Review

WINTER 1972

OAK RIDGE NATIONAL LABORATORY

STATE OF THE LABORATORY ISSUE

THE COVER: ". . . For example, we are assessing the impacts of central electrical plants; . . ." says ORNL Director Weinberg in his State of the Laboratory address, the complete text of which begins on the opposite page. Here Carolyn Young, graduate assistant in ecology, conducts studies on the effect of warm effluents from TVA's Bull Run Steam Plant on the growth of milfoil in Melton Hill Lake. Her work is under the supervision of C. C. Coutant, Division of Ecological Sciences, head of the Laboratory's Thermal Effects Program.

Editor
BARBARA LYON

Consulting Editors
DAVID A. SUNDBERG
A. H. SNELL

Assistance is provided by Graphic Arts, Photography, and Technical Publications Departments of the ORNL Information Division.

The *Review* is published quarterly and distributed to employees and others associated with the Oak Ridge National Laboratory. The editorial office is in Room 291, Building 4500-North, Oak Ridge National Laboratory, P.O. Box X, Oak Ridge, Tennessee 37830. Telephone: 483-8611, Extension 3-6265 (FTS 615-483-6265).

Review

OAK RIDGE NATIONAL LABORATORY

VOLUME 5, NUMBER 2 **WINTER 1972**

FEATURES

OAK RIDGE NATIONAL LABORATORY
OPERATED BY UNION CARBIDE CORPORATION • FOR THE U.S. ATOMIC ENERGY COMMISSION

State of the Laboratory—1971

ALVIN M. WEINBERG

1971 HAS BEEN A YEAR OF TRANSITION for Oak Ridge National Laboratory. We have reflected the changes that have taken place in the Atomic Energy Commission, in the role of science in our national life, and, as evidenced at the Geneva Conference, in the position of nuclear energy throughout the world. In reviewing the year at ORNL, I therefore shall try to relate local developments to the changes that have taken place elsewhere.

Calvert Cliffs and ORNL

Perhaps the most important event of the year in nuclear energy was legal, not scientific or technical. On July 23, 1971, Judge J. Skelly Wright, of the U.S. Court of Appeals for the District of Columbia, handed down a decision requiring AEC to examine the environmental impact of nuclear power plants in a depth and detail that would have been unthinkable a couple of years ago. Judge Wright invoked the National Environmental Policy Act as the basis for his decision; he stated that AEC's "crabbed interpretation of NEPA makes a mockery of the Act." The Commission is now required to examine thermal as well as radiological effects of reactors; it must consider alternatives to the use of nuclear power plants; it must evaluate all of these things independently and not depend on local regulations and standards; and it must summarize its findings in a cost-benefit analysis that weighs such imponderable costs as the destruction of a stand of timber against the economic benefit of lower-cost energy. What makes the whole matter so critical is that such environmental impact statements have now become so essential a part of the reactor licensing procedure. There is at stake about 100 million kilowatts of nuclear electricity, almost 25 percent of the total U.S. central station load.

Faced with a task of such urgency, the Commission turned for help to three of its laboratories — Battelle Northwest, Argonne, and ORNL. The job is formidable: 91 environmental impact statements to be completed by July of 1972 or as quickly thereafter as possible. Of these, ORNL already is working with the AEC Washington staff on 13, with another dozen or so expected. This task has been given the highest priority in the Commission and, in consequence, at the Laboratory.

Fortunately we had a skeleton organization, headed by E. G. Struxness of Health Physics and T. H. Row of the Reactor Division, which had been working on environmental impact statements prior to Judge Wright's decision. Moreover, our many moves into environmental matters (such as the Environmental Quality Study Program, the Nuclear Safety Information Center, the NSF Project on Technology Assessment and the Environment, and the work of the Ecological Sciences and Health Physics Divisions) had helped create at ORNL the sensitivity to environmental issues needed for a quick and effective response.

We have now assembled a full-time team of some 50 people from 14 ORNL divisions. The team has been helped by many part-time reviewers and consultants from almost every part of the Laboratory; altogether about 130 members of the scientific staff, and about 50 support personnel, are involved to some degree in preparation of Environmental Impact Statements.

Struxness and Row have organized the group into teams, each of which is responsible for a specific reactor; the teams are drawn from seven panels of experts covering generic subjects, such as radiological sources, thermal effects, cost-benefit analysis, and so on. Each impact statement is studied by an ORNL review panel and by management before the statement is released. To date, statements for Indian Point Unit 2, Palisades, Vermont Yankee, and Oconee have been completed.

The environmental impact project has meant that many have had to lay aside research for a few months, to put in long hours, to forego vacations. I hope that all those involved find compensation in the knowledge that what they are doing strikes at the heart of what the game is all about: nuclear energy, in fact any energy, in the United States simply must come to some terms with the environment. The serious, competent scientific investigation required for these reports will, I believe, help greatly in maintaining the public's confidence in nuclear energy.

There is another more direct benefit from our participation in the impact statements. These statements represent, perhaps by an order of magnitude, the largest exercise in applied ecology ever attempted. A sizable number of aquatic ecologists in the universities have been retained by the utilities to help prepare impact statements. The required analysis places the most diverse demands on the science of ecology: we must know such things as the nesting and mating behavior of striped bass in the estuarial waters of the Hudson or the spawning habits of alewives and ciscoes in southeastern Lake Michigan. These data are needed not simply to satisfy a craving for wonderment as we contemplate nature, but are serious requirements, needed to assess the full ecological impact of nuclear plants. Thus Judge Wright's decision is imposing upon the whole science of ecology a hard, no-nonsense demand to which ecology must respond. I have little doubt that the environmental impact statements will pose questions that ecologists will be answering for many years. The statements will force ecologists to formulate their problems and to seek answers in categories and modes that are relevant to real problems and that may go beyond what ecology, as an internally generated science, had arrived at.

The impact statements undoubtedly will create demands for more knowledge in several areas besides ecology — cooling tower technology, micrometeorology, possibly regional modeling, and the like. I would venture to suggest therefore that what may seem at the moment to be an awkward diversion from our main interests will in fact create new and more valid interests for many of the divisions at ORNL.

Environment and Salt

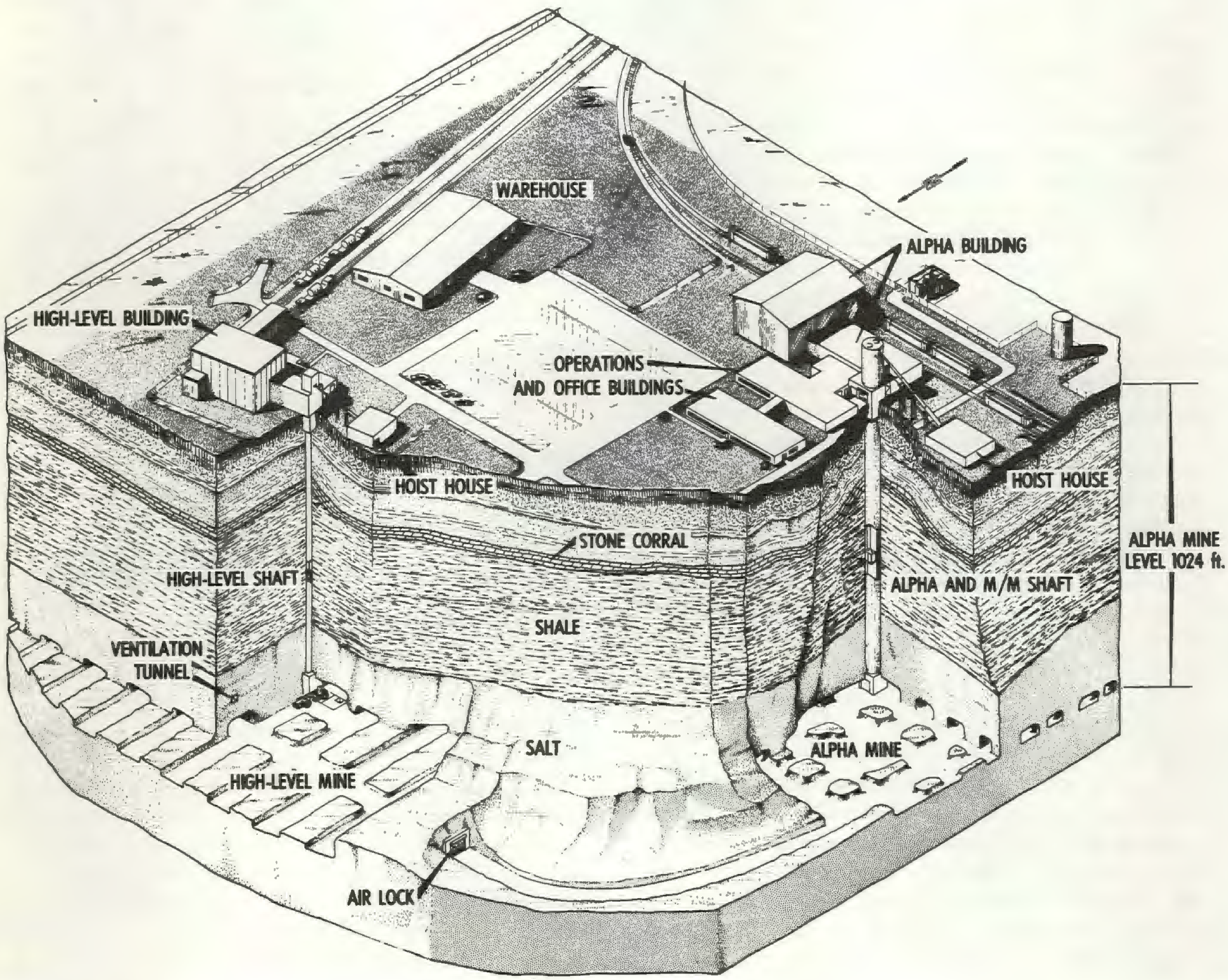
The environmental impact statements are only one of the near-crises surrounding the environment and nuclear energy. Of possibly even greater potential concern are the year's developments regarding the Kansas salt mine waste repository. Last year I announced that the National Academy of Sciences had issued a report in full support of the salt mine project. However, two technical developments have been uncovered this year by ORNL and its consultants which require us to look again at some old questions concerning permanent disposal in unmonitored salt mines (Fig. 1). We have identified some 30 oil wells or dry holes that have been dug through the salt formations around the proposed repository. These holes penetrate aquifers that conceivably could flood the mine. Moreover, we are now more sensitive to, and must study more carefully, the effects of hydraulic mining in the American Salt Company mine, some 2 miles away from the Lyons Site. Our contention that the salt mines are safe because groundwater has never been in contact with them is not fully tenable unless we can avoid or plug drill holes and hydraulic salt mine cavities.

Our consultants assure us that it ought to be possible to plug the holes, permanently, but that this will require development. As for the hydraulic mining, there is no reason why this cannot cease. Nevertheless, these uncertainties warrant additional investigation; in particular, the AEC has authorized the Kansas Geological Survey to make alternate site studies in the state.

The salt mine project has become a prime political issue in Kansas. A presidential commission is expected to be formed shortly to advise Mr. Nixon on the whole matter. But whether or not the salt project is finally approved, one implication of nuclear energy springs from our experience in Kansas. The wastes of nuclear energy will be dangerously radioactive for several hundred thousand years (the half-life of ^{239}Pu, which is a component of radioactive waste, is 24,000 years).

Our confidence in salt is based on the geologic evidence that for millions of years the strata have been undisturbed and have been untouched by water. All geologic evidence suggests that this will continue to be the case *if man does not intervene in the future.* Thus our commitment to salt as a permanent disposal site requires that no holes be drilled for as long as the wastes are dangerous; or that the consequences of such intervention can be neutralized or proved harmless. A proscription against drilling holes, almost into perpetuity, is a strange and almost unprecedented requirement: a commitment to a social order sufficiently stable to enforce such restraint for a time incredibly longer than we have ever planned the future of man's social institutions. There may be other ways of disposal, such as rocketing the wastes into the sun, that would not require long-term surveillance: but such schemes presently are myths. Every one of the proposed practical methods probably demands some measure of surveillance; but the salt mine has the advantage of requiring far less surveillance than most of the other schemes that have been proposed; and, even in the all but incredible event of flooding that might follow the drilling of holes, we have reason to believe that the results would not be catastrophic. This latter statement is based on estimates made this year of the dilution of the alpha-active species in the mine. Because the mine extends over several square miles, its average alpha activity hazard is of the same order as that of a naturally occurring uranium mine.

Fig. 1. Isometric view of proposed radioactive waste repository.



Where, then, do we stand on the salt project? While the political maneuvering is going on, A. L. Boch, J. O. Blomeke, W. C. McClain, B. F. Bottenfield, and some 14 others connected with the project continue to collect data on heat dissipation, radiation damage and stored energy in salt, transport of water of crystallization, migration of radionuclides, corrosion of containers, and so on. Altogether, the technical situation continues to look very good provided one can ensure that man does not intervene in the future by digging holes into the repository.

Geneva Conference

The salt project has caused all of us on the technological side at ORNL to realize the full social implication of mankind's commitment to nuclear energy. It was therefore interesting for us who had the privilege of attending the Fourth International Conference on Peaceful Uses of Atomic Energy at Geneva in September to compare the U.S. attitude in these matters with that of the rest of the world. At Geneva there was a sense of great excitement as country after country reported its growing investment in nuclear energy. Oak Ridge National Laboratory staff members contributed to 23 Conference papers.

The American investment in nuclear energy, 100 million kilowatts, is so much larger than that of any other country that, as we saw so clearly at Geneva, we have been obliged to face the problems of nuclear energy more realistically than have other nations. It is not simply that our environmentalists are noisier than are those of other countries; it is that we have relatively more at stake than others, and that we must act correspondingly.

