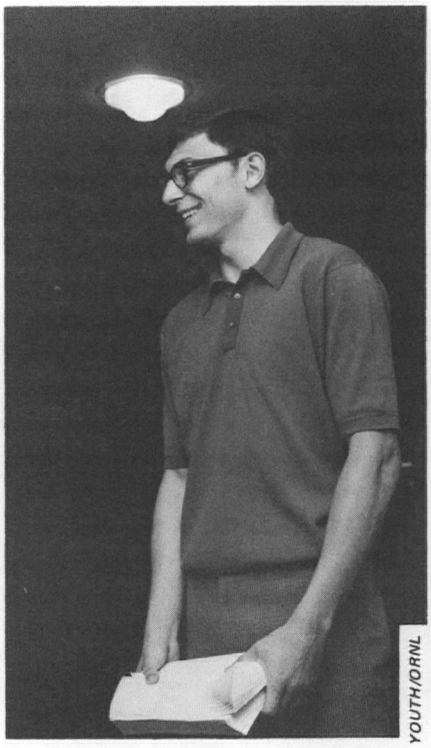
To overcome this limitation, considerable effort is being made at the Laboratory to develop more efficient polarizer-monochromators. From the point of view of reflectivity and ease of crystal growth, elemental iron has excellent properties. In the ordinary isotopic mixture, however, the polarization efficiency is very low. Of the isotopes of iron which exist, iron-57 has nearly the right scattering

This computer-driven triple-axis neutron polarizer is installed at the base of ORNL's High Flux Isotope Reactor.

properties to make a highly efficient polarizer. The AEC has authorized a program of separation of large amounts of iron-57 enriched to 85% for the purpose of preparing neutron polarizer-monochromators. The first 200 g will be used at ORNL; ultimately, 1 kg of this material will be collected and made available, as a national resource, to neutron diffraction groups all over the country. A gain in intensity at the counter of a factor of 30 over the Co-Fe crystals is anticipated.

A similar gain for more specialized applications may be achieved with manganese ferrite crystals. Developmental work on the preparation and growth of such crystals is in active progress at the Laboratory.

With these improved polarizer-monochromators and with the triple-axis instruments at the HFIR, many more areas of research, in many new dimensions, will be accessible to neutron diffraction at ORNL.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Weapons Radiation Shielding Computations

Many of the activities of the Atomic Energy Commission have a common expensive element in the matter of radiation shielding. Shielding questions are ubiquitous; they appear in the design of reactors, space vehicles, and accelerator facilities, in the handling of radioactive materials, and in the estimation of nuclear weapons effects.

For years the Neutron Physics Division has concerned itself with shielding; in fact, it was the original reason for the division's existence. The objective has always been to develop a calculational ability sound enough to give quick and reliable answers, thereby obviating expensive engineering tests by ORNL and others.

A milestone was reached in 1969, when the division released a comprehensive set of "air transport results" on computer magnetic tape. This problem pertains to shielding against the radiations from a weapon burst in air, and it answers the question, At a given time and a given distance from the burst, say a mile, how many neutrons are headed in each direction and with what energies? The calculations not only estimate the neutrons coming directly from the weapon, taking into account their capture and scattering in the air and ground, but also specify the field of gamma rays produced secondary to the neutron capture and scattering.

There are two general methods of attacking computations of this kind. One is the Monte Carlo method, in which each neutron is followed from random collision to random collision in its flight through matter, with probabilities applied at each collision to specify the relative likelihood of this or that change in the neutron's energy and direction or its disappearance by capture. When a large enough sample is used (say 100,000 neutrons), a statistical answer will indicate how many neutrons are likely to arrive at a given point and what their energies and directions of flight will be. Monte Carlo is, in fact, a "computer experiment."

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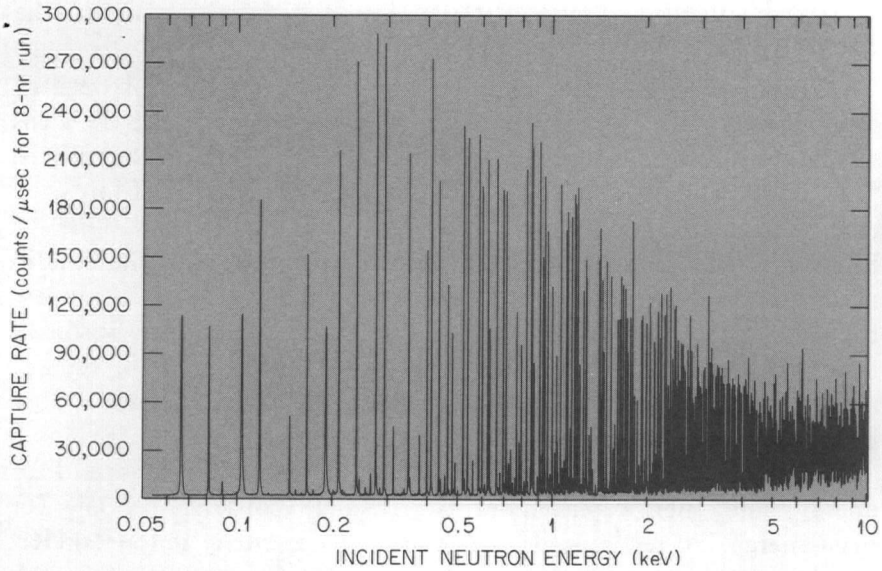
The other method is called the method of discrete ordinates. The shield (in this case air or ground) is considered to be subdivided into many space cells, and the neutrons are divided into different energy groups. The calculation is based on a balance between the neutron gains and losses in each cell. It starts with the highest energy group and sweeps through all the space cells in the system for all particle directions. Several sweeps (iterations) are required before the results converge to give the number of neutrons in each energy group in each space cell that are traveling in each direction. The procedure is repeated for each energy group in decreasing order. The final result is information about the number and the energy spectrum and the directions of motion of neutrons through the shield.

Obviously, calculations of this kind are massive and require the best of modern computers. With our new 360/91, the air-transport calculations took about 60 hr, but if we had used our "high-speed" computer of the early 1950's, the ORACLE, they would have taken 1000 years. The major portion of the work has been the development of computer codes, but the codes can be used for other types of transport calculations and are now available on magnetic tape from ORNL's Radiation Shielding Information Center.

The Oak Ridge Linear Accelerator

During 1969, ORELA, the high-current, short-pulse electron linear accelerator for neutron cross-section measurements, passed its acceptance tests, and several experiments were launched. Since acceptance on August 25, the accelerator has operated for over 1000 hr for neutron cross-section experiments. Six of the eleven paths have been used, and measurements have been made with flight paths of from 10 to 80 m. As many as three experimenters have taken data or have been "debugging" experimental equipment simultaneously. The time-of-flight data have been stored in two small computers having fixed-head disks, each of which can accumulate hundreds of thousands of channels of data.

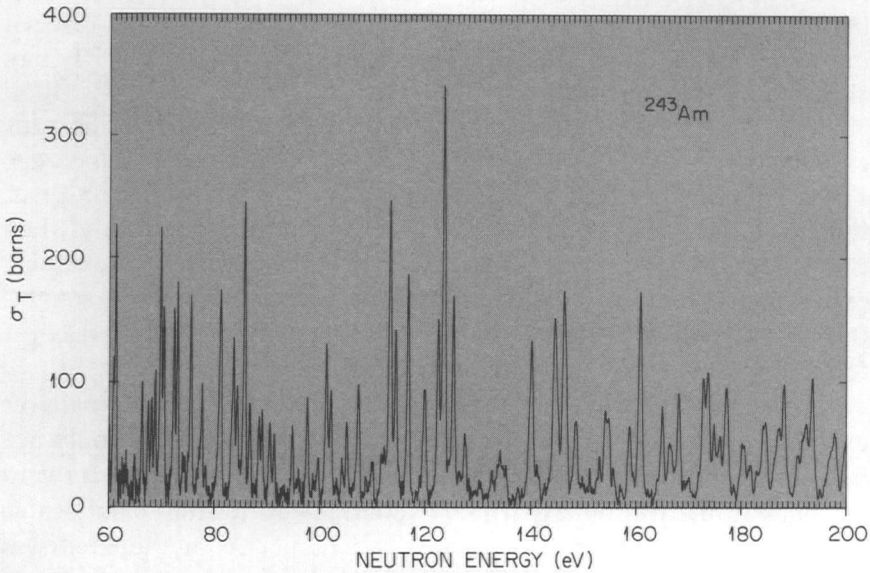
Two experiments in progress are of vital concern to designers and operators of breeder reactors. The results of an accurate measurement of the variation of the ratio of the number of fission neutrons to neutrons absorbed for uranium-233 within the significant energy range will appreciably reduce the largest nuclear data uncertainty for uranium-thorium breeder reactors. For plutonium-uranium fast breeder reactors, the capture cross section of uranium-238 in the keV neutron energy region is the cross section of greatest significance for calculations of the reactor performance. An excellent quality of capture cross-section data was achieved with a 0.635-mm-thick uranium-238 sample in a large liquid-scintillator detector located 40 m from the target. The results obtained from this experiment can be analyzed to give the neutron capture in individual resonances up to several keV neutron energy and the average capture cross section at higher neutron energies. The large scintillator tank combined with a



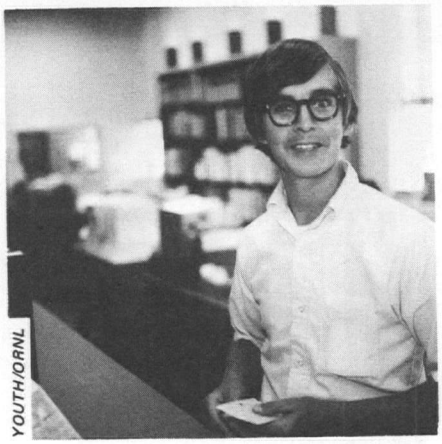
Violent fluctuations characteristic of the behavior of neutron cross sections in the "resonance" energy region are shown for uranium-238 in the keV energy region. The neutron energy is obtained from the velocity of the neutron, computed from the measured neutron flight time over a known distance. This cross-section information must be obtained with great detail, as shown in the figure, in order to calculate the performance of plutonium-239–uranium-238 breeder reactors.

fission chamber will be used to measure the ratio of the capture to the fission cross section for fissile nuclides up to hundreds of keV neutron energy.

Neutron time-of-flight data were taken using a small sample of americium-243 in the neutron beam (a transmission measurement). The data were taken with a lithium-6 glass scintillator at 18.5 m, 20-nsec bursts from the accelerator, and over 100 million 1-nsec timing channels. In the energy range 60 to 200 eV, the energy resolution ($\Delta E/E$) is not more than 0.3%. Over 100 resonances were observed in this energy region, whereas previous measurements with similar-sized samples yielded only parameters for resonances up to about 30 eV. This work is part of a cooperative program between physicists at the ORELA, Savannah River Laboratories, and Idaho Nuclear Corporation to obtain neutron cross-section measurements on small samples of radioactive transplutonium nuclides.



The "transmission" of a small sample of americium-243 shows the existence of over 100 resonances in the energy region 60 to 200 eV. Since the neutron resonance spacings of the transplutonium nuclides are small, very good neutron energy resolution is needed to resolve individual resonances.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Time-Reversal Invariance

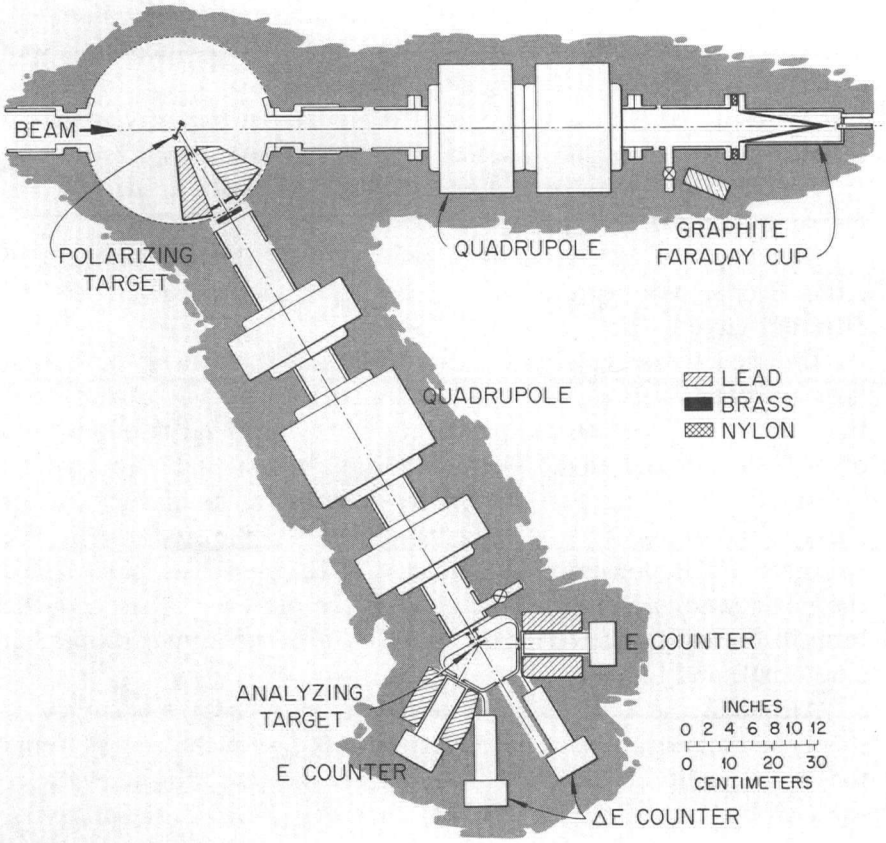
Conservation laws and symmetry principles have always been of great interest to scientists because they are basically simple ideas which are useful in describing a wide variety of phenomena. Perhaps the oldest and best known of the conservation laws are the conservation of energy and the conservation of mass. One of Einstein's most important contributions to physics was the combination of these two conservation laws into a single conservation law for mass-energy. Mass is now thought of as one of the many forms of potential energy which can be transformed into kinetic or radiant energy, and it is in this way that we now understand energy production in stars or in nuclear reactors.

The "downfall" of individual conservation laws for mass and for energy, and their replacement by a single conservation law for mass-energy, is recognized as a great advancement in our understanding of nature. The years between 1952 and 1956 saw the "downfall" of two other symmetry principles, charge-conjugation symmetry (C) and parity conservation (P), and their replacement by a single conservation law involving charge conjugation and parity combined, CP, just as mass and energy are now combined. Charge-conjugation symmetry means that if you could examine a motion picture record of physical phenomena you could not tell whether matter or antimatter was the actor. Parity conservation implies that from examination of the movie you could not tell whether the camera was recording the action directly or indirectly by way of a mirror.

That all elementary particle phenomena obeyed CP symmetry was the accepted rule until 1964, when a group of physicists from Princeton University reported violations of this principle in certain high-energy events. Now a famous theorem, the CPT theorem, states that the combined operation of charge conjugation, parity (or mirror) transformation, and time reversal (T) should be unchanged for a given type of phenomena. Thus a violation of CP symmetry is indirect evidence of a violation or breakdown in time-reversal invariance, since T must compensate for CP in order that CPT may always have the same value.

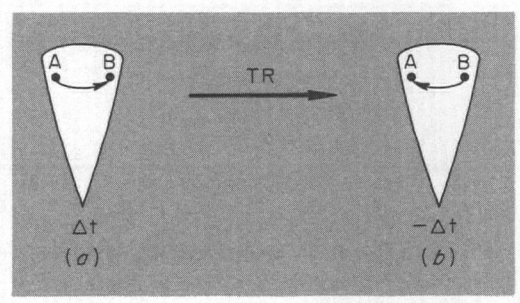
The discovery of CP violation has thus stimulated a host of experiments to detect direct violations of time-reversal invariance. These experiments have the following elements in common: First, they examine particle phenomena which can behave differently when the direction of time is reversed; second, they are exacting experiments requiring high precision because the effect sought, though of great importance, is very small; and third, no one has yet found any direct violation of time-reversal invariance.

According to the time-reversal invariance concept a viewer examining a motion picture record of particle phenomena should not be able to tell whether the projectionist is running the film forward or backward. In an experiment conducted at the Oak Ridge Isochronous Cyclotron, the particle phenomenon investigated was



In the measurement of polarization P at ORIC, the unpolarized proton beam impinges on a polarizing target (either carbon-12 or carbon-13) at the center of a scattering chamber. The undeflected beam is collected in a Faraday cup, while the scattered beam (a scattering angle of 60° was used) is transported by means of a quadrupole magnetic lens system to the second scattering target, carbon-12. The known polarizing power of carbon-12, together with a counter telescope measurement of the number of protons elastically scattered to the left and right of the second scatterer, provides a determination of P in the first scattering. The measurement of asymmetry A is similar except that the second scatterer is either carbon-12 or carbon-13 and the first scatterer is chosen to produce a scattered beam of known polarization.

the spin flip of protons elastically scattered from a carbon-13 target. Both protons and carbon-13 nuclei possess spin in the manner of simple tops. When the movie record of a clockwise-rotating top is run backward, the top appears to be rotating counterclockwise. The margin drawings show the path followed by a typical point on the surface of a spinning top. We see that a point initially at position A moves to the position B in the time interval Δt for a counterclockwise rotation when viewed from above. Stopping the movie record of this motion when the point is at position B and running the film backward (the operation of time reversal, T) we see the point move from position B back toward position A – a clockwise rotation when viewed from above.



Thus a spin-flip event from spin up to spin down (↑↓) would appear as a spin flip from spin down to spin up (↓↑) when reversed in time. The left-right elastic scattering asymmetry, A, measured with a polarized beam of polarization P_B is related to the polarization P produced by elastic scattering of an unpolarized beam as follows:

$$A = P_B\{P + 2(\uparrow\downarrow - \downarrow\uparrow)\} .$$

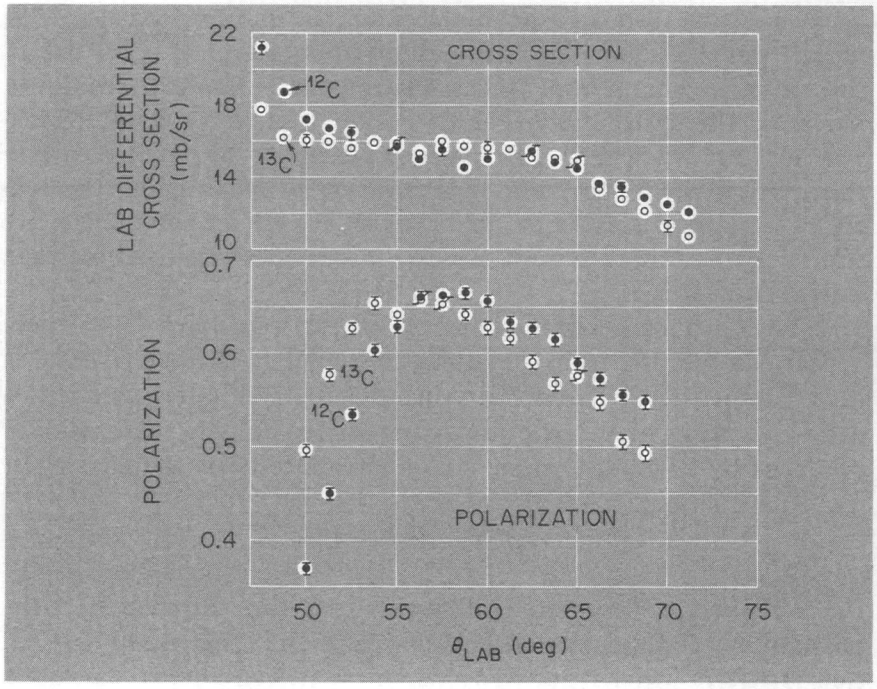
Here ↑↓ and ↓↑ are probabilities for the two different spin-flip possibilities. If time-reversal invariance is valid, that is, if ↑↓ = ↓↑, then $A = P_B P$, which is the so-called polarization-asymmetry relation.

Spin flip in the elastic scattering of protons from a spin-zero target does not occur if parity and angular momentum are conserved. Therefore we measure both A and P for carbon-13 (which has a spin equal to $\frac{1}{2}$) relative to the same measurements on carbon-12 (with spin equal to 0), where spin flip is forbidden. In this way we avoid the necessity for measuring either the absolute beam polarization P_B or the absolute analyzing power of the analyzer needed in the measurement of P.

Starting from an unpolarized proton beam, the measurement of either P or A requires the beam to be scattered successively by two different targets.

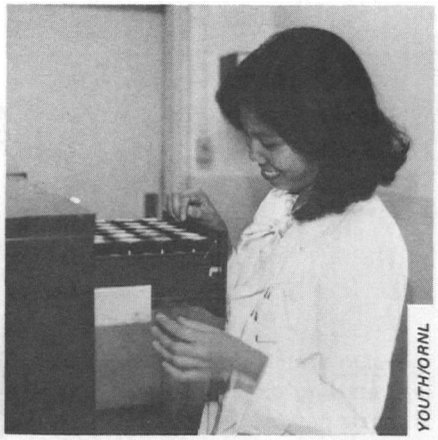
Detailed measurements on carbon-12 and carbon-13 show that near a proton energy of 33 MeV and a scattering angle of 60° both the elastic cross section and polarization are slowly varying functions of both energy and angle. These conditions are favorable for making a test of the polarization-asymmetry relation, since corrections for energy variations and misalignments are minimized. With the Laboratory's isochronous cyclotron, ORNL physicists have tested the polarization-asymmetry relation for the presence of the spin-flip term in the elastic scattering of 32.9-MeV protons from carbon-13 at a 60° angle and find $\uparrow\downarrow - \downarrow\uparrow \leqslant |0.004|$.

Although the Oak Ridge experiment improved the accuracy of this type of measurement by a factor of 100, no evidence was found for a nonequality of the two spin-flip processes, and thus no evidence for a violation of time-reversal invariance was provided. Nevertheless, this experiment and the many others of similar nature are part of the search in what may be as important a revolution of physical theory as the "downfall" of the conservation of energy or the "downfall" of the conservation of parity.



The elastic scattering cross section and the elastic polarization of 32.9-MeV protons from carbon-12 and carbon-13 are shown on expanded scales. The slow variation of both quantities with angle near 60° minimizes misalignment errors in an experiment to check the polarization-asymmetry relation. Such a check for the elastic scattering of protons from carbon-13 provides a test of time-reversal invariance in the spin-flip process.

The Nucleus: A Many-Bodied System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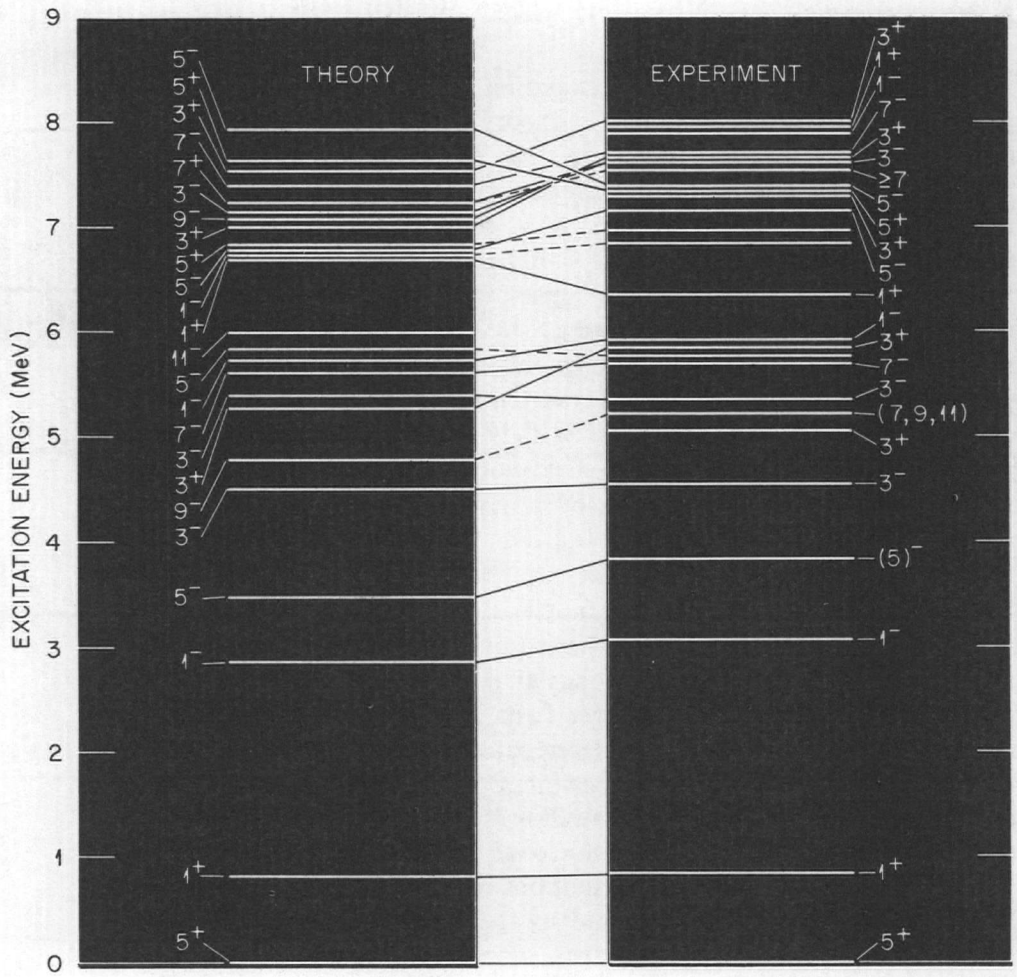
Fundamental to a real understanding and a mastery of nuclear processes is the development of a theory of nuclear structure. The objective of such a theory is to find a method to construct a mathematical function called a wave function which describes a given nucleus. Given such a function, it is possible to calculate those properties of the nucleus which can be observed experimentally, namely, the mass, the allowed energies of the states of excitation of the nucleus, the amounts of energy that can be emitted by the nucleus in the form of electromagnetic radiation (gamma rays) or particle radiation (alpha or beta rays), the rate at which this energy is emitted, etc. One of the most widely used models of nuclear structure theory is the so-called shell model. In the shell model the nucleus is assumed to consist of a given number of nucleons, neutrons or protons. There exist between nucleons various attractive and repulsive forces. Thus there are many forces of interaction between all the nucleons in the nucleus. The fundamental assumption of the shell model is that the major effect of all these mutual interactions is such that the nucleons all move independently of each other in one common central force field. Any effects due to specific mutual interactions between nucleons can then be calculated as small corrections by well-known procedures. This picture allows the construction of a nuclear wave function in which the coordinates are the coordinates of the individual nucleons of the nucleus.

The types of shell-model calculations which have been possible in the past have been severely limited by the amount of computational labor required. Laboratory scientists, in collaboration with scientists at the University of Rochester, have developed a system of computer programs to carry out such calculations. The system is the most powerful of its kind, and it is now in use in a number of laboratories in this country, as well as in Canada, Holland, Germany, and France.

There are a variety of significant investigations of nuclear structure which are possible as a result of the development of this system. In the sense that the shell model pictures the nucleus as a collection of nucleons, it is a microscopic theory. Many of the observed properties of nuclei can be accounted for by a macroscopic, or collective, model. In this picture the nucleus consists of a fluid-like material with a shape, a density, a surface tension, etc. It has been found that many of the collective properties of the nucleus are exhibited by this microscopic model.

