REVIEW

OAK RIDGE NATIONAL LABORATORY · FALL 74

THE COVER: In a high-contrast crop of the photograph on page 7, the cover of this issue tries to convey the excitement and absorption the MIT graduate engineers feel in the research they perform at ORNL, as well as the admiration and gratitude they inspire in the staff members who oversee their work. The whole story is told by Jeff Tester, beginning on the page opposite.

Editor
BARBARA LYON

Consulting Editor
ALEX ZUCKER

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REVIEW

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OAK RIDGE NATIONAL LABORATORY
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The MIT Chemical Engineering Practice School is an old tradition in Oak Ridge. Alumni can be found at all three of the Nuclear Division installations, and many more have worked here and gone on to advance their careers elsewhere. Jeff Tester, an assistant professor on the Institute's staff, holds the bachelor's and master's degrees in chemical engineering from Cornell, and his doctorate from MIT. He served as director of the Practice School here from 1972 until last spring, when he took leave of absence to work at Los Alamos with the geothermal energy group there. For him it was a return to familiar grounds, as LASL was the scene of his postdoctoral appointment in 1971–1972. As may be discerned from his account of the Practice School here, he sees it as an important contribution to the education of MIT's graduate engineers. The ORNL engineers see it as an important contribution to their programs as well. The students themselves are also enthusiastic, and Jeff's article shows why. He is shown here, left, with William C. Rousseau, visiting professor at MIT, during the latter's recent visit to ORNL.

The MIT Interns

By JEFFERSON W. TESTER

FOR TWENTY-FIVE YEARS NOW, ORNL has contributed to the practical education of a select group of chemical engineers from Massachusetts Institute of Technology. The program offers the students a dynamic challenge to develop their engineering and personal skills while supporting the research effort at the Laboratory. The overall success of the program perhaps is best illustrated by the careers of its former participants. The subsequent achievements of these men and women in industry and academia constitutes an almost overwhelming box score. At present, over 50 Practice School graduates are professors; of these, nine are currently department chairmen at MIT, University of Wisconsin, the University of California at Berkeley, Rutgers University, State University of New York at Buffalo, Cambridge University, Lowell Technological Institute, New Mexico State University, and Colorado State University. Several major oil companies (Standard Oil of Indiana, Imperial Oil of Canada, Atlantic Research), engineering design companies (Halcon International and Bechtel), and chemical companies (Rohm and Haas, Du Pont, Deering-Milliken) have presidents, vice-presidents, or board chairmen who have participated in the Practice School program. In addition, at least 20 graduates have worked for the Nuclear Division of Union Carbide.

Scope of the Practice School

Today, the School of Chemical Engineering Practice is still a key part of MIT's chemical engineering department's graduate program. Students spend one semester each at two field stations, one currently located at the American Cyanamid Company in Bound Brook, New Jersey, and the other at Oak Ridge. The contrast between operations at the two stations is striking. At the Bound Brook station, a student is given intimate exposure to process improvement, economics, and applied chemistry in a profit-motivated organic chemicals manufacturing operation. At Oak Ridge, this is balanced by advanced research and development in a government-sponsored laboratory.

At each of the stations, the student groups operate under the direction of two MIT staff members, using plant facilities as their laboratory. The chief objective of the program is to develop the student's ability to apply engineering principles to the solution of mission-oriented problems. The need to develop this sort of practical expertise is real and it is frequently humorously emphasized. (One program director came upon three of his fledgling students in the laboratory determinedly attempting to adjust the pH of 200 gallons of buffered seawater with a 25-milliliter burette of dilute acid solution; "The pH isn't changing very fast," one of them complained.) In essence, the Practice School is the engineering equivalent of a hospital internship for the young medical graduate. It operates much the same as a small consulting company, working intimately with the ORNL staff on both ongoing and developmental research programs.

In its over 60-year history, the program has been located at 17 different stations. These have ranged widely: a paper plant in Bangor, Maine, a cement factory in Allentown, Pennsylvania, a sugar refinery in Charlestown, Massachusetts, a steel mill in Buffalo, New York, and even an alcohol company in Everett, Massachusetts. Our history in Oak Ridge began in 1948, when Union Carbide first became a sponsor. The school was then located at the Oak Ridge Gaseous Diffusion Plant but served all three of the facilities in Oak Ridge. Since 1953, Alice Maxwell, as full-time secretary, has preserved the continuity of the program. The Practice School left ORGDP in 1962 and was reestablished in 1966 with ORNL as its headquarters.

The annual graduate enrollment in chemical engineering at MIT is over 150. More than half of these students are seeking a master's degree, and out of this half, over 70% will probably elect to attend Practice School in lieu of writing a master's thesis. Participants in the Practice School program are enrolled as full-time students, pay full tuition, and are granted full academic credit by the department.

Operational Format at ORNL

Problem work is assigned by the academic staff, normally one assistant professor and one instructor for a group of from 8 to 15 students. Most of the projects originate from suggestions by members of the technical staff at ORNL. Requirements for problem selection include (1) that the problems be of educational value to the group; (2) that the group be expected to utilize original thought, initiative, and technical judgment; and (3) that the solution to the problem be of practical importance to Oak Ridge National Laboratory. The ORNL staff members who suggested the problem are asked to serve as consultants to the student group. Normally, two to four students are assigned to any given problem for a four-week period, with one member of the group designated as leader.

The leader is responsible for organizing the effort and keeping the project consultant as well as the school staff informed of the group's progress. Although the student team bears the primary responsibility for the solution of the problem, they are expected to draw on the advice of the Practice School staff, the consultants, and operators and technicians in the plants and laboratories. On a weekly basis, one member of the group, not necessarily the leader, gives an oral presentation outlining the progress and future plans for his group. These sessions are attended by all participating students as well as interested consultants and the academic staff. Each group is asked to be critical in judging and redefining its approach to the problem and in analyzing the results. The development of engineering perspective and judgment is paramount since these may all too often be overlooked in formal academic education. At the end of each project, the group writes up the work in

Mottlene Wang, center, demonstrates an isotope leaching test with cement grout for Herschel Godbee and John Moore of Chemical Technology Division, while behind her her colleagues in the experiment, Rober Filiba and Bill Doerr, look on. Doerr is the new Assistant Director.

a report that is distributed to interested laboratory personnel, and the group leader makes a formal oral presentation to the Laboratory. Each student is given a chance to be a group leader.

The Swift Pace

The students work incredibly hard in Practice School, and the statistics are impressive. In the past eight years at ORNL, 230 students produced 194 reports amounting to more than 9600 pages, and in the past 25 years, over 800 reports (more than 30,000 pages) were issued from a total effort of approximately 500 students.

As might be expected, this joint attempt to do competent research and produce a solid report in four short weeks can generate intensive pressure. The students put in many late-night sessions collecting and analyzing data, discussing results, and preparing oral and written reports. But these frantic endeavors have their humorous side too. During the videotaping of a practice session for his oral presentation, one unfortunate student became so rattled he could do nothing but laugh hysterically and plead that the camera be turned off. We were convinced that the student would fall apart completely during the final presentation and were amazed that when the time came, the young man handled himself as coolly as if he'd been trained to the podium. One harried group leader took his responsibility so to heart that he became known as "the Tyrant" to his cohorts and apparently with good reason. One of his group members plotted some crucial data on logarithmic paper instead of semilogarithmic and displayed the results to a gathering of consultants and staff. The young leader stunned the visitors by bursting from his chair, raging, "I am going to kill you! NOW it is definite!" Some of the pressure is released when the students take on the staff and consultants in weekly games of basketball, volleyball, football, or occasionally soccer, or in their climbs up to Mount Le Conte's 6600-ft peak.

Variety of Projects

Problem suggestions are solicited from all divisions of the Laboratory. More than half of them originate in the Chemical Technology and Reactor Divisions, but the range of problem areas has been extremely broad. Projects have been undertaken with Environmental Sciences, Metals and Ceramics, Health Physics, Chemistry, and Biology Divisions as well as the NSF Environmental, Water Research, and Molecular Anatomy Programs. We use Oak Ridge's diversity to enhance the student's experience beyond what he receives on the Cambridge campus, since it is extremely important for engineers to be able to tackle important problems not necessarily in their disciplines.

The Practice School has made continual contributions both to ongoing and frontier-type research programs at the Laboratory. It would be difficult to summarize the entire scope of the school's efforts for the past 25 years, or even its recent 8-year history at ORNL, in a few pages, but in a discussion of my 2 past years some of the flavor should emerge. I have seen a significant change in the nature of the problem work conducted by the School, particularly in supplying new ideas and approaches to areas that are being considered for development at the Laboratory. We have participated in over 40 projects with widespread distribution among the various divisions at ORNL, some of which I mention below.