The difference between the United States and the rest of the world was dramatized at the session on waste disposal, where the United States, United Kingdom, and French positions were described. Floyd Culler presented the American position. In the United Kingdom the plan is to store wastes as liquids in tanks until, say 50 years hence, a better scheme is devised. To most of us in the United States such a plan seems to be unacceptable: in fact, as Floyd Culler expressed it, we pose heavy moral questions when we bequeath to the future materials as toxic as radioactive wastes without at the same time providing some kind of tenable, *permanent* methods of disposal; or, failing this, at least not foreclosing options for generations to come. Insofar as solidification and disposal in salt is a permanent solution, we have dealt with this moral implication of nuclear energy; insofar as there may still be second-order questions about salt, we must concede that we have more to learn before giving a totally satisfactory answer to the moral issues raised by Culler at Geneva.

Energy

Our developments in the technology of energy production must be viewed in the perspective of the new positions expressed in President Nixon's white paper on energy, and in AEC Chairman Schlesinger's much discussed address at the ANS-AIF banquet in Miami.

To take the President's white paper first: on June 4, 1971, the White House issued a statement covering almost every aspect of energy policy, both nuclear and nonnuclear. Of most immediate interest was the President's commitment, explicit and clear, to the Liquid Metal Fast Breeder Reactor (LMFBR) as a prime national goal. This was reinforced some three months later when the President, in a speech at Hanford, pledged support to two large demonstration LMFBR plants. The white paper spoke of reactor alternatives to the LMFBR: "The liquid metal fast breeder is the priority breeder reactor concept under development, but the Atomic Energy Commission is also supporting limited alternate reactor programs involving gas cooled reactors, molten salt reactors and light water breeders."

The President also expressed support for a stronger effort in controlled fusion.

The Laboratory's efforts in breeder technology reflect the priorities set in the President's white paper: we spent last year approximately $12,000,000 on the LMFBR, $5,000,000 on molten salt, an equal amount on controlled fusion, and $3,000,000 on gas-cooled breeders and converters.

Liquid Metal Fast Breeder Reactor

During the year we have emphasized those aspects of the LMFBR program that are relevant to the Fast-Flux Test Facility (FFTF), scheduled for criticality in June 1974, and the proposed demonstration plants (1978—1980). I can mention, and but briefly, only a few of our accomplishments.

Radiation-induced swelling and loss of ductility of the structural stainless steel continue to be major problems. E. E. Bloom, J. O. Stiegler, and their co-workers have demonstrated that some of these effects are reduced in the titanium-modified stainless steels developed at ORNL. These alloys have now been irradiated to fluences of about 3 X 10^{22} neutrons per cm^2. As illustrated in Fig. 2, the fracture elongation of irradiated titanium-modified alloys at 550–600°C ranges from 10 to 30 percent and the fracture mode is predominantly transgranular; by comparison, the fracture elongations of the standard alloys are only 0.5 to 4 percent and they fail intergranularly. Thus real progress is being made toward resolving a troublesome problem for fast reactors — radiation embrittlement of stainless steel.

I would like also to describe an important contribution we have made to the shielding of fast reactors. Two-dimensional, discrete-ordinate calculations by F. R. Mynatt and experimental verification at the Tower Shielding Facility by F. J. Muckenthaler have strongly influenced the design of the head and the core support plate of the FFTF reactor. Through these studies, the uncertainty in the calculated flux above the rotating plugs in the reactor head was reduced from three orders of magnitude to a factor of two; about $2,000,000 was saved thereby. Figure 3 shows four 11-foot-diameter tanks filled with sodium that are being used in experiments at the TSF to evaluate the analytical methods used in calculating the transport of neutrons through large thicknesses of sodium.

According to current LMFBR design assumptions, shutdown reactivity accidents are deemed impossible because the degree of shutdown of the reactor is supposedly known precisely at all times, and appropriate administrative control is taken to prevent inadvertent startup. N. J. Ackermann, A. R. Buhl, and R. C. Kryter are conducting analytical and experimental investigations to determine how well one can measure the degree of subcriticality of a fast reactor that is shut down. The experiments both in ZPR-9 at Argonne and at

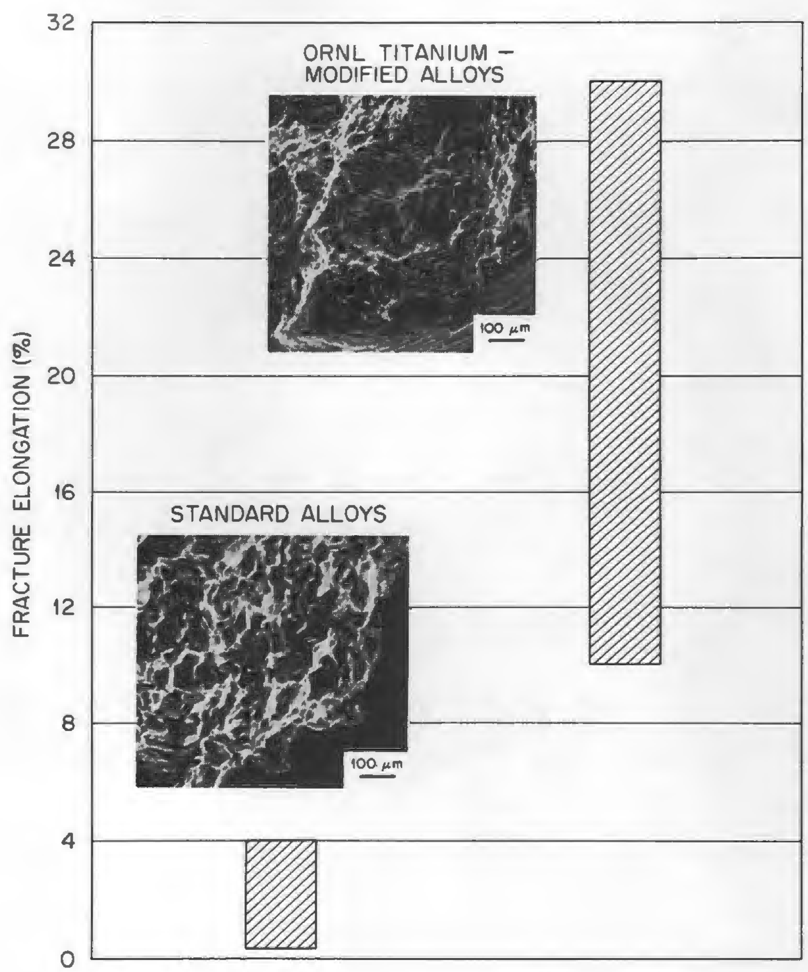


Fig. 2. Creep ductility of standard and titanium-modified 304 and 316 stainless steels after irradiation at 550–600°C to a fluence of 3.0 × 10^{22} neutrons/cm^2 (>0.1 MeV).

SEFOR were completely successful, and a subcriticality monitoring system based on these results is being incorporated into the FFTF design.

Finally, ORNL has responsibility for developing the methods for designing LMFBR structures: this is immensely complex because these structures creep at high temperature. B. L. Greenstreet and his colleagues recently developed the constitutive relationships to be used for inelastic analysis in the design of FFTF (and other high temperature reactor) components. I want to emphasize how important their contribution has been to this demanding subject; up until now such designs have been conducted on a rather empirical basis.

Molten-Salt Breeder Reactor

The Molten-Salt Reactor Program made several encouraging advances during 1971, but also turned up a potentially serious problem. Two of the advances concern the rapid processing systems needed for good performance in thermal breeders. In past years I have discussed processes in which protactinium and the rare earths are extracted from fuel salt into molten bismuth. A concern about these systems has been the problem of obtaining a material that will stand up to the bismuth. Molybdenum is quite resistant to molten bismuth, but difficulties with fabrication have restricted its use. Recently, however, Nancy C. Cole, J. R. DiStefano, R. E. McDonald, and A. J. Moorhead, working with H. E. McCoy and others, adapted some noteworthy techniques to forming and joining molybdenum; their progress is illustrated by Fig. 4, which shows a section of a molybdenum loop that is being built for processing experiments. Although these techniques are not new, their successful application to complicated

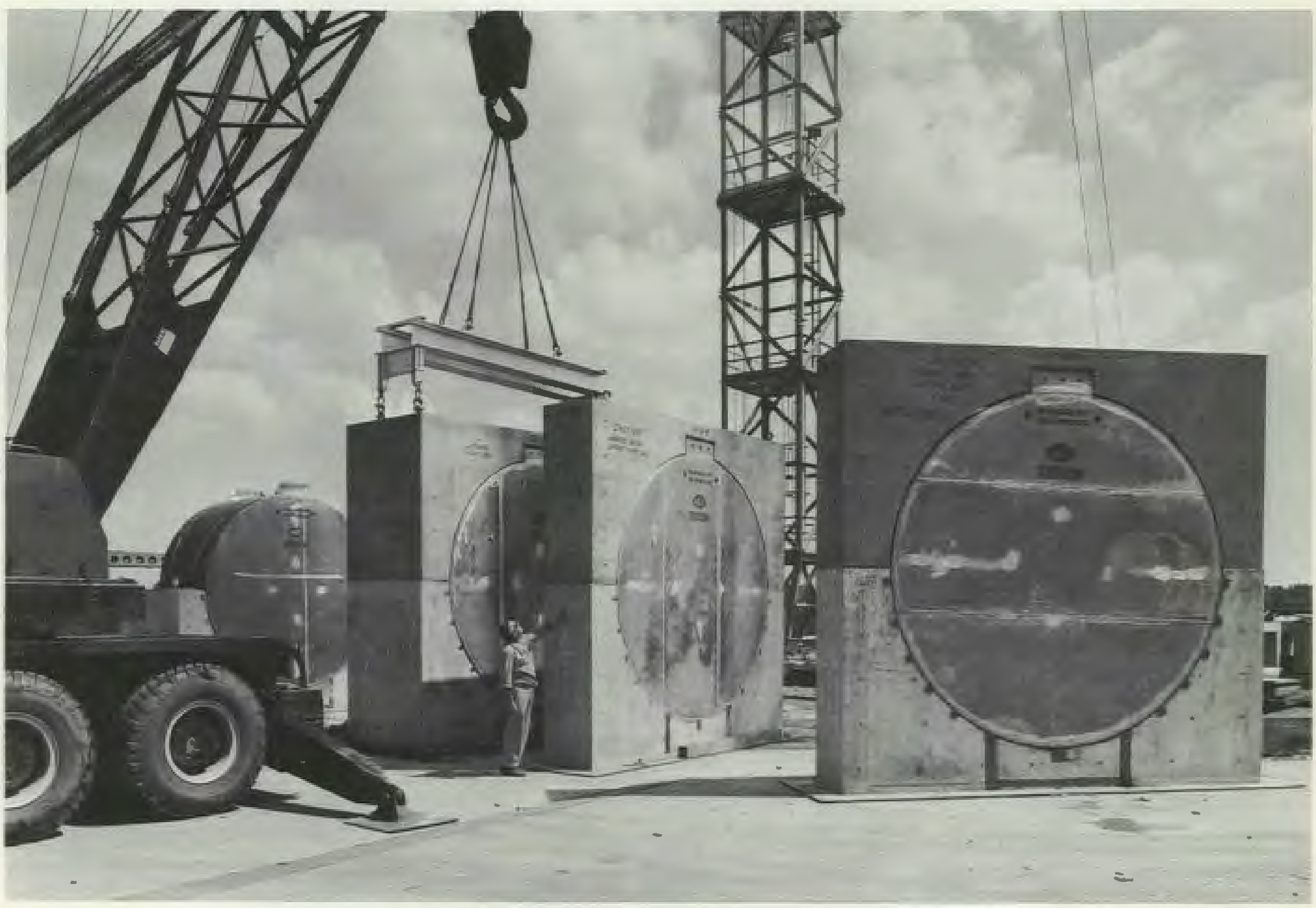


Fig. 3. Sodium-filled tanks used in tests of FFTF shield.

molybdenum systems represents a significant advance in molybdenum fabrication technology.

The second advance related to processing may provide an alternative to the use of liquid bismuth for removing protactinium. In the present process, removal of the much greater quantities of uranium has had to precede removal of protactinium. Consequently, we have always wanted a process that selectively removes the protactinium, and C. F. Baes, C. E. Bamberger, and R. G. Ross seem to have found it. At normal reactor conditions, addition of oxide to fuel salt precipitates protactinium as PaO_2, but it is accompanied by appreciable quantities of UO_2 and ThO_2 in solid solution. Baes and his associates have discovered, however, that if the redox potential is shifted enough to put the protactinium in the 5+ valence state, Pa_2O_5 forms that is much less soluble than the other oxides and precipitates as a pure phase. Whether this makes an attractive chemical process will depend on yet to be investigated engineering questions, such as the difficulty of separating the precipitate from the salt and the handling of solids that contain intense heat sources.