A given nucleus can exist in a number of states with different excitation energies. There have been numerous cases in which it has been necessary to apply several different models to different excited states in the same nucleus. A particular example of this is the set of oxygen isotopes. One shell-model calculation, carried out through a collaboration of scientists at Brookhaven National Laboratory and Oak Ridge, has now been made which accounts in a unified way for properties of a majority of the states at low excitation in the oxygen isotopes. An example of this is shown in the figure, where the



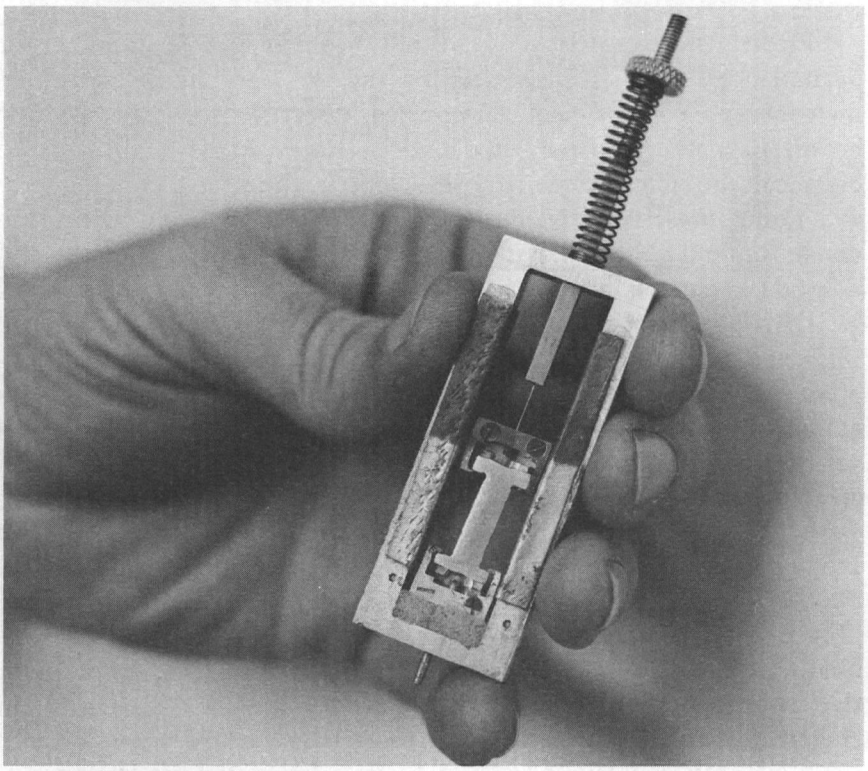
Calculated and observed energy levels of oxygen-17. The numbers beside each level are twice the total angular momentum of the indicated level. The lines between the two level diagrams connect the calculated level with the assumed analog in the experimental spectrum. If the calculation were perfect, all the lines would be parallel.

spectrum of excited states of oxygen-17 as determined from experiment is compared with the spectrum calculated from the shell model. No previous single calculation could account so well for all the observed low-lying levels of oxygen-17. The results of this calculation and others similar to this are of great interest to the field of astrophysics. Accurate information on the properties of the excited states in these light nuclei is essential to the understanding of the isotopic composition of stellar material. Obviously, accurate calculations of these properties are very useful when it is not possible to determine them experimentally.

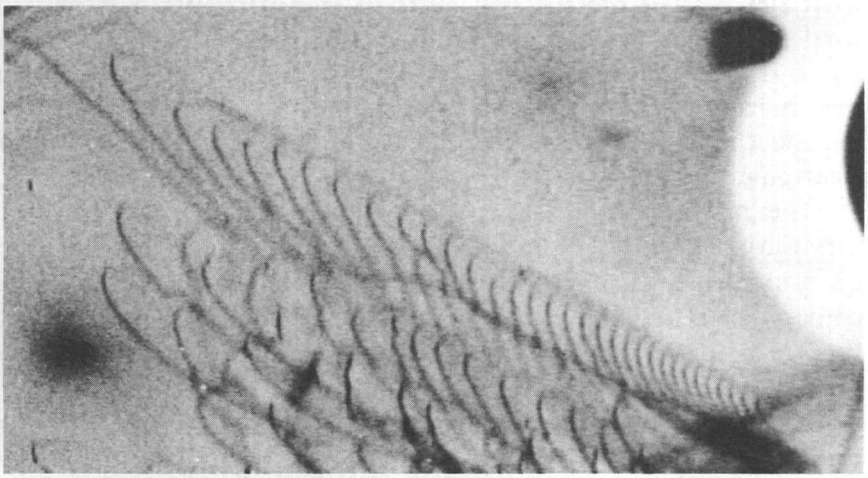
The nucleus is one example of a many-body system. Many-body systems are encountered in all branches of physical science. Two other examples are the complex molecules of molecular biology and the plasmas encountered in thermonuclear processes. The theory of many-body systems is thus relevant to all these fields. The nucleus is one of the best "laboratories" for the study of many-body systems. It has a relatively small number of bodies, yet it exhibits collective properties. Thus shell-model studies of the nucleus can contribute in a very direct way to understanding the other many-body systems in nature.

X-Ray Topography

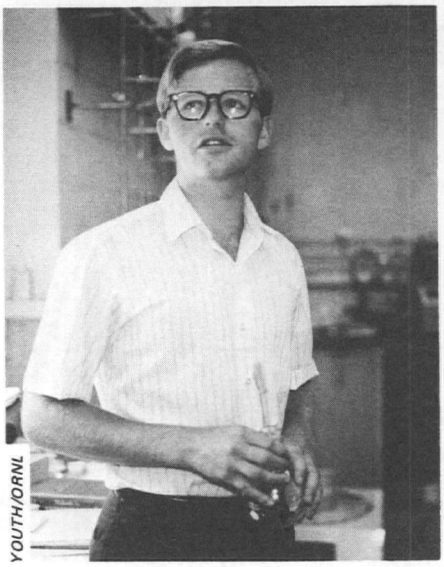
In the Laboratory's program of studies to assess radiation damage, it is very helpful to be able to observe the actual defect structure inside certain materials. A method has therefore been devised for photographing the defects that are produced in the interior of a crystal of a metal as it is placed under stress. Topographs of the deformation process of metal crystals, such as are seen here, give insights valuable to reactor designers. A refinement of this work is the development of stereo topographs that permit a three-dimensional view of the interior dislocations.



View of a nearly perfect copper crystal, 5 mm by 1 mm in cross section, mounted in a jig. The I-shaped metal piece can be stretched by rotating the thumbscrew at the top against the spring. Internal defects generated in the copper by placing it under tension may be observed by special x-ray techniques (Borrmann topographs) which show the induced faults as dark spots or lines in an otherwise featureless photographic image (see below). This technique is applicable only to nearly perfect crystals, whose preparation is an art in itself.



An x-ray transmission topograph or photograph showing the location in depth of a group of about 30 dislocations produced and moved from right to left into an initially perfect region of a copper crystal by an applied tensile stress of approximately one-third of an atmosphere (5 g/mm^2). The dislocations terminate at the crystal surface and curve inward to the lower right.



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Physics Division's electron spectrometer for the study of chemical bonding in many kinds of matter, from tRNA to moon dust.

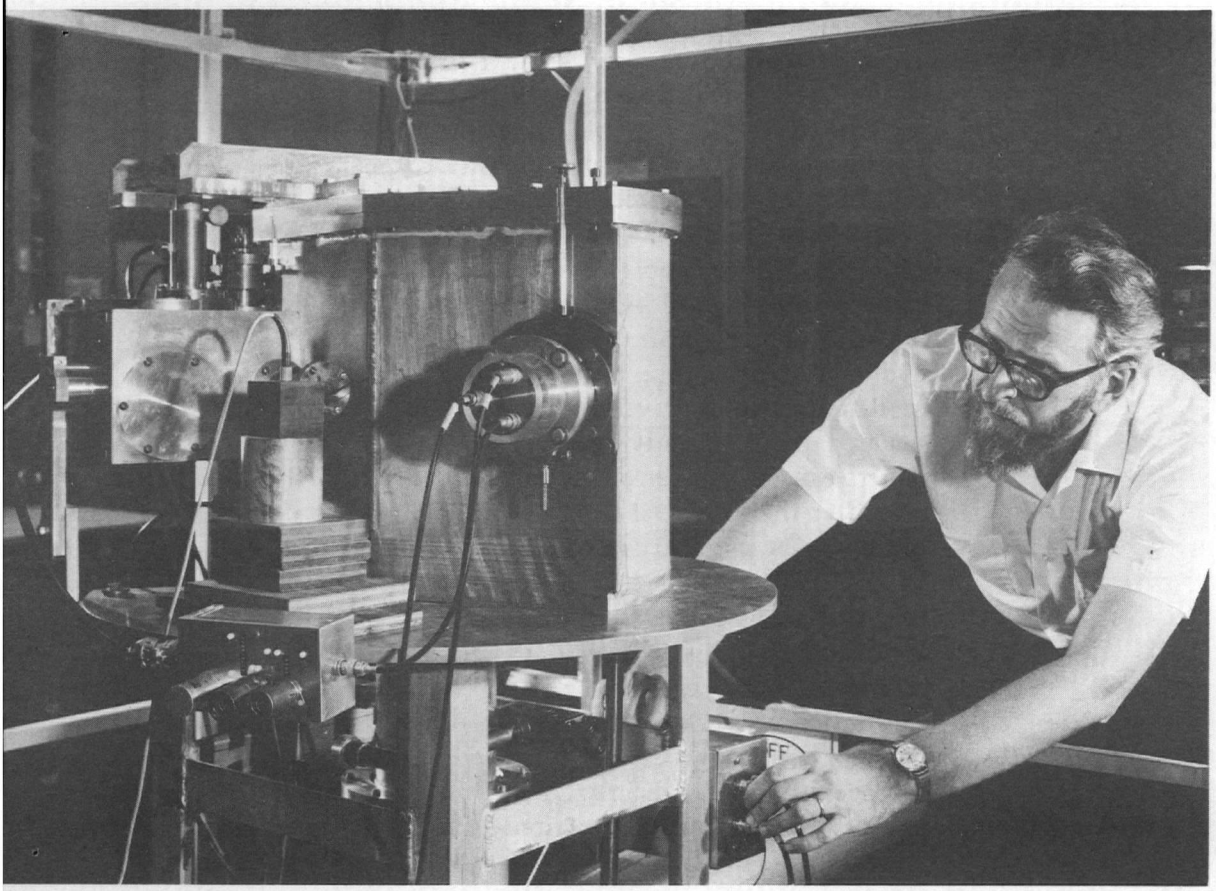
Chemistry

Electron Spectroscopy in Chemistry

Electron spectroscopy is an old tool. It has been used, for example, by nuclear physicists for many years in the study of high-energy electrons ejected in nuclear decay. In the last few years, however, there has been almost a revolution in its application to chemical problems. Chemistry has long required a technology for examining low-energy electrons from 0.1 to 1000 eV with high resolution and good detection. This challenge has now been met, and a flood of research in new and unexpected fields is emerging.

ORNL researchers in chemistry and physics have taken part in this development, and we have now built three electron spectrometers that have the necessary requirements for the work. The main application of high-resolution electron spectroscopy to chemistry is to measure the binding energies of the different atomic shells with great accuracy as a function of their chemical environment. This is done by knocking out an electron with a soft x ray or photon and then measuring the energy of the displaced electrons (called photoelectrons). The binding energy is the difference between the photon energy and the photoelectron energy. When one measures the binding energies of the inner shells of a given atom, one learns about the electron density surrounding that atom. Thus a new dimension in chemical analysis is added by photoelectron spectroscopy. From a photoelectron spectrum of a solid or gas the scientist can learn about what elements are present, how much of each element is present, and what the oxidation state or electron environment is surrounding each atom. If he is working with a gas and uses the photons from a helium gas discharge lamp, he can make measurements to the order of 0.001 eV and thus learn about molecules from their vibrational as well as electronic structure.

The most exciting aspect of electron spectroscopy is its great versatility. Under investigation at ORNL by this means are such disparate and little-understood materials as tRNA compounds, the controversial defoliant cacodylic acid, and samples of polluted air. Proposed for study in the near future are lunar material and fundamental research in ionization and the nature of surfaces. The work embraces, in its application, the entire field of inquiry about the nature of matter, uniting physics, chemistry, and biology.



Transuranium Element Production

The facilities for producing transuranium elements continue to operate well and provide ever-increasing amounts of the elements up through fermium. During the three and a half years that the High Flux Isotope Reactor and the Transuranium Processing Plant (TRU) have been in operation, more than 250 shipments of various isotopes of plutonium, americium, curium, berkelium, californium, einsteinium, and fermium have been made for use in research programs. Most have been sent to other AEC laboratories; several shipments have been made to universities and industrial organizations, and a few shipments have been made to foreign countries.

Over the years there has been an increase in the production rate of the heavier isotopes as a consequence of the nature of the buildup and decay of the transuranium elements. Initially the targets irradiated in the HFIR contained plutonium-242 or a mixture of americium-243 and curium-244. Even though these materials were irradiated as long as a year, only small amounts of the transcurium elements were produced. However, curium recovered from these irradiated targets contained significant quantities of the heavier isotopes: curium-246, -247, and -248. Reirradiation of this curium containing the heavier isotopes produces the transcurium elements

much more rapidly, and the rapid increase in production rate is expected to continue for the next several years as more and more curium is recycled through the HFIR.

The HFIR-TRU complex is used for various special projects in addition to the main-line production of transuranium elements. The versatility of this complex has been increased by the recent addition of two new facilities: (1) an underground hydraulic transfer tube from the HFIR pool to a shielded cave in the TRU and (2) equipment in the nearby Thorium-Uranium Recycle Facility (TURF) for californium purification and neutron source fabrication. The hydraulic transfer tube is about 700 ft long and was installed so that irradiated samples traveling from the HFIR to the TRU would be shielded by the overlying earth. Samples irradiated in small containers can be transferred to the shielded cell in the TRU within 10 min after their removal from the HFIR. Thus isotopes with half-lives of only a few minutes can now be studied.

The newly installed facilities in the TURF are located in shielded cells that are essentially free from curium-244 contamination. Thus it is possible to purify californium and fabricate it into neutron sources containing only about one part of curium-244 per million parts of californium. After much of the californium-252 has decayed and the neutron sources are too weak for further use, they may be reprocessed in this facility to recover the residual californium-252 and its decay daughter, curium-248, which is a valuable isotope because of its long half-life of 4.7×10^5 years.

Yearly Production of Selected Isotopes from the Transuranium Processing Facility

Isotope	First Year, 7/66–7/67	Second Year, 7/67–7/68	Third Year, 7/68–7/69	Fourth Year, 7/69–7/70
Plutonium-242 (g)	50	65	17	12
Curium-244 (g)	83	85[a]	57[a]	75
Berkelium-249 (mg)	0.2	0.5	2	7
Californium-252 (mg)	2	5	15	50
Einsteinium-253 (μg)	1	10	100	170
Fermium-257 (10^8 atoms)			2	7

[a]A mixture of about 210 g of americium-243 and 230 g of curium-244 was also recovered from the original Savannah River raffinate solution (from early processing). About half the total was recovered per year in the second and third years.

A Novel Method for Producing Isotopes at High Enrichment

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About the only practical method for producing significant quantities of the transuranium elements and neutron-rich isotopes of the other elements is to irradiate selected target materials with neutrons. This is feasible because of the huge quantities of neutrons available in nuclear reactors. However, it is not always possible to produce a desired material directly at high isotopic concentration. Such is the case when the desired product is an isotope of the same chemical element as the target material and when this desired isotope has a great affinity for neutrons and thus is destroyed by the very conditions used to create it. A good example is curium-247, which is highly desirable for many research programs, since it has a half-life of more than 10 million years. Curium-247 may be produced by the neutron irradiation of curium-244 (which is available in large quantities) or curium-246 (which is still very scarce). However, with either target, curium-247 cannot be expected to be more than 1 to 2% of the curium isotopes present at any time during the irradiation, since it has a large capture cross section for neutrons and is destroyed rapidly. Enrichment by electromagnetic separation is possible but is expensive and gives low product yields.

The classic Szilard-Chalmers reaction, discovered over 35 years ago, solved this problem in principle. In this reaction an atom bound in a compound or stable complex (such as bromine in bromoform or in the bromate ion) is ejected from its bonded state when the energy released in a nuclear reaction breaks a chemical bond. Under proper conditions the ejected atoms may be separated substantially from the atoms that have not undergone nuclear reaction. In general, however, the compounds or complexes required for this reaction are not stable enough to radiation from a nuclear reactor for useful production to be achieved. In any case, lanthanides and actinides do not readily form appropriate compounds.

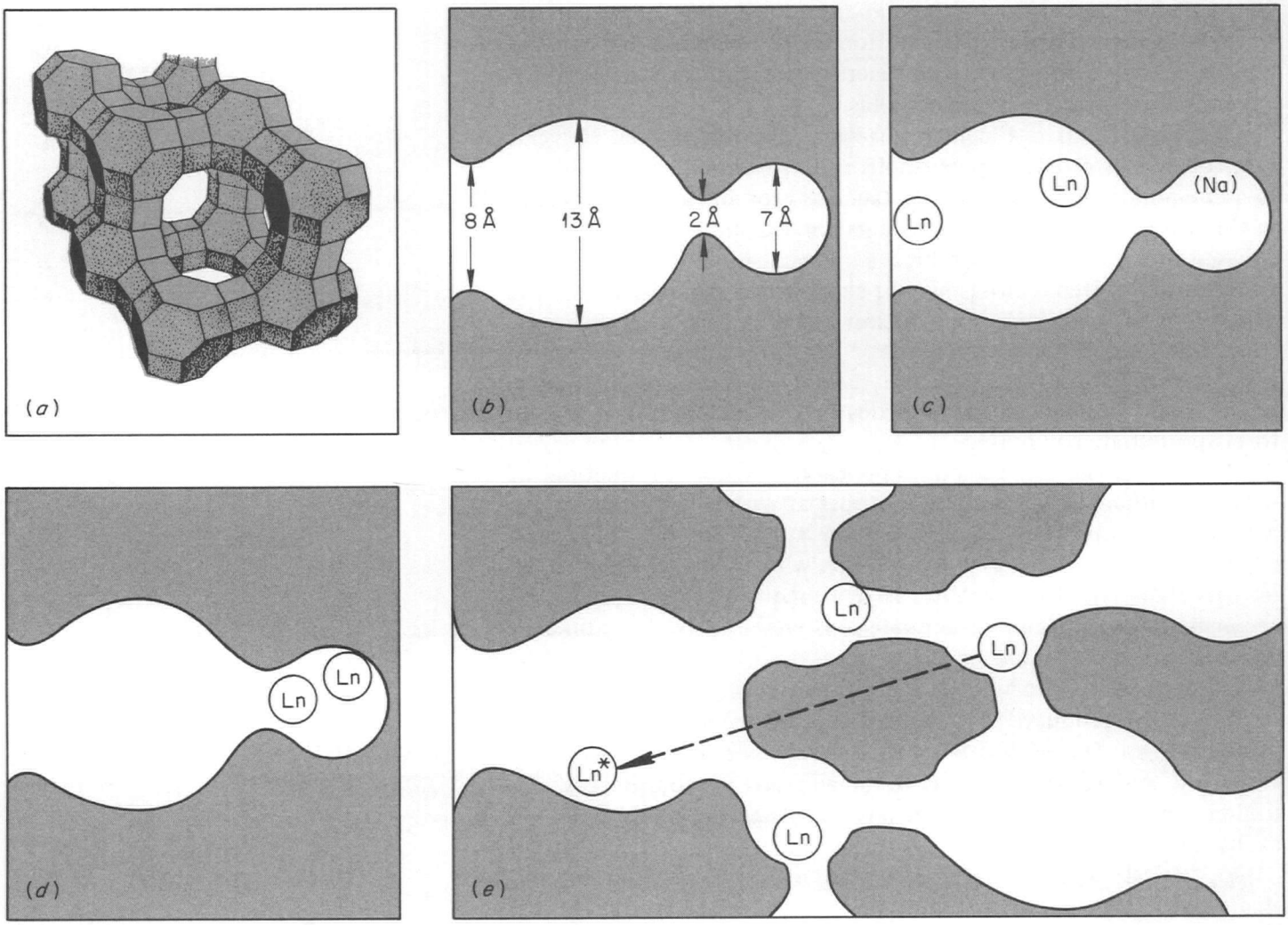
A new technique directly applicable to the production of selected lanthanide and actinide isotopes at enriched concentrations has been demonstrated on a laboratory scale. This new technique makes use of a particular type of zeolite, with the target atoms fixed into its structure. These zeolites have a unique structure which will accommodate lanthanide or actinide ions either at fixed positions or at sites accessible by ion exchange reactions. Target atoms can be loaded exclusively into the fixed positions. During irradiation, many of the atoms produced by neutron capture recoil from the fixed positions into the accessible sites. After irradiation the zeolite is eluted by contact with a concentrated aqueous salt solution, usually lithium chloride, which removes any exchangeable ions by an ion exchange process.

In typical experiments with several different lanthanides, the eluate product contained between 40 and 60% of the product atoms

A new technique based upon the use of a particular type of zeolite has been discovered for producing selected lanthanide and actinide isotopes at high enrichment.

The zeolite, Linde X, is an aluminosilicate that contains two interconnected networks of pores. In a, *the small pore system is shaded, and a window into a large pore is shown. The dual pore system is represented schematically in* b. *Even quite large molecules and ions can move freely through the large pore system, but the windows into the small pores are about the size of metal ions. When Linde X is contacted with a lanthanide salt solution, hydrated lanthanide ions enter the large pores* (c), *but they are too large to pass into the small pores. After dehydration by heating to 500°C, all the lanthanide ions are found in the small pores* (d), *from which they are not readily removed. The large pores are essentially unoccupied by lanthanide ions.*

When a lanthanide ion fixed in such a small pore (Ln in e*) absorbs a neutron to form the next heavier isotope, it immediately emits gamma radiation and recoils some distance through the crystal. Some fraction of the ejected product ions (Ln*) will, it is believed, come to rest in the large pores, from which they may be preferentially recovered by ion exchange.*

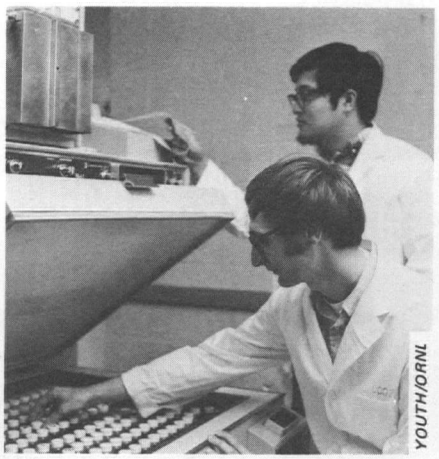


of the neutron capture reaction, along with less than 1% of the unreacted target atoms. Thus the product is enriched by a factor of about 50, compared with that produced in a normal irradiation. Similar results have been achieved in tests made with the actinides americium and curium, except that slightly larger amounts of the unreacted target atoms have been eluted with the products. Work is continuing in an effort to reduce the amount of target material in the product, since this largely controls the enrichment.

The effectiveness of this method for producing curium-247 has not yet been tested; however, if an enrichment factor of 50 can be attained, it is theoretically possible to produce curium-247 at an isotopic enrichment of 30%, as compared with the 1 to 2% attainable by normal irradiation techniques. We expect, however, that radiation damage will limit the enrichment attainable to less than this, perhaps 10 to 15%, since radiation damage ultimately limits the usefulness of nearly any material. No radiation damage effects have been observed, but production of curium-247 will require neutron exposures several thousand times those used for this work.

There are other applications for which much lower exposures are adequate. Even in tracer work, any target material in the product is generally an undesirable impurity. Since the zeolites have very low neutron capture cross sections and excellent thermal stability, they provide a convenient support for the target material, besides offering the possibility of product enrichment.

Although this process has been demonstrated only at moderate exposures in nuclear reactors (2.5×10^{16} neutrons/cm^2), it offers the possibility of producing certain isotopes that are essentially unobtainable by existing techniques. Therefore investigation will continue until the limits and capabilities of this new procedure have been determined.


YOUTH/ORNL

The Nature of Water Adsorbed on Oxide Surfaces

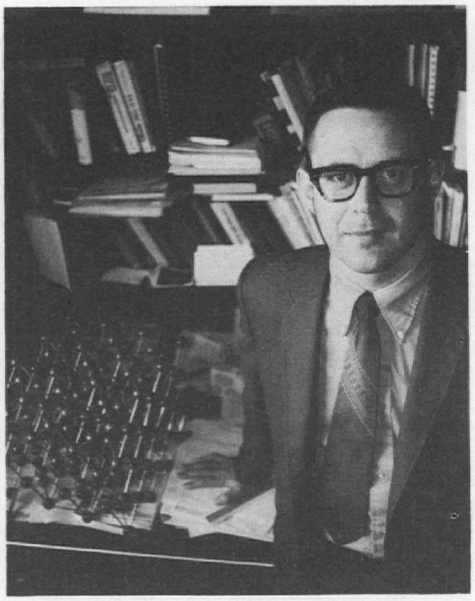
This three-faceted fundamental study of what really happens between water molecules and the surfaces of insoluble oxide particles had its beginning in the early attempts to understand the thorium oxide slurries of homogeneous reactors. The insights thus gained have proved valuable to research involving oxides in general. Dosimeters now in development that use beryllium oxide are affected by the state and amount of adsorbed water; ceramics processing is dependent on the interaction of oxide powders and water; the large majority of catalysts are oxides, and their properties want fuller understanding.

The surfaces of most, if not all, refractory materials are covered by a layer of water molecules chemically bonded in the form of hydroxyl groups at normal temperatures and pressures. This layer of water, removable only at high temperatures and low pressures, has a marked influence on many important properties of such solids.

AWARDS

Floyd L. Culler *was honored by the International Atoms for Peace Award. Atoms for Peace awards are granted annually to scientists throughout the world who make outstanding contributions to the peaceful uses of atomic energy. The first was presented to Niels Bohr in 1957. Mr. Culler's award was specifically for his work with the application of engineering principles in operating processes for the production of nuclear power and in the attainment of efficient plants to yield low-cost electricity and for his leadership in the field of nuclear desalination of water.*

Mr. Culler came to Oak Ridge with the Tennessee Eastman Company in 1943. He joined ORNL in 1947 and became Director of the Chemical Technology Division in 1953. In 1965 he became an Assistant Laboratory Director. He holds a degree in chemical engineering from Johns Hopkins University. In 1965 he was the recipient of the Ernest Orlando Lawrence Memorial Award.