Chemical Technology

Projects on radioactive waste treatment were undertaken to evaluate ion exchange and evaporation steps in the treatment of low- to intermediate-level liquid wastes. Another project tackled measurement of isotope diffusion under simulated salt mine repository conditions. Working with Herschel Godbee and K. H. Lin in these areas were five MIT students—Clarence Law, Lonnie Rood, Hong Kim, James Isenberg, and James Hildreth. Most recently, one team consisting of Bill Doerr, Mottlene Wang, and Rober Filiba working with John Moore, Herschel Godbee, and Dave Joy considered the development of a new isotope leaching test procedure for evaluating cement grouts. Two others dealt with high-temperature gas reactor fuel problems; specifically, UO^3 dissolution and cation exchange loading rates were examined for both natural and enriched UO^3 powders. This work was done by Mike Chen, Cyril Draffin, and Pablo Ricica with Paul Haas and Karl Notz serving as consultants as part of the HTGR's recent fuel development program in Chem Tech. In the second area, an experimental and theoretical analysis was conducted by James Arquette and Robert Blanchard on a prototype system intended for combustion of spent HTGR graphite core sections. This was part of the head-end reprocessing development work being carried out by Ray Wymer and his group.

Although the Practice School problem work is necessarily short term, we have the advantage of being able to put consecutive teams of students to work on different areas of the same project. Two problems from last year's work illustrate this point. As part of the molten-salt breeder reactor development, the Practice School, in conjunction with Jack Watson and Gene McNeese in Chem Tech, has been carrying on a continuing program of characterizing the hydrodynamics of high-density-difference liquid systems in counter-current flow in packed columns. The pioneering efforts of a half dozen Practice School groups extending back for, say, four years have been directed at correlating hydrodynamic data concerning the flooding and preflooding conditions of packed columns. Also, for a number of years, the Practice School has participated in the program that is characterizing the performance of open bubble columns as a possible method of recovering uranium from the fuel stream of the molten-salt breeder reactor. In this application, fluorine gas, bubbled countercurrently through a downward-flowing molten salt stream, reacts with the UF_4 present in the fuel to form volatile UF_6, which is then recovered from the exiting gas. One problem that became immediately apparent was that neither the hydrodynamically related axial backmixing (dispersion) effects nor mass transfer effects had received detailed treatment in the technical literature. In our early studies we characterized the dispersion hydrodynamic effects under a wide range of conditions. Recently we have attempted to examine mass transfer effects with a simulated liquid-phase controlling system of carbon dioxide and water, and for the first time have critically examined the importance of axial backmixing on the performance of a bubble column with respect to plug flow hydrodynamic conditions. In this area, H. D. Cochran, Jr., Gene McNeese, and Jack Watson have been active consultants.

Environmental

Another area stimulating to the graduate students in the program is the project work with the environmental and ecology groups at the Laboratory. In one such study, Chi Kim and Douglas Carlson worked with John Huckabee and Gordon Blaylock and examined mercury movement in a living aquatic system. They considered the movement of methylmercury in concentrations in the parts-per-trillion range as dispersed in a ⅛-acre pond containing carp, bass, bluegill, gambusia, and a high concentration of zooplankton and other types of aquatic life. The methylmercury contained tracer amounts of the radioisotope ^{203}Hg, which allowed for continuous monitoring of concentration levels in the aquatic life, in the water, and in the bottom sediments. We learned that the direct uptake of methylmercury from the water was much more rapid in the smaller species than the larger fish, suggesting the importance of surface-area-to-volume ratio of the species. Furthermore, some accumulation due to predation was found in the species higher on the food chain. This system was, by its very nature, extremely complex because of the many transfer paths possible for mercury movement, not to mention the difficulty of teaching two inexperienced anglers to catch fish samples for their measurements.

In a second study, suggested by Chuck Coutant and John Huckabee, students Tim Montgomery, Robert Casper, Larry Rosenbaum, and Abdullah El-Twatty examined the movement of mercury under improved conditions in the laboratory. In this case, we singled out a specific type of zooplankton, *Daphnia magna,* and examined the direct uptake of mercury in inorganic form, this time from solutions containing 10 parts per billion as $HgNO_3$, again using ^{203}Hg as a tag. The results in this case were quite conclusive in indicating that the rate of methylmercury uptake was rapid and continuous as long as the concentration levels were maintained. As a corollary, we also examined the temperature profiles and residence time distributions in the discharge channel at the Bull Run Steam Plant. Temperatures as high as 10°C above ambient are common in the discharge channel and can, according to our experimental findings, greatly increase the transfer rate of heavy metals such as mercury by approximately a factor of 2 for every 10°C, at constant mercury concentration of about 10 parts per trillion.

At the solar energy experiment outside the Practice School headquarters in Building 7509 (site of the MSRE), the team that put it together takes a few readings. On the left are, standing, Ray Mayer, outgoing Assistant Director of the Practice School; below him is Jeff Newman; to the right are Robert Orlandi, Bill Doerr, and Christos Demetriou.

Water Research

The Practice School has continued its efforts with Josh Johnson, Bob Minturn, and Art Shor of the Water Research group. In one project Gary Goetz, Les Bauer, and Stellious Demetriou examined the feasibility of a multistage hyperfiltration system involving high-flux cellulose acetate and dynamically formed hydrous zirconium(IV) oxide polyacrylic acid membranes for the desalting of seawater. The basic idea was to use a high-flux cellulose acetate membrane primarily intended for use with brackish water containing approximately 5000 ppm of total dissolved solids (TDS) to treat seawater (about 35,000 ppm TDS) as the first stage of treatment. This would be followed by a second stage using a dynamic membrane module developed by the Water Research group. In another application, Ted Bush, Makota Yonezawa, Jerry Toman, and Eric Suuberg considered using dynamic membranes for the treatment of textile dyeing effluent. Dynamic membrane systems should be advantageous in processing dye waste in concentrations of anywhere from 1000 to 16,000 ppm TDS over hollow fiber or spiral wound cellulose acetate membranes because of (1) their higher flux capacity (up to 150 gallons per square foot per day versus 1 to 20 gallons per square foot per day for commercially available cellulose acetate modules); (2) their stability at temperatures up to 100°C or so, which permits treatment and reuse of process water; and (3) the fact that *in situ* membrane regeneration is possible, thus reducing the permanent effects of fouling, which are often present with cellulose acetate hollow fiber systems. In addition to this hyperfiltration work, we have undertaken several studies involving possible applications for crossflow filtration. In one such study, the treatment of primary sewage effluent at the ORNL sewage treatment plant was considered by a team of four students. Steve Murtha, Jeffrey Newman, Rober Filiba, and Robert Orlandi successfully operated the pilot plant for extended periods and demonstrated that adequate backwashing could be maintained without risking flux decline or product quality.

Metals and Ceramics

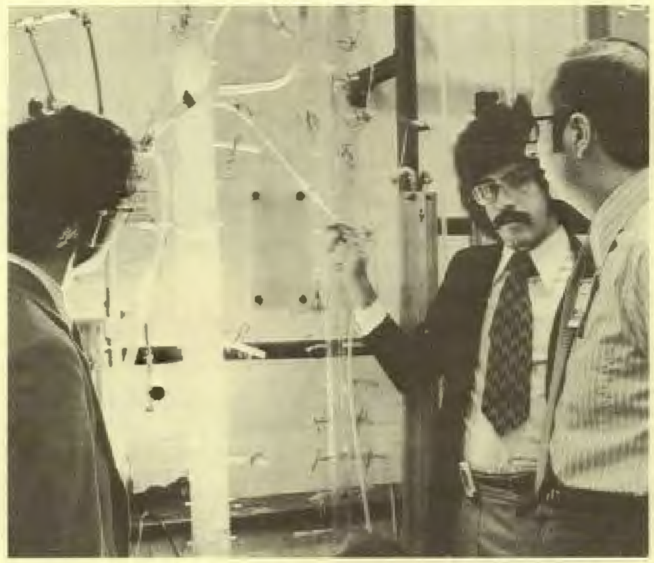
We have recently increased our participation with the Metals and Ceramics Division through a number of projects ranging from localized corrosion research to studies of radiation damage effects in several materials. Four Practice School teams involving 11 students have worked with H. S. Isaacs in an attempt to characterize the fundamental mechanisms that might apply to pitting corrosion under a variety of conditions for both stainless steel and nickel. The importance of a concentration driving force for mass transfer, the presence of nonhalide anions, and the chloride activity has been quantitatively verified by experiments and by a proposed mass transfer model. In our radiation damage work, we used a characteristic of most young engineers—their great versatility with computer programming—in two separate but related studies. Douglas Carlson and Hong Kim modeled helium bubble growth during neutron bombardment of an austenitic stainless steel, and Les Bauer and Stella Jones examined the kinetics of radiation-induced void growth in similar materials under neutron bombardment. In another project, Clarence Law and Raymond Mayer proposed a liquid-metal heat pipe design suitable for maintaining high-temperature isothermal conditions necessary to the long-term creep rupture testing program for LMFBR materials evaluation. These projects were carried out with Ev Bloom, Jim Stiegler, Jim Leitnaker, William Martin, Jack DeVan, and Dave Lloyd serving as consultants. Corrosion and radiation damage studies make direct contributions to both the liquid metal fast breeder reactor and controlled thermonuclear reactor programs. Consequently, we can use the projects as a way of introducing chemical engineers to problems that are extremely important to the success of both programs.