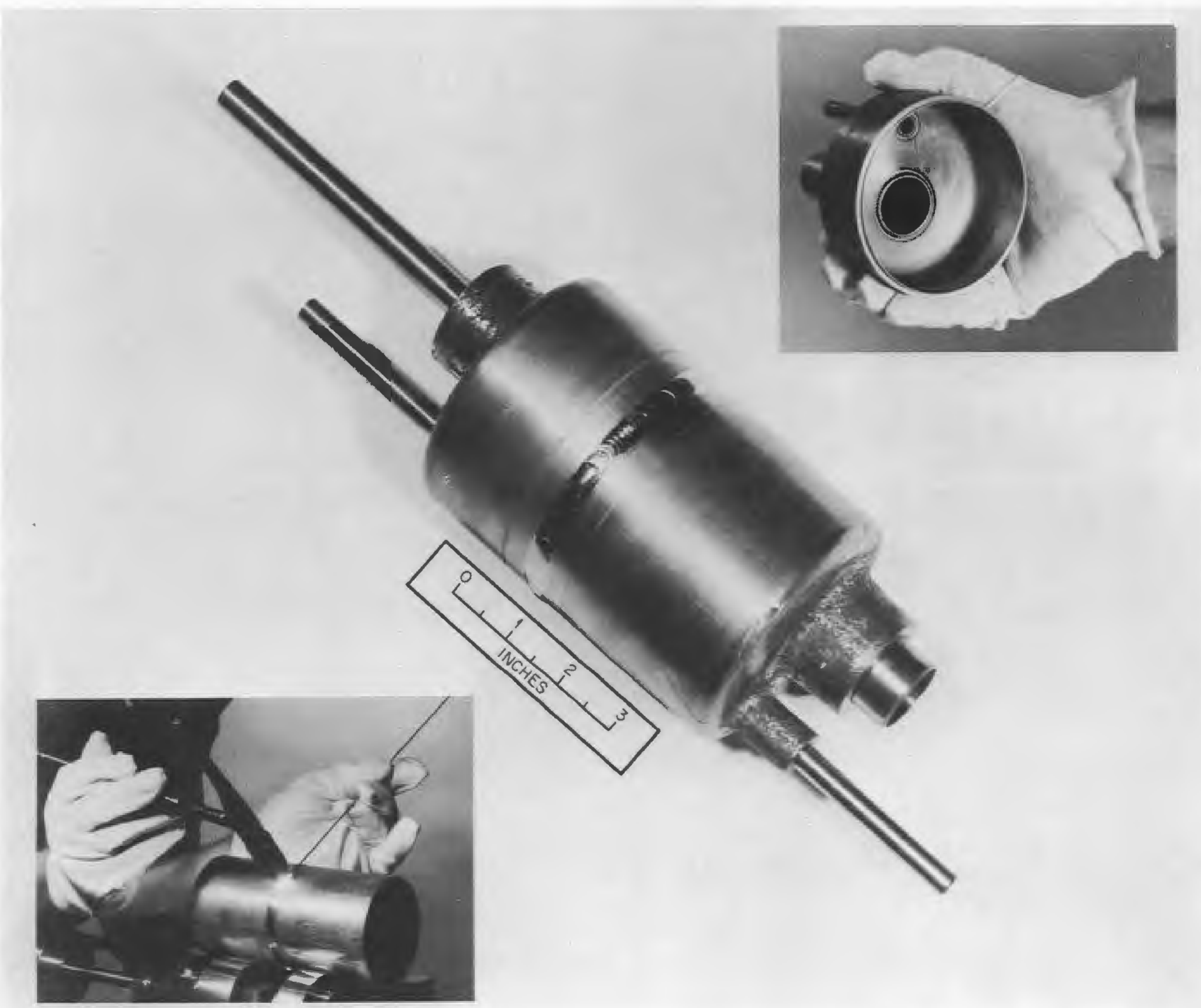


Fig. 4. Chemical processing equipment made of molybdenum.

Now I turn to what may be a serious problem for molten-salt reactors. During operation of the MSRE, small tensile specimens of Hastelloy-N were exposed to the salt in a sample assembly that was in the middle of the core. Upon examining these tensile specimens, as well as heat-exchanger tubes, control rod thimbles, and other metals that had been in contact with fissioning fuel salt, we found profuse cracks that showed up when the samples were stressed. This is dramatically illustrated by Fig. 5, which shows a section of a heat-exchanger tube with almost every grain boundary on the fuel-salt side opened up but with very few cracks on the side exposed only to the coolant salt.

When layers of metal from near the surface of these specimens were analyzed, several fission products were found to have penetrated to depths comparable to those of the cracks. Most notable was tellurium, which was found at about 100 ppm to a depth of several mils. Tellurium is chemically similar to sulfur, which is well known to be extremely embrittling to nickel at quite small concentrations. We cannot yet be certain that tellurium actually caused the cracks observed in the MSRE, however, since selective removal of chromium from grain boundaries has also been observed to cause similar-looking fissures in molten-salt loops, and we have learned that grain boundary attack to a depth of a few grains is sometimes seen in metals exposed to water and to sodium. However, as of the moment, fission product tellurium is our prime suspect.

There is some encouragement in the MSRE data. Although the number of cracks went up with time, the maximum depth did not increase with length of exposure, and the strength and other mechanical properties of even the heavily crazed specimens do not seem to have been worse than those of specimens irradiated to comparable doses out of contact with salt. Nevertheless, these observations have brought into question one of our most basic claims about molten-salt reactors — that of excellent compatibility of Hastelloy-N with fuel salt. The staff of the Molten-Salt Program is devoting its most urgent effort to the problem.

Controlled Fusion

The activities on the controlled fusion front have been particularly interesting during the past year. World-wide optimism remains strong, as was evident at the Geneva Conference. Here at Oak Ridge, ORMAK has been in low-field operation, and is just now switching to high magnetic fields, where it will break new ground for the world-wide

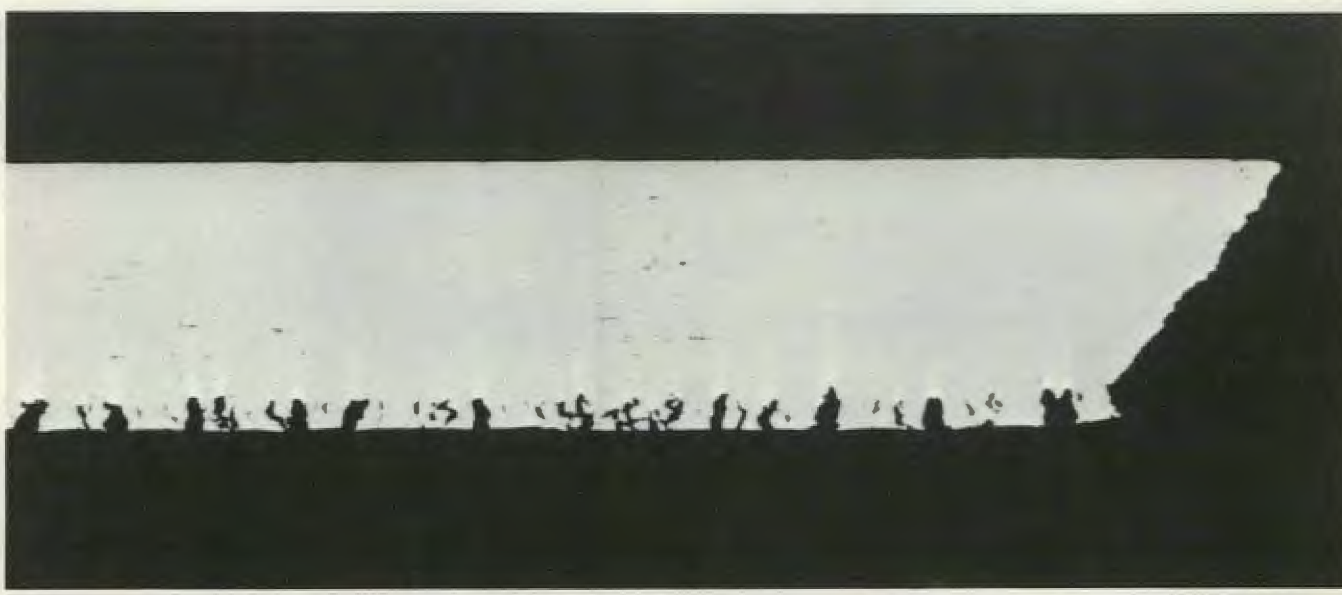


Fig. 5. Surface cracking in Hastelloy N exposed to MSRE fuel salt for 23,000 hours. The cracks penetrate to a maximum depth of 7 mils.

family of Tokamaks. High-field operation requires that all coils be cooled to liquid-nitrogen temperature — in all, more than 20 tons of metal. Then, when the big generators are thrown onto the windings, the toroidal magnetic field will pulse up to 25 kilogauss for a tenth of a second, and the linking transformer core will induce a plasma current of up to 400,000 amperes around the evacuated torus.

But to get to the so-called collisionless regime of the fusion plasma, another ingredient has to be added, and that is ion temperature. (The heating by transformer action alone is self-limiting because, as the current-carrying electrons get hotter, they collide less with the ions.) To get the ions above 1 keV in mean energy during the time of the pulse a special heating source is required. Here, O. B. Morgan and his colleagues have made a notable contribution. They propose to inject hot neutral atoms across the magnetic field and into the plasma ring as shown in Fig. 6. They will be ionized and trapped, and will add their energy to the total ion population. In the diagram one notes four injectors opposed in pairs. In bench tests, a single injector has produced 2.2 amperes equivalent of mixed atomic and molecular hydrogen particles at 30 keV equivalent energy, going through a 9-cm-diameter hole one meter away, as is required by ORMAK. Computations have shown that the eight amperes equivalent from the four injectors should boost the ion temperature during the ORMAK pulse from about 1 keV to about 5 keV, which is getting very close to fusion temperatures. In fact, ORMAK may well give the first experi-

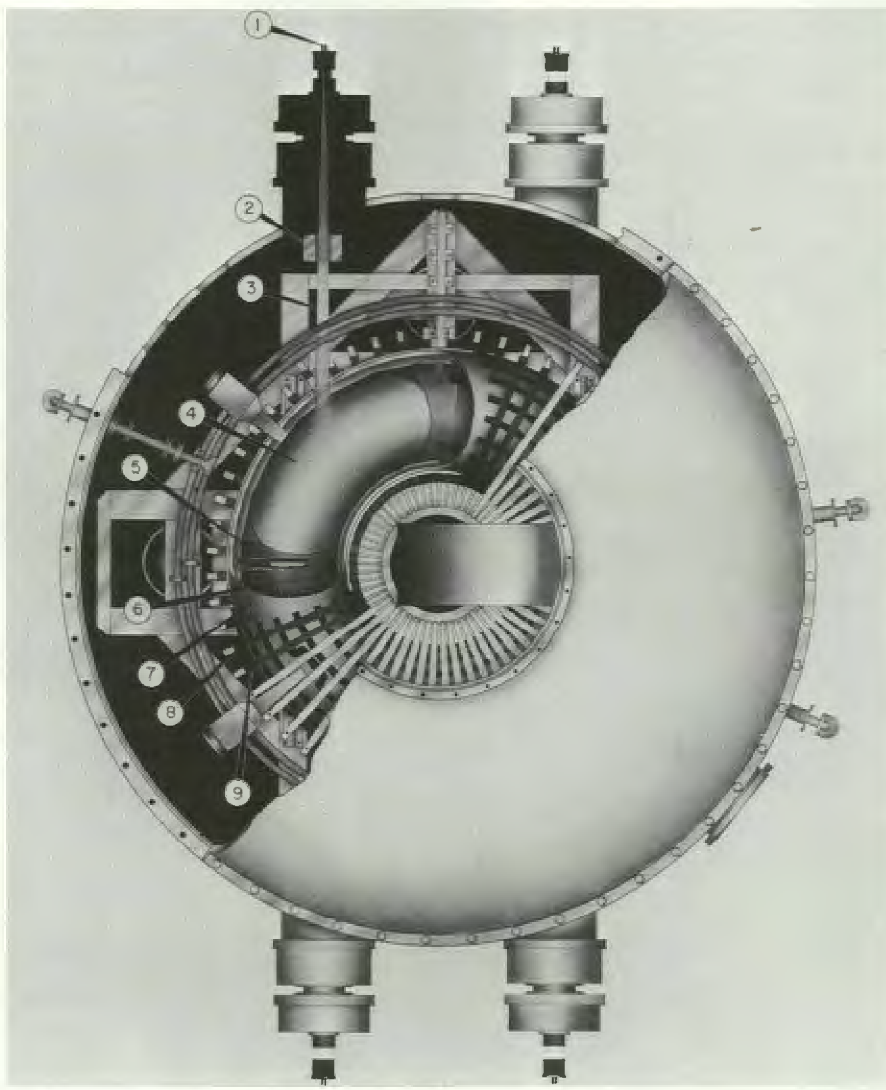


Fig. 6. ORMAK with injection heating.
1. *Ion source*
2. *Charge exchange cell*
3. *30-keV H^0 beam*
4. *Plasma ring*
5. *Liner*
6. *Vertical field coil*
7. *Conducting shell*
8. *Plasma current primary coil*
9. *Toroidal field coil*

mental "feel" for fusion-temperature plasmas that last for tenths of seconds.

In addition to all of this, a new concept for a fusion device has taken firm shape during the past year. For ten years or more, R. A. Dandl together with A. C. England, H. Odell Eason, and others have been working with plasmas heated by microwave power at electron cyclotron resonance. In these experiments, a copper microwave cavity with perforated ends is placed between two parallel mirror coils. Especially when microwaves of two different frequencies are used, one being above the cyclotron resonance frequency, the plasma is found to be stable in the steady state and has sufficient energy content that, so to speak, it "digs its own hole" in the magnetic field. This is a useful situation, but the disadvantage of the whole scheme has been that the ions remain cold. As soon as they start to warm up, they scatter and are lost through the ends of the mirror trap. The usual answer to this has always been to put a number of the mirror elements end to end, and double them around into a circle so the plasma swallows its tail. Before this could be done, two crucial tests had to be made. In one, Dandl arranged mirror coils on hinges, and indeed found that they could be canted 15° out of parallel without damaging loss of plasma stability. In the second, it was demonstrated that the perforated metal ends of the microwave cavity are not necessary for stability, and presumably can be dispensed with. Meanwhile, a theoretical inquiry by Gareth E. Guest, C. L. Hedrick, and others gives encouraging support for the concept, so we plan to proceed with the experiment. Figures 7 and 8 show the ELMO Bumpy Torus, or rather half of it. The toroidal tube and the circle of coils are inside a lead x-ray shield, with the microwave power fed in from outside. With the ions now in inescapable, steady-state contact with the hot electrons, they will warm up, and the plasma will dispose into 24 interconnecting nodules around the main circle. It will take about a year to build the apparatus, but this is an original Oak Ridge approach to the fusion problem; and, needless to say, we shall all watch with the greatest of interest.

President Nixon's policy on energy takes on added significance in view of new legislation which strikes the word *atomic* from Section 33 of the Atomic Energy Act and in Section 31 further authorizes the Commission to work on "the preservation and enhancement of a viable environment by developing more efficient methods to meet the Nation's energy needs." Exactly what this means in practice it is difficult to say; taken at face value, it authorizes the Commission to develop nonnuclear, as well as nuclear, methods of producing energy. As of now, ORNL is engaged in around $2,000,000 worth of research and development concerned with energy that is not nuclear. For example, we are assessing the impacts of central electrical plants; developing methods of sorbing SO_2 from fossil fuels; and designing urban power systems, to mention only a few of the studies.