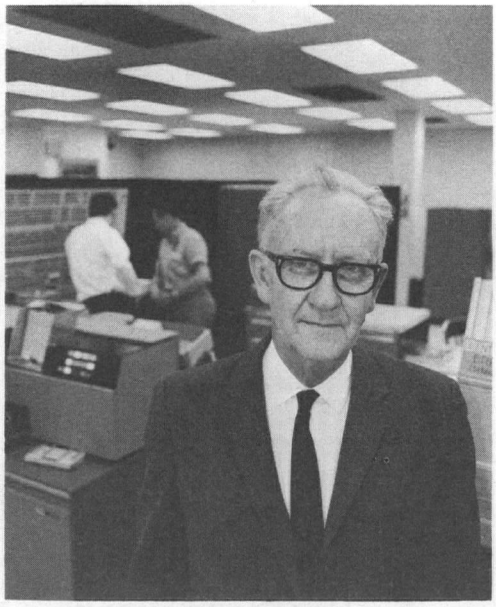


Thomas O. Baldwin *of the Solid State Division was granted the Sidhu Award in 1969. The Sidhu Award is given annually to a young scientist who has made an outstanding contribution to the field of diffraction. It honors the memory of Dr. Surain Sidhu, one of the founders of the Pittsburgh Diffraction Conference, who made numerous contributions to the fields of x-ray diffraction and neutron diffraction.*

Dr. Baldwin received his undergraduate and graduate training at the University of Missouri and began work at Oak Ridge National Laboratory in June 1964. Here he has been concerned with the detection of lattice defects in crystals with the aid of x-ray diffraction techniques. His particular accomplishment has been the detection of minute defects in crystals heretofore thought perfect, using x-ray diffraction measurements. At the Pittsburgh Diffraction Conference on the occasion of the Award, he delivered an address entitled "X-Ray Studies of Point Defects and Small Defect Clusters in Nearly Perfect Crystals."

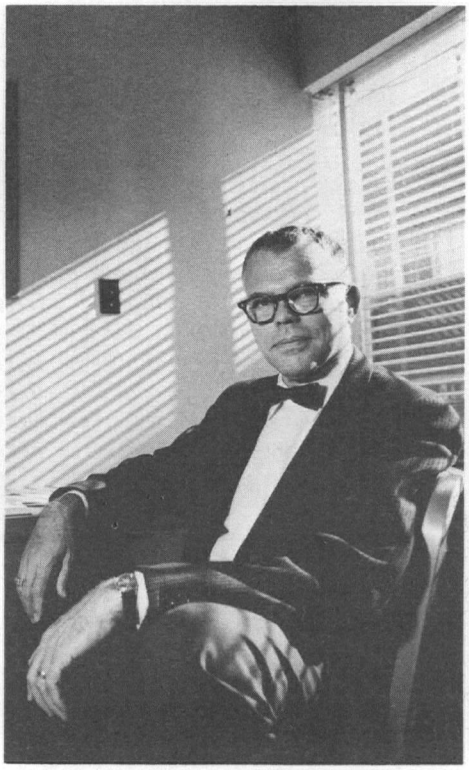
George E. Boyd *was awarded the $1000 American Chemical Society Award for Nuclear Applications in Chemistry. This award, sponsored by Nuclear-Chicago Corporation, was established in 1953 to recognize, encourage, and stimulate isotopic applications in the field of chemistry. Dr. Boyd was recognized primarily for his research on ion exchange as applied to the separation of plutonium from uranium and fission products and especially for the basic information he has provided on the element technetium.*

As a member of the chemistry faculty at the University of Chicago, where he had received his undergraduate and graduate degrees, Dr. Boyd joined the Manhattan Project's Metallurgical Laboratory there in 1942. The next year he was transferred to the Project's Oak Ridge site as a member of the staff of Clinton Laboratories, which later became ORNL. In 1955 he became Assistant Laboratory Director. In addition to his professional activities, he has been a Guggenheim Fellow, a Fulbright Research Scholar, a Reilly lecturer at Notre Dame University, and a Distinguished Service Visiting Professor in Chemistry at Purdue University.



Alston S. Householder, *consultant to ORNL and the past Director of the Mathematics Division, was awarded the 1969 Harry Goode Memorial Award from the American Federation of Information Processing Societies. The award was presented for Dr. Householder's impact and influence on computer science in general and digital computation in particular, for his many publications, including books which have provided guidance to countless users, for his leadership and behind-the-scenes work on committees of the field's professional societies, which have benefited everyone in the computer industry, and for his many instances of contributions to the field as editor and conference organizer.*

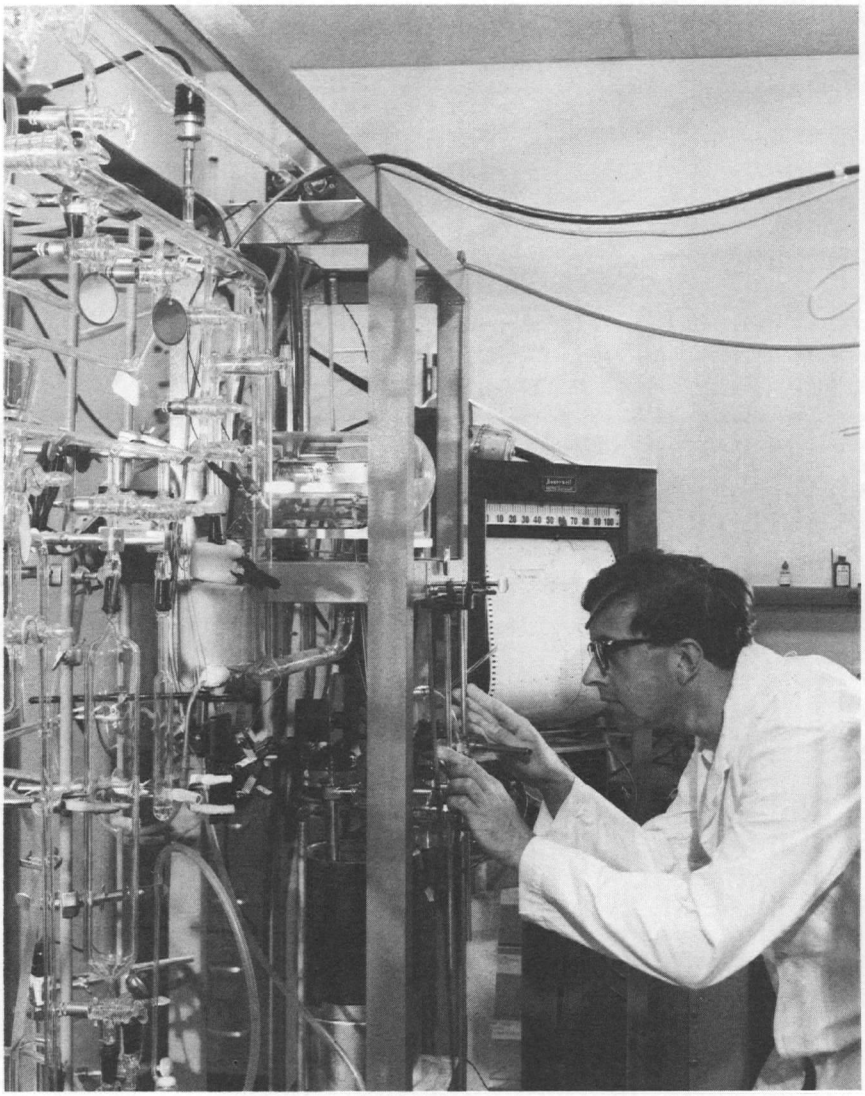
Before coming to ORNL in 1946 to begin the Mathematics Division he received his undergraduate degree at Northwestern University and his graduate degrees from Cornell University and the University of Chicago. He has taught mathematics at Northwestern University, Washburn College, and the University of Tennessee, where he is now interim head of the Mathematics Department. In 1965 he was awarded an honorary degree from the University of Munich, Germany. He has authored two books on numerical analysis. His contributions to the field of mathematics are legion.

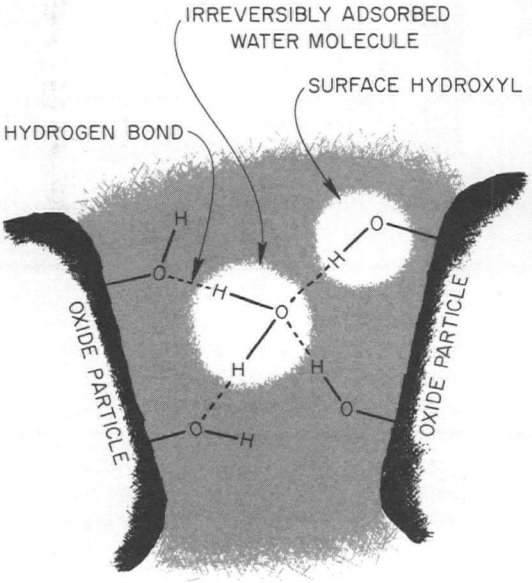


Dale J. Fisher *received the $2000 American Chemical Society Award in Chemical Instrumentation. The award is sponsored by Sargent-Welch Scientific Company and was given for meritorious contributions to the design and construction of versatile chemical instrumentation especially applicable to nuclear technology. The award is presented annually to recognize and encourage achievement in the origination and improvement of analytical methods by instrumentation. Recipients must have accomplished a practical and significant simplification of analytical procedures by means of instrumental techniques.*

Dr. Fisher joined ORNL in 1951 after completing his undergraduate work at Wisconsin State University and his graduate work at Indiana University, where he was an All-American Fellow. Presently he is a group leader in the Analytical Chemistry Division. His work and publications are primarily concerned with the design, development, and application of instruments in chemical research.

Research on gas-surface interactions requires experimental techniques that are accurate and sensitive. This is an apparatus capable of studying such interactions over the temperature range −196 to 1000°C and at pressures ranging from a high vacuum to 1 atm. The heart of this equipment is a recording electronic microbalance that can detect weight changes of one part in ten million. With this apparatus, the adsorption of water on thorium oxide surfaces has been measured under a variety of carefully controlled conditions. A comparison of surface areas derived from the adsorption of different gases is obtained by using gases such as nitrogen and argon as the adsorbing species.





This drawing shows how irreversibly adsorbed water molecules can (1) block entrance to micropores, (2) reduce effective surface area, (3) effectively "glue" particles together, and (4) block an active catalytic site by strong hydrogen bonding to chemisorbed water. These particles are so strongly bonded that it requires a temperature of 1000°C and a vacuum of 10^{-6} torr to separate them.

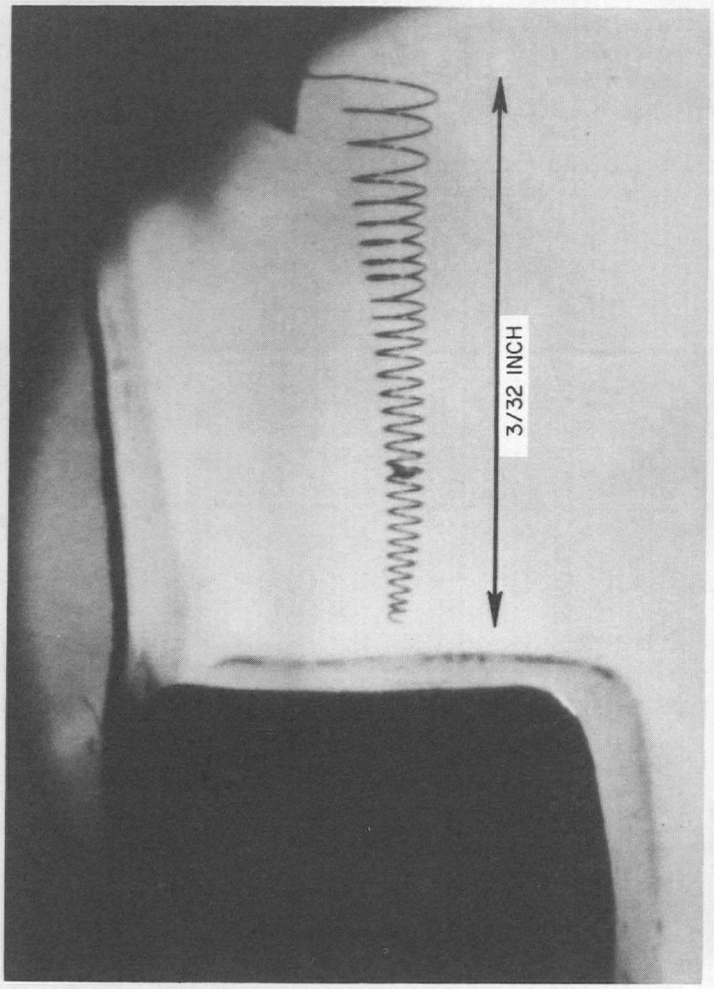
Because of its chemical nature and potential importance, thorium oxide is a suitable material for studying the chemistry of the interaction between water and an oxide surface. The inquiry at ORNL has taken three forms: The energy changes have been studied in terms of the amount of heat released when the oxide particles make contact with the water, the quantity of water in equilibrium with thorium oxide surfaces at different temperatures and pressures has been measured, and surface bonding and structure have been studied by infrared spectroscopy.

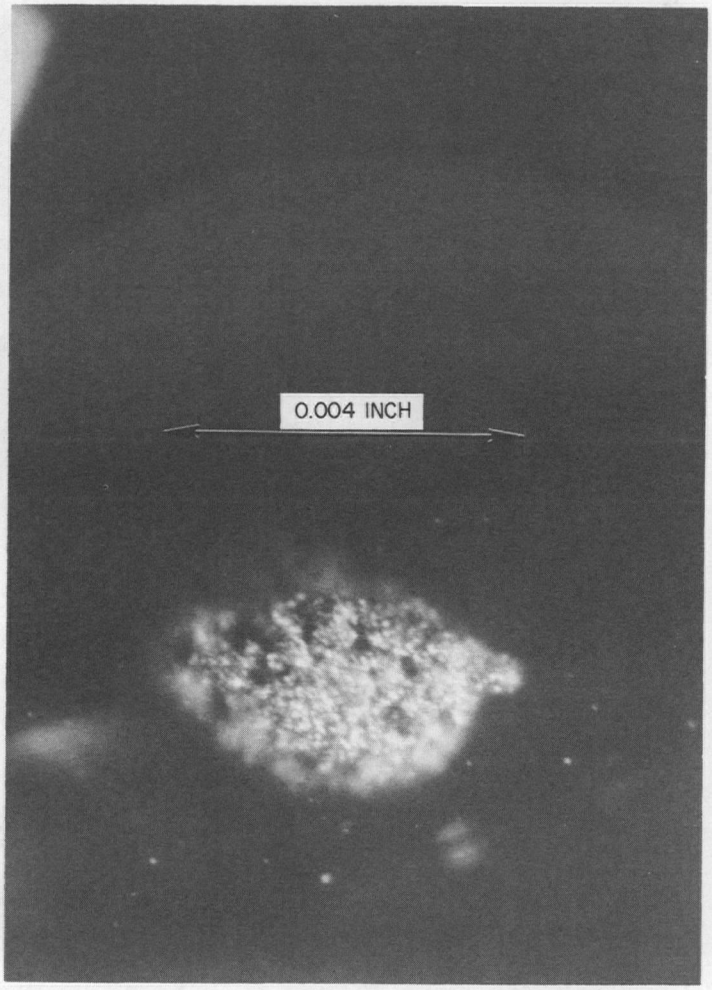
The data obtained through these three interrelated experimental approaches have led to the construction of an acceptable model for the adsorption of water on thorium oxide surfaces, a model that is discovered to be generally valid for other oxides as well. At normal temperatures and pressures, the surfaces of such oxides retain, in addition to the water that is chemisorbed as surface hydroxyl groups, a layer of molecular water that is extensively hydrogen-bonded and rigidly oriented in a manner dictated by the substrate structure.

Handling Transuranics

The emerging technology that results from the production of the highly radioactive transuranics is producing landmarks in ingenuity. Two man-made isotopes at ORNL gave rise to the highly original developmental work described below.

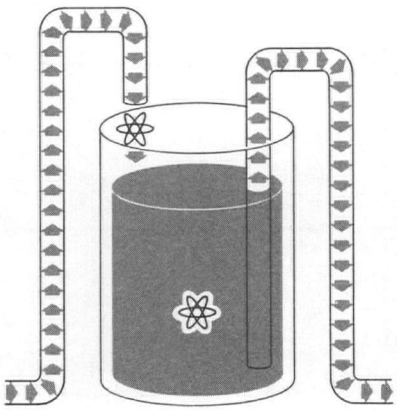
Preparation of Berkelium Metal. *Special techniques must be developed for research with the minute amounts of transcurium elements available. On the left is an enlarged photograph of some of the equipment used in the preparation of the tiny amount of berkelium metal (about one billionth of a pound) shown on the right. To prepare the metal, a pure solution of berkelium nitrate is contacted with a single ion exchange resin bead, on which the berkelium loads. The bead is carefully heated to burn away the resin, which leaves berkelium oxide. The berkelium oxide is further treated with hydrogen fluoride gas to convert it to berkelium fluoride. This bead is then suspended on a small spiral of molybdenum wire (see center of left photograph). This wire is hung from the small chairlike stand, which is fabricated from tungsten metal. The entire assembly is inserted in a small reactor, and the berkelium fluoride is reduced to the metal with metallic lithium vapor.*





Pelletizing of Californium-252

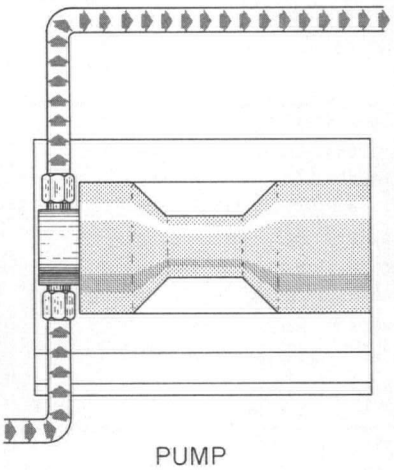
1



NITRIC ACID

The material is transmitted by underground hydraulic tube from the HFIR to the TRU facility next door, emerging inside a hot cell.

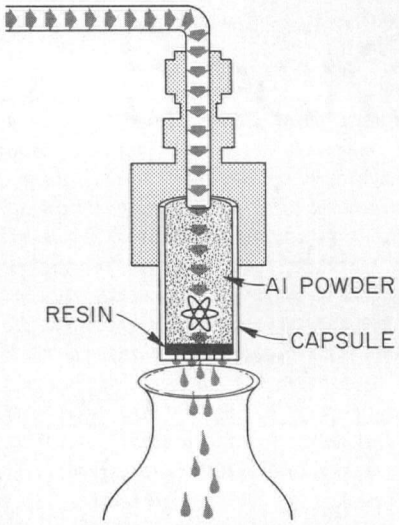
2



PUMP

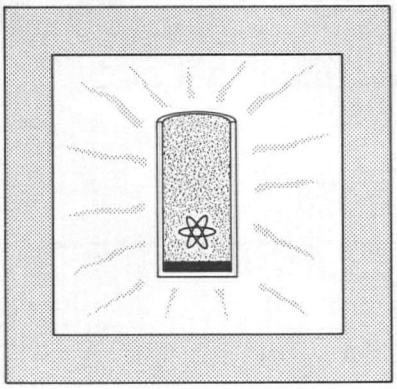
Here it is placed in a solution of nitric acid and transferred to a capsule partially filled with a mixture of aluminum powder and ion exchange beads, open at the top and plugged at the bottom with a porous layer of aluminum powder.

3



As it is pumped through this tube, the californium is quantitatively deposited on the ion exchange resin as the dilute nitric acid solution passes on out the bottom.

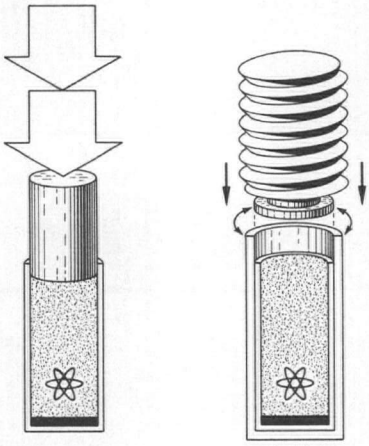
4



OVEN

The aluminum tube is then heated to a temperature high enough to carbonize the resin particles and convert the californium to an oxide (without melting the aluminum),

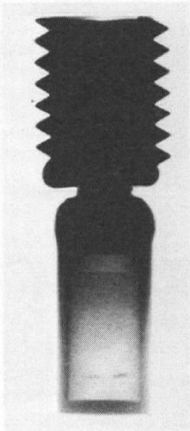
5



COMPRESSED WELDED

and then placed in a hydraulic press, which compresses the material into a solid pellet inside the tube. This then is welded into a stainless steel container,

6

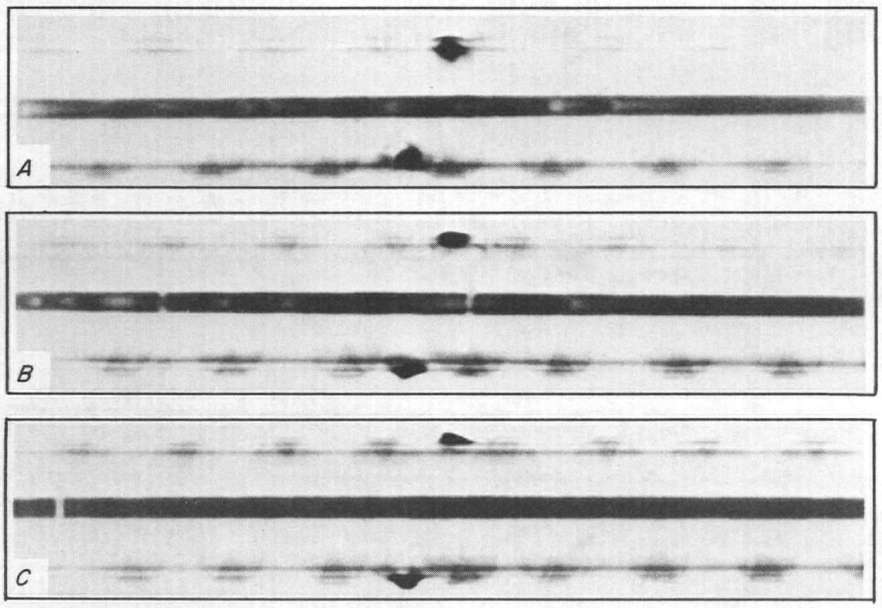


X-RAY

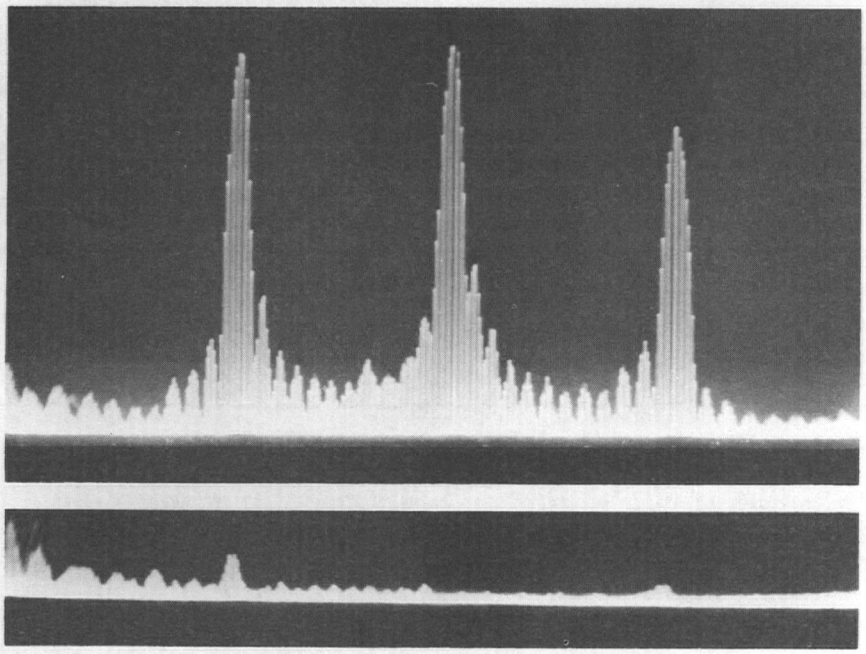
an x-ray photograph of which is shown above, actual size. The white area near the bottom shows the location of the 1 mg of californium-252. The container is threaded at the top for ease of remote handling.

Materials Testing

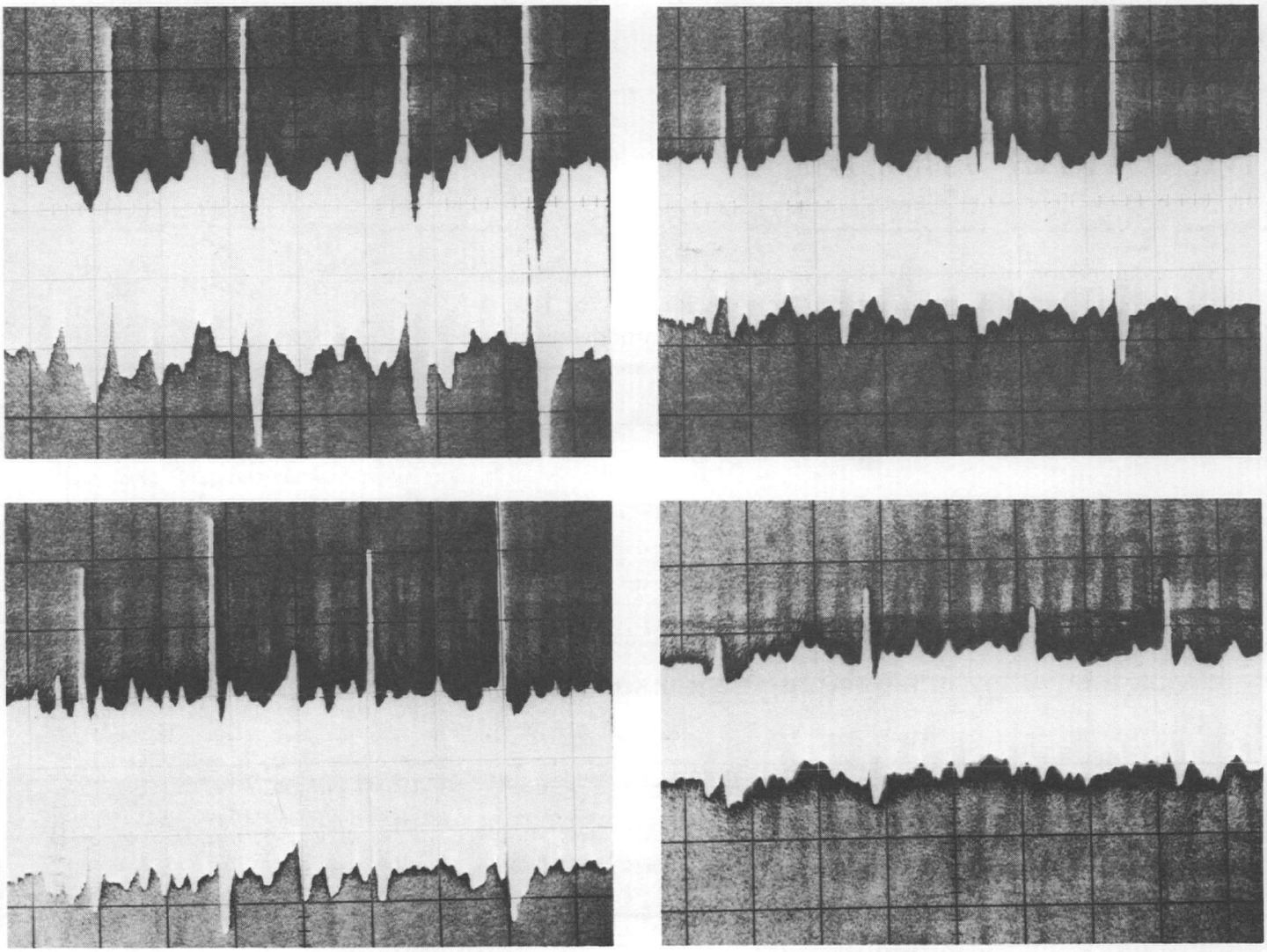
The examination of materials as they respond to the extremes to which they are exposed in the interior of a nuclear reactor is an ongoing program at Oak Ridge National Laboratory. Following are descriptions of some of the highlights in materials research in 1969.