Biology

Another area that has been of considerable interest to our graduate students is the Molecular Anatomy Program under the direction of Norman Anderson, John Eveleigh, and associates. In one study, James Hildreth and Kavas Petigara attempted to optimize a proposed antigen-antibody separation by affinity chromatography. In the cases examined, antibody proteins were immobilized on a matrix consisting of Sepharose 4B, a cross-linked beaded dextran, activated with cyanogen bromide. In the two studies that followed this work, an alternative immobilization scheme was considered, involving polymerizing either antigens or antibodies in a polyacrylamide matrix. These studies determined the polyacrylamide gel's capacity for protein as well as the immunological activity of the immobilized antibody or antigen. In their work in this area, the students applied theoretical principles obtained both in polymer chemistry courses and in basic chemical engineering courses that deal with specific absorption phenomena.

Energy

At this time of fuel crises, projects relating to energy resources are particularly significant. I believe one of the strengths of the Practice School was illustrated very nicely in some of our most recent project work beginning in the fall of 1973. As ORNL becomes active in the energy R and D area, the Practice School can supply talent and ideas during the pioneering phases. We have been involved primarily in four areas. In one study, Elsa Kam-Lum, Bulent Eczacibasi, Kevin O'Neill, and Larry Krussel examined both the kinetic and thermodynamic aspects of hydrogen production by an enzyme-catalyzed cyclic process being considered by C. D. Scott and B. Zane Egan of the Chemical Technology Division. In another project, A. P. Fraas of the Reactor Division suggested that the Practice School build and characterize the performance of a cylindrical parabolic focusing solar energy collector for use in Oak Ridge. The project was successful and will lead to future work in this and related areas. In particular, we plan to continue the characterization of the focusing system and have built a flat plate collector system to be run simultaneously with the focusing system for comparison purposes under a wide range of sky conditions for the Oak Ridge area. These data should be useful in considering the possibility of utilizing solar energy for heating and air conditioning for the new Environmental Sciences building under consideration at ORNL. The third area again represents an innovative effort suggested by the Cold Vapor Technology group of the Reactor Division, which includes R. N. Lyon, S. L. Milora, and L. C. Fuller. We have considered various energy conversion schemes for extracting an optimal amount of energy from such low-temperature heat sources as geothermal, gas turbine, waste heat, sea thermal, solar, and related sources. Gary Goetz, working with Eric Hirst in the ORNL-NSF Environmental Program, examined energy use patterns in U.S. manufacturing industries for the period 1950 to 1970. Although this was purely a paper study, it provided valuable information in the area of energy supply and demand that should enable energy suppliers in the petroleum/coal utility industry to project future energy requirements and to plan future capacities. Local planners can benefit by utilizing this information in assessing the energy of an industry wishing to locate in a given area.



Mike Holtz and Alex Grauer, l to r, go over the fine points of an experiment on mass transfer between liquid and gas in open bubble columns for Jack Watson of Chemical Technology. The experiment, although originally for the Molten Salt Reactor Experiment, proved to be so basic to other phases of chemical engineering that it was continued even after the MSRE was closed. Now, of course, it is germane to the reactivated Molten Salt Breeder Program.

I hope I have done justice here to the contributions that the MIT student groups have made and the exposure they have received to a number of different scientific areas, important both to them and to ORNL. The facts are that over 50 technical publications and several patents have resulted directly from Practice School work. I would like to emphasize that the lifeline of the Practice School is maintained in the problems suggested by the entire Laboratory. Without constant interaction among the consultants on the projects, the student groups, and the MIT staff, the program could not continue. In a testimonial to its success, one MIT alumnus affirmed, "Such an exacting regimen represents training for leadership which, to my knowledge, is not equaled in breadth or depth at other educational institutions. It would be difficult, if not impossible, to devise a more intimate and mutually profitable contact between industry and education."

BOOKS

By EUGENE EICHLER

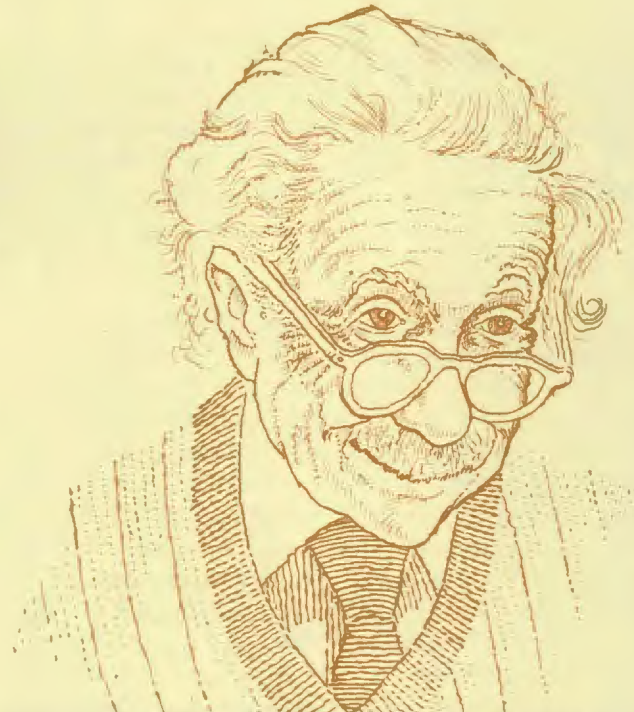
"Einstein" by Jeremy Bernstein in the Modern Masters series, Frank Kermode, ed. Viking Press, New York (1973), 242 + xii pages, $6.95

GROWING UP IN THE 1930's in a small midwestern industrial town, I developed a brilliant array of heroes. The list included many baseball players, lots of radio serial stars, several aviators, and, finally, one scientist—Albert Einstein. Any discussion with my buddies of a subject even vaguely scientific led unerringly to the ritualistic recital of the credo: "Only five people in the whole world understand Einstein's theory of relativity!"

Jeremy Bernstein's "Einstein" is designed for a hero-worshiper like me. It is a compassionate and admiring book—highly anecdotal, with the two themes of life story and the birth of modern physics neatly intertwined. Bernstein packs an incredible amount of information into a little book. With a style that is almost conversational, he rarely resists the temptation to divert to an appropriate story about Einstein and one of his contemporaries—even the bibliography contains an anecdote.

The organization of the book is a curious one. It is divided into three parts, each headed by a preamble. After the preamble that touches on Einstein's later years, Part I sketches Einstein's youth, traces the history of classical physics through the Michelson-Morley experiment, and then describes the consequences of the 1905 paper on special relativity.

The preamble to Part II, though mainly concerned with Einstein's life through his tenure in



the Swiss patent office, gives a vivid description of the Einstein personality as manifested throughout his life. In the body of this section, Bernstein deals with the reactions of Lorentz and Poincaré to the special theory and the mass-energy equivalence.

He traces the contributions of Minkowski and Mach to Einstein's magnum opus—the 1916 paper on the general theory of relativity. With the aid of the gravitational light-bending observation, Bernstein gives a lucid word description of the general theory and finally discusses the cosmological consequences of the new theory.

In the preamble to Part III, Bernstein indulges in another time transformation—he gives us Isaac Newton as a contrast to Einstein. This final section then describes Einstein's contributions to the quantum theory—first his explanation of the Brownian movement and then the photoelectric effect. Then follows a brief recounting of Einstein's refusal to abandon the world of determinism for the Heisenberg uncertainty principle. The final section details the role Einstein played in alerting the U.S. Government to the dangers of possible German atomic bomb development, thus setting in motion the Manhattan Project.

Although Bernstein faithfully records the well-known and standard facts of Einstein's career—the job in the Berne patent office, the slow but sure climb up the academic ladder after his publication splurge of 1905, and his rocketing fame when the gravitational light-bending prediction was confirmed by Eddington—the strength and charm of the book lie in its less familiar insights and stories.