It seems likely that we shall be encouraged to move more strongly into nonnuclear energy, mostly under the auspices of the Atomic Energy Commission, but also under the auspices of the Research Applied to National Needs (RANN) program of the National Science Foundation. NSF now is considering proposals from ORNL to work on the environmental impact of electricity production; environmental monitoring, measurement, and analysis; and toxic materials in the environment — all of which have some flavor of energy.

Most of the work we do on energy, and particularly on nuclear energy, is aimed at developing new technological options — for example, developing breeders or fusion reactors. That this will continue to be a central focus for a good many years, I have no doubt. Yet I think we ought to be prepared for some changes — at least this is the message I get from Chairman Schlesinger's speech at Miami in October. After reaffirming the historic " . . . responsibility of the AEC vigorously to develop new technical options and to bring those options to the point of commercial application . . . ," the Chairman continued in a rather different vein:

"Environmentalists have raised many legitimate questions. A number have bad manners, but I believe that broadside diatribes against environmentalists to be not only in bad taste, but wrong. . . . The question had been raised, by Michael McCloskey of the Sierra Club among others, whether our society for environmental reasons viewed broadly ought not to curb its appetite for energy and for electric power. It is a legitimate social question. It is not unreasonable to question whether neon signs or even air conditioning are essential ingredients in the American way of life."

The Commission will almost surely become even more involved with the environmental implications of its new technological options. At ORNL we have seen this thread in our work grow from year to year: it will, I predict, continue to grow.

Some Basic Research Vignettes During 1971

So much publicity and concern has centered on the environmental crisis in applied nuclear energy that I fear we may lose sight of the many elegant findings in basic science that we have made during the year. I mention two, taken in some measure at random, that have struck my fancy. First is the very ingenious method for measuring the electrical conductivity of electrolytes developed by E. J. Kelly of the Chemistry Division. Kelly observes the transient response during the first few microseconds after a voltage has been impressed on the system. The method, originally used to study titanium corrosion, should have wide applicability to the study of good electrolytes. I mention also the very pretty observations of surface plasmon oscillations in metals by L. H. Jenkins, with the associated theoretical work of R. H. Ritchie.

I would like to dwell at some length on developments in heavy-element physics and chemistry during the past year. One striking finding was

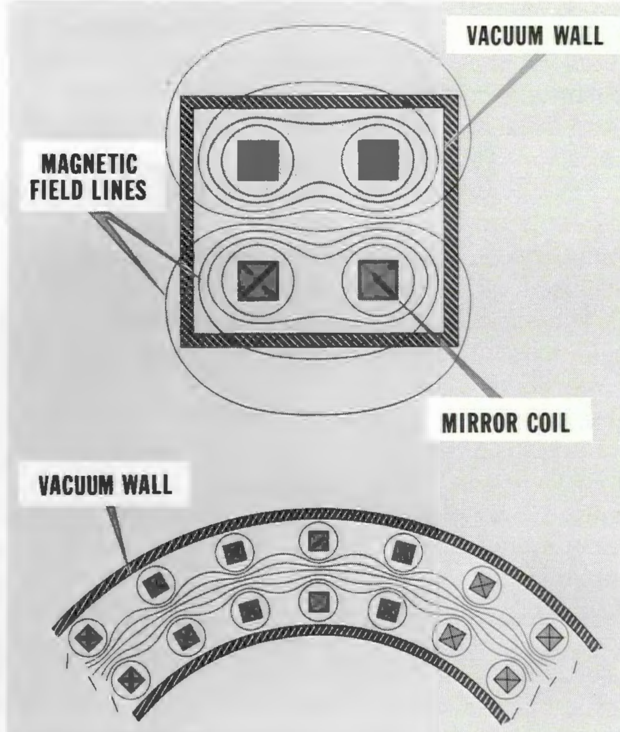


Fig. 7. Bumpy torus. Schematic view of magnetic field lines.

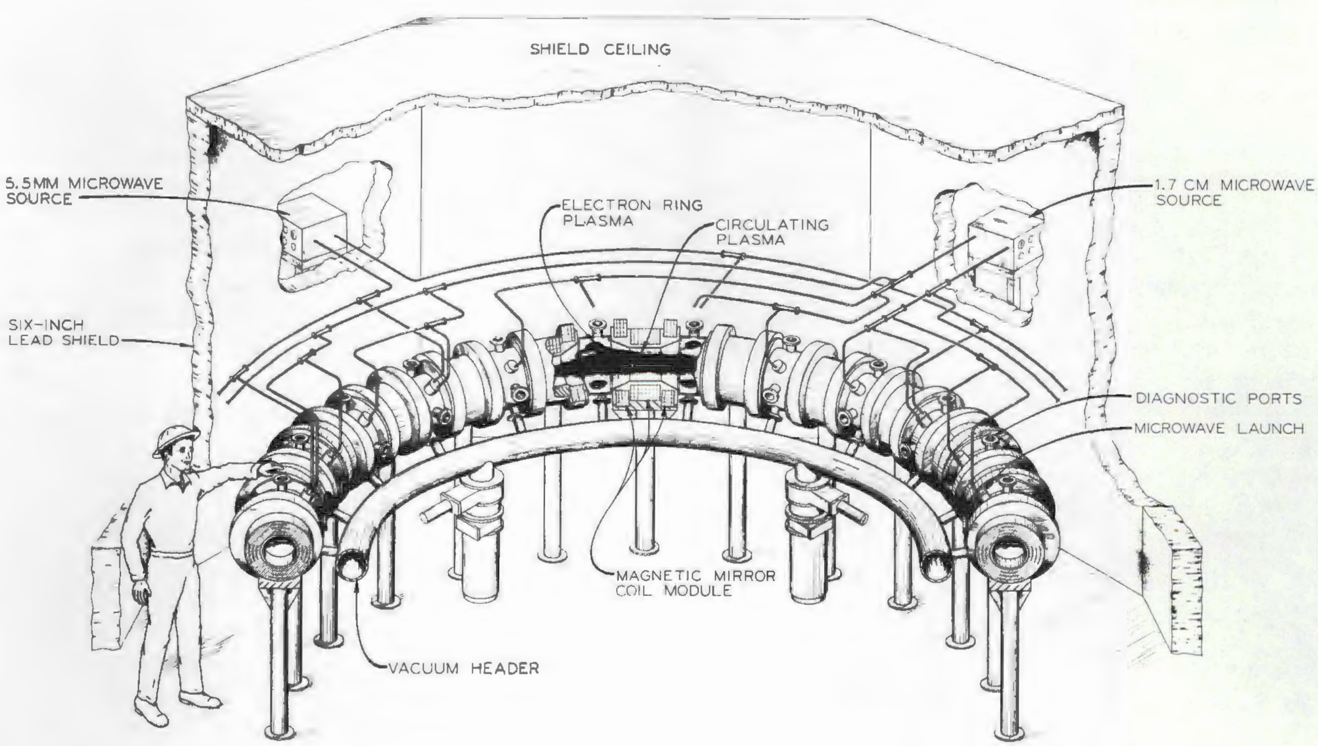


Fig. 8. ELMO bumpy torus.

that some heavy nuclei have a rather fancy shape, as shown in W. N. Tillery's photograph of a scale model of the ^{234}U nucleus (Fig. 9). This shape, which goes by the formidable name of a hexadecapole distortion, shows up in the modes of excitation following inelastic scattering of alpha particles. These experiments were performed at the tandem Van de Graaff by F. K. McGowan, C. E. Bemis, Jr., J. L. C. Ford, Jr., W. T. Milner, R. L. Robinson, and P. H. Stelson.

I mention also the several attempts (all of them, alas, unsuccessful to date) to identify superheavy elements in nature: J. S. Drury's trek to the Western States and Canada to bring back pounds and pounds of rocks which were then examined for unusual fission events; or the extremely elaborate neutron emission counter designed by R. L. Macklin and used by R. W. Stoughton and Joseph Halperin to detect fission events of very high multiplicity in such exotic materials as scrapings from zinc smelters; or the unusual pleochroic haloes in mica that consultant R. V. Gentry of Columbia Union College has observed, and that conceivably may be associated with as yet unidentified alpha emitters; or the beautifully elegant method of C. E. Bemis and P. F. Dittner for identifying short-lived heavy elements by observing their characteristic x-ray emission. The search for ultra-heavies is a tedious, yet exciting, business — made the more exciting, though no less tedious, by the apparently premature announcement last February of element 112 in the tungsten target of the CERN proton synchrotron.

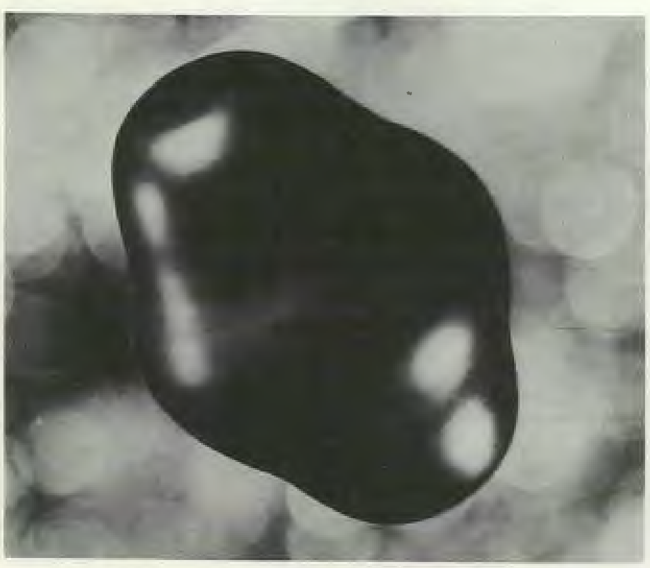


Fig. 9. Model of ^{234}U nucleus showing hexadecapole distortion.

I mention these vignettes in heavy-element physics and chemistry as an introduction to where we stand on APACHE — Accelerator for the Physics and Chemistry of Heavy Elements. APACHE is a combination Van de Graaff—cyclotron that would impart about 10 MeV energy per nucleon to nuclei as heavy as ^{238}U. To save money, we have simplified the proposal: our accelerator now has a reduced energy capability for protons. However, the field of heavy-ion nuclear physics is growing so rapidly that a specially constituted advisory committee has urged us to move as aggressively as possible in presenting APACHE to the Atomic Energy Commission — not simply as an Oak Ridge or even Southern regional accelerator but rather as a national facility to be used by scientists from all over the United States. A steering committee chaired by Paul Stelson recently has been set up to redraft the proposal we previously submitted to the Commission.

Biomedical Sciences — Cancer and Aging

Whereas the basic physical sciences, particularly physics and chemistry, have been hit badly by budget squeezes, the biomedical sciences seem to be on the verge of a boom. Two areas that are particularly ripe, both scientifically and politically, are cancer and aging; and in both of these ORNL has much to contribute. The cancer picture is dominated by the action of Congress to launch a major "Conquest of Cancer" campaign, to the extent of perhaps $500,000,000 per year. I believe a large expansion in cancer research is a good idea; but, along with most others, I am turned off by the phrase "conquest of cancer." We still are not sure where to seek a "cure" for cancer: the soundest strategy would seem to be to strengthen existing cancer research centers, and perhaps establish new ones so that every likely possibility will be covered.

At ORNL we have many salients in cancer, and I think we are making good progress: F. T. Kenney, who heads the National Cancer Institute program on carcinogenesis, R. W. Tennant, and William Tuominen have shown that synthetic polynucleotides, such as polyadenylic acid, inhibit the replication of leukemia virus. N. G. Anderson, J. H. Coggin, and their associates continue to develop new insights into fetal antigens and cancer to the extent that the October 1, 1971, lead editorial in *Nature* was devoted to their work, and the first nation-wide conference on fetal antigens was held at ORNL last spring. The group under C. J. Borkowski has developed an extremely accurate proportional counter camera for visualizing very small tumors, and our shielding group and the heavy-ion people have ideas about how to improve the tumor-to-skin dose ratio in radiation therapy. When these capabilities are added to those at ORAU, and at UT Memorial Hospital and the UT biological science departments, one has the potential for an impressive cancer center. ORNL has therefore cooperated with these three institutions in proposing that such a center be established in the Knoxville—Oak Ridge area. At present the University has asked for a planning grant: if this is approved, the next step could be a full-fledged proposal that might lead to a major cancer center, hopefully involving ORNL, in a few years; but whatever the fate of the cancer center concept, ORNL will continue to push for broader support in its particular areas of cancer research expertise.

As for aging, Takashi Makinodan has been working on senescence of the immune system and the methods of accelerating aging by injecting spleen cells from old animals into young. These studies have established Makinodan's group as one of the foremost in aging research. With this very strong program as a start, the Biomedical Graduate School has applied to the National Institute of Child Health and Human Development for a 3.5×10^6, five-year program project grant in aging. This grant will involve some 35 senior investigators in the Biology Division, though not all full time. We hope that the grant will be approved early next year.

Other Cooperative Educational and Research Activities

I mention two other cooperative endeavors with neighboring universities that have come to fruition this year — UNISOR and the Southern Regional Demographic Group.

UNISOR (University Isotopes Separator Oak Ridge) involves a group of 11 universities which have banded together and raised money to procure an on-line isotope separator (90° Danfysik design) to be used in conjunction with the ORNL cyclotron (ORIC). The Laboratory has assisted the project in important ways, including the building and equipping of experimental areas needed to house the separator. AEC is contributing both operating and capital money. We expect that the UNISOR experimental program, using its unique facility, will start during the first part of 1972, delving especially into the properties of many nuclear species lying far from stability. These unknown nuclei can be produced by use of the prolific heavy-ion beams now available on ORIC; and their properties can be studied effectively through the on-line mass separator techniques (Fig. 10).