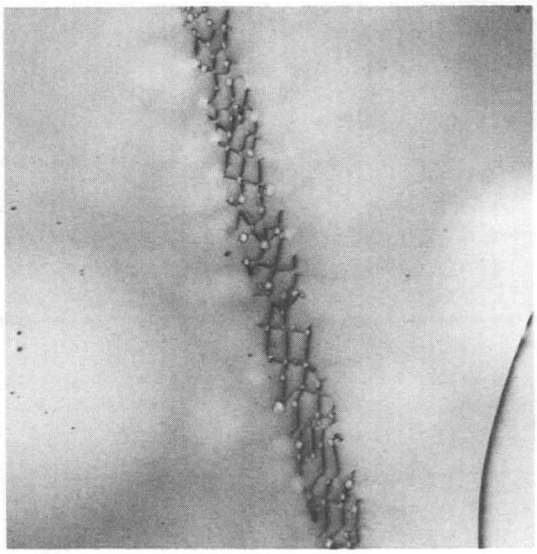
Sol-Gel Fuel Rods. *Neutron radiographs of sol-gel uranium-plutonium oxide fuel rods exposed in the Transient Test Reactor at the National Reactor Testing Station in Idaho to brief peak powers eight times normal. Rods A and B were prepared by the Sphere-Pac process, in which spherical fuel particles of different sizes are packed by vibration into the cladding tube. Both rods show conical voids, and rod B has two separations in the fuel column, but neither shows any tendency toward failure. Rod C, loaded with pellets, operated at 30% less power than the other rods. Separation between pellets is seen at one location; again no sign of failure is evident. The soundness of the rods was verified by destructive examination.*



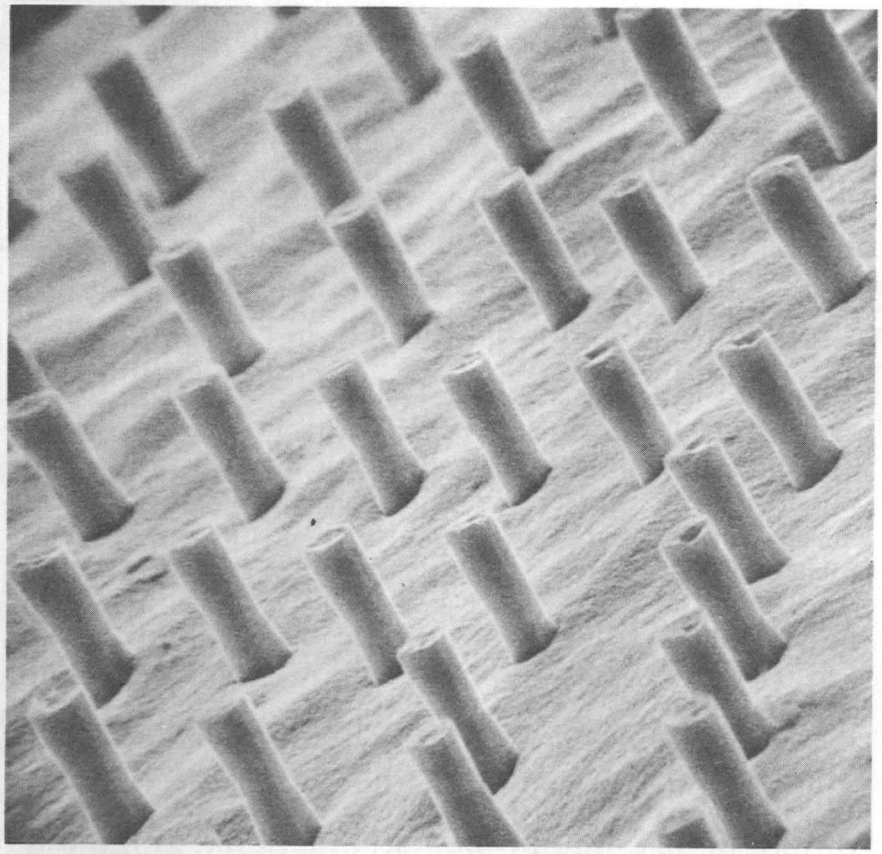
Ultrasonic Testing. *Oscilloscope display of spectrum of ultrasound reflected from poorly bonded area of stainless steel cladding on copper. The peaks are at 1.80, 3.73, and 5.65 MHz. Ultrasound at these frequencies is resonant in the cladding; an instrument sharply tuned away from these frequencies would not detect the flaw. The lower photo shows the lack of reflection from a defect-free bond.*



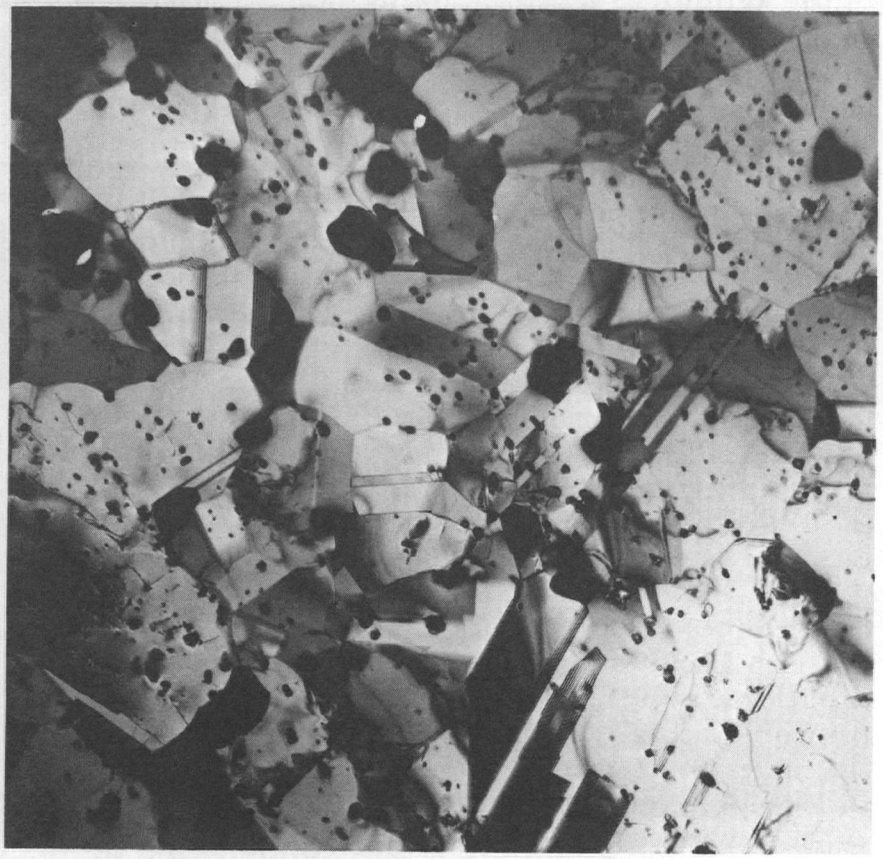
Infrared Microscopic Testing. *Oscilloscope display showing response of ORNL infrared microscope to defects in Plexiglas only 0.01 mm deep. Defects examined are: upper left, on the surface; lower left, 1.6 mm below the surface; upper right, 3.2 mm below; lower right, 4.8 mm below. The depth of the flaws can be distinguished. The infrared microscope permits nondestructive examination of materials transparent to infrared but not amenable to previous inspection methods; the ORNL instrument can scan an area larger than half this page in less than 2 min.*



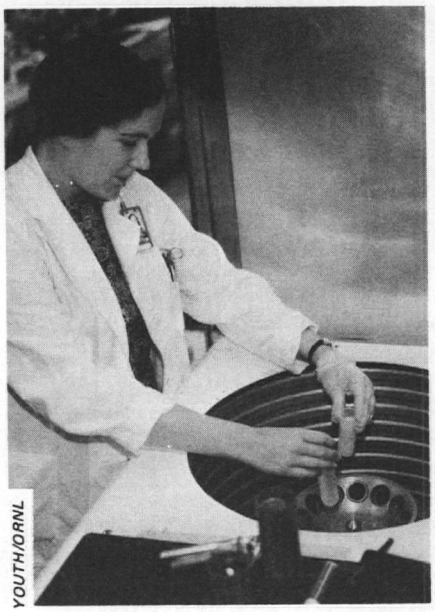
Formation of Voids in Uranium Dioxide. *Transmission electron micrograph of voids produced in uranium dioxide by addition and removal of oxygen. The voids are located on an array of dislocations (lines of atomic mismatch), which forms a boundary between subgrains (regions with nearly the same orientation of planes of atoms). Magnification 60,000X.*



Tungsten Crystal Growth. *Single-crystal rods of tungsten in a single crystal of uranium dioxide, grown by the ORNL internal centrifugal zone growth process. The ORNL-grown composite is shown in this Georgia Institute of Technology scanning electron micrograph, magnified 20,800 times. The* UO_2 *was chemically etched away to a depth of about a ten-thousandth of an inch to reveal the isolated tungsten rods.*



Increasing Resistance of Steel Cladding to Radiation. *To reduce the concentration of voids produced during irradiation, reduce swelling, and extend the useful life of the cladding for fast breeder reactor fuel rods, ORNL metallurgists have succeeded in reducing the grain size of the material. Modifying standard commercial tube-drawing practice by alternating steps of mechanical metalworking with carefully controlled heat treatment, they achieved an average grain diameter of 0.002 to 0.003 mm, one-tenth of the smallest commercially available. In this micrograph, enlarged 10,000 times by the electron microscope, the dark spots show the very finely dispersed carbon. Compared with the best commercial tubing, the ultrafine-grained alloy is substantially stronger without loss of ductility, and at elevated temperatures its ductility is improved. Samples are in the Experimental Breeder Reactor-II for further testing.*



YOUTH/ORNL

Life Sciences

Research on Aging: A Convergence of Disciplines

Since its inception in the late 1940's, ORNL's Biology Division has studied biological changes occurring naturally in animals as they age. This interest in aging developed from one of our earliest major projects – the study of long-term biological effects from exposure to ionizing radiation. Such studies will give insight into many current problems of human illness: for example, arthritis, cancer, and organ transplants. The study of aging is complex and involves many disciplines. Biostatistics, biophysics, biochemistry, genetics, physiology, embryology, immunology, pathology, and medicine all enter the picture.

The Division has long been structured to promote cross-disciplinary cooperation in solving broad biologic problems. When fundamental studies in immunology, cryobiology, and mammalian cell genetics were initiated, they appeared to be only distantly related. As they were expanded, however, their common relevance to the subject of aging became apparent, and they began to converge.

Immunology

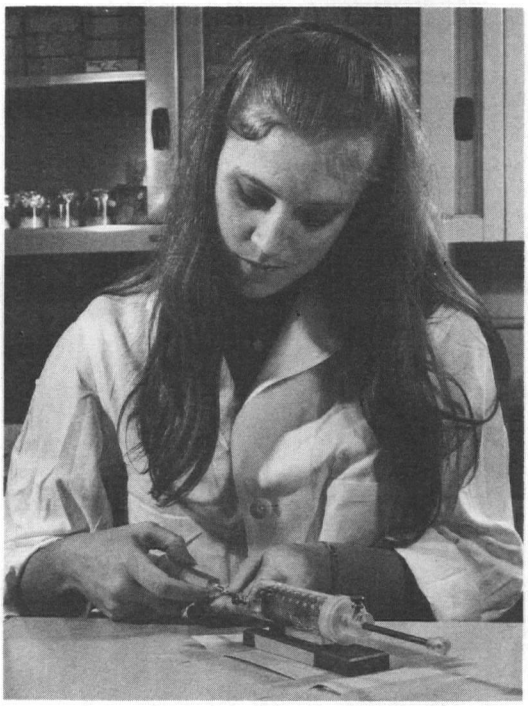
Studies in immunology were concerned initially with the cellular mechanism of the immune response and its relation to radiation insults. These led to studies on age-dependent changes of the immune system, which revealed that in mice, as in men, the activity of the immune system reaches its peak during young adulthood and then gradually decreases, even before any pathological diseases currently known to be associated with old age are manifested. This decrease in the activity of the immune system is accompanied by an increase in frequency of autoimmune diseases of various organs (joints, blood, skin, kidney, thyroid, etc.) and cell components (nuclear proteins and DNA). Age produces in the body an internal conflict among cells.

Decrease of the immune system is also associated with an increase in the frequency of cancer. Recently, clinicians have shown that even among young adults the incidence of cancer is highest among those whose immune system has been suppressed, similarly to the way it is in aging. Predictably, suppressed immunologic activity also increases susceptibility to infections; however, the Biology Division has recently demonstrated that immune systems in the aged can be rejuvenated. Aged mice, which are highly sensitive to typhoid

infection, successfully withstood supralethal doses of infective bacteria after infusion with cells from young donors previously treated with typhoid vaccine to produce immunocompetence. This indicates that immunologic rejuvenation is feasible, provided immunocompetent cells are readily accessible and can be stored for an extended period without loss of activity.

Mammalian Cell Genetics

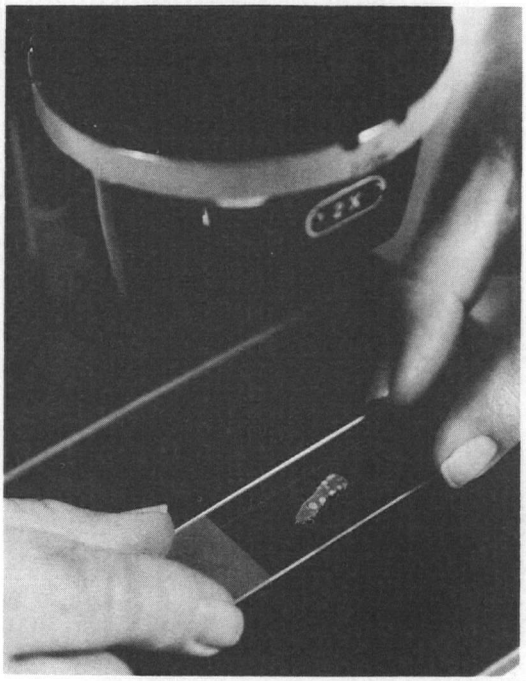
Mammalian cell culture techniques have been among the most successful approaches to studies of function, transmission, and possible changes of the hereditary unit, the gene. The Biology Division has used cell cultures from normal persons and from individuals with metabolic diseases for these studies. In both human and rodent cell cultures, mutations have been shown to occur either spontaneously or as a result of treatment with chemicals or radiation. The nature of some of the changes has been identified, and the cell culture method has also been applied in measuring the mutagenic effects of radiation and chemicals that are present in the environment. In addition, we have some clues that certain known cancer-producing chemical compounds can also cause mutations. Thus mutation in the cells of mammals, including man, may be related to the problems of cancer formation and autoimmune diseases associated with aging. The fact that cancer cells are immunologically foreign to the host indicates that they are descendants of precursor cells that have undergone mutation. It follows, then, that an understanding of the nature and cause of hereditary changes or mutations of somatic cells would contribute immensely to our knowledge of old-age-associated diseases.



In the Laboratory's Biology Division, one of the programs that contribute to aging studies concerns irradiated mice injected with bone marrow cells from animals of the same strain. After seven to ten days the treated mice develop colonies of bone marrow cells on their spleens, as shown on the glass slide (below). With marrow from extremely old animals very few colonies develop.

Cryobiology

If immunological rejuvenation is ever to have widespread clinical application, a way must be found to obtain immunocompenent cells from young individuals and to store them in a viable state for long periods, perhaps as long as 50 years. Holding the cells in liquid nitrogen at −196°C can eliminate the problem of extended storage; however, this requires the ability to freeze the cells to this temperature and later thaw them without injury. Understanding the basic factors responsible for the injurious effects of freezing and thawing has been an object of research in the Biology Division for the past ten years. Early studies examined the effects of freezing on yeast, bacteria, and bacterial viruses. These organisms were chosen because they are easier and cheaper to experiment with than mammalian cells and because there is reason to believe that the killing of both microorganisms and mammalian cells results from the same fundamental factors. This expectation was subsequently confirmed by ORNL biologists in the experimental freezing of mammalian bone marrow cells and tissue culture cells two years ago. Knowledge gained from the earlier work on microorganisms led directly to techniques of freezing these mammalian cells with little or no injury.



The ability to maintain cells and tissues in a frozen state has many implications, not only for rejuvenation but also for transplantation of organs and of bone marrow or white blood cells. Widespread use of organ transplants, for example, will require the existence of large inventories of stored viable organs that are immunologically compatible with the intended patients. Again, white blood cells and blood-forming bone marrow cells can be destroyed in an individual by diseases, chemicals, or radiation, usually resulting in fatal infection. If white cells or bone marrow cells compatible with patients' tissues could be transplanted, death could be prevented in many cases. Bone marrow and some kinds of white cells can be frozen successfully now, but other types of white cells and all organs so far tried have not survived freezing. Before organ storage in the frozen state will be feasible, a more complete understanding of the basic mechanisms of freezing injury and its prevention is required.

Training Program

In support of the convergence of the many disciplines involved in the study of aging, a training program has been initiated here to utilize both the facilities and experience of the Division.

The presence of a graduate school within the Biology Division has made it possible to establish such a training program. The University of Tennessee–Oak Ridge Graduate School of Biomedical Sciences was established in 1966 and received its first students in 1967. It operates as a separate entity within the Biology Division, utilizing the staff and extensive research facilities of the Division. As staff members of the School, many of the biologists became eligible to apply for a training grant sponsored by the National Institutes of Health, and they did so a year later, in the area of aging. In 1969 the National Institute of Child Health and Human Development awarded a five-year grant to the School for the purpose of training terminal predoctoral and postdoctoral fellows in research in aging.

Currently there are six postdoctoral fellows supported by the program, receiving training in various disciplines including developmental biology, physiology, biochemistry, and genetics. By the end of this fiscal year, four more are expected to receive training in biophysics, immunology, and pathology. As an essential part of the overall training, a lectureship program was established through which a series of distinguished scientists engaged in research in aging are invited to speak to members of the Division and the Biomedical Graduate School.

Besides the formal training program, it was decided that the Division should sponsor, for the 1970 Annual Gatlinburg Conference, a symposium on Molecular and Cellular Mechanisms of Aging, for participation by the world's leading researchers in the field.

ORNL's educational program of research in aging is now well begun; the disciplines of the Laboratory are set to make their contributions to the studies that are designed to attack the pressing problems associated with aging.

Mathematics

Enhancement of Computer Capability

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In April 1969, ORNL installed an IBM System/360 model 91 computer system. This, with our IBM System/360 model 75 computer system, gives the Laboratory one of the most powerful general-purpose computing complexes in the world.

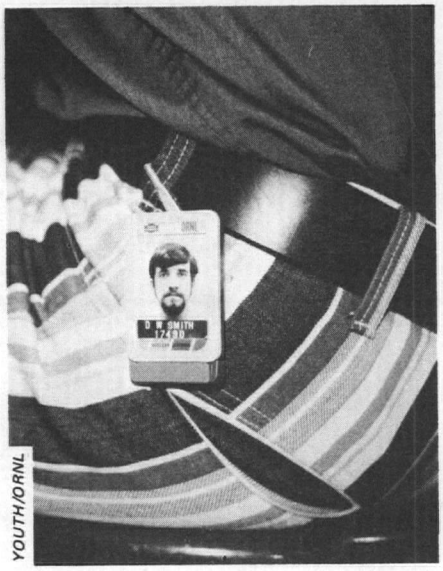
The model 91 is among the most advanced computer systems installed thus far by IBM. The system was offered on a controlled basis to a select group of large-scale scientific users, and only 14 such computers are installed throughout the world. At the time of its conception it was to be an ultrahigh-performance version of the newly announced third generation of computers. It was designed to improve significantly upon third-generation circuit-packaging and storage technologies. These technologies included the development of advanced solid logic technology and monolithic circuits.

A significant feature of the ORNL model 91 system is its large-capacity, high-speed memory. With a directly addressable memory of 2,097,152 bytes (8 binary digits per byte), very large problems can be accommodated efficiently. By comparison, the capacity of the main memory of this system is 10 times that of most second-generation computers. Its speed and power result primarily from advanced circuit technology, fast access to storage, fast execution times, a high degree of concurrency in internal operations, and highly efficient floating-point arithmetic operations.

In the model 91, five separate units, each almost entirely autonomous and each containing more logical circuitry than most contemporary computers, can be operating concurrently and at the same time perform several simultaneous functions. Elaborate circuits have been provided for error detection and interlocking to prevent undetected computer mistakes.

The operator controls the computer and communicates with its operating system program by means of an interactive cathode-ray-tube display console together with an attached keyboard and a light pen. Messages to the operator appear on the screen of the tube. He, in turn, sends messages to the computer by typing on the keyboard or selecting from alternative procedures by pointing the light pen at certain areas on the screen.

The system was officially turned over to the Laboratory on April 22, 1969. The 30-day acceptance test was begun on May 12 and was completed on June 11. During the remainder of calendar year 1969,



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more than 60,000 different jobs were processed on the model 91.

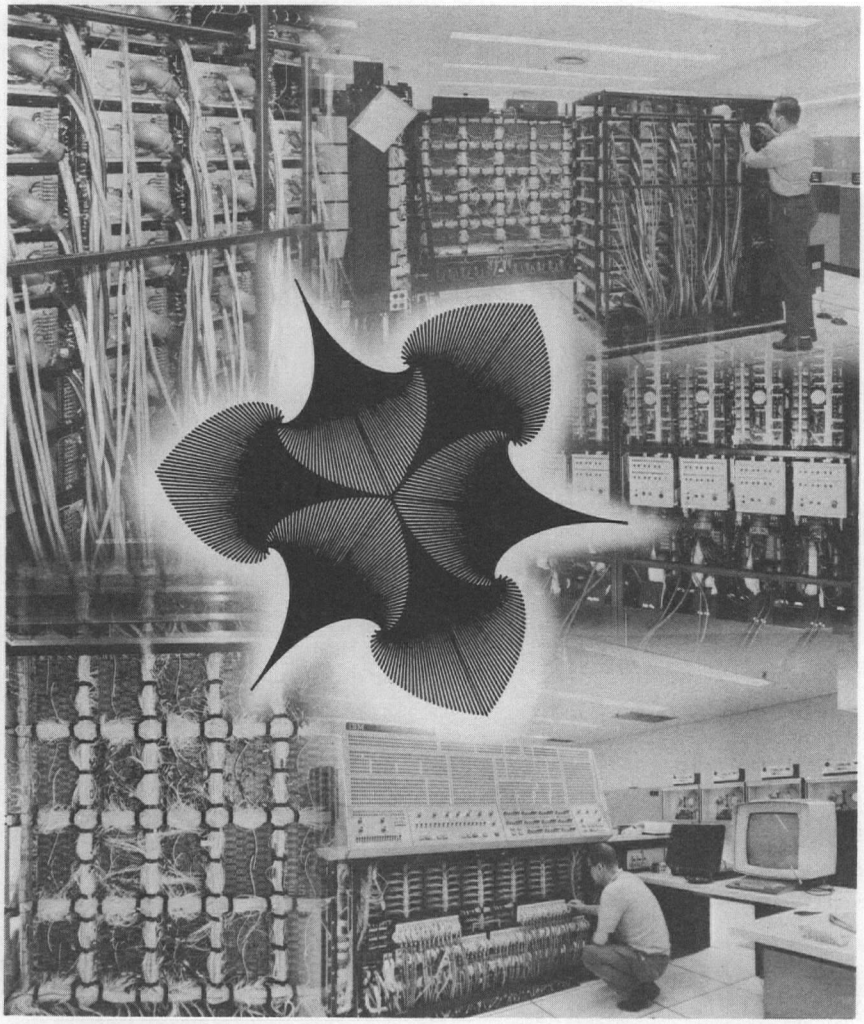
With the installation of the model 91, problems that require very fast computation and very large directly addressable storage can now be attempted.

An example of this is the reactor code CITATION developed on the model 91 by the Reactor Division. In the nuclear design of a power reactor, several of the problems to be considered are interrelated. At any given time the neutron population in the reactor is influenced by the distribution of fissionable material (e.g., uranium-235), moderator materials (light water, graphite), and neutron absorbers (structural materials, coolants, fission products, control rods, etc.) and by the physical state of these materials. One task of the reactor designer is to predict the behavior of the neutron population in the reactor in the presence of all these diverse influences, and central to this task is what is called the "flux-eigenvalue" problem. Basically, the question to be answered is, Given a specific distribution and physical state of materials in a reactor, will the neutron population increase, remain stable, or decrease over a period of time?

The neutron population in a reactor is a function of position in the reactor, because the reactor is finite and consists of many different materials of diverse properties. It is also a function of neutron energy; neutrons are liberated in fission with energies around a million electron volts, and in a thermal reactor the neutrons causing further fissions have energies in the range of a few hundredths of an electron volt. The neutron absorption cross sections of almost all materials vary with neutron energy in highly complicated ways. To deal with this complexity, many mathematical models have been developed, and of these, many have been used in one form or another as the basis of digital computer programs for the study of neutron populations in a reactor. A form particularly suited to digital computation is a finite-difference representation of the partial differential equations that describe the behavior of the neutron population as a function of position, energy, and time. The neutron population is studied at discrete space points in one, two, or three dimensions and over small ranges in energy, generally called neutron energy groups; the time-dependent behavior is also represented by differences between neutron populations at various times.

Important though it is, the flux-eigenvalue problem is really only the beginning of the story, because in addition to the behavior of the neutron population at a particular time, the reactor designer is concerned with the behavior of the reactor over long periods of time. The amounts of certain materials in the reactor change with time: the original fuel is gradually consumed, the fission products build up and decay, and, if we are dealing with a breeder reactor, fertile material is converted into new fuel. These problems are generally called depletion problems.

Further, the physical state of the materials in the reactor depends in turn on the neutron population. The power level and hence the heat generated in the reactor also depend directly on the neutron

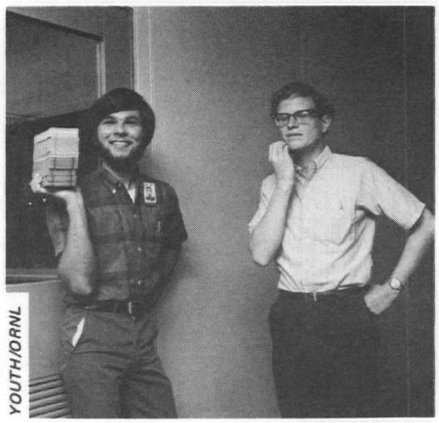


The versatility of the new computer facility is implied in this multifaceted montage of some of the scenes around the complex installation. Center design is a Cal-Comp plot of an experiment with tangent lines.

population, and the temperatures of the materials in the reactor depend on the rates of heat generation and removal. The neutron cross sections of the reactor materials depend on the temperature of the materials.