I will give a random sampling.

It is certainly customary to think of Einstein as one of the titans of modern physics, but this slight book reminds us that Einstein's life (1879-1955) and career covered the complete revolution in science from the emergence of the atom at the turn of the century to the "nuclear age." Though a champion of change in physics, he had some difficulty leaving the economic world of the 19th century. When in 1933 he became the first professor of the newly founded Institute for Advanced Study in Princeton he was asked to name his salary. Einstein thought $3,000 a year would be reasonable; he actually received $16,000.

AMAZEMENT, DEEP AND THOROUGH AMAZEMENT, is the only response to the story of the 1905 paper on the special theory of relativity. A 26-year-old physicist, an indifferent product of the Zurich Polytechnic, a simple clerk at the Berne patent office, with little access to the scientific literature, destroyed in a single blow the concepts of space and time that had come down through the years from the all-knowing Sir Isaac Newton. Perhaps his station in life, his separation from the scientific mainstream, his very personality—questioning, rebellious—cast him in the role of iconoclast. But most astonishing of all is the casual confidence borne by Einstein in his joust with the fundamentals of physics.

The scientific world was in a turmoil over the famous Michelson-Morley experiment, which had been devised—and a new powerful instrument, the interferometer, invented—to prove the existence of the "ether." The "ether," for those too young to remember, was a mysterious construct dreamed up by 19th century scientists to explain propagation of electromagnetic waves—especially in a vacuum. The all-pervasive ether was the stuff that oscillated!

But if the ether was truly there, the Michelson-Morley experiment with exquisite sensitivity would detect it. Embarrassingly it failed (although, of course, it triumphed). Michelson was deeply disappointed; he made no mention of the result in his Nobel Prize lecture in 1907 (two years after Einstein had deeply interred the ether). Lorentz, Poincaré, and others struggled to explain the interferometer result and save the ether with spatial contractions. Einstein could break cleanly with the past by stating flatly in the introduction to the special relativity paper:

"The introduction of the luminiferous ether will prove to be superfluous inasmuch as the view here to be developed will not require an 'absolutely stationary space.' "

He alludes in passing to the class of unsuccessful attempts to detect motion of the earth relative to the "light medium" with no specific reference to Michelson. (In fact, the paper has no reference at all.)

When asked about this matter late in his life, Einstein responded:

"In my own development Michelson's result has not had a considerable influence. I even do not remember if I knew of it at all when I wrote my first paper on the subject (1905). The explanation is that I was, for general reasons, firmly convinced that there does not exist absolute motion and my problem was only how this could be reconciled with our knowledge of electro-dynamics. One can therefore understand why in my personal struggle Michelson's experiment played no role or at least no decisive role."

Curiously, in his April 1974 *Physics Today* article on Michelson, R. S. Shankland extracts a laudatory quote from Einstein that seems to give a great deal of credit for the relativity theory to the Michelson experiment, in sharp constrast with the Bernstein scenario.

Bernstein returns often to consider the creative process and to the part played by experimental results. On the one hand Einstein—like all great theorists—was guided by the state of nature known from observed quantities. But the successful geniuses first winnow through the "facts," rejecting the irrelevant. Then comes the leap into the unknown. "Creative thinking" Bernstein calls it. Einstein actually labored over the question of moving bodies from the age of 16, when he considered that in the Newtonian view an observer moving at the velocity of light would not observe the wave motion of a light ray. His tussle with this dilemma went on as a background to his checkered academic and early employment careers. When the inspiration came, the denouement was rapid. The final calculations and the writing of the 30-page paper took six weeks. The details of what tipped the scales—Einstein had considered a variety of solutions, including some utilizing the ether—remain clothed in mystery. Einstein himself recalled only the clear logical path to the "right" answer. What we glean from this is the vital part played by intuition in all scientific work.

Two aspects of Einstein's life seem to have been in conflict. They are on the one hand his personality: that of a warm, jolly, even convivial person—solitary only because of his unwanted fame. In short, he was a "beautiful" person in the 70's parlance. In opposition to this seems to be his stubborn—some thought, pigheaded—refusal to accept the uncertainty principle of quantum mechanics.

Let us consider first Einstein's demeanor. Bernstein has sprinkled his little book abundantly with examples of Einstein's warm-hearted nature, but he concentrates on this aspect in the preamble to Part II—the picture of a simple, direct man who "behaved the same way to everybody, leading officials of the university or the scrubwoman in the laboratory" and who loved to tell and hear jokes. His laughter seems to have been spectacular, a unique thing to observe. Take the report of Abraham Pais, a colleague at Princeton:

"We discussed physics; very often it concerned the foundations of quantum mechanics. On a number of occasions Gödel, the logician, would join. Even though there was not much of an agreement, I would always come away feeling better for these talks. On one occasion I told Einstein a joke to which he responded with one of the most extraordinary kinds of laughter I have ever heard, then or since. It was rather like the barking of a seal. It was a happy laughter. From that time on, I would save a good story for our next meeting, for the sheer pleasure of Einstein's laugh, which would light up his face and make him look almost like a boy enjoying a good prank."

TURNING TO THE UNCERTAINTY CONTROVERSY, we should not lose sight of Einstein's many contributions to the development of quantum mechanics. But it was his unswerving assertion that:

"Quantum mechanics demands serious attention. But an inner voice tells me that this is not the true Jacob. The theory accomplishes a lot, but it does not bring us close to the secrets of the Old One. In any case, I am convinced that He does not play dice."

Einstein's rejection stunned and saddened many of his colleagues, who expected more of a community spirit from him. In truth he was being fully consistent with the questioning nature he manifested in his earliest work. His intuition told him there must be something more, that probabilistic descriptions, although confirmed by experiment, were only the overlay of an as-yet indiscernible deterministic universe.

There was never a note of bitterness in the struggle. The arguments with Niels Bohr and his associates took the form of thought experiments that Einstein proposed that would disprove uncertainty. During the Solway Conference of 1930, Einstein came up with his ultimate mental mechanical marvel—an imaginary box filled with clocks, doors, scales, and springs. Bohr feared he had been defeated and agonized with his colleagues the entire night till they found the solution—the uncertainty principle was secure. To commemorate this crucial battle the Copenhagen group presented Einstein with a polished wooden model of his *Gedankenexperiment.*

I hope that these examples have whetted the reader's appetite for this tasty little book. It is not faultless. I would have liked some simple diagrams to aid in the technical discussions, a few pictures of Einstein spaced throughout his life, or perhaps the official photos of the Solway Conferences, those unbelievable collections of all of modern physics in one small rectangle. These are minor matters, for most important, you feel that Bernstein has captured the essential man.

There are two other books on Einstein—one published in 1971 by R. W. Clark and a very recent one by Hoffman and Dukas. The Clark book is a full-blown comprehensive biography by a nonscientist—from all reports thorough but weak on the human side. Since Banesh Hoffman is an excellent science writer, who did collaborate briefly with Einstein, and Helen Dukas was Einstein's secretary for 27 years, one can expect from them a new and authentic view of the man whom C. P. Snow described thus:

"Einstein was the greatest mind of this century, and one of the three or four greatest in the history of human thought. He was much more. He was a man of the loftiest moral stature. I have said before, and I say again, that, after having met a number of men whom the world reveres, I found him by far the most impressive. He was also, in some respects, the most different in kind from other men. He was unassuming. He could be, even when Nazism was pressing upon him, jolly and rollicking: but in the grave moments, it was something like meeting the Second Isaiah."

Klaus Becker has taken a keen interest in archaeological findings in Central and South America. He examines here a replica of an antique mask, a common tourist item in many of the countries south of the States. He points out in this article that the principle he has been employing in his dosimetry development at ORNL is very useful in the determination of the age of old and not-so-old artifacts.