The Southern Regional Demographic Group is an organization of demographers in the South, which is affiliated with ORAU and with ORNL. The group, whose president is Everett S. Lee of the University of Georgia and ORNL, encourages cooperative studies in demography of the South. Our Laboratory helps the group by making available to it our computing facilities and our bank of census tapes; the group helps the Laboratory establish contact with distinguished demographers who advise us on demographic problems in civil defense, urban development, and reactor siting.

Where Do We Go From Here?

It is fitting that I mention two activities as different as demography and UNISOR in the same paragraph: this strange juxtaposition illustrates how far ORNL has gone since its founding in 1943 as a pilot plant for the extraction of plutonium from spent reactor slugs. We are now concerned with energy, environment, the city, civil defense, water, cancer, aging, radiation biology, as well as our traditional nuclear and other physical research; and I have not exhausted the list. That each of these new fields made sense at the time we entered it does not relieve us of responsibility for examining our various areas of work from time to time to determine whether we really like the directions in which we are going.

I see the future no more clearly than anyone else. Yet, as I implied at the beginning of my remarks, there are changes in our national priorities; and insofar as we as a National Laboratory ought to be responsive to these changes, it is inevitable that we too must change.

In some degree, what may at times appear to be a scattering of our efforts is illusion: energy and the environment are intimately connected, as is the environment with cancer; energy with water; environment with the city, and so on. I therefore would look upon these new salients as enriching and deepening our capacity to respond to national needs — in reintegrating at the working level the

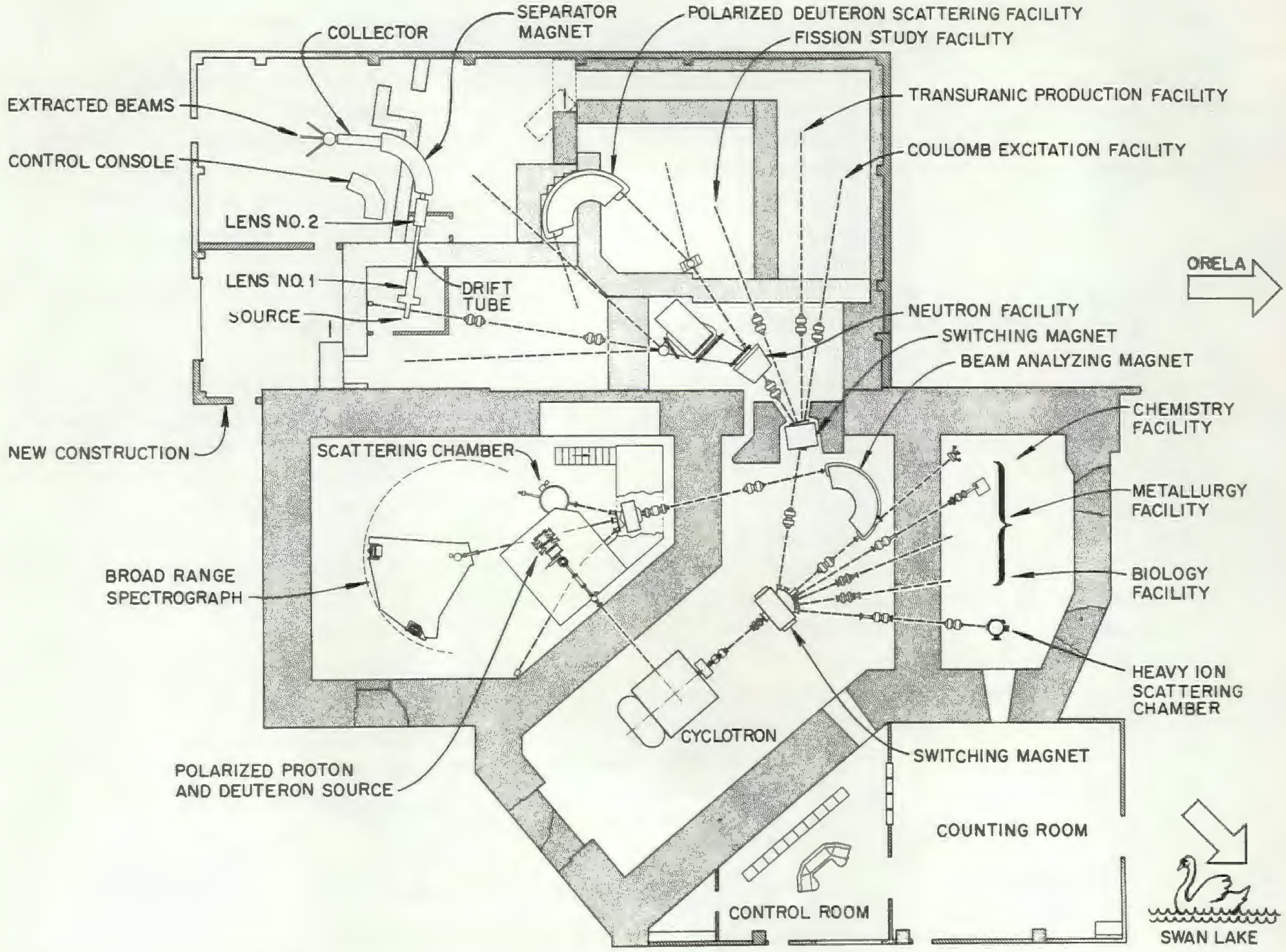


Fig. 10. Plan view of UNISOR.

fragments into which socio-technological problems are split by bureaucracy. Moreover, the alignment in Washington *is* changing. I remind you again that *atomic* has been struck from an important section of the Atomic Energy Act, and that we have been encouraged by AEC to work with other agencies.

From my contacts in Washington, both with the AEC and with other agencies with which we work, I have the impression that this ORNL style — our attempts to move where the action is — has made for us more friends than enemies. That some of the action, as in the environmental impact exercise, seems to move us away from science, does not overly disturb me — if at all times we retain our scientific judgment and faculty for self-criticism, and if these nonscientific deviations are of limited scope. We are engaged, in a real sense, in a renewal of our institution — a renewal that should appeal to our younger staff (since it is in the nature of youth to want change and renewal) and that should challenge our older staff who seek new perspectives and new possibilities.

It is important to end on this note of optimism, since for many this has been a trying year. The reductions in staff that we were compelled to make were very difficult; I am pleased to report that almost all who left have now been relocated.

I cannot promise that the dislocations of 1971 will never be repeated; the nature of our institution and its avenues of government support make this too much to expect. Yet, with our diversification into many areas that are recognized as central in the highest places in government, I can only convey to you a strong confidence in the future that I believe will be justified by the events of 1972.

BOOKS

Inadvertent Climate Modification, report of 1971 Study of Man's Impact on Climate, hosted by Sweden's Royal Academies of Sciences and Engineering. MIT Press (1971), 295 pages plus index, paperback, $2.95.

(Reviewed by F. A. Gifford, director of the Atmospheric Turbulence and Diffusion Laboratory in Oak Ridge, under the National Oceanic and Atmospheric Administration, U.S. Department of Commerce.)

ORDINARILY I WOULDN'T EXPECT to be able to recommend a book written by a committee any more than a ride on that putative committee-designed vehicle, a camel. But this is an unusual book, and besides I don't really know that camel rides are all that bad. "Inadvertent Climate Modification" summarizes the conclusions of thirty scientists who met for three weeks this summer to evaluate man's impact on climate. It would be difficult to think of a more capable group of experts in this field, and judging by the result they must have worked very hard and well. This Study of Man's Impact on Climate (SMIC) originated in last year's Study of Critical Environmental Problems (SCEP). The 1970 SCEP report identified the problem of inadvertent climate modification as one requiring prompt scientific evaluation, and the SMIC report is the response to that concern.

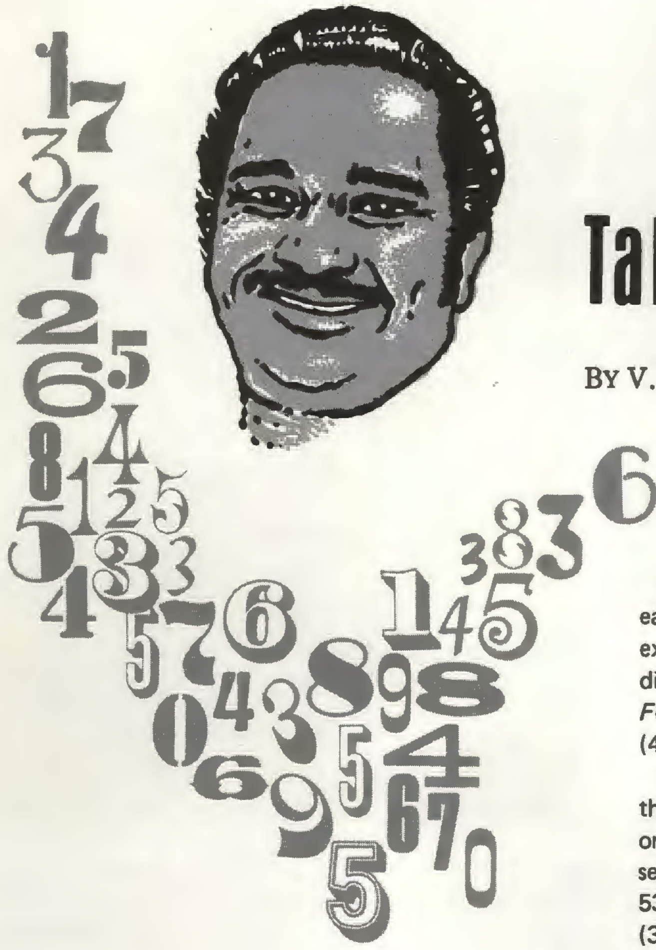
Following a summary of the major findings of the study, there are chapters on climate history and dynamics, man's activities that influence climate, processes governing climate, theory and modeling of climate, effects of man-made surface changes, tropospheric modifications, and stratospheric modifications. Each of these chapters is, first of all, a concise and expert technical summary of the known facts. But there are also reports of new research, for instance Manabe's 3-D model of temperature change resulting from CO_2 doubling, which shows a much greater warming effect at high latitudes than did the previous 1-D model. The presence of such significant new information is a good indication of the competence and authority of this report.

The review of the history of climate points out the long, even interperiods during which the poles were free of ice and fluctuations of temperature were minor, interspersed with comparatively short glacial epochs during which large midlatitude temperature fluctuations occurred. The high noise level of natural climate fluctuations in the present glacial era makes it hard to isolate purely man-made effects. Man influences the environment by releasing pollutants of all sorts including heat, by controlling animal grazing practices, by building cities, by modifying surface water flows, and most recently by intentional cloud and storm seeding. Consequently it is all the more urgent to study mathematical models of climate, so as to understand the possible impacts, and the physics and mathematics of this subject are skillfully outlined. Recent results of such studies suggest the key role played by the arctic sea-ice pack in controlling the climate of our epoch. A small change in the mean air temperature or in solar radiation received at the ground could result in major expansion or shrinking of the ice pack, which would of course mean major climate changes. Mankind's role in such possibilities is explored in detail in the last three chapters.

The most important conclusion of this book, stated in various ways in discussing a large number of atmospheric processes, theories, and effects, is that there is no conclusion. We don't really know, for sure, what our impact on climate will be. In some cases this is because we don't know the global, as opposed to the local, physics of the matter. For instance, increasing the small particle loading (turbidity) of the atmosphere will, it is generally agreed, increase the earth's albedo or (global) reflectivity. At the same time particles are believed to increase the "greenhouse" effect, resulting in surface warming but high-level cooling of the atmosphere. The extent of this depends strongly on conditions at and above a particular place. As a result the net effect, even the sign of the net effect, on surface temperature, for example, is hard to estimate. In other cases the problem may be lack of detailed knowledge of some fundamental process, such as dynamic and thermodynamic coupling between the atmosphere and the oceans. Each of these fluid systems is both a reservoir and a conduit for solar energy, but their characteristic time constants differ widely. Another example of this sort of thing is the fact that when we come to try to estimate the impact of, for instance, SST pollution in the stratosphere, we find that the problem is made very difficult by uncertainties about the relative speed of chemical reaction rates and atmospheric transport and dispersion rates there.

Naturally, considering the above and many other examples, the principal recommendation coming out of this book can be boiled down to the fact that much more research needs to be done. We know enough to be very worried, but not enough to give positive assurance (one way or the other) in every case. A meteorologist reviewing a book written primarily by meteorologists, all more or less in the research business, naturally mentions this point with some diffidence. But if we are to avoid the two extremes of unbridled technology and paralysis by what Lederberg aptly calls technophobia, resolution of the problems identified in this excellent book is essential.

Readers of the ORNL *Review* are the audience, *par excellence*, that the book is trying to reach. I hope you do read it. If you do I think you will agree, as you put it away on your bookshelf alongside all the other recent environment paperbacks, that it's neither a screamer, a breast-beater, nor a tub-thumper. What it says has to be taken seriously. It is an appropriate, not to mention an admirable, response by the scientific community to genuine concern on the part of that segment of its experts having competence in this problem. It doesn't forbid us to act, but it does try to identify and put a rational scientific price tag on the difficulties we face in making intelligent decisions that involve possible impacts on the only climate we have.



Take A Number.....

BY V. R. R. UPPULURI

Alphametics

(4) times (1963) is equal to 7852. One notices that each of the digits 1, 2, 3, 4, 5, 6, 7, 8, and 9 occurs exactly once in this relation. If one tries to find distinct digits $A, B, \ldots, H, I$ such that $(A)(BCDE) = FGHI$, then one obtains the only other solution to be (4) times (1738) is equal to 6952.

If one tries to solve for $(AB)(CDE) = FGHI$ such that each of the digits 1, 2, . . . , 9 occurs exactly once in this relation, then one can find the following seven solutions: (12) (483) = 5796, (18) (297) = 5346, (27) (198) = 5346, (28) (157) = 4396, (39) (186) = 7254, (42) (138) = 5796, and (48) (159) = 7632. There do not seem to be any analytical methods available to show that these are the only possible solutions.