Still further, the reactor designer would like to study the behavior of a reactor which is receiving new fuel from various sources and sending depleted fuel to chemical reprocessing plants. These fuel management problems may also include the behavior of systems consisting of many different reactors and many reprocessing plants, and may in addition be concerned with the economic aspects of nuclear power generation.

All these problems have been studied extensively in the past with the aid of digital computers. Previous digital computers have been severely taxed just by the solution of the flux-eigenvalue problem. Much ingenuity went into the development of computer programs for the solution of this problem in various approximations; however, the effort required was usually so large as to limit the amount of work that could be done on the larger problems of depletion, dynamics, and fuel management. Generally the previous generation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of computers was so limited that the flux-eigenvalue problem was considered central; depletion, dynamics, and fuel management were considered peripheral problems. The computer programs were for the most part designed only for the solution of a particular approximate form of the flux-eigenvalue problem. Communication of the necessary data to other programs for depletion, dynamics, and fuel management was so difficult that the programs were not written to allow easy modification.

With the acquisition of a third-generation computer at ORNL, it was feasible to consider a new system of computer programs with the following properties:

1. the ability to direct the calculation through a variety of related subprograms;
2. the de-emphasis of the flux-eigenvalue problem;
3. the treatment of as large as possible multidimensional, multi-neutron-energy-group finite-difference problems with all the problem data stored in fast memory;
4. the flexibility to allow the addition of new mathematical models or the extension of the existing treatment.

The CITATION program is an attempt to meet these objectives. This program is designed to use computers with at least 500,000 words of directly addressable storage to solve general reactor core depletion and dynamics problems. CITATION is currently capable of solving flux-eigenvalue problems in a finite-group form with arbitrary scattering.

It is being used extensively to solve problems in reactor design associated with many important reactor projects such as the LMFBR, HFIR, TLPR, and MSBR. For "fast" reactor problems, the model 91 is up to 40 times as fast as the model 75.

Another class of problems in which both the large memory capacity and high computing speed of the model 91 are vital is radiation shielding calculations. Recently a study was made of neutron and gamma-ray transmission through a cylindrical concrete shield 10 ft thick and 20 ft in diameter. Several ducts penetrated this shield, and part of the object of the study was to determine the effect of offsets in the ducts at various positions inside the shield. The large size of the shield required a large number of finite-difference mesh intervals; the presence of the ducts required that calculations be made of neutron and gamma-ray transport along several directions, and the fact that gamma rays of various energies are produced when neutrons are absorbed by the materials in the shield required that many energy groups be used. The computational effort in this problem is roughly that needed for solving a system of 10 million simultaneous equations. With the model 91, answers were obtained after about 12 hr of computing time during one week; alternative techniques not using the model 91 could have produced the answers but only with the expenditure of hundreds of hours of computing time on slower computers spread out over six months.

Importance of Sample Size

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For many years radiation biologists have debated about the nature of the biological response curve for very small doses of radiation. The views of two schools of opinion can be summarized simply as follows: One school believes that any dose of radiation, however small, will have a deleterious effect upon the exposed material; another believes that no harm will be done until at least some reasonable dose is administered. Currently the debate has reached the point at which responsible members of the scientific community are once again asking what resources would be necessary to lay the controversy to rest on the basis of laboratory experimentation.

If a geneticist were to observe a $\frac{1}{2}\%$ increase in mutation frequency among progeny of mice exposed to 5 rads of ionizing radiation, how many mutations would he have to see before he could conclude with, say, a 95% degree of confidence that the mutation frequency can be expected to be higher at 5 rads than at zero rads? By adding the terms of the binomial expansion, the answer to this question is 218,108 mutations in the irradiated group and 217,000 in the control group. These are fairly large numbers, but they are insignificant when compared with the number of progeny one would need to raise to observe this many mutations. It is sufficient to know that the spontaneous mutation rate in mice is 52.5×10^{-6} per gamete. Simple arithmetic indicates that the sample size for such an experiment would exceed 8 billion mice. If the largest existing commercial mouse-breeding installation in the United States were to devote its entire effort to this one experiment, it could complete the job in about 8000 years.

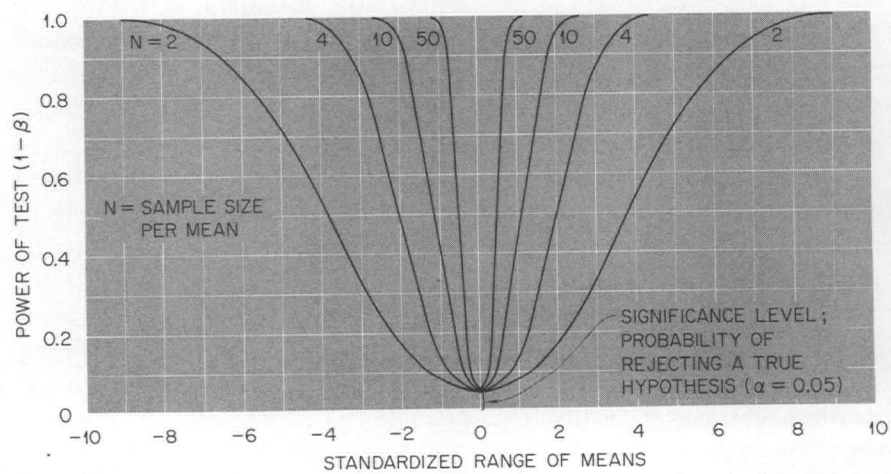
When answers to questions are so obviously ridiculous, straightforward decisions can be made about the advisability of performing such experiments. However, the mathematical techniques which led to these arithmetic results are applicable to many situations in which the answers are neither ridiculous nor even obvious.

An experimenter who is interested in determining sample sizes necessary for testing hypotheses about the equality of several Gaussian means can refer to one of the existing articles on this subject in the statistical literature. Much of this information appears in a wide assortment of statistical journals, some of which are obscure and unavailable. Moreover, many of the tables that accompany these articles are limited in scope, thereby restricting their applicability. As a result, the experimenter has been obliged to operate within the narrow range of tabulated values or to evaluate the appropriate mathematical function for each specific set of conditions. Both situations are constraining, and neither has encouraged a wider use of correct techniques for determining adequate sample sizes by the very people who are performing experiments.

Answers to questions concerning adequate sample size depend on consideration of such things as the number of categories to be compared, the levels of risk the experimenter is willing to assume,

and some reasonable guess about the size of the maximum standardized range of the means that will be observed. In 1969 several statisticians at ORNL set themselves the task of providing answers to a wide assortment of questions dealing with sample size. These answers appear in the form of tables, which require a minimum amount of background to understand and to use. Illustrative examples from the engineering and biological sciences are a part of the text that accompanies the tables.

An important aspect of the tables is that the concept of "power" has been considered in the calculations. Power, as synonymous with force, energy, strength, authority, jurisdiction, control, is used in statistical jargon to describe the ability of a test procedure to reject a false hypothesis. It is measured on a scale between zero and 1, and its complement is the risk or probability of accepting a false hypothesis. In any specific experimental situation the power of a statistical test will increase with the number of observations. When conclusions based on the outcome of an experiment depend solely on the statistical evaluation of an observed set of data, the size of the sample (the number of observations) is critical.



This "peacock's tail" graph shows how an experiment's "power," that is, its ability to reject a false hypothesis, is enhanced as the number of samples tested is increased.

The importance of taking into account the "power" of a test may be illustrated as follows: An engineer wants to determine whether a newly developed 3-kΩ resistor is better than the standard he has been using. Suppose he takes into account only the probability of significant difference by fixing his risk at 0.05. This guarantees that if there is no real difference between the two types of resistors, significance will be indicated only 5% of the time. In this case it would not be necessary to perform an experiment at all. It would suffice to draw a ball at random from an urn containing 19 white balls and one red ball. If it is white, he concludes that there is no difference between resistors; if red, he concludes that there is a difference. Using this procedure, he will always reject the hypothesis of no difference 5% of the time, which also, in this case, is the "power" of the test.

Instruments

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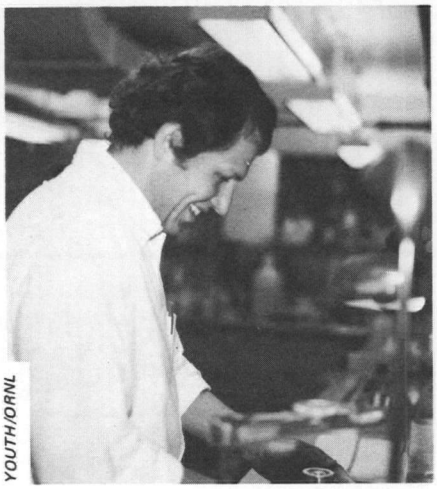
MAN Program Analyzers

The development of separations technology for the biological and medical sciences has been the central theme of the Molecular Anatomy (MAN) Program. As development has progressed, the new technology has provided solutions to various specific problems. This has been true for the development of the zonal centrifuge, for the isolation of purified vaccine, and for the development of the GeMSAEC analyzer for fast clinical analyses; it is also true for the high-resolution analytical systems being developed in the Body Fluids Analyses Program (a subprogram of the MAN Program). Significant advances have been made in the Body Fluids Program during the past year, and many interesting and useful data have been collected from prototype automated instruments being evaluated at ORNL and other laboratories.

The trend in medical research in recent years indicates that most human disease will ultimately be understood and controlled at the molecular level. Further, it has been shown that the concentrations of hundreds of molecular constituents in human body fluids may be indicative of body malfunction or of various pathologic states. Therefore it would be desirable to develop techniques that can determine these molecular constituents. The resulting "chemical profile" of the body fluid would indeed be a powerful aid in the diagnosis and treatment of the abnormal state.

The principal requirement for analyzing the numerous chemical species in body fluids is a system capable of high-resolution analysis of a single fluid for all or many of its constituents simultaneously. The Body Fluids Analyses Program was established to develop just such automated high-resolution systems (or analyzers) for the clinical research laboratory.

To date, emphasis has been centered on the analysis of low-molecular-weight (below 1000) constituents of urine, blood serum, and other body fluids, using two different analytical systems: a UV analyzer for detecting and quantifying the ultraviolet-absorbing constituents and a carbohydrate analyzer for detecting and quantifying carbohydrates. Both systems use high-pressure ion exchange chromatography (up to 5000 psi) for separating the constituents of the physiologic sample and continuous photometry or colorimetry for determining the separated constituents. Provisions are also available for automated sample introduction and, in some instances,



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for automated data analysis by an on-line digital computer.

The results from these analyzers are presented graphically on strip charts as plots of the absorbance of light by the chromatographic column effluent as a function of time, or the data are sent directly to an on-line computer for acquisition and analysis. The UV analyzer can resolve up to 150 chromatographic peaks from as little as 0.1 cc of a body fluid sample, whereas the carbohydrate analyzer will yield up to 60 chromatographic peaks from a typical sample.

More than 40 ultraviolet-absorbing and 16 carbohydrate constituents of body fluids that have been isolated by the chromatographic separation systems have been identified by chemical and spectral tests. In many cases, only microgram amounts of sample were available. Many of the identified constituents are known to have pathologic significance.

The early prototype analyzers required a relatively long period of time for analysis (40 hr for the UV analyzer and 20 hr for the carbohydrate analyzer); however, recent advances have resulted in miniaturized models that permit analysis in about half the original time.

As improvements of both types of analyzers evolve and are evaluated, more-advanced prototype models are designed, built, and sent to other laboratories for evaluation and scientific use. Currently, four prototype systems of our model Mark II series – one carbohydrate analyzer and three UV analyzers – are being tested in other laboratories. Three additional prototype analyzers are under construction for delivery to three other medical laboratories.

The carbohydrate analyzer is undergoing evaluation at the Clinical Center of NIH, where it is being used for in-depth analyses of the urine from hospital patients. One of the UV analyzers is being used by the Department of Medicine at Duke University Medical Center to study the effects of drugs in treating inborn errors in metabolism. The second UV analyzer prototype has been placed at the Clinical Center of NIH, where it will be used to study a variety of diseases, and the third has been placed in the Department of Pediatrics at Johns Hopkins Medical Center, where it will be used to study inborn errors in metabolism in the infant. An additional UV analyzer was built for the Analytical Chemistry Division of ORNL for the analysis of nucleotides, nucleosides, bases, and related compounds.

Frequent evaluations of the prototype analyzers are made to determine operability and to estimate future design needs. ORNL has been designated as a data collection center for the results of these analyzers, and meetings and symposia on subjects relating to high-resolution analysis are held periodically.

Several hundred analyses of both normal and pathologic body fluids of humans have been made at ORNL and at the institutes that are evaluating the prototype systems. The body fluids of a few laboratory animals have also been analyzed. In general the body fluids of normal subjects have produced very similar chromatograms,

although some dietary differences have been noted. On the other hand the body fluids from several subjects with both known and unknown abnormal states have shown some striking differences. For example, urine samples from patients with acute lymphocytic leukemia were shown by the UV analyzer to contain very small amounts of hippuric acid, normally one of the predominant constituents of urine. In other cases it was found that urine from patients with schizophrenia had two relatively large unknown chromatographic peaks that are absent in normal urine; patients undergoing phenacetin therapy excreted a newly recognized metabolite of phenacetin; and allopurinol, the drug used in the treatment of gout, has been shown to have an unexpected effect on pyrimidine metabolism.

Analytical results from the carbohydrate analyzer showed, among other things, that urine samples from hospital patients with liver disease and diabetes mellitus contained large quantities of sugars other than glucose; urine samples from patients with lactose deficiency, galactosemia, and essential pentosuria illustrated, in each case, the consequences of the deficiency of an enzyme important in carbohydrate metabolism; and analyses of urine during a xylose tolerance test indicated that xylose can be metabolized, thus making that test difficult to evaluate.

Several different body fluids have now been analyzed by both types of analyzers. These fluids include urine, blood serum, cerebrospinal fluid, saliva, and perspiration. Work on the analysis of amniotic fluid has just begun. Initial results have shown that the low-molecular-weight constituents of normal amniotic fluid are present in about the same quantities as in blood serum. Such analyses should have a large potential for the future.

The development of small flow photometers, high-pressure injection valves, and other components has made it possible to build miniaturized versions of the previous analyzer models. These new analyzers (model Mark III series) have separation systems that are about a tenth the size of previous models, requiring no more than 0.05- to 0.1-cc samples for analysis. Resolution in these smaller systems is comparable with that in the larger models, while analysis time is decreased by a factor of 2. The miniaturized analyzers are bench-top instruments that cost less than $10,000 to make. Commercial manufacture of the miniaturized analyzers and some of their individual components is now being investigated by two instrument companies.

Other developmental efforts are directed toward combining the two analytical systems into a single instrument package and adding a small on-line computer for data acquisition and analysis. The analysis of pathologic body fluids will continue, and additional separated unknown molecular constituents will be isolated and identified.

Recently a new rapid method of blood typing based on fast chromatography on cellulose wicks has been developed. Automation of this procedure is expected to reduce transfusion errors markedly.

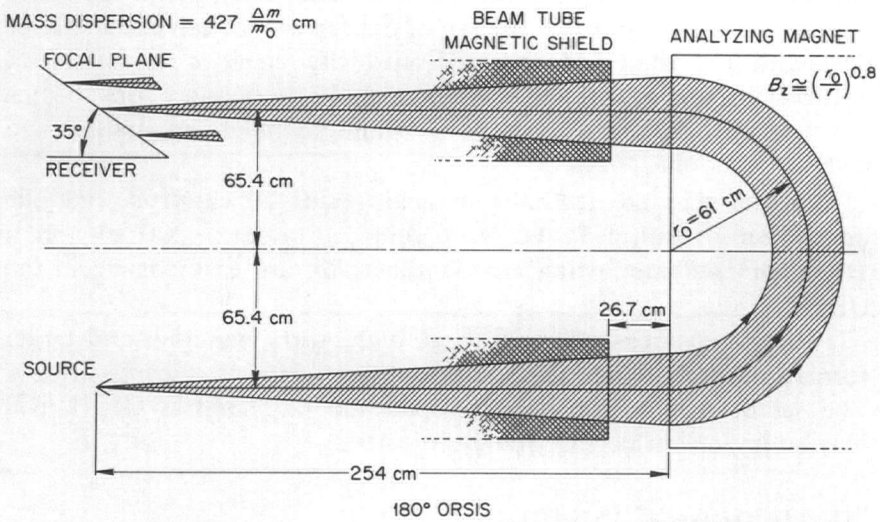
Ultraviolet analyzer, table top model. Even more miniaturizing is expected in the future.

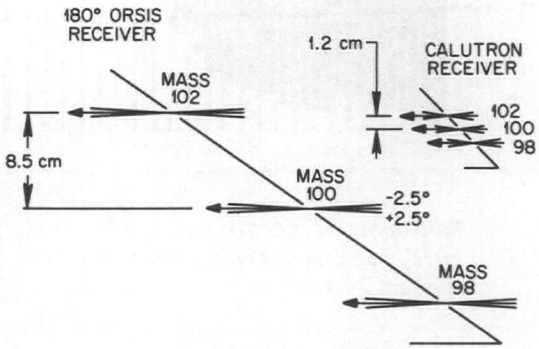
Oak Ridge Sector Isotope Separator

The ORNL calutrons, designed with high-throughput capabilities for electromagnetic separation of uranium-235 during World War II, have provided milligram to kilogram quantities of over 250 stable and radioactive isotopes during the past 25 years. From the first investigations using isotopically enriched copper-63 made in 1946 until 1969, when over 4000 investigations were made using literally millions of dollars' worth of enriched materials, the program has grown at a phenomenal rate. Beginning with two separators in late 1945 with the purpose of providing small amounts of enriched isotopes, the demand has grown until at present there are about 40 separators making kilogram quantities of highly enriched isotopes available to users throughout the free world. In addition to the increase in quantity, the required purity has changed, so that it is not unusual to get requests for 99% purity or higher; and sometimes the requests are for material approaching 99.999% in isotopic purity.

While calutron-separated isotopes are adequate for most investigators, there are special research or medical projects requiring enrichments beyond first-pass capabilities of the calutron. These high-purity requests have sometimes been met by a second-pass separation in a calutron or by small separators developed principally by the Europeans; however, the output from these machines is but a small fraction of that of the calutron. While useful for specific projects, separators of the type developed in Europe do not have the capacity to meet the existing demand, much less its projected growth, nor do they operate at economic cost levels.

The 180° focusing shims for the ORNL Sector Isotope Separator, which has an inhomogeneity of 0.8.





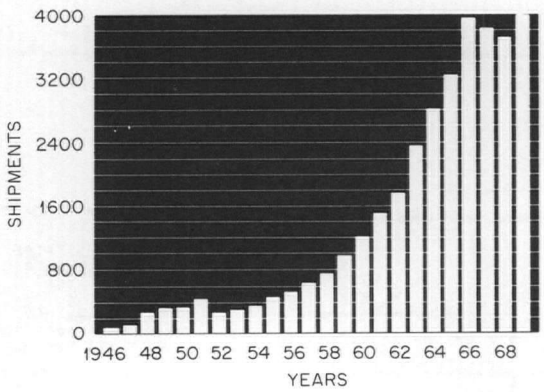
MASS DISPERSION COMPARISON

Diagram of the 180° Oak Ridge Sector Isotope Separator (upper left) showing the route taken by the sample as it enters the powerful magnet at the lower end and is whipped around and out the top, where its mass dispersion is nearly eight times that achieved by the calutron, as shown in the accompanying sketch.

The demand for isotopic purity, coupled with economic considerations, made it apparent that a separator was needed in the Laboratory isotopes program that would combine the desirable features of the European type of separators with the high throughput of the calutrons. The electromagnetic isotope separations group undertook the design of a sector type of separator that would fill this gap, hoping at the same time to make maximum use of spare calutron parts. The separator that resulted, the Oak Ridge Sector Isotope Separator (ORSIS), has a unique circularly symmetric 180°-sector magnetic field with an inhomogeneity of 0.8; it is the only known separator with inhomogeneity greater than 0.5. The high degree of inhomogeneity increases the dispersive power and provides the ORSIS with a greater separation between masses per unit radius than any other known separator: at mass 100 the separation per atomic mass unit is approximately 6 mm in the calutron, whereas in the ORSIS it is about 40 mm.

In exploratory runs the separator is providing isotopes of higher enrichment to satisfy needs in purity that are beyond the capability of a first-pass calutron separation; isotopic enrichments are up by ten times or more, with outputs at least one-tenth of those of the calutron. Further development of the magnetic field and equipment, now under way, will result in purer isotopes at even higher beam currents than those now obtained. Previously, multiple-pass separations would have been required to obtain strontium-84 with a purity higher than 99%; now, milligram quantities of 99.7% strontium-84 (useful in earth science research and production of high-purity metastable strontium-85) have been recovered from single-pass separations in the ORSIS. Approximately 80% strontium-84 was the highest purity available from standard calutron separations.

The great flexibility of this separator is also being exploited for the preparation of beam-deposited isotopic targets. Highly resolved ion beams of any element are available over an energy range from



Shipments of electromagnetically separated stable isotopes from ORNL over the past 24 years.

zero to more than 80 keV at beam currents ranging from submicroampere values to over 5 mA. This range in depositional energy is available through the use of a receiver that can accelerate or decelerate the 40-keV ion beam. Even higher energies are possible at reduced intensities through the use of multiply charged ions; beams for this purpose are obtainable in submicroampere to milliampere levels.

Targets that are difficult to achieve in the calutron, like the deposition of sulfur-34 at 50 $\mu g/cm^2$ at around 200 eV on a 10-$\mu g/cm^2$ self-supporting carbon substrate, are easily made in the ORSIS.

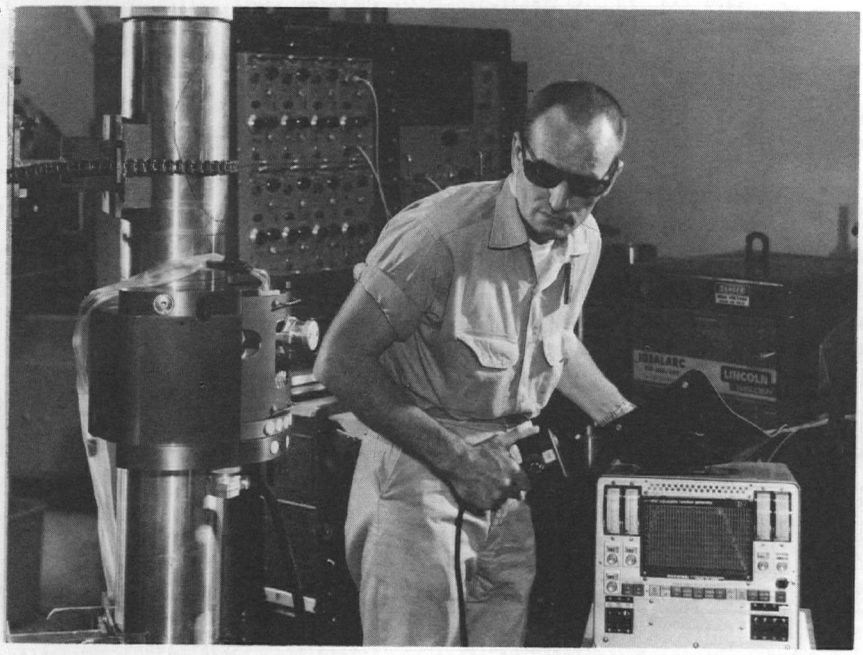
These two areas of application, high-purity materials and target formation, are of increasing importance in current research efforts. The sector machine being developed and perfected at ORNL will play an important part in filling these needs.

"Push Button" Welding

An ORNL study of the methods and equipment used to make repairs in the high-radiation zones of many different nuclear reactor systems has revealed that each repair job has been handled as a special case, with equipment and techniques devised on the spot to meet the specific needs. Finding no commercially available cutting equipment for remotely controlled removal of system components or sections of pipe which had failed, and no remote welding equipment for installing replacements, Laboratory engineers sought equipment which would be most suitable for further development to provide remotely controlled operations and consistently reliable performance. An automated pipe-cutting and welding system developed for the U.S. Air Force by North American Rockwell Corporation showed promise for such development.

Upon request, the Air Force provided design information and also loaned some equipment to ORNL for testing. As a result, a complete automated cutting and welding system with design modifications has been fabricated for use in ORNL's development of remote maintenance equipment. With additional refinements to incorporate adaptive welding controls through the use of feedback circuits, the modified system has demonstrated such good and consistent performance for indirect work that it has given rise to a second objective – a completely automated welder for direct application in reactor construction.

Manual welds at the reactor construction site must be performed by specially qualified welders, which usually means that the construction contractor must conduct an extensive welder training program. In addition, nuclear-quality welding by hand is slow and is plagued with a high percentage of rejects. The automated welding equipment being developed at ORNL makes consistent high-quality welds with zero defects and without the necessity for long-term qualification training on the part of the operator. An experienced welder can learn to weld with the equipment in two or three days.



Automated cutting and welding system at ORNL. Adapted from a system designed elsewhere for the Air Force, the above welding system permits complete welds and cuts to be made from preset programs that have been fed into the electronic programmer on the right. The "orbital" carriage, shown on the left, is clamped around the pipe and drives itself and the welding head around the circumference of the pipe. Adaptive controls can sense changes from feedback signals and automatically adjust for pipe ovality and for the difference between welding up and down as the carriage moves around the pipe.

Once he has mastered it, he can then produce flawless welds at least six times as fast as is usually achieved in manual welding. Additional time is saved by the fact that adaptive controls permit high-quality welds to be made without such careful joint preparation and alignment as would otherwise be required.

The equipment consists of an "orbital" carriage that clamps onto a pipe and propels the welding apparatus around the circumference of the pipe. The carriage accommodates interchangeable heads for cutting pipe and for making tungsten–inert-gas arc welds. There is an automatic welding programmer-controller that constantly maintains all conditions necessary to produce flawless welds. There is also a hand-operated pendant unit to provide alternative start and stop controls. To begin automatic welding, an appropriate procedure for the type of weld desired is dialed into the programmer-controller, a button is pushed, and the machine takes over to produce the weld and then shut itself off.

Keen interest on the part of industry and of the AEC has made automatic welding for reactor construction an attractive objective for the immediate future. It seems assured that the automated welder will produce important savings in time and cost in constructing pipe systems while also increasing the reliability of the welds.

Solid-State Dosimetry

Solid-state dosimetry, which is replacing ionization methods and photographic film dosimetry in an increasing number of important areas, has been a major area of research in the Health Physics Division's Radiation Dosimetry Research Section. A few examples of how solid-state detectors help to control man's radiation environment and contribute to pollution research can be mentioned here.