A Glow from the Distant Past

Thermoluminescence in Ancient Pottery

By KLAUS BECKER

INTEREST in a little-known scientific technique is shared these days by peasants in remote villages of Mexico and Egypt, by archaelogists, art dealers, and museum directors all over the world, and by solid-state dosimetrists in about a dozen laboratories in England, Denmark, and the U.S. The technique is the authentication or dating of ancient pottery by the thermoluminescence method. Although I have followed the progress made in this exciting field for many years, particularly that of Martin Aitken and his group at Oxford, my own involvement only began last year during the three-week vacation period I spent teaching at the National University (UNAM) in Mexico City. Following this visit, Augusto Moreno of the Physics Department of UNAM spent two months with our group at the ORNL Health Physics Division. The famous

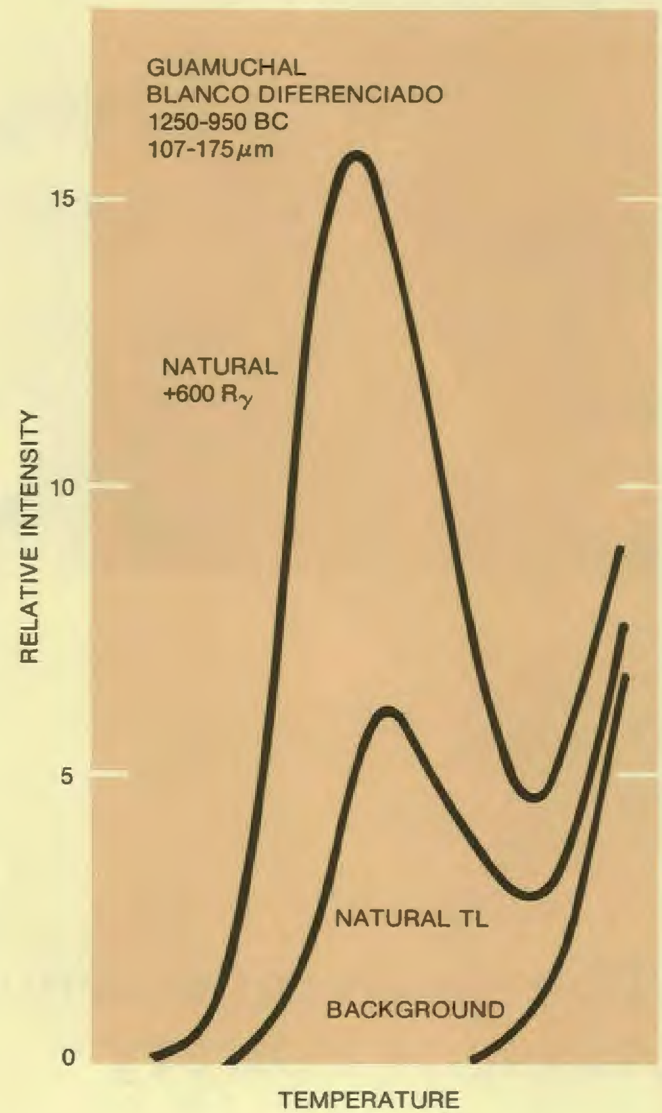
National Museum of Anthropology in Mexico as well as friendly neighbors in Oak Ridge provided us with a variety of samples, some unquestionably authentic and others of dubious antiquity. The results represent one of the more amusing spin-offs of our solid-state dosimetry research efforts.

Pottery (most frequently just potsherds from short-lived containers for liquids and food) is the most abundant of the lasting relics of preindustrial man's activities. Ceramics have also served since prehistoric times as ritual objects, such as urns or statues of deities, and have always been one of man's favorite means of artistic expression. Beautiful ancient vases or statues were already highly treasured in antiquity, and the temptation to fake them is by no means new. For example, Kuan Wares of the Sung period were widely copied in 18th century China, and these copies are now very valuable in their own right.

It is, therefore, not easy to define a forgery. Beautiful objects in the ancient style were still made by Indians in remote areas of Mesoamerica long after the conquest. They may possess the same intrinsic artistic and historic value which the truly pre-Columbian artifacts have. If, on the other hand, a whole modern village in Mexico or Guatemala is now in the business of mass-producing "pre-Columbian" pottery for the tourist market, the value of such forgeries is obviously small—even if the use of ancient molds, of the same clay and firing techniques, and careful aging by impregnation with urine and burying makes them virtually indistinguishable from old objects, by chemical, mineralogical, microscopic, or stylistic analysis.

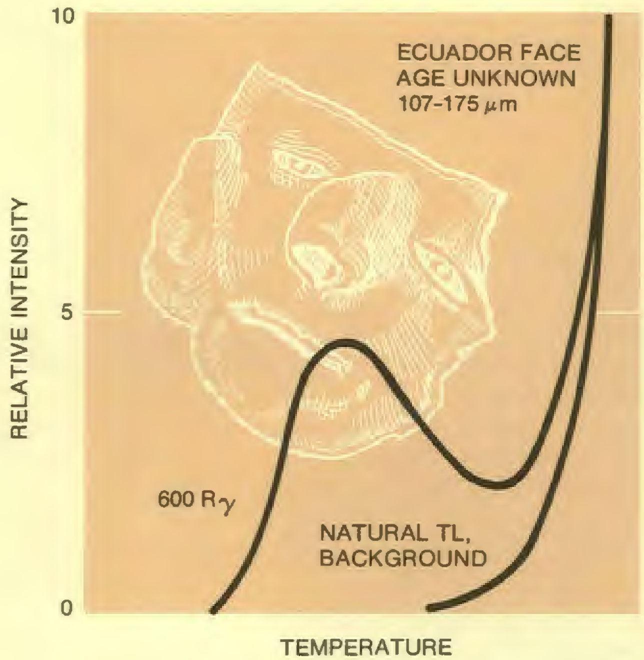
Prices of ancient art increase even faster than those for everything else. Just recently, two beautiful pieces of ancient pottery, the controversial Euphronius crater now in the Metropolitan Museum in New York and a Chinese vase in London, changed hands for one million dollars each. Such objects become in many countries national treasures of the highest importance. Their theft or smuggling out of the country constitutes a major crime, often with diplomatic repercussions. With the demand by museums and private collectors already high, and going higher, it is not surprising that estimates for the percentage of fakes on, for example, the Mesoamerican art market range as high as 80%. Governments have been known to be lenient in prosecuting the fakers or dealers in such faked art. In many cases this may be because of outdated laws or inefficient law enforcement, but perhaps it is also because they feel that it helps to protect the real treasures of their national heritage from disappearing.

The first heating of large quartz grains from a 3000-year-old pottery sample to about 400°C produces a strong thermoluminescence light signal at about 350°C due to the accumulated radiation dose. This is compared for calibration purposes with the signal produced by a recent irradiation to a known gamma-radiation dose.



In this situation, a relatively simple method for testing the authenticity of an art object is of great interest to everybody involved. It was first pointed out almost 20 years ago that measuring the radiation-induced thermoluminescence (TL) signal that had accumulated in quartz, feldspar, or

The absence of a natural "ancient" thermoluminescence signal in a supposedly pre-Columbian artifact indicates that it is clearly a recent forgery. By comparison, the calibration dose produces a strong signal.



other constituents of a ceramic piece since its manufacture provided such a method. Its principle is simple: Over geological periods of time, the mineral constituents of clay have been exposed to a high integrated radiation dose caused by cosmic radiation and radioactive materials in the soil. A small percentage of this radiation, stored in the crystals, can be released in the form of visible light by heating. The amount of TL is usually proportional to the accumulated radiation dose.

This internal clock is zeroed by the firing temperatures, about 800°C, necessary to the artifact's manufacture. Subsequent to this time zero, it resumes its accumulation of radiation. By heating and measuring the TL signal with a photomultiplier, the length of time since firing can be determined if the background radiation level is known.

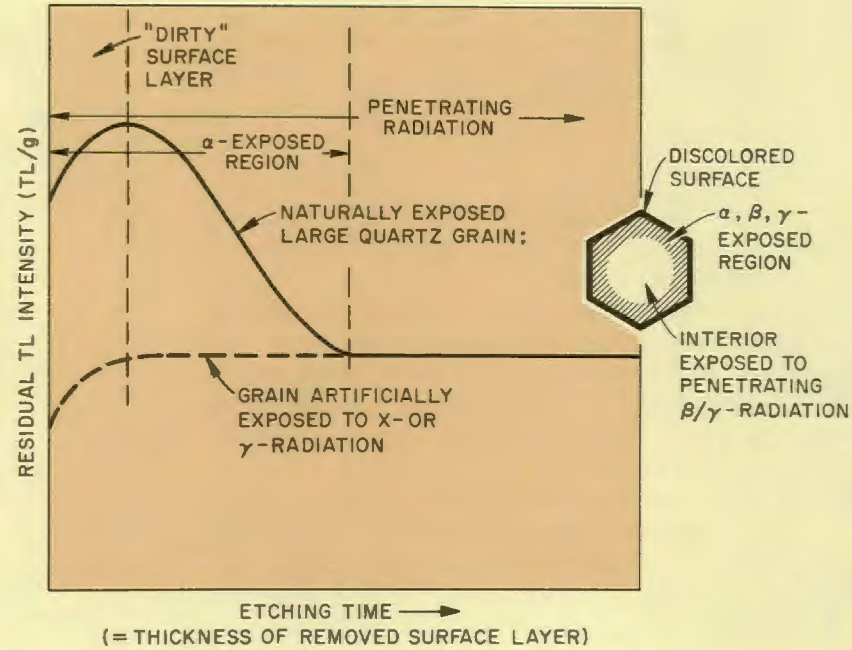
Of course, in practice the method is more complicated, and many potentially disturbing factors have to be dealt with. For example, thermal fading of the TL signal is in some samples more pronounced than in others; visible light bleaches the signal and has to be excluded by discarding the material from the surface of samples (our lab is, when working with light-sensitive samples, also known in Building 7710 as "the red light district"); and even traces of oxygen in the atmosphere surrounding a sample during heating produce strong spurious signals. Nevertheless, dating accuracies of 5 to 10% have been obtained, which in many cases compare favorably with ^{14}C and other "absolute" dating methods.