A Question of Existence

A chord will divide a circular disk into two parts. By making the chord pass through the center, one can render the two parts equal in area. Two chords will divide the disk into at most four parts; by making the two chords as perpendicular diameters, one can render these four parts to be equal in area. Can one say anything more generally?

For instance, three chords can divide the circular disk into a maximum of seven parts, with a triangle in the middle. The question is: Do there exist three chords which divide the disk into exactly seven parts, such that all the seven areas are equal? The conjecture is that this is not possible, and the author will be obliged for any proof.

Triangles with Integer Sides

At the turn of this century, it was discovered that the only triangles the sum of whose integer-valued sides equals the area of the triangle are (5, 12, 13), (6, 8, 10), (6, 25, 29), (7, 15, 20), and (9, 10, 17). It can be seen that the triangle with sides (3, 4, 5) has the property that the sum of its sides is equal to twice its area. It is interesting to note that this is the only triangle with integer sides such that the perimeter is equal to twice the area. How about a triangle with integer sides such that the perimeter is equal to thrice the area?

A graduate in electrical engineering from the University of Tennessee, Harry Walker served as a power engineer for TVA until he moved into design engineering in ORNL's General Engineering Division in 1946. He is responsible for the electrical design of many of the Laboratory facilities, including Tower Shielding, the ORR, and the Isochronous Cyclotron. Following the historic blackout in the northeastern U.S. in 1965, he performed a study of the event in response to a request from New York's Governor Rockefeller, delivered by ORNL consultant Eugene Wigner. Recently he has taken an active role in the study of advanced technology of energy systems, particularly in electric power transmission. In this article, he clarifies the need for integrated and interconnected power grids.

No More BLACKOUTS!

A Blueprint for Electric Power Reliability

By HARRY K. WALKER

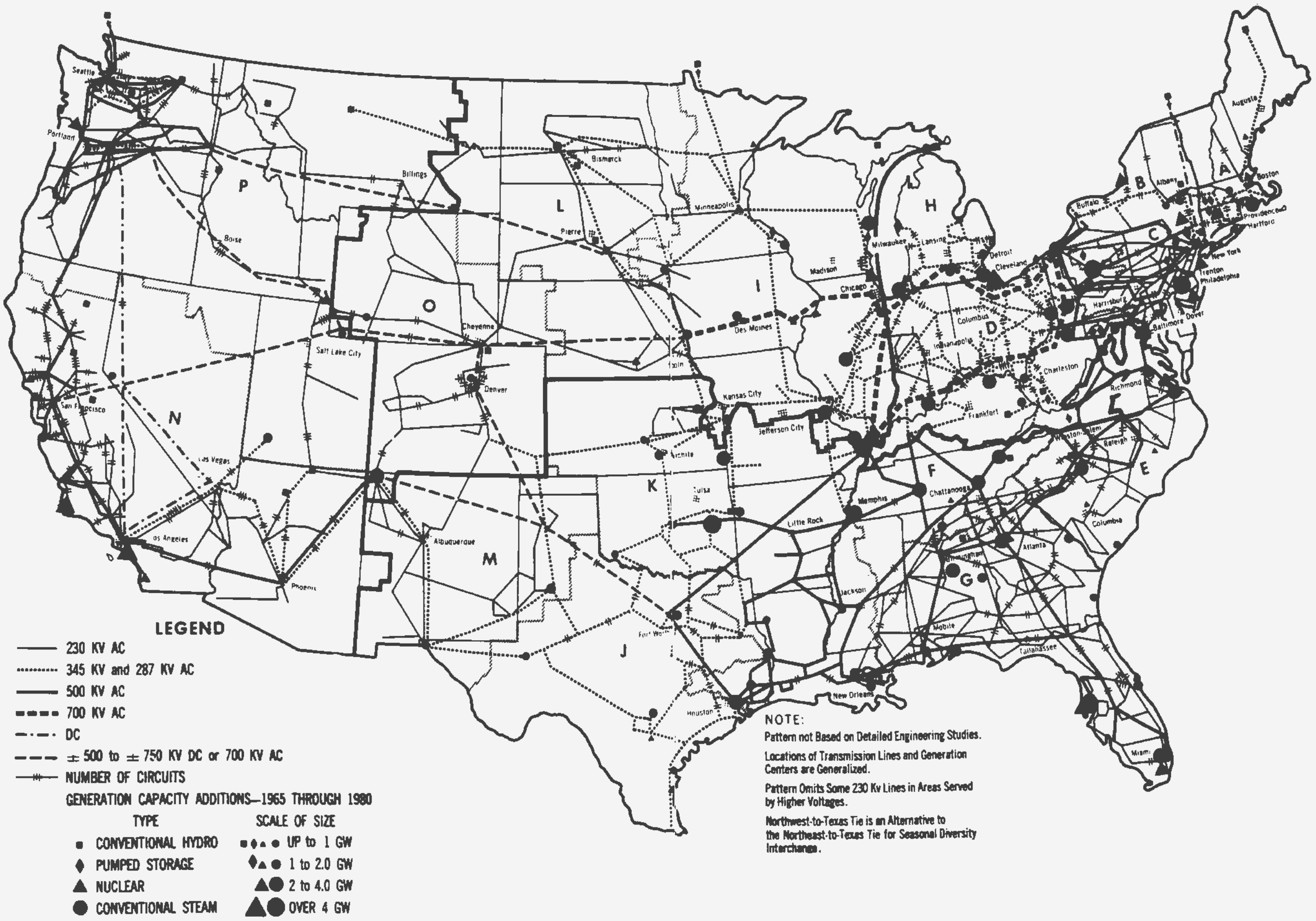
COMPLEXITY, GROWTH, AND CHANGE are characteristic of our times. Systems that previously operated on a more or less independent basis are moving more and more into conditions of interdependency. One important group of such systems is that of the electric power industry, comprising 480 investor-owned companies. System engineering for the integrated and coordinated operation of the whole industry is a desirable objective. Understanding the nature and characteristics of electric systems and their relationships in integrated operation with each other should lead to a better understanding of what is involved in attaining service reliability within an overall grid system.

National demands for electrical energy have increased at a compound rate of 7.5% per year for the past 20 years. The demand for fuel supplies and for facilities for electrical generation, transmission, and distribution shows a corresponding growth. Long lead times must be allowed for planning and constructing these facilities in order to serve the demand reliably.

Following the northeast U.S. power failure of November 1965, the Federal Power Commission reviewed it and 20 subsequent interruptions of significance, issuing its report in June 1967. In it, the FPC placed primary emphasis on the need to strengthen transmission networks in almost all parts of the U.S.

The goal of the electric utility industry has been to provide reliable service to consumers at low cost with a favorable return on the invested capital. To the customer, whether a city, an industrial plant, a research center, a public building, or a private dwelling, reliable service means the continuous satisfaction of power requirements. The percentage of time that the service meets these requirements is better than 99.9% to the average U.S. consumer.

The universal and increasing dependence on electricity makes any local power failure at least an inconvenience, and often costly; any widespread interruption is seriously disruptive. The electric



Possible pattern of electric power generation and transmission by 1980, as projected by the National Power Survey.

utility industry, already providing good service, must therefore strive for virtually perfect service.

Certain basic characteristics of the technology affect the economics of electric power supply. First, since the industry is one in which capital investment is unusually high, unit costs can be greatly reduced by better utilization of equipment. Second, unit costs also decline with increased capacity of equipment. Third, production and use must be simultaneous because electricity cannot be stored. Enough capacity is required to meet the coincident demand or peak load of all customers. When the peak loads of individual customers occur at different times, therefore, an interconnected network can operate more economically.

The combined effect of these factors is that the most economical arrangement of electric service to all customers in a given service area is a strongly interconnected and coordinated complex of generation and transmission facilities with the sole responsibility for meeting all the power requirements in the area.

Providing electric power involves three functions: generation, transmission, and distribution. The combined generation and transmission functions are referred to as the "bulk power supply," and distribution is the final leg of the journey to the customer.

The general characteristic of all electric utility systems is a widespread distribution of electric loads supplied with power from a limited number of electric generators. These generators may be remote from the load areas because of their location near waterfalls, near coal supplies, or adjacent to large supplies of cooling water. Connection between the loads and generators is through a network of transmission lines with loads supplied at many intermediate substations. Transmission lines also provide paths for electric energy to flow between utilities. These lines, or interconnections, enable utilities to operate as a team to obtain benefits that would not otherwise be available.

When generating units are electrically connected by transmission lines to form a system, they must operate at the same frequency, and the pulsing of the alternating current must be coordinated. Generator speeds, which determine frequency, must also be coordinated. The various plants are then said to be operating "in synchronism," and the system will be said to be stable. A sharp change in loading at a plant will affect the frequency, but if the plant is strongly interconnected with others, they will help to absorb the effect of the changed loading so that the change in frequency will be negligible and stability will not be affected. Since each connected generating unit helps to cushion the effect of a disturbance anywhere in a system, a large system with ample generating capacity that is solidly interconnected has great strength in meeting emergencies. Conversely, if generating capacity is inadequate or the interconnections are weak, the result could be system instability and a consequent cascading of trouble.

Interconnections among neighboring systems, then, are no different in principle from those that connect the stations of a single utility. However, the prerequisite for satisfactory performance is a reliable and adequately developed transmission system within each of the component systems. In short, adequate interconnection is the coordinating medium that makes possible the most efficient use of facilities in any area or region.

Today, 95% of the nation's generating capacity is to a greater or lesser degree interconnected in nine large regional networks. Most of the networks were not designed for and are incapable of achieving full coordination. However, they represent a solid beginning for the stronger interties now being built and planned for the future.

The Designed Network

The failure of any part of a network can affect large geographic areas, and it is important to determine that the loss of a generator or a transmission tie will not cause the cascade failure of other equipment and result in a general shutdown. In a fully integrated and coordinated network, computer studies cover the consequences of all credible incidents, determining then the need for any additional facilities.

Effective interconnected operation between utility systems requires transmission networks strong enough to handle heavy flows of power under both normal and emergency conditions. This calls for extra-high-voltage lines, many of which are being added to the networks today.

The functions of the transmission network visualized for 1980 will be:

- permit the construction of large and more economical generating units and the transmission of bulk power from generating sources to major load centers;
- permit reduced reserve requirements by the sharing of capacity among areas and sectors;
- provide capacity savings by seasonal exchange of capacity between areas that have opposing summer and winter peaks;
- permit capacity savings from time zone and random diversity;
- facilitate the transmission of off-peak energy; and
- provide the flexibility to meet unforeseen demands.

Many variations in possible loads must be taken into consideration in network analyses so that line capacities and network configurations will be selected that will assure stable operation at reasonable cost. In alternating-current networks, short-time overloading is usually permissible if stability is not endangered. In direct-current systems, line capacities are capable of major overloading, but terminal equipment cannot be pressed much beyond the rated capacity even for relatively short periods.

The history of electric utilities showed a steadily increasing availability and reliability of power up until a few years ago. Right now, however, some utilities are operating under near crisis conditions, while many are down to seriously thin reserves. During the peak load season, which comes in summer in many parts of the country, some utilities have found it necessary to cut back on power supplied to individual customers. How did the electric power companies get into this condition? While demand for electric power increased immensely, the building of new facilities was hampered in one way or another. One factor that has slowed the construction of new facilities has been the frequent delay in approval from regulating bodies, largely due to public concern about safety and the environment. Slow delivery is said to be another factor. A third factor has been a succession of breakdowns in generating equipment. The seriousness of these breakdowns is in proportion to the size of the failed equipment, particularly when a single generating unit represents a sizable segment of the capacity of a utility system. It is notable that most of the large units are steam-electric units, which produce four out of every five kilowatt-hours generated.

In previous years, a 200-MW generator was a common size to be installed in a power system. Recently the tendency has been to double that unit size. The possibility of building generating units with capacities of 1600 MW and greater has also been discussed. Technological development has steadily reduced the amount of fuel required to generate a kilowatt-hour of electricity in conventional steam-electric plants. This has encouraged manufacturers to build units of even greater capacity, and confidence in improved reliability of modern materials and techniques has furthered the trend.

The increases in unit size, as well as the trend toward higher transmission voltages, have broadened the opportunities for integration of generation and transmission facilities. By scheduling their new generating capacity to meet their combined load growth, companies within pools that coordinate their expansion are able to install larger and more economical units than they could justify separately. A 1000-MW coal-burning unit should show savings of 20 to 30% in capital costs over a 100-MW unit. The use of larger generating units and the relative flexibility of locating them have also enabled power pools to utilize nuclear plants to advantage where the small independent systems could not. Capital and operating costs of small nuclear power plants are high when compared with those of equivalent steam plants, but the costs fall rapidly with increases in size.

In addition to lowering the cost of producing electricity, large generating units in fully integrated power pools permit each member to reduce the total amount of generating capacity necessary to meet reserve requirements. Reserve generating capacity protects against underestimates of loads and/or breakdown of generating units. Additional reserves may also be needed to cover scheduled maintenance and transmission outages in some cases. By sharing reserves through interconnections, a group of electric companies can reduce the combined reserve needed for unscheduled outages.

The pooling of reserves is based on the same principle as the pooling of risks by insurance companies. The large size of the units increases the value of reserve pooling because each system needs access to a reserve at least as large as its largest unit. As the systems expand and extend their coordination to more systems, the size of a unit or combination of units in relation to the total capacity becomes less, and the proportion of capacity required for reserve is reduced. An FPC analysis indicates that the reserve requirements for forced outages associated with large unit sizes for the year 1980 would be only about 8% of the peak with nationwide pooling of reserves, but this reserve requirement for the same units would be 17% of the peak, or more than twice as great, if the reserves are pooled separately.