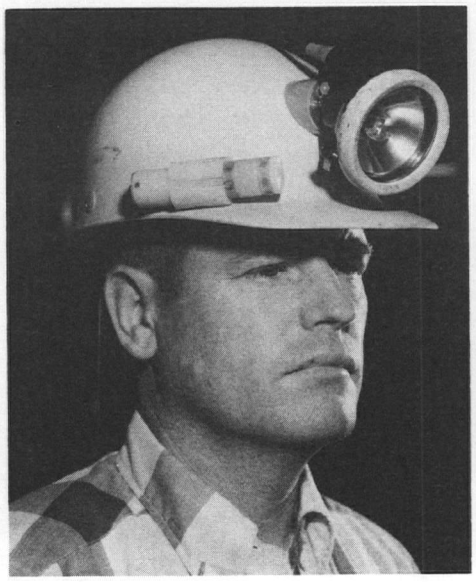
For instance, many uranium miners have died from lung cancer, largely because no method was available for selectively measuring the amount of airborne material bearing alpha-emitting daughter products of radon present in the atmosphere of the mine. A personnel dosimeter for uranium miners, currently undergoing its final testing, solves this problem. It consists of a miniature battery-operated motor that pumps a continuous flow of air through a filter monitored by an alpha-particle detector. At regular intervals, this detector, a thin cellulose nitrate foil, is removed and etched in a caustic solution, causing a microscopic perforation in the foil at the location of each alpha-particle impact.

These holes, the number of which is indicative of the amount of radon in the air, can then be automatically counted by placing the foil on one of two electrodes and covering it with an aluminized plastic foil. A potential between this and the other electrode produces electrical discharges, each spark of which evaporates the aluminum coating in an area larger than the original hole, which forms a visible replica of the alpha track distribution. The number of sparks is counted by a scaler.

This technique has also been used in alpha autoradiography. If a bone sample containing radium-226 is kept in contact with a cellulose nitrate foil for a time comparable with that required to get a photographic autoradiograph, a high-resolution autoradiograph is directly visible in the etched foil. By spark counting, the sensitivity can be increased by a factor of 100, and quantitative data can be obtained in an extremely simple way.

The presence of minute amounts of fissionable materials can be detected in minerals, alloys, biological samples, liquids, gases, etc., using a similar principle. For example, tap water and distilled water have been measured for the presence of uranium by evaporating a

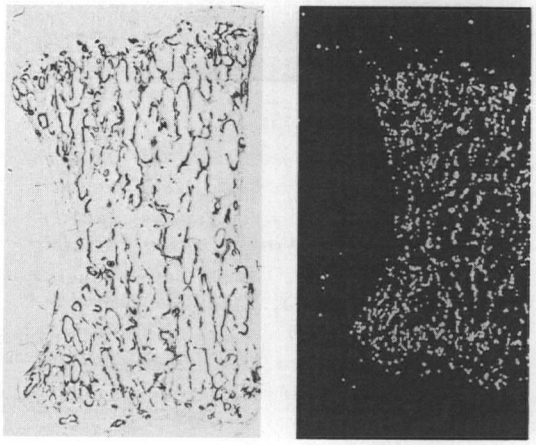
Prototype of a personnel dosimetry system for uranium miners, which responds only to the dangerous aerosol-attached radon progeny, consists of small cylindrical dosimeters to be worn on the helmet, a unit for recharging them between shifts, and a simple automatic counter to measure the number of alpha-particle impacts accumulated over a specified time period in a sensitive polymer foil.



drop of each containing as little as 10^{-14} g of uranium on a foil that can be punctured by fission fragments. Alternatively, a filter through which a measured amount of air has passed can be placed in contact with a similar foil. After exposure to a known thermal-neutron fluence, followed by the process of etching and sparking described above, the distribution as well as the concentration of the fissile elements in these three samples becomes directly visible.

Another ultrasensitive method for quantitative integrating radiation measurements is based on a completely different principle: If an ionic crystal is heated after irradiation, frequently low-energy electrons (average energy around 0.2 eV) are ejected from a very thin surface layer at one or several characteristic temperatures. The number of electrons, which can be counted by heating the sample inside a gas-flow Geiger-Mueller counter, can be made proportional to the radiation dose. This effect of thermally stimulated exoelectron emission (TSEE) has been studied in great detail at ORNL, and detectors which permit the measurement of 10^{-6} R have been developed. One of the most recent applications of TSEE is the investigation of the thermal and radiation history of lunar samples. Lunar fines from Apollo 11 exhibit TSEE peaks at 142, 268, and 465°C at a constant heating rate of 1°C/sec. Samples from Apollo 12 will be studied next.

Alpha autoradiograph in cellulose nitrate of a beagle bone containing radium after extended exposure and etching (left) and replica in an aluminized Mylar foil after short exposure and sparking (right).



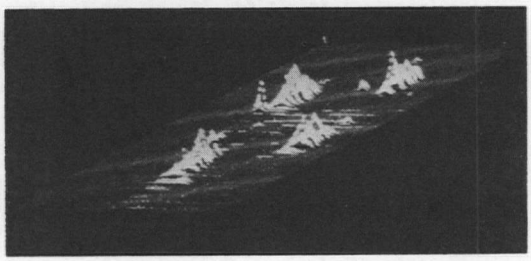
Two New Detectors

The Fly's Eye: A Wide-Angle Position-Sensing Counting System for Neutron Diffraction

With present-day neutron diffraction techniques, locating the positions of atoms in complex molecules such as proteins is a tedious task that can take many man-years. Tens of thousands of reflected beams of neutrons must be measured one at a time with a single detector. Under Project Fly's Eye, a wide-angle position-sensing counting system for thermal neutrons has been developed to count hundreds of reflections simultaneously with a proportionate reduction in data collection time. A prototype is now being tested at the Oak Ridge Research Reactor.

The detector, which combines television and nuclear electronics, is in fact many detectors operating at once, like the lenses of a fly's eye. It consists of a neutron-sensitive phosphor screen placed near the molecular crystal under study so that it intercepts a large fraction of the reflected neutrons. The screen scintillates when struck by neutrons, and the individual scintillations, increased in brightness by an image intensifier, are picked up by a television camera. Their positions on the phosphor screen convey the necessary direction information. The camera tube converts the light flashes into localized electric charges, which are stored temporarily on a dielectric target.

The target is scanned in a TV raster by an electron beam, which neutralizes the localized charges representing the neutron events. This neutralization process removes electrons from the beam,



The picture above shows the display of counting data from multiple neutron reflections recorded simultaneously with the Fly's Eye System. The test object was a crystal of natural rock salt, 1 cm on a side. The crystal was placed in a monochromatic neutron beam, and the detector screen was placed parallel to the beam so as to intercept 100° horizontally and vertically. Both crystal and detector were stationary during the run. The heights of the peaks are proportional to the intensity of the reflections. The locations of the peaks on the "plain" correspond to the positions of the beams as they struck the detector screen. The single sharp peak indicates the resolution obtainable and shows that the jagged structure of the main peaks caused by crystal imperfections is real.

effectively modulating it. The modulated beam then contains the position of each event as time information measured from the beginning of the scan. These time signals are used to address a computer memory to store the events in memory locations assigned to them. As each position on the target is neutralized, it is ready for another event. Thus the screen acts as many thousands of detectors operating independently over a solid angle many times as large as the single-detector systems in current use. As the experiment proceeds, the computer keeps a running sum of the events occurring at each point of the screen, and a quantitative diffraction pattern is recorded.

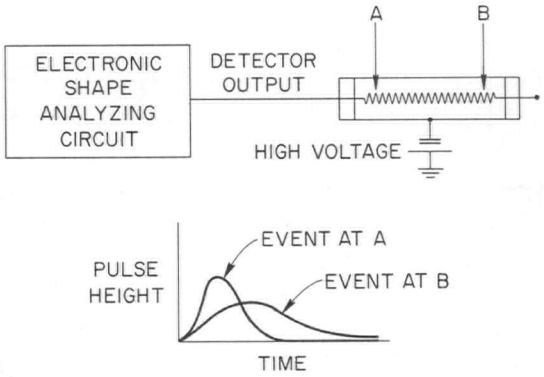
Besides providing a counter with spatial resolution better than 1 mm, the system enables the experimenter to "see" the neutrons on a television monitor, with the localized reflected beams appearing as three-dimensional peaks. The monitor can be used as a guide when an experiment is set up, and it will also permit qualitative observation as the experiment progresses. The neutron events can be recorded on video tape and later counted and recorded at an off-line shared computer center.

Since many neutrons can be counted which would be wasted by the conventional single-detector method, the new system opens the possibility of neutron diffraction studies to institutions with low-intensity neutron sources. The more complex structure determinations, of course, will still require high flux intensities.

Two-Dimensional Position-Sensitive Proportional Counters

A host of nuclear measurements require a knowledge and a registration of the location of an ionizing event. Examples are the recording of neutron or x-ray diffraction patterns, the recording of the display of a particle spectrometer, medical scanning, and autoradiographic processes. A classical instrument for the purpose is the photographic plate, but for years it has been considered slow and often quantitatively unreliable.

Using a new method a two-dimensional display detector has now been developed at the Laboratory that seems to fill the need, with an advantage that not only is the location recorded, but also the energy associated with the event.

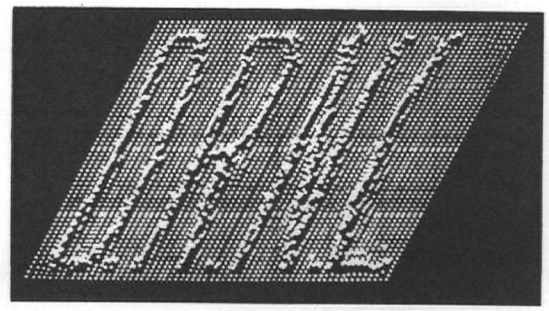


To take the one-dimensional case first, consider the proportional counter in the diagram on the left. The wire is made resistive, and the counter has the behavior of a distributed resistance-capacitance line. An ionizing event at location *B* will then give a wider pulse than one at *A*, because of the diffusive character of the portion of the detector connected between the event location and the detector output. The electronic circuit analyzes the shapes of the pulses, associating a given shape with a given distance along the wire and registering a given pulse in the proper channel of the recorder. The energies of the ionizing pulses are sensed from the areas within the pulse envelopes.

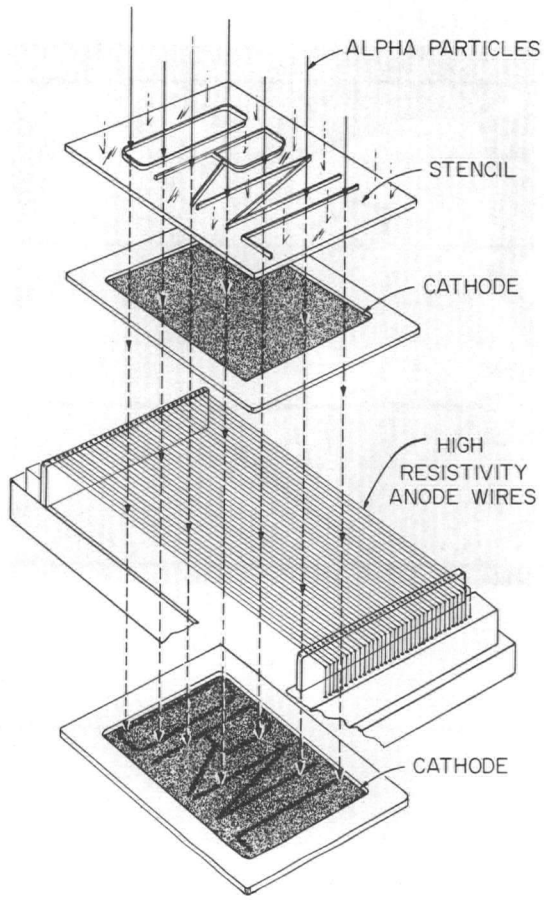
To make the detector two-dimensional, many parallel wires are strung within a counter box. Resistances are inserted between adjacent wires, and the electronic circuit can now tell at which wire, and where on that wire, an ionizing event has occurred. The sensitive area may be typically a square foot in size.

The pictures show cathode-ray-tube displays of a counter pattern obtained by using collimated alpha particles that penetrate into the grid of counter wires. Using only four amplifiers, the instrument can distinguish between 24,000 locations when a 30-wire counter covers an area 7.5×12 cm^2. In a typical linear system, an event can be distinguished from another only 0.15 mm away when collimated alpha particles or collimated x rays are used.

Some of the potential applications of these position-sensitive proportional counters are in the structure determination of large molecules using x-ray or neutron diffraction, x-ray spectrochemical analysis, small-angle scattering experiments with x rays or neutrons, magnetic spectroscopy of protons and other charged particles, x-ray astronomy, as an improved substitute for the wire spark chamber in high-energy physics experiments, two-dimensional chromatography, and medical studies for the localization of radioactive tracers.



(b)



(a)

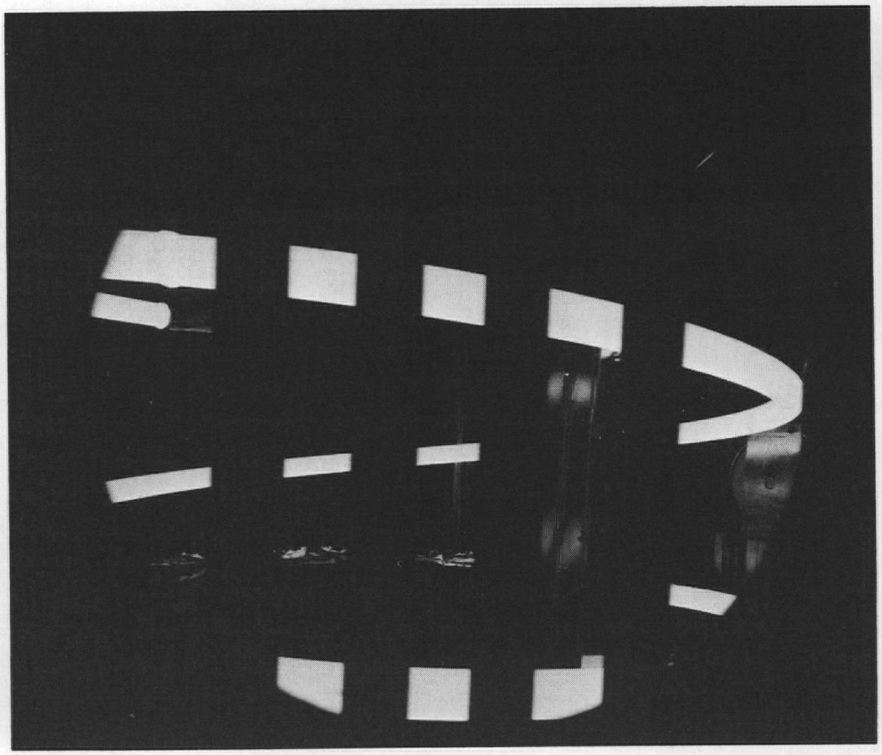
Results of an alpha-particle imaging test using the two-dimensional position-sensitive proportional detector. (a) *Illustration of the experimental arrangement; a collimating stencil was placed between an alpha-particle source with a large area and the multiwire detector.* (b) *Isometric representation of the image of the stencil as produced by the detector and displayed on an oscilloscope screen; the information is displayed by scanning the 64 X 64 channel memory of a two-parameter multichannel analyzer.*

Lithium Loop Experiment

When heat is converted to electricity, the higher the temperature at which the heat is supplied, the more efficiently it is converted. Nevertheless, a portion of the heat must always be rejected at a lower temperature. Thus the way to increase the efficiency of power production and decrease the associated "thermal pollution" by the waste heat is to increase the temperature at which reactors and associated power conversion equipment can operate. When one seeks to generate power in the vacuum of outer space, the desire for higher temperature becomes a demand. Greater efficiency means less weight to be orbited. But also there is no body of water, or even poorer heat sink, to carry away the waste heat. Therefore it must be radiated, and the ability of a radiator to send heat through the vacuum of space increases sharply with increasing temperature. The need for power in space is thus the prime incentive for developing high-temperature systems.

In space power plants, alkali metals, which have melting points well under 400°F, will replace the steam and water of earthbound power plants. Piping must therefore be of refractory alloys such as those based on tungsten or tantalum. Operating temperatures will far exceed the range of familiar experience. To gain experience with corrosion, heat transfer, and operating problems of such systems, reactor and materials engineers at ORNL are operating a test loop in which liquid lithium is circulated, heated to 2500°F, and cooled by radiation to 2200°F. The loop has operated at this intended temperature range for its scheduled 3000-hr test program. Major trouble was encountered after 1700 hr when a lithium leak occurred,

Operation of ORNL's liquid lithium forced circulation loop. The loop is protected from the atmosphere by an 1100-gal vacuum chamber. The operator is determining the loop temperature by sighting through a port in the vacuum chamber with an optical pyrometer. The inset shows the loop inside, its tantalum alloy tubing glowing with the heat of the 2500°F lithium it carries.



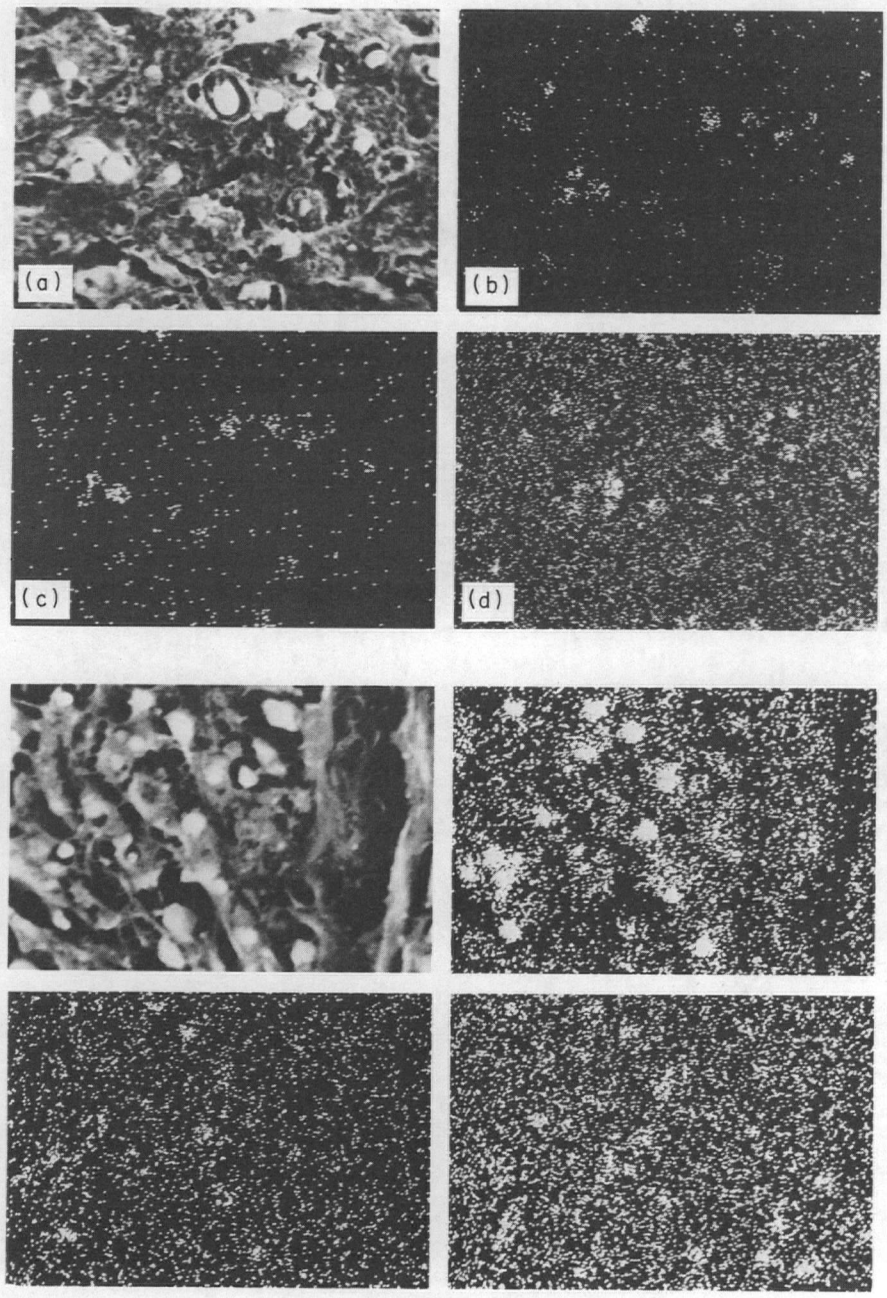
but repairs were successfully made, and the test was completed without further incidents. The loop's peak operating temperature is the highest ever achieved with an alkali metal circulating at high velocity.

The loop carrying the liquid lithium is fabricated of T-111, an alloy of tantalum with 8% tungsten and 2% hafnium. Since refractory metals, like the filament of a light bulb, need to be protected from air when hot, parts were welded in an argon-filled glove box. The loop was fabricated into three main subassemblies, which were connected at the loop site by means of an automatic welding rig that provided a protective environment. In operation the loop is protected by a vacuum chamber with a pressure well below one billionth of atmospheric. A helical induction pump operating at 2200°F circulates the lithium at 5.4 gpm, giving flow velocities up to 19 fps.

A test section containing 80 T-111 specimens for study of corrosion and other metallurgical changes makes up the "hot leg," in which the lithium is brought to top temperature with 3600 A of heating current, and the "economizer," a concentric double pipe in which the heated lithium gives up some heat to cooled lithium from the pump.

New Use for Metallurgists' Microprobe

A new use was found in 1969 for a tool that had previously been used only by metallurgists. Metals and Ceramics' electron microprobe x-ray analyzer, designated originally for study of the physical properties of inorganic materials, proved to be useful in the examination of biological tissue. Concentrations of specific elements as low as 1 wt % were detected in suitably segregated samples of both human and hamster tissue. The following micrographs illustrate how this procedure may be used to determine the presence of suspected pathology.



The analytical versatility of the electron microprobe has been shown on some human tissue for the Biology Division. These photographs show the instrument's first venture into microprobe analysis of soft tissue, results that open the way for more such work with this instrument. Specimens of human testis tissue were examined for signs of malacoplakia, a disease that results in small (less than 7-μ-diam) crystal bodies in the testes. Samples were taken from tissue that had given a positive histochemical test for the disease and from tissue suspected of having the disease without the positive histochemical test. The pictures above show (a) *a secondary electron display of the known affected tissue and* (b, c, *and* d) *microprobe scans for calcium, phosphorus, and iron. In the photographs below, similar studies have been made on the suspected tissue, revealing the presence of these elements in similar quantity, leading to the conclusion that malacoplakia is indeed present.*

ORNL 1969

ORNL and Apollo

ORNL in Space

Preliminary Programs

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Oak Ridge National Laboratory has undertaken a number of projects for NASA in response to the space agency's requests and specific programs submitted to the Atomic Energy Commission. Among these programs, a number were submitted to the Division of Biology and Medicine of the AEC that were undertaken by ORNL's Biology Division and that assisted in the preparations necessary to the successful Apollo missions in 1969.

Biological Studies

One such program was to measure chromosomal aberration frequencies in peripheral blood samples taken before and after flights from the crew members of the Apollo earth orbital and lunar missions. Such measurements were to make it possible to make biological radiation dose estimates of the exposures received by astronauts during their missions. The work was a continuation of an earlier contract with NASA in which chromosome analyses from the Gemini astronauts of flights 3 through 12 were carried out. A summary statement of this work is that to date no major chromosome abnormalities have resulted in the astronauts as a result of space radiation or other factors such as weightlessness or vibration associated with lift-off.

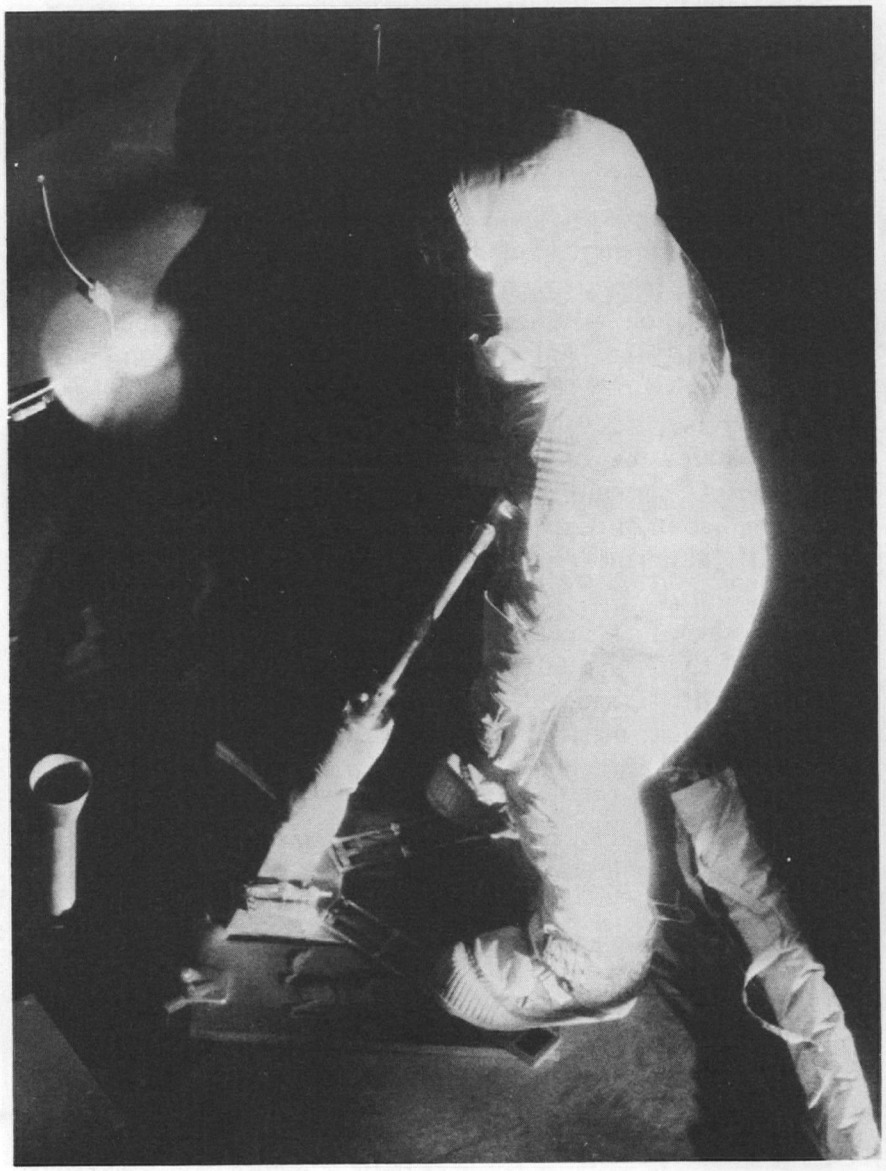
In addition to the contractual agreements between NASA and the AEC, there has been at least one short-term consultantship involving a Laboratory staff member. This was a biologist's work in connection with attempts to detect microorganisms in the first shipment of lunar material. The work consisted in looking for an enlargement of lymph nodes after injection of moon dust in mice that initially were germfree. Such an enlargement would have indicated the presence of biological contamination in the dust. No such reaction was observed.