Much easier than the actual dating is the testing of a sample's authenticity. This normally implies only finding out whether it is a few years or many centuries old; in other words, whether there is a strong or a very weak light emission. For this test, we first crush a few hundred milligrams of the pottery and isolate the larger (0.1 to 0.2 mm) quartz crystals by mechanical and magnetic separation, etch with hydrofluoric acid, and wash. Part of the crystals are irradiated with a known radiation dose, for calibration. For the TL measurement, we are the first to use a commercial TL dosimeter reader instead of the more complex and expensive devices used in other laboratories.

In a pottery fragment known to be about 3000 years old, for instance, there was a strong "ancient" TL peak. On the other hand, in tests performed on a fragment of a small mask which I had picked up in a shop in Quito, Ecuador, a few years ago, the total absence of an ancient TL signal indicated clearly that it is a recent fake, as were some of the statues from the collections of my neighbors.

However, the situation is not always that simple. For example, refiring of an ancient sample, which is occasionally done for repair purposes, would make it appear recent. On the other hand, sophisticated fakers could try to simulate old age by external irradiation with the proper dose of x or gamma radiation. Although we have not yet any evidence that this is actually done, there is at least one trick we could employ to detect such attempts.

It is based on the fact that the distribution of the radiation dose throughout an "old" quartz grain is not homogeneous. If the grain is "peeled" by fractionated etching with hydrofluoric acid, the TL signal first increases due to the removal of a light-absorbing dirty surface layer. Then it decreases because those parts of the quartz crystal are removed that had been exposed to short-range alpha radiation from the uranium and thorium decay chains in the fine-grained clay matrix. (Natural quartz itself contains virtually no radioactivity.) If, however, the grain has been exposed to penetrating radiation throughout, there will only be an increase, no decrease. An ul-



"Peeling" of a quartz grain by etching with hydrofluoric acid reveals that the TL light signal varies as a function of depth in old samples because only the surface layer is exposed to nonpenetrating alpha radiation. In a sample artificially exposed to external penetrating radiation, the dose distribution in the grain is uniform once a surface "dirt" layer has been removed.

trasophisticated faker may, of course, consider exposing his specimen to radon gas in order to beat even this method, but it is less likely that he has access to the necessary equipment and know-how.

But what has all this to do with Health Physics? One of the reasons why we spend even the slight amount of time we do on this topic is the recent interest in the environmental monitoring of low dose levels around nuclear facilities. It is known that the background radiation level varies substantially as a function of the time of day, the soil humidity, snow cover, solar cycle, etc.; little is known, however, about long-term averages against which recent natural or man-caused variations should be measured. We believe that we can, with samples of well-established age, taken from different locations, use the TL signal from the interior of large quartz grains to establish values for the penetrating radiation component averaged over hundreds or thousands of years. For example, the dose rate in Aquiles Serdan, a site in the province of Chiapas, Mexico, was thus measured to average about 117 mR per year over the last 3000 years.

And so, from the need to protect national collections from fakes and forgeries has evolved a possible method for assessing the radiation increment in the neighborhood of nuclear facilities.

Staff quote:

"IDA-72 stands for isotope dilution analysis experiment initiated in 1972 for the purpose of testing internationally the possibilities of using isotope dilution mass spectrometry techniques as a means of safeguarding uranium and plutonium on an international basis. ORNL's participation in the IDA-72 exercise was at the invitation and expense of the U.S. Arms Control and Disarmament Agency (ACDA). The reasons for this are that the Mass Spectrometry Group in the Analytical Chemistry Division at ORNL is recognized internationally and is viewed as a model mass spectrometry laboratory, and because of this distinction, other laboratories are encouraged to upgrade their mass spectrometry facilities and capabilities. Our two- and three-stage mass spectrometers, with their high abundance sensitivities and ion counting detection systems, can analyze nanogram-size samples compared to microgram size for most other MS labs."—Joel Carter, Analytical Chemistry Division, describing his participation in the IDA-72 meeting at Karlsruhe, Germany, early this year.

Awards and Appointments

Listed in this new department will be awards, appointments to scientific review and advisory committees of national significance, fellowships in societies, honorary degrees, and other ways in which members of the ORNL staff have achieved recognition. It is predictable and regrettable that names will be omitted, but with the cooperation of the Laboratory staff and management we will try to keep omissions to a minimum. Please inform the Review office of possible entries for this department.

Deputy Director **Floyd Culler** has been appointed, by election of the Board of Governors, to membership on the Scientific Advisory Committee to the International Atomic Energy Agency, where he will represent the U.S.A. He was also elected to membership this year in the National Academy of Engineering. And during the observance of National Engineers' Week, the Engineering and Technical Community of Oak Ridge, comprising the local chapters of 16 technical societies, cited him for its Outstanding Achievement Award. The citation bears the signatures of R. J. Hart, manager of AEC-ORO, A. J. Wagner, chairman of TVA, and Dixy Lee Ray, chairman of USAEC.

At the 1974 Pittsburgh Diffraction Conference, affiliated with the American Crystallographic Association, this year's Sidhu Award, given each year to a physicist under the age of 33 for having shown excellence in diffraction research, was bestowed on **Bennett C. Larson.**

Clifford A. Burchsted received the 1974 Seligman Award for outstanding service in the field of environmental sciences from the Institute of Environmental Sciences.

At the 1974 meeting of the American Society for Metals, the Henry Marion Howe Medal, for the best paper delivered at the 1973 meeting, was awarded to **Gregory J. Yurek.**

Natalie E. Tarr received the Health Physics Society's Meritorious Performance Award at the annual meeting last July for her outstanding services to the society's journal and editorial office.

In the 16th Annual Industrial Film Awards Competition, sponsored by *Industrial Photography*, ORNL's entry, *The Bioengineers*, produced by **Fleming Reeder** and **Edward R. Matney,** was the only film to win two awards: first place in the Research and Development category, and the Angenieux Award for Best Creative Cinematography. The film was also honored by being selected for viewing at the Sixth International Scientific Film Festival at Rio de Janeiro this year.

The last two recipients of the E. O. Lawrence Award are now on the staff of ORNL: in addition to 1973's winner, **James R. Weir, Jr.,** the new Associate Director, **Chester R. Richmond,** comes with the 1974 medal, awarded to him while he was still at LASL.

Newly elected fellows: in the American Nuclear Society, **Franklin T. Binford, James A. Cox, Jack E. Cunningham, E. P. Epler;** in the American Physical Society, **Joseph B. McGrory, Russell L. Robinson;** in the American Society for Metals, **James R. Weir, Jr., Robert Gray.**

NASA bestowed its Public Service Group Achievement Award, for outstanding contribution to the timely design, development, and manufacture of the radioisotopic thermoelectric generators that provided the power source in the Pioneer 10 mission to Jupiter, to the Pioneer 10 Radioisotopic Thermoelectric Generator Contractor Team, ORNL members of which were: **Henry Inouye, Chain-Tsuan Liu, Richard E. Pawel, Ernest L. Long, Jr., R. W. Knight, Harrel E. Reesor, Herbert McCoy, Jr., Bennie McNabb, Jr., Claude M. Benge, Ralph L. Clark, Ralph G. Donnelly.**

Honorary degrees: **Percy A. Staats,** D.Sc. from Fisk University, for his outstanding services to the Infrared Spectroscopy Institute; **Donald B. Trauger,** D.Sc. from Nebraska Wesleyan University, for his "outstanding achievements as scientist, administrator, and community and church leader, which reflect with distinction on Nebraska Wesleyan University."