However, some engineers have begun to wonder whether the rising incidence of failure is not directly related to the extreme size of generating units. Perhaps the size of these turbine generators has introduced subtle design problems that are not yet completely understood. There are differing opinions among power experts about the sizing of generators in relationship to other characteristics of an individual system or to a power pool. Some feel that no unit should be larger than 10% of the system capacity, while others have suggested that the unit size may be as large as the spinning reserves within the system. Still others suggest that power pooling on a fully integrated and coordinated scale changes the criterion for sizing the generators. Three major factors that may slow the rate of increase in unit size are (1) the decreasing thermal attractiveness of large units, (2) a somewhat decreased economic attractiveness of larger units, and (3) the present lower availability of the existing large units. Operating experience has shown that the unit availability of large generating units with capacities of 400 MW and above has suffered about 4%.

Let's look at the difference between failure of equipment and failure of service. The former is a danger at any time, often greater in the early stages of development of a new technology.

In a well-designed power system, however, the risks of equipment failure should not constitute a jeopardy to continuity of service, because of the safety factors incorporated in the design of the system. Equipment failures occur from time to time in power systems throughout the nation without causing interruption of service. One sizable generating plant failure was the loss of the Tennessee Valley Authority's 1250-MW Paradise Steam Plant in 1964, but strong interties both within the TVA system and with neighboring utilities prevented any interruption of service. The frequency of the system declined by only 0.05 Hz. Usually in such cases all the customer will see is the flicker of his lights.

There are vast differences in the power grids of the nation. Some are designed with such strength as to be virtually invulnerable to any outages, short of catastrophe, while others are linked only loosely. The power companies affected by the Northeast power failure of November 1965 were interconnected, but they were not operated as a fully integrated and coordinated network. Each of the 14 utility companies within the affected area operated its system as a grid of its own with interties to adjoining systems for the principal purpose of exchanging surplus or firm power on a scheduled basis. Interties of this type are the forerunners of more integrated power networks, but during this period of transition, more consideration should be given to the internal strength of adjoining systems and to the magnitude of the interties.

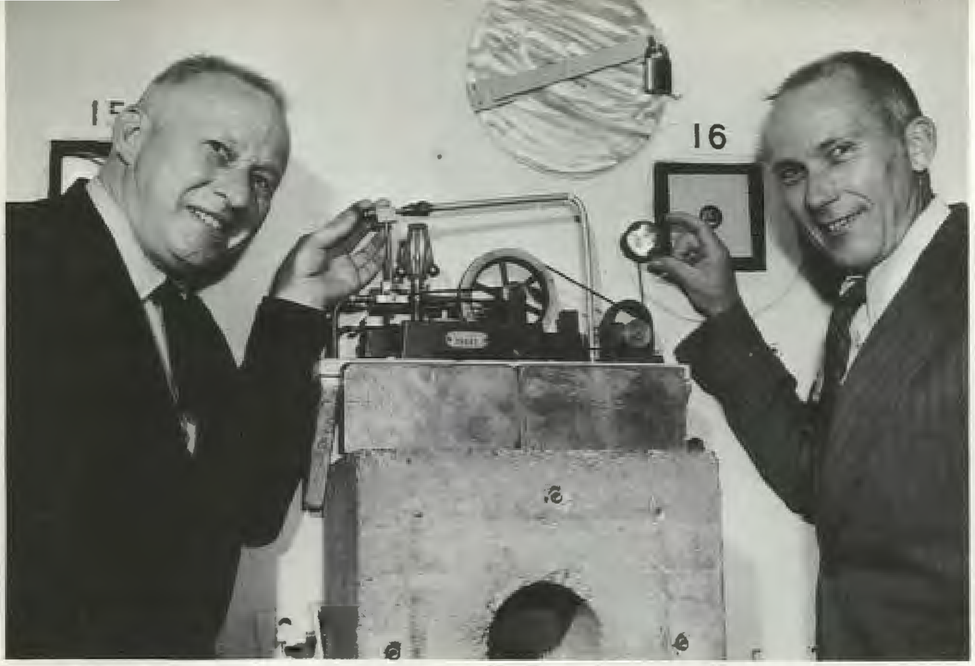
The physical interconnection of adjoining utility companies creates the need for an administrative group that will accept the responsibility of coordinating the planning and operation of the systems involved. It should be noted here that there is no governing body which establishes or enforces rules for power systems and interconnected grid operation. The Federal Power Commission has no specific responsibility for the service of the electric power industry, and it has no licensing or certifying jurisdiction over generating and transmission facilities other than hydroelectric facilities. The commission has established guidelines for the coordinated growth of the electric power industry, but it is limited to encouraging voluntary interconnection programs among utility companies and cannot become involved in appraisals or service reliability or the operation of any system or group of systems. Permanent unified organizations responsible for planning and operating power pools have been set up in some areas of the country. In other areas, informal committees have been entrusted with these responsibilities. It would seem advisable for all individual systems and pools to broaden the scope of their institutional arrangements and establish formal planning and coordinating groups.

Electric energy has become a vital force in the development of our nation and in furthering the welfare of its people. The versatility and acceptability of electric energy have resulted in a doubling of its use every 10 years, with the prospect that such a growth will continue over the next few decades. Meeting of this demand will require that the electric power industry put forth a concentrated effort to overcome the major difficulties confronting it.

The ultimate plan is to provide reliable electric power to the nation's consumers through nine fully integrated power networks. If utility systems are to be developed to take maximum advantage of the economies that full integration can offer in the years ahead, that goal should be accepted by the industry now. Since the electric power industry is composed of hundreds of independent utility systems, the achievement of this goal will require coordination among neighboring systems and groups of systems. This coordination must cover system planning and operation with respect to load diversity, reserve capacity, generator unit sizes, types of units, location of existing and new plants and units, transmission capacity, spinning reserves, peaking sources, and load dispatching and maintenance schedules. Such coordination will provide the nation with a total electric power system with the capability to surmount major emergencies and load shifts and with the flexibility required to meet new power demands.

The industry has taken exceptional steps in the direction of wider coordination. Regional power pools of interconnected utilities have been organized not only for greater economy through the sharing of reserves but to provide more flexibility and reliability by offsetting the difficulties encountered by individual utility systems. However, further interconnection and coordination among systems of existing power pools should not be considered by the industry to be a goal in itself. On the contrary, each investment must be justified by economic considerations such as direct cost savings, improved service, or greater flexibility and reliability.

The history of the electric power industry is one marked by imagination and progress, but only a continued aggressive research and development program directed toward the solution of major technological problems for growth and cooperative planning among all utility companies for reliable service will assure provision of the nation's future electric power demands.



LAB ANECDOTE

0106-72

The Little ENGINE that Could

During the early days of the Manhattan Project, an improvement of one thousand in one year was common. From one microgram of plutonium in 1942 at Berkeley and one milligram in 1943, the Manhattan Project went to one gram in 1944 here in Oak Ridge and a kilogram in 1945 at Hanford. From the West Stands experiment performed by Fermi in 1942 at one-half watt, the Project went to a million watts in 1943 at the Graphite Reactor in Oak Ridge and a hundred times as much in 1944 at Hanford.

The first electric power generation was at five millivolts and ten microwatts delivered by a thermopile in the Oak Ridge Graphite Reactor in 1943; then the Project went to three volts and 300 milliwatts in 1948, to eight thousand volts and five million watts in 1951, to the submarine prototype in 1953, and to a commercial power station in 1957. The "three volt" demonstration of 1948 has not been previously reported, probably because it seemed too trivial and even embarrassing. After all, there was an AEC Commissioner who stated that there would not be one watt of nuclear electric power for 20 years.

In February 1946, C. Rogers McCullough and Eleanor E. Hawk of the Clinton Laboratories (now ORNL) published a one-page diagram of a nuclear reactor driving a turbogenerator to produce useful electrical power. It was an unclassified statement for the press from the Manhattan Project on peaceful uses of nuclear power. Two years later, several members of the Graphite Reactor staff didn't wish to wait for full-scale power and decided to run their own modest experiment. An aluminum boiler with ten uranium slugs was inserted into the reactor, and the steam was taken out by pipe to a small generator of a type usually sold in hobby shops. In August 1948, they produced enough electric power to light up a flashlight bulb for several hours at a time with a calculated system efficiency of two percent. The unpublished report of the test says that "Design and construction of this miniature power plant bypassed most of the difficult engineering problems which have to be solved to make power from atomic fuel both feasible and economical. Solution of the many intricate problems involved is the future goal of the Power Pile Division." This, then, was a low-pressure version of the modern boiling water reactor.

The small generator set was saved by several men close to the reactor operations at ORNL. It is pictured here with Mansell Ramsey (l.) and Charles Cagle, both still at ORNL twenty-three years later, who took a suggestion from Logan Emlet and designed and operated this one-thousandth-horsepower BWR that was "not recommended for commercial use," and is not listed in the AEC's "Chronology of Principal Events in the United States Atomic Energy Program." — Herb Pomerance.

Warren Grimes, director of the Reactor Chemistry Division since its beginning in 1958, has devoted his entire professional life to the U.S. nuclear energy effort. He had received his B.S. in Chemistry at Wabash College and was in his third year of graduate study toward a doctorate in Physical Chemistry at Purdue when he joined the Manhattan Project at Columbia University in 1944. Since then he has performed and directed research and development in a wide variety of aspects of the chemistry of nuclear reactor systems. For the past 15 years his primary interest has been in behavior of molten salts for use in the Molten Salt Reactor Program. Although work on this type of power reactor has been curtailed in the U.S., interest in it is still very much alive in the European power reactor community. Here he recounts some of the contacts he made on a recent trip to countries on both sides of the Iron Curtain.

Molten Salt Development Abroad

A View from Russia and Western Europe

By WARREN GRIMES

As MOST *REVIEW* READERS KNOW, Oak Ridge National Laboratory has been developing molten salt nuclear reactors for more than 20 years. This venture has required us to create a new technology, and it gave us the opportunity to conduct, during many years and with talents from many divisions of the Laboratory, a broad program in molten salt science. ORNL is truly one of the places "where the action is" in this field. But it is not the only one; many laboratories around the world are doing good work in molten salt technology. Since I have been, as an administrator and an occasional contributor, associated with this program throughout its history, I have had several opportunities to visit in some of these laboratories.

Some 18 months ago, I was invited to describe our molten salt reactor program at the Molten Salt Conference sponsored by EUCHEM in France. At the same time, I had the opportunity, through a special invitation from the Ukrainian Academy of Sciences, to visit several research institutes in Kiev and in Moscow. These, in combination with invitations to lecture at other laboratories in the United Kingdom, Germany, the Netherlands, and Sweden, let me spend more than three weeks in a hard look at researches abroad. Mrs. Grimes accompanied me on the entire trip; I am grateful to her for many recollections and impressions of what we saw.

We had several objectives for this trip. Renewing old friendships and enjoying new places were not trivial parts of the agenda. I wanted to learn, if I could, how research is administered in the U.S.S.R., and, of course, I hoped to learn things that could benefit our molten salt program. Finally, I hoped to assess whether molten salt science, which expanded markedly in the middle 1950's and which has flourished since with few if any spectacular technological successes, might be losing its steam. I will try here to hit some high points of the trip, with emphasis on parts of the Russian visit, and to tell some of what I learned.

It became increasingly clear to me that the scientific depression is as widespread and severe in Europe as it is in the U.S.A. At every stop, including those in the U.S.S.R., I learned that budgets were down, that research funds were tight, and that worse was probably to come. I expected to find this at Harwell. I was surprised, however, that scientific austerity prevailed in Germany and Sweden, where — to the casual visitor — business showed every sign of booming. Very hard times had hit the academic scientists in the Netherlands. Those whom I visited in the U.S.S.R. had not had to reduce their technical staffs, but they clearly had no money for equipment (or even for books) from the hard currency countries. Those who had new facilities or equipment told me how fortunate they were not to have to get them in the present financial climate. From the economic point of view much of the trip was depressing.

I realized also that, although news stories should have prepared me, I had grossly underestimated the disruption of scientific effort by militant students in many of the universities. I saw examples of deliberate sabotage of scientific exhibits and equipment at the universities in Karlsruhe and Heidelberg; at the latter, scientists told me that laboratory work was essentially at a standstill. Research laboratories at the University of Amsterdam were locked and guarded, and these precautions had (though those in Germany had not) proved sufficient protection so far. My Russian hosts, in contrast, reported absolutely no such problems and, indeed, seemed to find such items incomprehensible. The situation at Heidelberg was truly frightening.

I should make clear, however, that although the talks I gave at several of these centers were modestly publicized, my seminars and I were in no way picketed, heckled, or otherwise threatened.

AERE, Harwell, United Kingdom

Molten salt researches at Harwell are concerned principally with development of molten chloride fuels for an advanced fast reactor; heat is to be removed by cooling with molten lead mixed directly with the molten salt fuel. The small group (under the direction of Dr. Geoffrey Long, an ORNL alumnus and a friend of many Oak Ridgers) have apparently shown that suitable chloride mixtures exist and that these materials can be effectively freed from the sparingly soluble oxides. They have not, in my view, yet dealt with their most formidable problem, that is, with the simultaneous corrosion of the molten chlorides and molten lead. They have a real and long-range objective (though it is one I feel will be very difficult to accomplish), and they are pursuing it with imagination and zeal.

Nearly all my friends at Harwell wanted to talk about the "Industrial Research Program." I had long discussions of this venture with Dr. Keith Dawson, director of the Applied Chemistry Division. Briefly, Harwell decided about four years ago, in the face of shrinking funds, to encourage a substantial portion of its more energetic staff to invent and develop new products and processes of commercial value. If a new idea seems likely to yield economic or social benefits and to be within Harwell's expertise, a market survey is launched to define the economic potential and to establish which company should be interested. If the company is interested, several kinds of contractual arrangements are possible; in some cases Harwell even assumes part of the development cost and shares in the ultimate profit. A key feature of any such arrangement is that Harwell commits itself to work with the company all the way through to the marketing stage. I was particularly interested to learn that organization of such efforts — whether or not they cross divisional lines — is very much like the ORNL Project system. I found many people who were quite optimistic about prospects for this program and some who were downright appalled by it. It seems safe to say that few people at Harwell are neutral on the subject.