Apollo Lunar Aseptic Sampler

Elsewhere at Oak Ridge, mechanical design and development engineers, biologists, radiochemists, and several fabricators, in a joint ORNL–Y-12 effort, all played a role in designing the lunar aseptic sampler used in the Apollo missions. NASA's charge to the Oak Ridge researchers was to design a small, lightweight device that

1. could be cleaned and kept free of all earth-originated organic or inorganic contaminants,
2. was limited in size and weight to fit an existing sample return container (the "rock box"),
3. could be transported to the moon, assembled, and operated by a suited astronaut to take an aseptic sample of lunar soil,
4. could then house the aseptic soil sample during its transport path to the Manned Spacecraft Center Lunar Receiving Laboratory,
5. could be qualified as an item of flight hardware for the Apollo lunar missions.

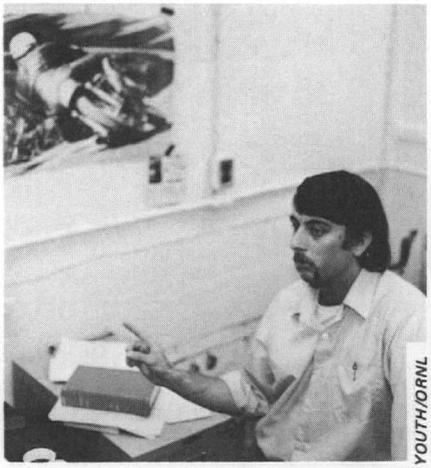
Astronaut operating the aseptic sampler in chamber B of NASA's Space Environmental Simulation Laboratory.



The sampler's primary purpose was to assist in determining whether any type of organic life or bacteria normally exists on the moon.

Four hundred sixty-six individual parts were ultimately assembled to complete the sampler assembly, which weighed in at approximately 6 lb (1 lb on the lunar surface). Development tests helped establish specific design parameters for the sampler. Human engineering, mechanical component, mechanical assembly, and material tests were conducted. Studies included simulated decontamination of "lunar soil" and simulating its sterilization by radiant energy. The problem was complicated by the fact that the lunar surface would be contaminated by the exhaust from the lunar module and that the astronauts themselves must be considered a continuous source of biological contamination. A mechanical method was finally devised for preventing earth-originated contamination. It proceeded as follows: The sampling area was first isolated, a ¾-in. layer of topsoil was displaced, and then a clean sample tube was forced into the surface to trap an aseptic lunar soil sample. The sample tube with its contents was then withdrawn into a Teflon biological bag for its return trip to the earth.

Qualification testing of the sampler included cleaning, premission conditioning, vibration testing, shock testing, and thermovacuum testing at 10^{-5} torr in a temperature range from 150 to −45°F.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Gamma-Ray Spectrometry of Returned Lunar Samples

At the request of NASA, ORNL developed a gamma-ray spectrometer of low background for use in the Lunar Receiving Laboratory at Houston during Apollo missions and was responsible for radiation counting experiments during the preliminary examination of lunar material returned in 1969. In addition, a cooperative program between staff members of the Laboratory and the NASA Manned Spacecraft Center provided for further studies to obtain more detailed results. The detector system constructed at Houston was patterned from a prototype developed at ORNL. The prototype is now engaged in studies of lunar material at the Laboratory that complement the work done with the Houston equipment.

Gamma-ray spectrometry is a useful method for radiochemical analysis of geological samples. The method as applied here is nondestructive, and lunar samples from 7 g to 2 kg have been analyzed by this method. The concentrations of the naturally radioactive elements potassium, thorium, and uranium have been determined on large suites of samples from Apollo 11 and 12.

Because the moon has neither an atmosphere nor a significant magnetic field to protect it from bombardment by galactic cosmic rays and heavy charged particles from the sun, a variety of radioactive nuclei are constantly being formed in the lunar surface

that can be measured by gamma-ray spectrometry. Further, since the lunar samples have been irradiated in known locations in space and are free of atmospheric ablation, they are in some respects more suitable objects for study of cosmic-ray and solar-proton effects than meteorites. Careful studies of the Apollo samples have already yielded important information on the bombardment history of the lunar surface and the history of the particle fluxes responsible for the observed species.

The chemical composition of the crystalline rocks from Apollo 11 is remarkably constant, except for a small group of elements which include potassium, thorium, and uranium. These latter elements appear to distinguish two classes of rocks from Mare Tranquillitatis; on the other hand, the crystalline rocks brought from Oceanus Procellarum by Apollo 12 show much greater uniformity and chemically resemble the coarse-grained rocks of the Apollo 11 site.

The concentrations of the naturally radioactive elements are of great importance to the thermal history of the moon. Potassium concentrations for lunar basalts range from 480 to 2550 ppm and lie in the general concentration range of stony meteorites. Although the average potassium concentration is less than one-tenth of the average concentration in the earth's crust, the thorium and uranium contents are near those of terrestrial basalts. The concentration of radioactive elements in the lunar surface materials is much greater than that inferred from thermal models for the mean radioactive element content of the moon. It appears that the differentiation implied by these results must have been caused by melting to considerable depth; however, it is as yet not resolved whether the source of the heat required arose from impact or internal heating.

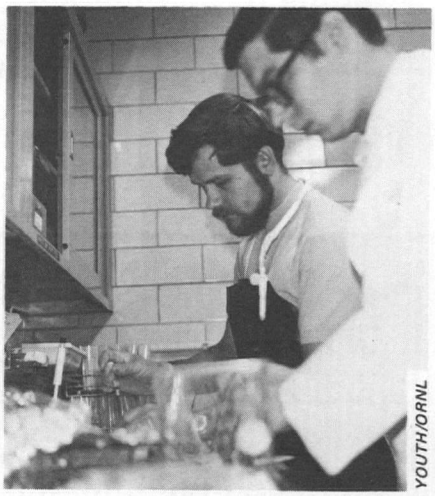
The concentration ratio of potassium to uranium for lunar material varies from about 1400 to 3200, which implies that potassium contributes relatively little to radiogenic heating of the moon. These low values of K/U are distinct from eucrites (5000), terrestrial rocks (10,000), or chondrites (70,000).

An extensive series of cosmogenic radionuclides was determined in the lunar surface materials. The yields of these nuclides appear consistent with the known cosmic-ray flux and bombardment cross sections.

Cosmic-ray exposure ages determined by the ORNL-NASA team show that one of the rocks was within about a meter of the lunar surface for about 350 million years; other rocks showed evidence of shorter exposure, to a minimum of about 40 million years. These variations in cosmic-ray exposure ages are consistent with a continual series of disturbances on the lunar surface due to impact.

The lunar material is a useful indicator of solar flare activity. The exposed surfaces of Apollo 11 and 12 rocks showed high concentrations of short-lived cobalt-56 and vanadium-48, which are produced almost entirely by low-energy protons from solar flares. The high concentration gradients for these and other nuclides induced at least partially by solar protons have made it possible for the radiation

counting group to derive the orientation of lunar rocks with respect to the sun more accurately than from lunar surface photography. The yields of long-lived species produced by solar-particle bombardment permit the conclusion that solar flares, and presumably sunspots, have been occurring for at least the past 10^5 to 10^6 years. Surface concentration gradients for aluminum-26 suggest that the rate at which the crystalline rocks are being eroded by meteoritic impact is about 1 mm per million years.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Magnetic Resonance of Lunar Material

Preparatory to the arrival at ORNL of lunar material to be examined for magnetic resonance properties, Laboratory physicists performed such investigations on certain terrestrial rocks and minerals that were expected to be similar to the moon material, based on results from Surveyor experiments. Several mineral components were also subjected to detailed study. Glassy material was expected in lunar rocks, so part of the preparatory research was devoted to vitrification and devitrification processes. The structure of the spectral components of a particular ion of manganese, Mn^{2+}, when present in dilute concentrations in a glass-forming compound such as zinc chloride, is a sensitive indicator of these processes. The natural abundance of manganese in lunar material was expected to be about the same as in meteorites and terrestrial basalts, providing another reason for choosing this ion. Subsequent interpretation of the spectrum of Mn^{2+} in lunar material proved to be greatly aided by the preliminary study. Results of analyzing the spectrum of Mn^{2+} in olivine showed that manganese was ordered with respect to two possible sites. Ordering or its lack in lunar crystals will be informative for processes of crystallization and for subsequent thermal history.

Proton irradiations of terrestrial silicate rocks and minerals were made to determine whether radiation damage produced characteristic magnetic-resonance spectra that could be related to radiation damage produced by solar protons. Characteristic spectra were observed in all of the terrestrial silicate materials irradiated. An incidental benefit from these studies has been the development of a library of spectra.

Magnetic-resonance studies are now under way on samples from Apollo 11 and 12. Laboratory physicists have requested additional samples from Apollo 11 and 12 material and expect also to receive samples from later flights for study.

Electron magnetic resonance of samples from the first two flights, measured as a function of frequency (9 and 35 GHz) and temperature (−270 to 25°C), have intense spectral components which are attributed to various chemical and magnetic states of iron ions. The paramagnetic and ferrimagnetic resonance spectra of the lunar materials on which ORNL measurements were made have some similarities to the vesicular basalts and chondritic meteorites found on earth. However, the differences are significant. Samples of lunar soil and compacts of it (breccias) have a distinctive spectrum. In

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shape, in width at half maximum intensity, and in the dependence of these parameters upon temperature, this spectrum is similar to the spectrum produced in iron oxide heated to 1000°C at low oxygen pressure (around 10^{-4} torr) for 20 hr. The resonance spectrum of metallic iron has also been detected. One fragment of meteoritic iron-nickel was identified. Its spectrum was similar to that of a dilute mixture of iron particles in silica powder. Spectral components of Mn^{2+} in lunar rocks and minerals have a structure similar to those of Mn^{2+} in glasses. This similarity is evidence for an atomic disorder of the sites occupied by Mn^{2+}. Such a structure has been observed in one mineral fraction of lunar samples which, on the basis of x-ray diffraction measurements, is crystalline. (The nuclear magnetic-resonance spectrum of aluminum has a structure which may also be attributed to an atomic disorder of the sites occupied by Al.) Rapid cooling of the crystalline material from a high temperature, such as perhaps the temperature of the liquid from which the mineral crystallized, is a possible cause of the disorder. (This theory has corroboration from those who have made mineralogical and petrographical measurements.)

Paramagnetic-resonance spectra that could be attributed to radiation damage processes were detected only in one small fragment selected from the ORNL lunar soil.

Samples were measured encapsulated in special vacuum containers in which a simulation of lunar atmospheric pressure was attempted. They were then exposed to nitrogen gas, followed by their release to the atmosphere. Successive exposure to these conditions produced no detectable changes in the spectra. However, all the samples had been at higher pressures prior to their encapsulation in the special containers. Samples much closer to their pristine condition are necessary before paramagnetic states are detected which are sensitive to the earth's atmosphere.

A separate program was initiated and supported by NASA for the design and construction at ORNL of vacuum containers for storing lunar samples. These storage containers were to be filled and sealed inside the Lunar Receiving Laboratory vacuum chamber, F201. NASA also requested that ORNL develop and produce containers for optical and magnetic-resonance experiments that could also be filled and sealed inside F201. In some cases "ion pumps" were attached to these containers while inside F201. After removal to the atmosphere, pressures inside these containers were reduced to less than 10^{-8} torr. Over 4000 storage containers and approximately 40 of the special experiment containers were delivered to the Manned Spacecraft Center. Both types of containers have been successfully used.

In summary, although the magnetic-resonance properties of the moon material were distinct from those of earth materials, a very significant difference is apparent between the spectra of lunar soil and the crystalline rocks of the moon, a difference that correlates with the difference in radiogenic ages of the two materials. One inference from this could be that the materials had two different conditions of formation.

ORNL 1969 Environmental Studies

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ORNL and the Environment

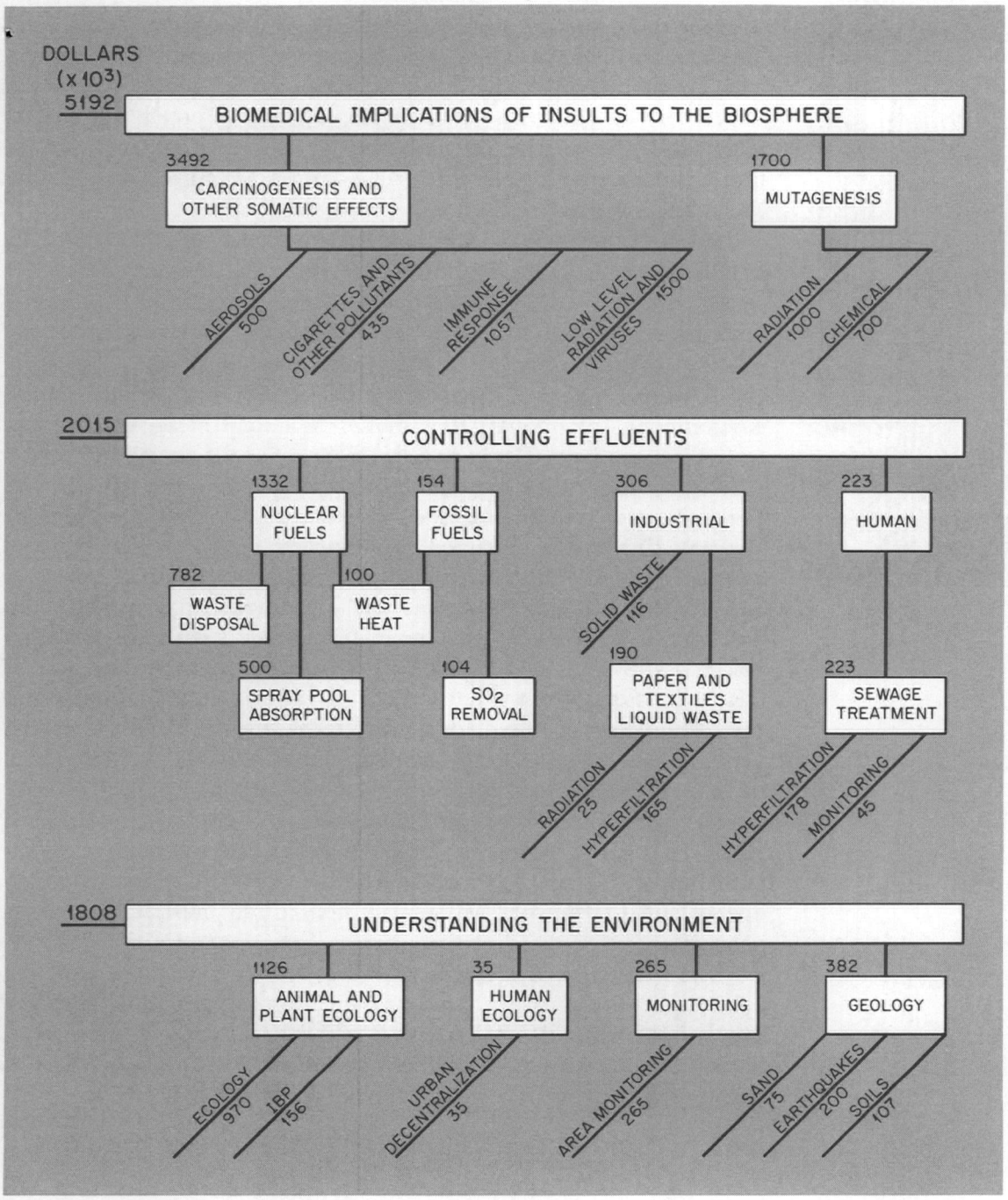
Nuclear energy and the environment have been inseparable since the beginning of the nuclear era. The reason is not hard to understand. The nuclear pioneers at Chicago and Oak Ridge realized that, in releasing nuclear energy on a massive scale, they would be creating radioactive materials of unprecedented potential hazard. These radioactive materials simply could not be discharged to the environment except under the strictest surveillance and control.

Oak Ridge was the first place in the world to handle radioactivity on a really large scale. It was therefore natural that ORNL should have developed, during the past quarter of a century, a strong commitment to, and concern for, the environment. We could not survive as a nuclear energy installation if we were not prudent about the environment and the effect of radioactivity upon it.

The current excitement about environment in all its aspects therefore has a *déjà vu* aspect for us at ORNL. During 1969 we spent about $9 million, almost 10% of our total operating budget, on matters having environmental implication.

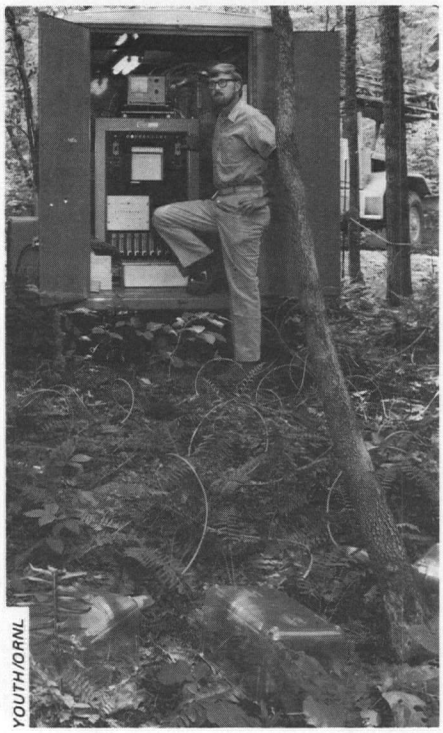
The environmental work at the Laboratory during 1969 can be divided broadly into three major categories: understanding the environment ($1.8 million), controlling effluents ($2.0 million), and biomedical implications of insults to the biosphere ($5.2 million). Most of the tasks undertaken under these categories are closely related to nuclear energy. For example, most of our ecological studies are aimed at understanding the passage of radionuclides through the food chains that support man. And of course, ever since the Oak Ridge area was established, we have had to monitor the area in detail. For example, the Clinch River Study, conducted in collaboration with the Tennessee Valley Authority, stands as one of the few fairly complete studies of the passage of inorganic contaminants in a natural body of water.

From this primary involvement with radioactive insult to the environment, the Laboratory has moved, especially during 1969, toward concern with other environmental matters. Because Oak Ridge had so large a group of ecologists, it was natural that ORNL should become the manager of the Eastern Deciduous biome of the International Biological Program, sponsored jointly by the AEC and the National Science Foundation. This is a program conducted jointly with eight universities and the United States Department of Agriculture in the region between the Mississippi River and the Atlantic Ocean and is aimed at understanding the base-line environment. These and selected studies concerned with making a safe nuclear energy have led us to propose, and the AEC to fund, a program for ultimate disposal of radioactive wastes in salt mines.



Environmental Studies at ORNL: $9,015,000.

From our expertise in desalting (which itself stemmed from our experience in radiochemical reprocessing) we developed methods for sewage treatment based on the use of dynamic membranes. A small sewage treatment pilot plant based on ORNL ideas came into full operation during 1969. Our experience in performing long-term animal experiments aimed at quantifying the mutagenic and carcinogenic actions of radiation has led to joint efforts with the National Institutes of Health to apply these techniques to other carcinogens and mutagens.



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Just this year we have joined with the NSF in another very broad program on the environment and technology assessment, a program which, when coupled with the AEC programs, is helping to give the Laboratory an ability to take a very broad view of possible untoward impacts of developing technologies on the environment. Such a broad prospective look should suggest ways to prevent or alleviate such effects.

Much of the extended scope of ORNL's environmental work falls within the spirit of the 1967 amendment to the Atomic Energy Act which directed the Commission "to conduct through its own facilities research and development or training activities for others, relating to the protection of the public health and safety." Despite the expansion and broadening of the Laboratory's involvement in the environment, our primary environmental commitment remains control of radioactivity. For in a sense this is really the crucial key to the success of the entire nuclear enterprise. Back in the 1950's, Dr. James B. Conant, distinguished chemist and former president of Harvard University, predicted that nuclear energy would "not be worth the candle" because it would prove too difficult to sequester and control the enormous amounts of radioactivity produced by reactors. Now, some 20 years later, Dr. Conant's concerns are being voiced loudly by many critics. The primary environmental job of ORNL is to establish the facts related to radioactivity and to develop the technologies required for its safe management. From everything we have learned, we see no reason to doubt that radioactivity, even on the scale created by large reactors, can be handled without causing deterioration of our environment. This demonstration is surely among the most important tasks that face the nuclear energy community: it is one to which ORNL during 1969 has devoted much energy and to which it will remain committed until full success is achieved.

The programs described here are but two examples of the applicability to broader problems inherent in the work that has grown out of this effort. Elsewhere in this Report are descriptions of some of the other projects undertaken in 1969 that are pertinent to man's efforts to preserve his natural environment.

Land Management Technology

The rapidly increasing population will inevitably result in tremendous land-use pressures as the world strives to feed, clothe, and house its inhabitants from the finite resources available. Human demands for a higher material standard of living are in conflict with the equally human desire for a higher quality of life. An affluent society requires more space per person than a less prosperous one,

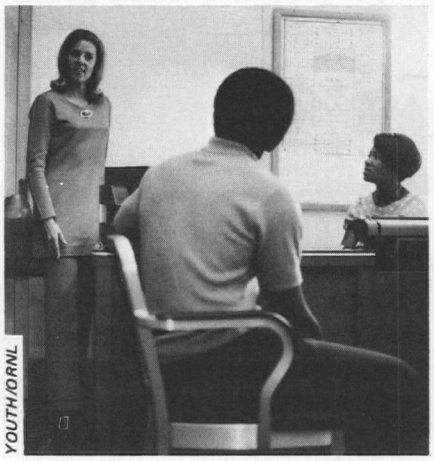
because it is more mobile and generates a greater proportion of waste by-products. If we are to address ourselves to providing an acceptable standard of living for the world's population, it will be necessary to allocate our limited resources among sometimes conflicting uses. In general, we must increase the productivity and capacity of the earth to support human needs. As land use is adjusted to meet the demands of population growth, many factors – urban expansion, recreation demands, and agricultural needs among them – will work their attrition on available timber lands; yet this same population growth will place higher demands for wood and fiber production on the reduced land base.

Recent developments in land management technology indicate that forest productivity can be increased significantly by a combination of genetic selection and fertilization. It is highly probable that the forest industry will rely heavily upon these techniques to meet future demands. Genetic selection and tree breeding would have little forcible impact on environmental quality, but extensive use of forest fertilization could result in seriously impaired water quality. Similar problems have developed in water bodies and watercourses adjacent to agricultural areas from intrusion of agricultural fertilizers and animal wastes. When normally innocuous inorganic fertilizers flow into streams via groundwater and runoff, a chemical enrichment results which can cause eutrophication of the water, resulting in excessive plant growth and impairment of water quality. Fertilization of large acreages of forest presents a potential problem because our water supplies originate in upland forested regions, later entering the agricultural and industrial regions downstream. At present, these virgin waters contain only natural chemical enrichment resulting from normal cycling and decomposition. If, however, the watersheds also contribute significant inorganic salts lost from fertilized forests, the problem will compound the effect of present agricultural, industrial, and urban pollution and perhaps exceed a threshold which could result in a costly and serious degradation of water quality. Problems of this kind offer unusual opportunities for the use of radiotracers to study pollution effects.

An assessment of the potential ecological problems associated with forest fertilization is being conducted on Walker Branch watershed. The objective of the project is to anticipate any detrimental effects that forest fertilization may have on water quality and stream productivity before it becomes a widespread cultural practice. Pretreatment characteristics of the vegetation, soils, and stream systems are being documented. Transfer paths and rates of chemical transfer from the soil into stream water are being monitored. Radioisotopes are being used to quantify the rate of primary production in the stream, to investigate the rate of organic decomposition, and to establish the rates of movement of mineral elements through the soil-water system.

In 1972 the watershed will be fertilized, and the effect of fertilization on forest productivity will be measured. Movement of the fertilizer elements through the soil-water system will be studied

One of the many weirs in the Walker Branch watershed managed by the ecology group at ORNL. Cycling studies performed here have enabled Laboratory ecologists to make a fresh evaluation of current forest management practices.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to evaluate the rate of loss of nutrient elements to surface waters. Intensive studies will be made of the stream system to document the effects that fertilizer elements may have on stream productivity and water quality. Particular attention will be paid to the chronic effects which may result in subtle and obscure responses. The chronic effects of land-use practices such as fertilization are often the most devastating, yet they often go undetected until the problem manifests itself in a spectacular way. The use of watershed ecosystems as a study unit offers great potential for evaluating the ecological impact of newly developing land management technology.

Inhalation Studies

Research at ORNL on inhalation of pollutants represents a multidisciplinary approach to a very complex problem involving and supported by a number of staff members from many divisions: In the Biology Division, pathologists, veterinarians, virologists, microbiologists, inhalation engineers, radiobiologists, and immunologists are engaged; in addition, biostatisticians from the Mathematics Division, chemists in the Isotopes and Analytical Chemistry Divisions, and particle physicists from Health Physics are contributing their efforts to the studies.

Respiratory Carcinogenesis

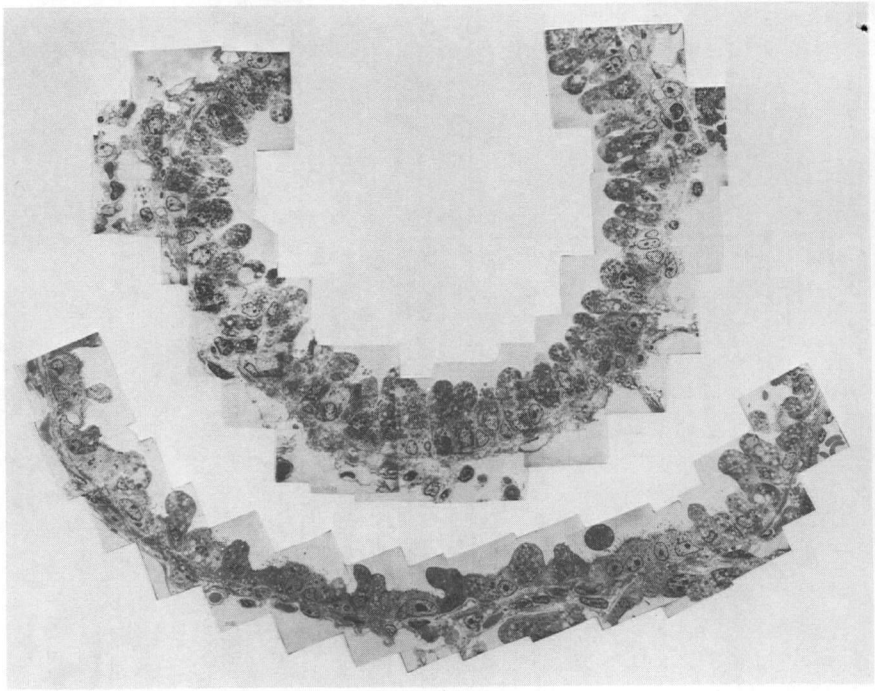
For the last five years the Respiratory Carcinogenesis Group in the Biology Division has been trying to determine the role of various air pollutants in the development of lung cancer. This program is jointly sponsored by the Atomic Energy Commission and the National Cancer Institute.