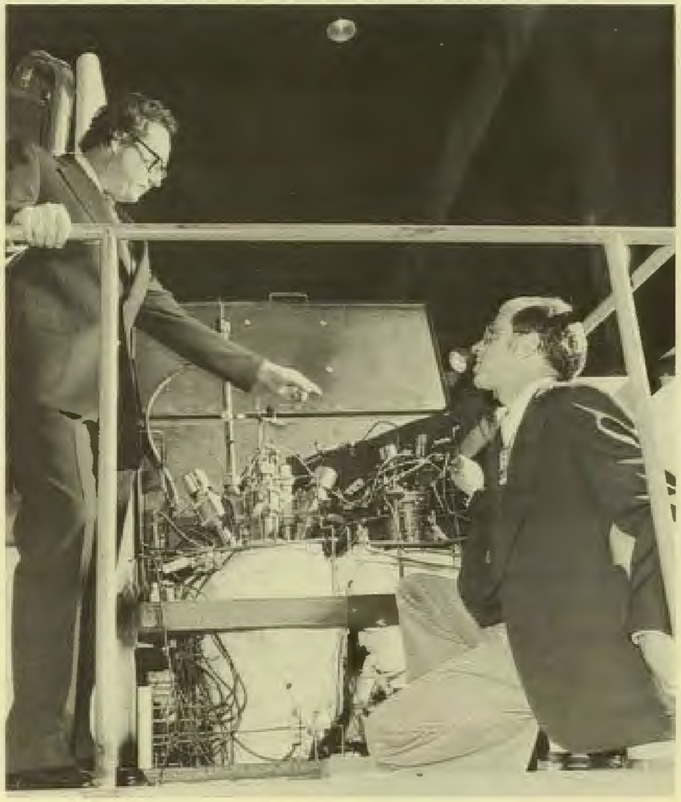
The Professional Photographers of America, Inc., awarded the degree of Photographic Craftsman to **Ward Bandy.**

Donald A. Gardiner has been elected to the Board of Directors of the American Statistical Association, representing its section on Physical and Engineering Sciences, for a three-year term beginning January 1, 1975. He has been a fellow of the association since 1967.

G. Davis O'Kelley was appointed to the Committee on Nuclear Science, and the chairmanship of the Subcommittee on Radiochemistry, of the National Research Council of the National Academy of Sciences. **C. J. McHargue** was appointed to the NRC's Panel on the Use of Accelerators for the Study of Radiation Effects. **David E. Reichle** was appointed to the Environmental Studies Board of the NRC's Commission on Natural Resources, where he will serve on the Committee for International Environmental Programs.

The American Nuclear Society announces the following appointments: Chairman of the Power Section, **S. E. Beall, Jr.;** Chairman of Shielding and Dosimetry Section, **David K. Trubey;** also a member of that section is **Betty Maskewitz;** Vice chairman and chairman-elect of the Nuclear Reactor Safety Section, **Mario Fontana;** Secretary-Treasurer of the Nuclear Fuel Cycle Section is **Raymond E. Blanco,** with **William D. Burch** on the executive committee; member of the executive committee of the Reactor Physics Section is **Gerard de Saussure.**

ORNL administrative appointments: **Chester R. Richmond,** Associate Director for Biomedical and Environmental Sciences; **O. Lewis Keller,** Director of the Chemistry Division; **Carol J. Oen,** Coordinator of Industrial Cooperation Program.



Gene McNeese, shown here, left, examining with Richard Engel the access ports for electrochemical analysis of coolant salt at the Coolant-Salt Technology Facility in Building 9201-3, is the director of ORNL's reactivated Molten Salt Reactor Program. He is a chemical engineer, with degrees from Texas Technological University and the University of Tennessee (M.S.). He has been at the Laboratory, in the Chemical Technology Division, since 1957, working principally on nonaqueous processing of reactor fuels, starting on fuels for molten salt breeder reactors in 1965. Prior to his current assignment, he was chief of the Unit Operations Section in Chem Tech. The recent revitalizing of the molten salt reactor development is good news to many ORNL staff members, and this account serves as a progress report.

Molten-Salt Breeder Reactor:
Development Status and Future Program

By L. E. McNEESE

IN FEBRUARY 1973 the USAEC development program for molten-salt reactors was terminated for budgetary reasons, and further development of this reactor concept appeared unlikely. However, the outlook brightened when the AEC program was reinstated earlier this year, and work was resumed at ORNL. Meanwhile, the Molten-Salt group, headed by Ebasco Services with participation by Babcock and Wilcox, Byron-Jackson, Cabot Corporation, Continental Oil, and Union Carbide, has been attempting to put together an industrial MSR development program. The first stage of their proposal calls for equal support from U.S. utilities, the AEC, and Japanese industry for a \$464 million effort aimed at constructing and operating a 250-MW(e) test reactor. Further, a small but promising MSR development program is being carried out by the French AEC with industrial participation, and interest continues in several other countries.

Background

The molten-salt reactor concept originated at ORNL in 1947 when participants in the Aircraft Nuclear Propulsion Program concluded that molten fluoride salts had useful attributes for the fuel of an aircraft reactor—high uranium solubility, excellent chemical stability, and good physical properties. The 2.5-MW(t) Aircraft Reactor Experiment operated successfully in 1954 at temperatures exceeding 1500°F. Early in the program came the recognition that molten-salt technology offered important advantages as well for civilian power generation, and in 1956 ORNL chemists and engineers began to investigate molten-salt reactors for generation of electricity. Construction of the Molten-Salt Reactor Experiment was authorized in 1960, and by 1965 the 7.4-MW(t) MSRE achieved criticality. It was shut down in late 1969 after operating at around 1200°F for a total of 2½ years.

The success of the MSRE was of major importance to the molten-salt concept. The system provided a remarkable demonstration of operability. Starting in late 1966, an uninterrupted one-month run was made, then a three-month run, and finally a six-month run. Next, the partially enriched ^{235}U fuel was replaced in the salt by ^{233}U. The MSRE then operated a final year on ^{233}U, which makes it the only reactor to have operated on this fuel, and for a period plutonium was used as the makeup fuel.

As a result of the MSRE's success, funding was increased to permit work on molten-salt breeder reactors. The most significant product of this effort was the development of a new chemical processing method which allowed extraction of protactinium and rare earths from a fuel salt that contains both uranium and thorium. The rare earths and protactinium, the intermediate in the breeding chain between thorium and ^{233}U, have significant neutron capture cross sections and must be kept out of the core of a thermal breeder to obtain good breeding performance. The new chemical processing method, coupled with an advance in core design which produces a fertile blanket using a salt that contains uranium and thorium, made feasible a single-fluid breeder and obviated the need for the separate uranium- and thorium-containing salts that had greatly complicated earlier designs. The MSRE experience was directly applicable to the single-fluid breeder, and in 1969 the Molten-Salt Reactor Program was redirected to the development of this reactor type.

The fuel of the single-fluid breeder, a mixture of lithium-7, beryllium, thorium, and uranium fluorides, flows through the channels of a graphite core. The salt is pumped upward through the core, where it is heated to 1300°F, and is then pumped through a heat exchanger to a sodium fluoroborate intermediate coolant. The coolant carries the heat to a steam system, where supercritical steam at 1000°F is generated, leading to an overall thermal efficiency of 44%.

The noble-gas fission products, including ^{135}Xe, are purged from the fuel salt with helium. A small side stream of fuel salt (1 gpm) passes through a chemical processing plant to remove protactinium and the salt-soluble fission products.

If one assumes that MSR development costs are largely absorbed and that the construction and licensing of plants have become routine, the capital costs of molten-salt and light-water reactors appear to be about the same. While MSRs have some features that add costs, particularly the provisions for remote maintenance, their high thermal efficiency and low-pressure primary system also reduce costs. In addition, while the MSBR offers a relatively low breeding gain, it requires a compensatingly small fissile inventory; these factors will allow it to serve a growing nuclear power economy, and it shows promise for producing power at a competitive cost.

Characteristics of the single-fluid breeder	
Fissile uranium inventory of reactor and processing plant	1500 kg
Breeding ratio	1.07
Fuel doubling time (exponential) at 80% plant factor	19 years
Fixed charges on fuel and salt at 13.2% per year	0.44 mills/kWhr
Thorium and carrier salt makeup	0.04 mills/kWhr
Fixed charges on processing plant at 13.7% per year	0.49–0.69 mills/kWhr
Processing plant operating costs	0.05 mills/kWhr
Fuel production operating costs	−0.09 mills/kWhr
Net fuel cycle cost	0.9–1.1 mills/kWhr

Status of Development

The status of MSBR technology and developments needed for design of molten-salt reactors can be summarized as follows:

Reactor Physics and Fuel Cycles. In a fluid-fuel reactor, many reactor physics problems, such as power distribution, localized burnup, and reactivity lifetime, either are not very demanding or are nonexistent. The most important question in the MSBR is accurate prediction of breeding ratio. Existing data show that for the reference MSBR, the uncertainty due to all sources of error in reactor physics is only ±0.016. (Possible additional uncertainties about the behavior of fission products would add to this.)