The EUCHEM Conference

The 1970 EUCHEM Conference, organized by the staff at the University of Strasbourg, with Professor J. Brenet as chairman, was held at the Grand Hotel, Les Trois Epis, near Colmar in the Alsace district of France. The nearly 100 participants at the conference came from 14 countries. Eastern Europe (with one Czech and one Russian) was badly under-represented; otherwise the conference seemed reasonably representative of the relative interest in (and degree of funding of) molten salt researches in Europe.

One of the papers that I found truly exciting was presented by L. V. Woodcock, a graduate student with Professor Singer at Royal Hollowell College in the United Kingdom. He had made calculations of the properties of solid and liquid KCl by a Monte Carlo method using 216 particles. Computer analysis of the configuration after every 2,000 individual particle movements yielded radial distribution functions from which he obtained thermodynamic properties for the KCl. Agreement of these calculated values with those obtained by direct experiments on KCl was amazingly good.

My own paper, which led off one of the conference sessions, was well received, and it prompted a spirited question-answer session. (One tends to view such a success as due to one's brilliant delivery, but the fact is that since our reactor is one of the more successful molten salt ventures it provides great stimulation to such meetings. It would really be difficult to lay an egg with that speech.) The conference participants were gratifyingly knowledgeable about our program. They were — as had been evident from private discussions during the week — tremendously interested in, and excited about, our hopes and plans.

Kiev and Moscow, U.S.S.R.

We went to the U.S.S.R. at the invitation of Professor Y. K. Delimarsky on behalf of the Ukrainian Academy of Sciences. Professor Delimarsky, a noted molten salt scientist whom I have known for years, holds a professorship at the University of Kiev, is director of the Institute for General and Inorganic Chemistry in Kiev, and is a senior member of the Ukrainian Academy. During our week-long stay in the U.S.S.R. I was able to visit four institutes, three of which had extensive programs in molten salt technology. Since the most detail I learned was about Professor Delimarsky's Institute, I will describe it and add only general comments about the others.

I need to insert one or two brief notes on the personal side. The trip into Kiev was a memorable experience. The leg from Amsterdam to Warsaw on Air France was routine, but the twin-engine 50-passenger plane (Polish Airline) carried a crew of four with only three passengers from Warsaw to Kiev. Dr. Russ Chernov, Professor Delimarsky's able lieutenant, who speaks excellent English, met us at the Kiev airport bearing a lovely bouquet for Mrs. Grimes. He stayed with us nearly every waking moment during our stay. I am absolutely convinced that he was not assigned to steer or to keep track of us. He stayed with us simply because tourists with little knowledge of the language tend to fare badly in the U.S.S.R. While in Kiev we stayed in the picturesque old Hotel Ukrainia in the central city. We were on the sixth floor in a room with a fine view. (Alas, it is true that the elevators do not always work.) On Sunday, we were shown several churches, historical monuments (including the Gate), the magnificent botanical garden of Kiev, and many fine parks and buildings. We traveled at midweek to Moscow on a very comfortable and fast overnight train, and there we were housed in the new and modern Hotel of the Academy of Sciences. With Dr. Chernov as our guide we made a brief call at the headquarters of the U.S.S.R. Academy of Sciences and then saw all the usual sights, including St. Basil's, the Red Square, the very large new hotels, old churches, some modern downtown areas, and spent nearly two hours at the enormous University of Moscow. I cannot overemphasize how well we were treated, what pleasure they expressed at having American visitors, and how much our hosts everywhere wanted us to like their country.

The Institute of General and Inorganic Chemistry is in the suburbs of Kiev, where six modern buildings in a large park house many of the scientific institutes of Kiev. Professor Delimarsky's institute occupies nearly one-half of one of these buildings. The building is less than three years old, and its exterior is attractive. Unfortunately, the interior design is not particularly efficient, and the structure seems already to be coming unglued.

I was delighted when Professor Delimarsky invited me to compare research management in the U.S.A. and the U.S.S.R. He then began by stating his salary and asking mine. In our considerable discussion of all this it developed that (after allowing for chauffeured limousines, apartment rents, Black Sea vacations, income taxes, insurance, etc.) our salaries were not far from equal. There was no doubt, however, that his research ruble went further than my research dollar, and that this was due primarily to the lower salaries of his people. We did ultimately get to a discussion of research management, and I learned quite a bit about the Institute. Professor Delimarsky does little or no teaching at the University, I gathered, but his institute is responsible for training and thesis direction of graduate students. Insofar as possible, the Institute is also a mission-oriented laboratory; it has responsibilities for direct assistance to Soviet industry, and it conducts researches to develop new or to improve old industrial processes. Delimarsky clearly has a voice in (but not sole control of) choice of the processes to be studied. The Institute has more than 100 researchers, about one-half of whom are graduate students. Nearly one-half of the staff are women (not surprising when one remembers that nearly 90% of the women of Russia hold regular jobs), and the average age was lower than at ORNL.

Professor Delimarsky listed eight sections of his institute, not all of which were working in molten salt chemistry or electrochemistry, and I was able in the time available to visit three. (I have every reason to believe that I would have been shown anything I chose.) I was shown work on aqueous processing of titanium to yield a suitably white TiO_2 paint pigment; in this area they said their technology was much behind ours. The researchers seemed quite knowledgeable in hydrolytic equilibria and were aware of hydrolysis studies by Kurt Kraus and by Charlie Baes of ORNL. I was shown several laboratories in which electrochemical reduction of heavy metals was under study.

I presented a lecture "Molten Fluorides as Nuclear Reactor Fuels" to about 75 people in a moderately good auditorium at Delimarsky's institute. My speech was translated line by line (I had written it out for the translator) to this audience. I had grave misgivings as to its reception in this form, but I need not have worried. A real discussion ensued. It became clear to me that my remarks about lack of appreciable corrosion in the reactor were simply not believed; subsequent discussion revealed the reason for this disbelief. Their fluoride melts, to which they have added relatively impure metal concentrates for electrorefining, are handled in air, and are quite corrosive. I finally (I think) got across my point that our very pure melts in very clean systems with quite inert atmospheres were different.

In Delimarsky's laboratories, as in all others that I visited, I found the science to be sensible and well conducted. Many of the researchers were young, a very high fraction were women, and they all seemed to know what they were doing and why. They seemed to enjoy what they were doing. Equipment seemed adequate, though generally far from lavish, and all was from the U.S.S.R. or Eastern Europe. I can recall essentially no automatic equipment. Surprisingly, I saw (neither in Kiev nor in Moscow) no computer facilities — not even card decks or key punch equipment. I was advised that computational facilities were available, but (insofar as I could see) they were not part of the day-to-day equipment available to most chemical researchers.

Germany, Netherlands, and Sweden

I had a good visit with Professor W. Seelmann-Eggebert, who has charge of most of the nuclear and radiochemistry program of the Nuclear Research Center outside Karlsruhe. Our talk ranged over such diverse topics as molten salt reactors, our wartime experiences in atomic research (he was with Otto Hahn during the war and emigrated to Argentina afterward), research management techniques in the U.S.A. and Germany, and the great changes in the German people during the past 25 years.

Professor E. U. Franck, director of Karlsruhe University's Institute of Physical Chemistry and Electrochemistry, showed me the impressive facilities of what is probably the world's best high pressure laboratory. The apparatus for measuring electrical conductance in molten salts at very high pressures, which was pioneered by Arvin Quist of my ORNL division while on leave with Professor Franck in 1969, was particularly fine.

At Professor W. Sundermeyer's invitation, I spent a day at his Institute for Inorganic Chemistry in the new portion of Heidelberg University. It is primarily devoted to preparation of special compounds using molten salt reaction media at ordinary pressures.

The Electrochemical Laboratory of Amsterdam University, where Professor J. A. Ketelaar and his colleagues have studied fused salts and fuel cells for many years, seemed to me to be doing a fine job with very limited funding. I saw adequate equipment and well conceived studies of molten salt systems, but I gained the distinct impression that this fine institute was badly under-financed, and I wondered if it could long continue as a very high quality research institute. I hope I was mistaken.

The situation was somewhat better at Chalmers Institute in Goteborg in Sweden. Professor Arnold Lunden, an old friend of ORNL, showed me his extremely precise studies of index of refraction and of electrical conductivity in molten salt systems. He has an able program, a strong team of researchers, and (he says) a difficult funding problem.

Summary

What did I get for the taxpayers' money — and some of my own? I couldn't say that I observed any great breakthroughs, though I came home with an idea or two that may still pay off modestly. I saw many old friends and, I hope, made a few new ones. I was reminded again that people are much the same everywhere, and that different systems of government and economics need not be barriers to personal relationships. I had long talks with dedicated people who were struggling with maintaining research quality and staff morale in the face of shrinking budgets — a situation with which I have some experience and for which I have few answers. These are not negligible benefits, and I am grateful for them.

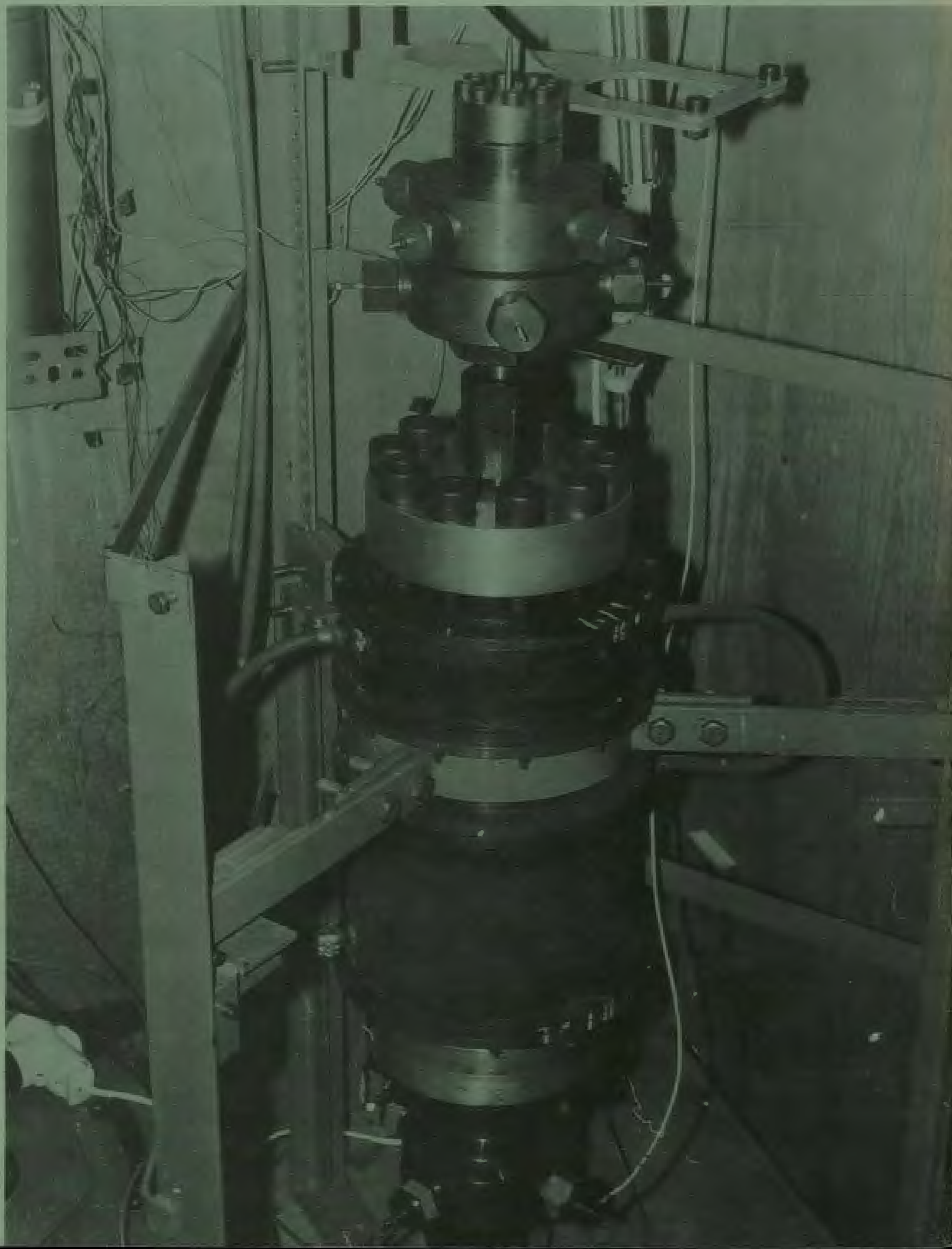
What of the big question? Is the game still viable? I came home feeling better on that score than I had expected. The Russian efforts — which range in quality from adequate to very good — are certainly alive and strong. With specific technological problems to solve, a reasonable mix of basic research with the applied studies, and with graduate students to train in the science, they seem to have a sound situation. In spite of funding problems, molten salt researches in western Europe also seem to be holding up. Even so, I am still convinced that a shot in the arm — the kind provided by some real technological success — may soon be necessary and would certainly be welcome.

On opposite page: Mrs. Grimes, Dr. Russ Chernov, and Prof. Y. A. Delimarsky (l. to r.) at the main entrance of the Institute of General and Inorganic Chemistry in Kiev, of which Prof. Delimarsky is the director. Below: The Institute's imposing exterior.

OAK RIDGE NATIONAL LABORATORY *REVIEW*
P. O. BOX X: OAK RIDGE, TENNESSEE 37830

U.S. Postage
PAID
BULK RATE
Oak Ridge, Tenn.
Permit No. 3

POSTMASTER: DO NOT FORWARD: IF ADDRESSEE HAS MOVED, RETURN TO SENDER IMMEDIATELY. RETURN POSTAGE GUARANTEED.



Molten Salt Development Abroad (page 24). While visiting Prof. E. U. Franck's institute at Karlsruhe, Grimes mentions seeing this unique pressure vessel, designed by ORNL's Arvin Quist, Reactor Chemistry Division, when he was there in 1969. Developed for the purpose of measuring the electrical conductivity of molten salts under pressures as high as 5500 atmospheres, it is the only vessel of its kind to attain such pressure using gas (argon) as its compressor medium.