With the rapidly growing industrialization and the development of heavily populated metropolitan areas, pollution of the occupational and general environmental air with a great number of chemical waste products has increased precipitously. Many of these air pollutants are irritants to the respiratory tract and cause a number of chronic lung diseases and may also contribute to the alarming rise in lung cancer observed over the last few decades. Epidemiological evidence has linked another contaminant of the breathing air, cigarette smoke, with chronic lung disease and lung cancer in particular. Polluted air and cigarette smoke are highly complex mixtures of chemicals, some of which are known carcinogens, some of which are irritants of various potency, and some of which are thought to be biologically "inert." Evidence has recently developed suggesting that some of these irritant chemicals and even the so-called "inert" materials may potentiate the effect of carcinogenic

Biologists performing necropsies on mice that have been exposed to carcinogens and are suspected of having contracted lung cancer.

agents. The development of lung cancer thus is the result of complex interaction of a number of factors. The relative importance of each of these in carcinogenesis, however, is poorly understood.

The Respiratory Carcinogenesis Group has concentrated on obtaining experimental information on the relative importance of common air pollutants such as smog and dusts with different physical and chemical characteristics (ferric oxide, chromium oxide, calcium chromate) on lung tumor induction and their synergistic and potentiating effect on known carcinogenic agents. One phase of these studies involves chronic inhalation exposure of experimental animals. Such experiments require elaborate barrier facilities to keep inadvertent infection out of the animal colony. The first long-term inhalation experiment, with several thousand mice exposed to a number of agents singly or in combination, was recently completed and showed that contamination of the breathing air with "artificial smog" (lead-free gasoline vapors mixed with ozone) doubled the incidence of lung tumors. These studies also showed that animals exposed to a single low dose of whole-body x irradiation develop significantly more lung tumors than unirradiated control animals. The second chronic inhalation experiment, recently started, involves approximately 1300 hamsters. These animals, when exposed to carcinogens, develop tumors in their respiratory tract very similar to those observed in man. The main goal of this experiment is to test the potentiating effect of air pollutants (artificial smog, ferric oxide dust, and a combination of the two) on the carcinogenic activity of a known carcinogenic agent. A low dose of the carcinogen diethylnitrosamine (which produces respiratory carcinomas when injected into hamsters) is injected repeatedly into the animals, which are daily



Electron micrographs of cross sections of bronchioles of mice. Top: *bronchiole of a mouse breathing filtered air; note high cylindrical epithelium and numerous secretory cells.* Bottom: *bronchiole of a mouse breathing artificial smog; note atrophy, flattening, and irregularity of epithelium and sparsity of secretory cells.*

exposed for their entire life-span to the two widespread urban air pollutants. This study will show whether the effect of the carcinogens is enhanced in animals breathing polluted air. It will not be completed until 1971.

Another phase of the program centers around short-term effects of air pollutants on respiratory tissue. These studies are aimed at understanding mechanisms of injury and capacity for repair of the various functional entities of the respiratory tract. They involve investigations of the proliferative, regenerative, and differentiative capacity of the various cellular elements in the tracheobronchial tree and the lung parenchyma, using radioactive compounds as cell markers. Other studies are concerned with the effect of viral and bacterial pneumonitis on the capacity of the respiratory tract to eliminate inhaled particles, using neutron-activated chromium dust. If pneumonitis interferes with particle clearance from the lung, as some preliminary experiments suggest, then these experiments might give some clue as to the possible role of respiratory infection in development of lung cancer.

Another activity of the Respiratory Carcinogenesis Group was to organize two meetings, one in October 1969 on inhalation carcinogenesis and the other in May 1970 on morphology of experimental respiratory carcinogenesis. These meetings were sponsored by the National Cancer Institute and the U.S. Atomic Energy Commission. Their purpose was to bring together representatives of the numerous disciplines engaged in and contributing to the rapidly expanding field of respiratory carcinogenesis, to evaluate the various experimental approaches and technological advances, and to discuss the most recent experimental findings.

Cigarette Smoke Research

In the Analytical Chemistry Division a new facility is working out the chemical characterization of the smokes of experimental cigarettes. The work is an integral part of the National Cancer Institute's efforts to define the characteristics of a "safer" cigarette. The study may also help clarify whether the inhalation of cigarette smoke causes cancers.

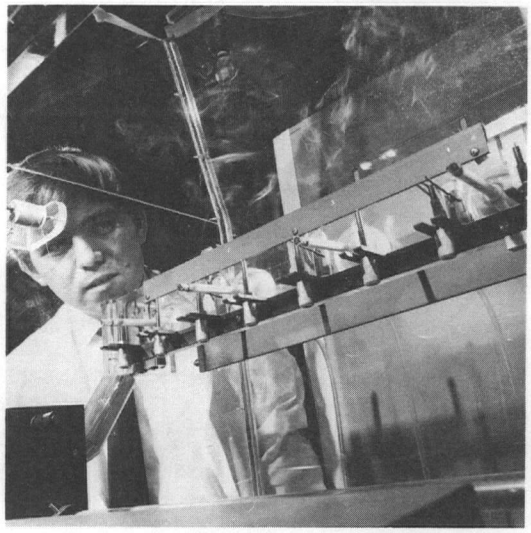
Experimental cigarettes of carefully defined composition are smoked by a machine in a temperature- and humidity-controlled laboratory. The smokes are condensed in cold traps and the condensate analyzed for carcinogenic hydrocarbons, tumor-promoting phenols, acid content, nicotine, and other chemicals. The same analyses are carried out on cigarette smoke condensates produced elsewhere by the National Cancer Institute for biological testing.

A second smoking machine generates samples of the particulate phase of cigarette smokes. The particulates are analyzed for water by gas chromatography and for nicotine by spectrophotometry. Knowing the weight of the particulates and the determined weights of water and nicotine, the workers can calculate the "tar" content of the cigarette smoke. The nicotine and "tar" values further serve to characterize the samples.

A third smoking machine produces samples of the gaseous phase of smokes. Depending on the chemical to be determined, the gas phase is trapped in appropriate reagents or routed directly to a gas chromatograph for analysis. Hydrogen cyanide, formaldehyde, acrolein, and oxides of nitrogen and carbon are among the gas-phase components this machine determines.

Although procedures are rigidly specified, the complexity of the matrix and of the analyses yields many avenues for research and development. The smoking-machine–gas-chromatograph assembly should allow scores of gas-phase components to be quantitatively determined in a single puff of smoke. Specialty gas chromatography detectors also on hand may allow important but currently impractical analyses to be carried out regularly. Other ORNL-developed methodology may allow the simultaneous assay of many phenols and acids in smoke condensate as well.

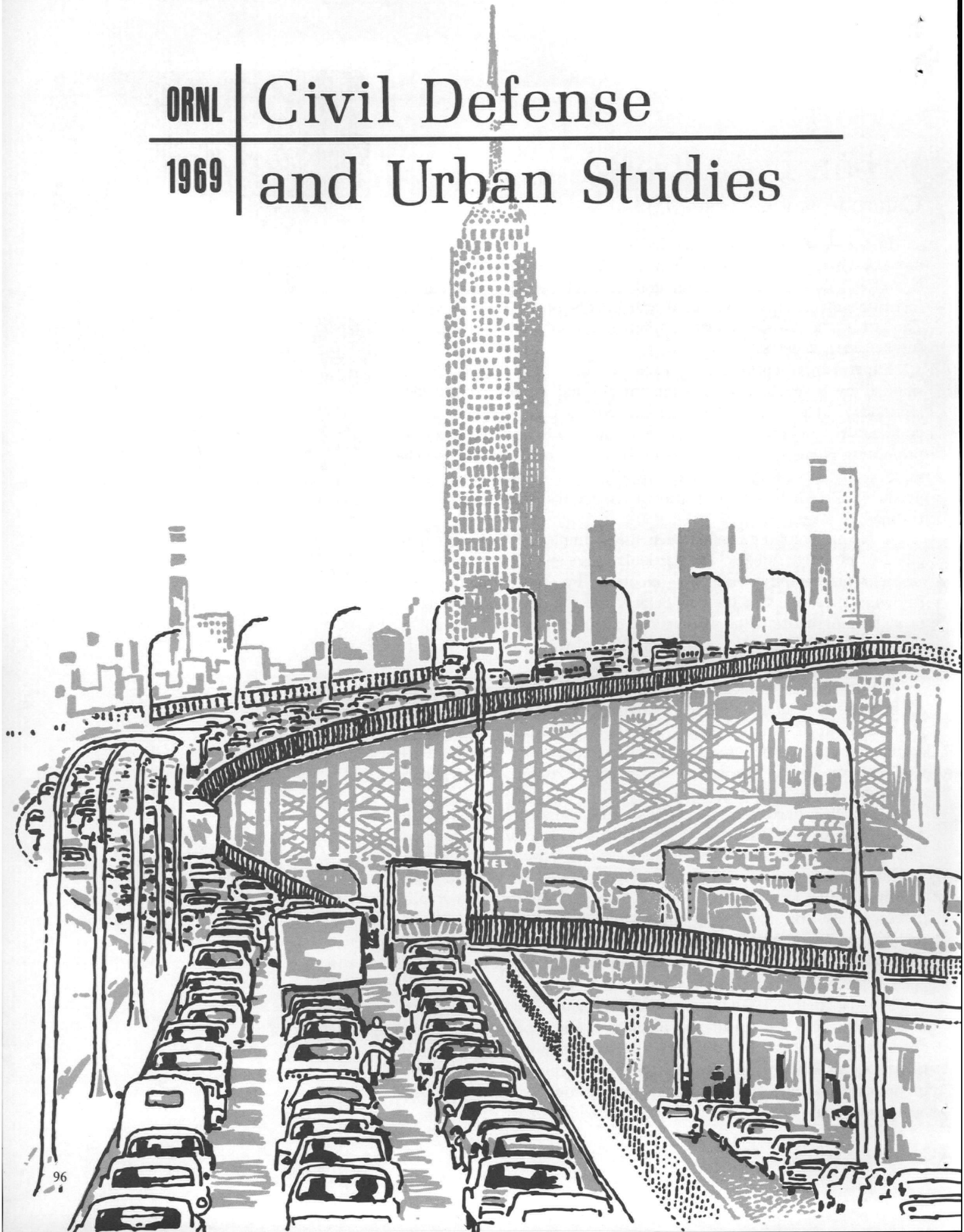
The use of highly defined cigarettes, rigidly specified smoking conditions, and a wealth of biological and chemical data to characterize the cigarettes make this project unique. At the close of this two-year study, positive conclusions concerning results to health of modifying cigarettes and the relationship between chemical composition and health effects may finally be possible.



ORNL's smoking machine, which is analyzing the smoke from 23 different kinds of specially prepared cigarettes supplied by the National Cancer Institute. By determining the presence and amounts of certain chemicals in cigarettes of different blends and papers, chemists are hoping to gain insight into the relationship between cigarette smoking and health.

ORNL 1969

Civil Defense and Urban Studies



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Urban Decentralization

Problems of our cities are continuously in the limelight. The rapid growth of the urban sector in the past two decades has exposed the gravity of such social problems as poverty, disease, pollution, crime, and drug addiction. Meanwhile, as the cities and their suburbs sprawl, the rural areas lose population and vitality. If present migration trends continue, both the problems of density and overconcentration in the cities and the problem of depletion in small towns and rural areas will intensify. It is generally agreed that only governmental intervention of unprecedented magnitude could reverse the present trend.

Problems of Cities

For ten weeks this past summer an interdisciplinary group of 15 social scientists and 9 physical scientists and engineers undertook a preliminary study of urban decentralization under the auspices of the Civil Defense Research Project. Concern about American cities is no new subject for civil defense planners. The vulnerability of areas of high population density has focused the thinking of the Project, since its inception, on ways to protect these areas. But urban populations are not static. Thus long-term planning must take into account not only the present size and location of cities but also their possible future growth patterns. Such prediction involves the identification of past trends and the possible reasons for these trends. Only then can future urban systems be planned realistically.

Some of the more striking findings of the summer study are as follows:

1. A major difficulty in our present population distribution is the concentration of people with problems (the poor, the aged, the uneducated, the infirm) in central cities, or in areas drained of much of their human potential. For example, while the number of families headed by men decreased by 750,000 in central cities, the number headed by women rose by 150,000 during the past eight years.
2. In New York City, although the number of white collar jobs increased considerably, the number on relief rose to 1,000,000, with 600,000 more eligible for relief, out of a population of about 8,000,000.
3. Infant mortality ranges up to 90 or 100 per thousand in some metropolitan census tracts, as against an average of 22 for the United States.

4. Illegitimacy in Harlem in recent years accounts for more than half the births.

A preliminary analysis made by the summer study of school and psychological data suggests that factors associated with improvement in performance among whites are not necessarily associated with upward changes among nonwhites.

Migration is the Key

The key process in rapid population change, responsible for the acute nature of many of these problems, is migration. While high migration rates have created concentrations of population in large cities, the out-migration of the young in rural areas has created population structures that are topheavy with old people. In some counties there are more people between 70 and 80 than between 20 and 30. Migration is also highly selective along lines other than age: it is the person with a better than average education and of a higher socioeconomic status who moves.

Fortunately for future study, migration patterns appear to be predictable. Migration potential is highest for young adults and declines regularly with age. Moreover, an analysis of a 1948 opinion poll on desired place of residence was shown to correlate highly with actual movement patterns over the next two decades, suggesting that similar analyses of current polls might give valuable indications of future movement.

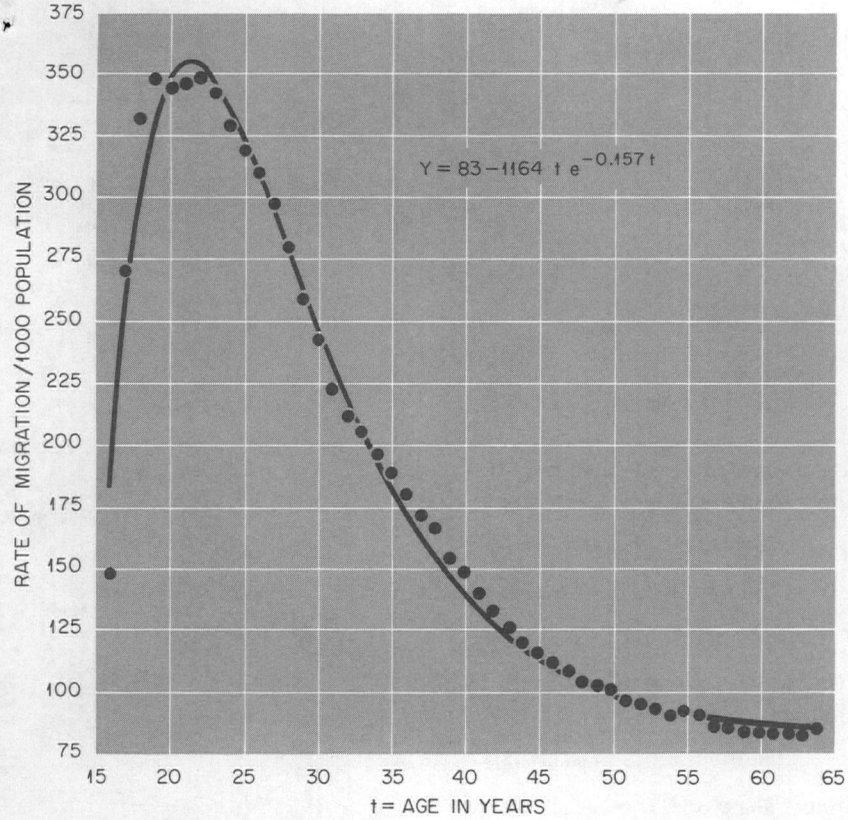
Reversal of Past Trend?

There is some indication that the pattern of location of the last few decades – that of increasing concentration in urban places – may be showing signs of reversal. One explanation for this trend is Wilbur Thompson's "trickle down" theory of industrial location: the most technologically advanced industries develop in urban centers and then filter down to more dispersed localities as the industry matures and becomes less dependent upon the highly skilled technicians and the infrastructure provided by the center. Other forces leading to decentralization include improved transportation networks and lower power and labor costs in rural areas.

Yet the "natural" forces at work leading to decentralization are slight. If the spatial configuration of the American economy is to be altered significantly, a national policy, coordinated with appropriate state and local government policies, is needed to reinforce certain desirable trends in industrial development.

New Growth Centers

Possible solutions to the problem of undesirable population distribution include the development of new towns, rejuvenating the central cities, and strengthening the growth of certain towns and rural counties which have "growth potential." This "growth center"



The number of people per thousand who have moved to another county during the previous five years, by age at the end of the period (1955–60). The points follow a curve called a "gamma density function," commonly used to describe electromagnetic waves. This unexpected similarity between a physical and a social phenomenon illustrates the value of collaboration of physical and social scientists.

approach would seek to break the vicious downward spiral (the self-breeding mechanism of decline due to poor schools, limited transport facilities, underdeveloped business services, etc.) in those places where a marginal investment would provide the greatest returns.

Potential locations for growth centers or new cities are along interstate highways, particularly at their intersections. There are many such intersections, and those which have good supplies of water and are strategically located in relation to large cities show special promise. The summer study indicated a number of such locations and singled out six Eastern towns for special attention.

New technologies are needed to deal with problems of pollution and power supply. One attractive concept is the location of energy centers and new cities in relationship to one another. A nuclear power plant could furnish energy for the city which would provide comfort, clean air, and clean water. At the same time, it could heat hundreds of acres of greenhouses for vegetable production and attract industries that have heavy power uses. The initial use of heat for agriculture could then be shifted to higher-value industrial uses.

Perhaps one of the most important results of the decentralization study was to demonstrate that significant results with policy implications can be obtained rapidly with existing information resources – that while the subject is complex and requires an interdisciplinary approach, it is indeed possible to substitute quantitative, testable theory for intuitive generalizations in the formulation of the future growth policy of the United States.

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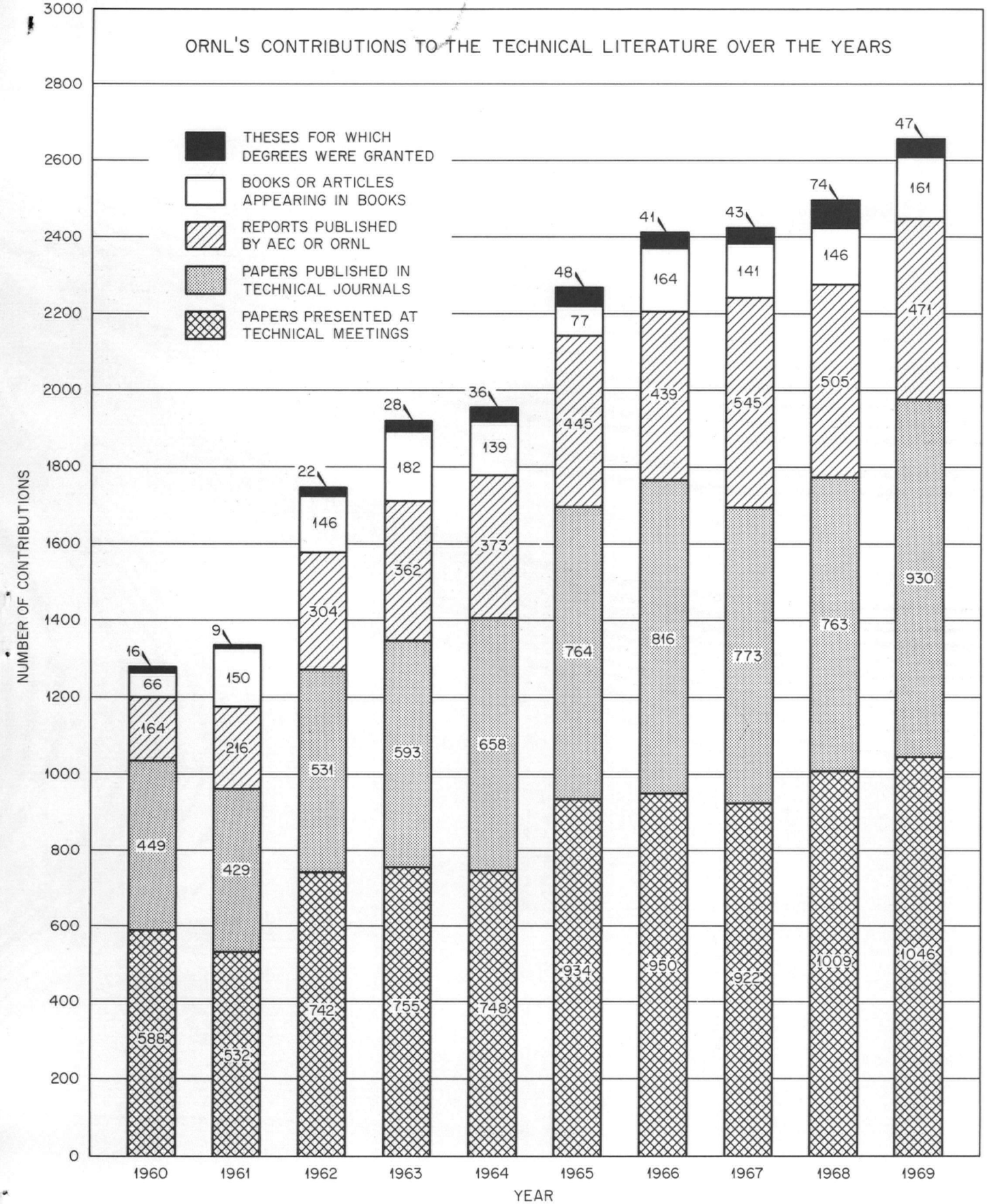
P.O. Box X,
Oak Ridge, Tennessee 37830.

MAJOR MEETINGS SPONSORED BY ORNL IN 1969

Symposium on Automated High-Resolution Analyses in the Clinical Laboratory	March 13–14
Chairman: C. D. Scott, ORNL	
Annual Biology Research Conference	March 30–April 3
Chairman: Elliot Volkin, ORNL	
Effective Use of Computers in the Nuclear Industry	April 20–23
Chairman: Betty Maskewitz, ORNL	
Annual Sherwood Theoretical Meeting	April 24–25
Chairman: G. E. Guest, ORNL	
Southern Area Research and Development Safety Symposium	April 27–30
Chairman: H. C. Hoy, Y-12 Plant, P.O. Box Y, Oak Ridge	
Isotopes Application Conference	April 27–30
Chairman: J. H. Gillette, ORNL	
Association for Gnotobiotics Conference	June 11–13
Chairman: D. M. Robie, ORNL	
Blood Platelet Conference	June 23–24
Chairman: T. T. Odell, Jr., ORNL	
Conference on Analytical Chemistry in Nuclear Technology	September 30–October 2
Chairman: L. J. Brady, ORNL	
DOT-XSDRN Seminar Workshop	September 30–October 3
Chairman: D. K. Trubey, ORNL	
Inhalation Carcinogenesis Conference	October 8–11
Chairman: M. G. Hanna, Jr., ORNL	
Gaseous Electronics Conference	October 28–31
Chairman: C. F. Barnett, ORNL	
Symposium on Neutrons in Radiobiology	November 11–14
Chairman: J. A. Auxier, ORNL	


ORNL'S CONTRIBUTIONS TO THE TECHNICAL LITERATURE OVER THE YEARS
THESES FOR WHICH DEGREES WERE GRANTED
BOOKS OR ARTICLES APPEARING IN BOOKS
REPORTS PUBLISHED BY AEC OR ORNL
PAPERS PUBLISHED IN TECHNICAL JOURNALS
PAPERS PRESENTED AT TECHNICAL MEETINGS
NUMBER OF CONTRIBUTIONS
YEAR
0
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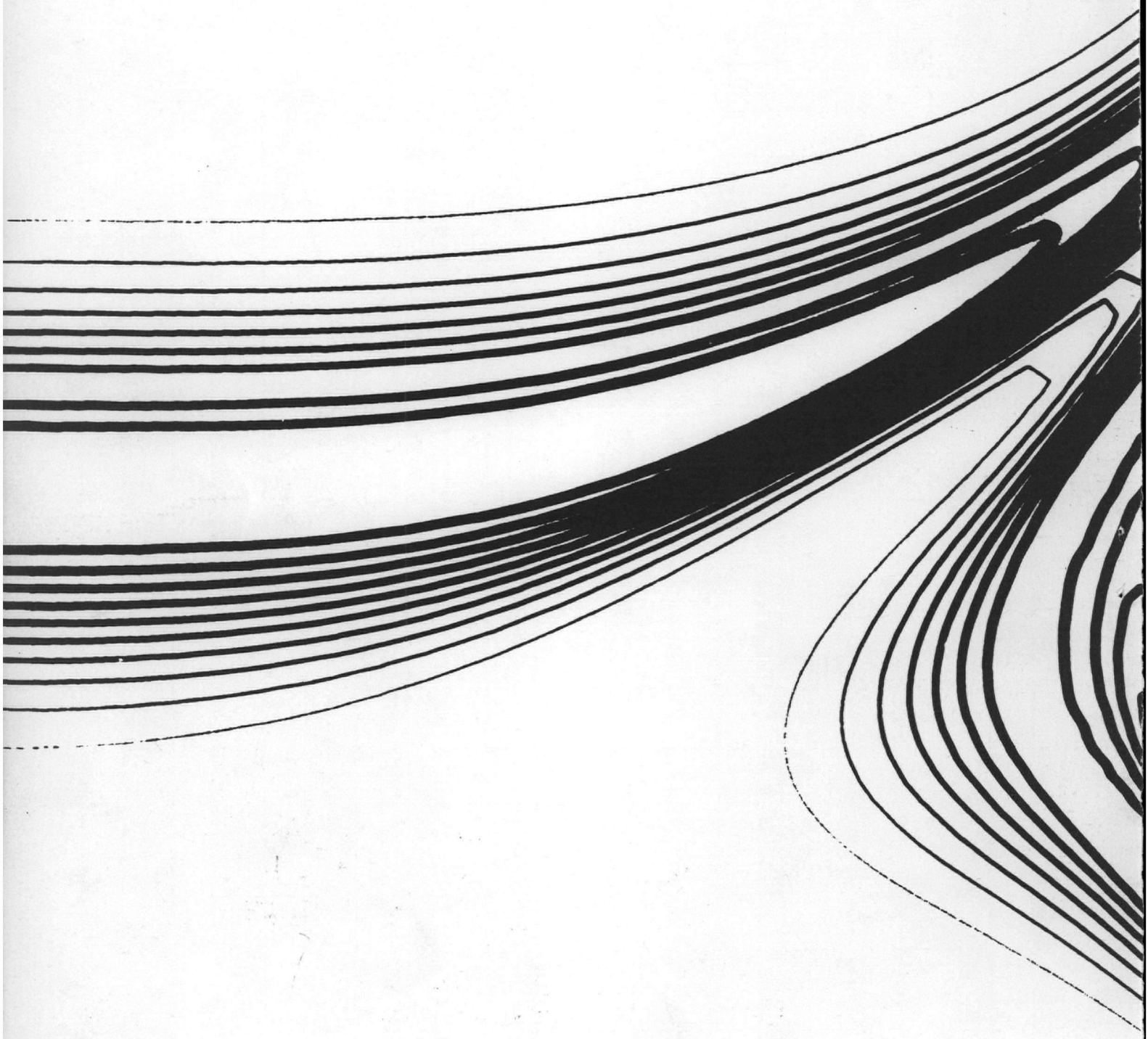
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