The dynamics of MSBRs are influenced by the circulation of the fuel, but these effects are well understood and predictable. A negative prompt temperature coefficient and a long neutron lifetime contribute to the stability, and as shown by operation of the MSRE, the small delayed neutron fraction of ^{233}U causes no problem. Thus, an extensive reactor physics program is not needed.

Fuel and Coolant Chemistry. There is little uncertainty about the choice of fuel salt for the MSBR—the LiF-BeF_2-ThF_4-UF_4 system meets the requirements better than any other mixture. Its most serious shortcoming is the low solubility of oxide (30 ppm O^{2-}), which will require minimizing the ingress of air and moisture. Here the MSRE experience provides confidence, since the oxide content of the salt changed little during reactor life, in spite of periodic insertion and removal of corrosion specimens.

Fission-product chemistry in fluoride salts is well understood, with substantial input from the MSRE experience. The physical behavior of the fission products that exist in metallic form in a molten salt cannot be predicted with full confidence, and the reactor designed must use conservative assumptions about their transport and deposition until data from operation of another reactor have reduced the uncertainties.

A fluoroborate mixture (the 92-8 mole % $NaBF_4$-NaF eutectic) appears to be the best choice for the coolant loop, although we are currently examining other salts. Two of the matters for study are the corrosion effects from steam and the consequences of mixing fluoroborate and fuel. We also need to understand better the behavior of hydroxide ion, as well as the mechanisms by which tritium, diffusing from the fuel system, can be trapped in the fluoroborate.

Fuel and coolant salt samples from the MSRE have in the past been analyzed in the laboratory; however, considerable progress has been made in the last few years in developing on-line electroanalytical methods. One corrosion loop has operated with a controlled voltametry instrument that measured the U^{3+}/U^{4+} ratio in the salt, which is important in the reactor's operation. Ways of detecting hydrogen, corrosion products and other salt impurities, and certain fission products are beginning to emerge from this development effort.

Graphite in molten-salt breeder reactors must withstand neutron irradiation, the pores must be small enough to exclude the nonwetting fuel salt, and the graphite must be sufficiently impermeable to gases to limit the absorption of ^{135}Xe. Although the MSRE graphite showed no effect of 2½ years' contact with fuel salt, it would not have met the radiation damage and gas permeability requirements of an MSBR.

Radiation damage causes most graphites to shrink and then expand at neutron fluences below those of interest for MSBRs. However, some grades of graphite show little shrinkage under neutron irradiation, and a longer period before rapid expansion begins, and one commercially available graphite has been found to meet the 4-year life assumption of the reference design. A growing understanding of radiation behavior should lead to longer irradiation life.

Graphite can be sealed adequately to exclude xenon by a deposit of pyrolytic carbon either in the surface pores or in a thin layer on the surface. The permeability of most of the small samples tested, however, has increased excessively under neutron irradiation. The failures may have resulted from some microscopic defects seen in the surface coating of the unirradiated material. A new procedure for depositing the coating has produced flaw-free samples; however, the behavior of these samples during irradiation has not been determined fully. Scale-up of the process to accommodate large pieces remains to be accomplished if the new method is successful.

If a suitable method for sealing graphite is not developed, ^{135}Xe absorption will lower the breeding ratio of the MSBR by 0.005–0.01, depending on the effectiveness of the noble-gas sparging system.

Metals for Containing Salt. Hastelloy N, a nickel-base alloy containing 16% Mo, 7% Cr, and 5% Fe, was the structural material for the MSRE (see Fall '69 *Review*). While the MSRE was being built, experiments revealed that the creep ductility of Hastelloy N is reduced via helium produced by neutron absorptions in the trace impurity boron and fast neutron interactions with nickel. Stresses in the MSRE were low enough for safe operation in spite of decreased ductility, but this will not necessarily be true of commercial MSBRs, and a development program was undertaken to solve the problem. The approach pursued was that of adding carbide-forming elements, which have been shown to lessen the embrittlement effect of fast neutrons on stainless steel. The addition of 2% titanium was found to sustain the ductility of Hastelloy N adequately at MSBR design temperatures. Some further ductility gain is also made by including niobium.

Extensive loop tests demonstrated that the corrosion rate of Hastelloy N by clean fuel salt is low, and salt analyses and surveillance specimens from the MSRE showed very low generalized corrosion rates. The postoperation examination, however, revealed that all Hastelloy N that had been in contact with fuel salt showed shallow intergranular surface cracks when strained at room temperature, apparently caused by the fission product tellurium. Consequently, a variety of nickel-base and iron-base alloys have been tested, and indications are that some alloys are not affected by tellurium; among these are modifications of Hastelloy N. Except for the stainless steels, where the work has already been done, a change to one of these materials is likely to mean that modifications to provide radiation resistance will have to be developed.

Component Design

The design requirements for some of the components for an MSBR power plant are different from those for solid-fuel reactors, and a number are unique to molten-salt systems. Many components were investigated in the development programs for the aircraft reactor and the MSRE, but not all have been developed; and increases in size or performance are required in most cases.

Vertical-shaft centrifugal pumps with overhung impellers were developed and used satisfactorily on the Aircraft Reactor Experiment, the MSRE, and a number of salt loops. Although a 10- to 15-fold increase in capacity will be needed in progressing from the MSRE to full-size MSBRs, the same basic design is specified in the reference MSBR design, and the scale-up should be relatively straightforward.

The MSRE intermediate heat exchanger and air-cooled radiator operated without difficulty, and analyses showed no decrease in performance throughout the plant life. The aspects of the MSBR that differ from the MSRE, aside from size, have to do with the need for high performance in the MSBR to limit the fuel-salt inventory and the requirement that failed tubes be able either to be repaired *in situ* or to be replaced.

There has been no experience with generation of steam using high-melting salts. In conventional steam cycles the feedwater enters the system below the melting point of the coolant salt (725°F); as a result, measures must be taken to keep salt from freezing on the tubes. Allowing a layer of salt to form might be acceptable, but in the reference concept the steam cycle was altered to increase the inlet steam temperature. The result is a small penalty in the form of some additional equipment and a small loss in efficiency. Other ways of overcoming the salt freezing problem are also under study.

Chemistry Development

The noble gases are only lightly soluble in fuel salt, and consequently, the fission product poisoning in an MSBR can be greatly reduced by sparging xenon from the salt, as was demonstrated in the MSRE, where over 80% of the ^{135}Xe was removed. However, the somewhat different sparging system proposed for the MSBR requires demonstration, and tests with salt will be performed in an MSRE-scale loop nearing completion.

Achievement of a significant breeding gain in a single-fluid MSBR is dependent on rapid removal of the fission products from the fuel salt. The underlying chemistry involved in the processes appears to be well established. However, engineering development and the demonstration of satisfactory container materials have not progressed nearly so far.

Fluorination to recover uranium from radioactive fuel has been used several times, most recently in processing the MSRE fuel. However, MSBR processing involves continuous fluorination, and the necessary experiments are now under way.

Reduction of UF_6 for return to the reactor by its absorption into fuel salt that is subsequently contacted with hydrogen has been demonstrated in small laboratory experiments; an engineering development program is being initiated.

All steps in the metal transfer process for rare earth removal have been demonstrated in small single-stage integrated experiments, and preliminary design of a larger multistage experiment has begun.

Losses of fissile material from the processing plant must be kept low. Although the process fluids circulate repeatedly through the plant, losses can occur only in the wastes, from which the traces of uranium can be recovered by batch fluorination before discard.

Fuel salt and lithium chloride are compatible with some common construction materials, but nickel dissolves in bismuth, and iron is too soluble for a system having a significant temperature gradient. Consequently, materials such as graphite, molybdenum, and tantalum will be required. Many of the difficulties of molybdenum fabrication are being overcome. Graphite should be less expensive than molybdenum, and the processing vessel for a three-stage metal transfer experiment will be made of graphite. However, we still don't know enough about the compatibility of graphite with bismuth containing high concentrations of lithium or trace quantities of other materials.

Carry-over of significant quantities of bismuth to the reactor, where it could attack Hastelloy N, must be avoided. One Hastelloy N natural-circulation loop containing fuel salt has been operated with an open capsule of molten bismuth in contact with the salt without detrimental effects. Experimental evidence indicates that the solubility of bismuth in salt is probably very low, but further work in this area is necessary.

Maintenance Requirements

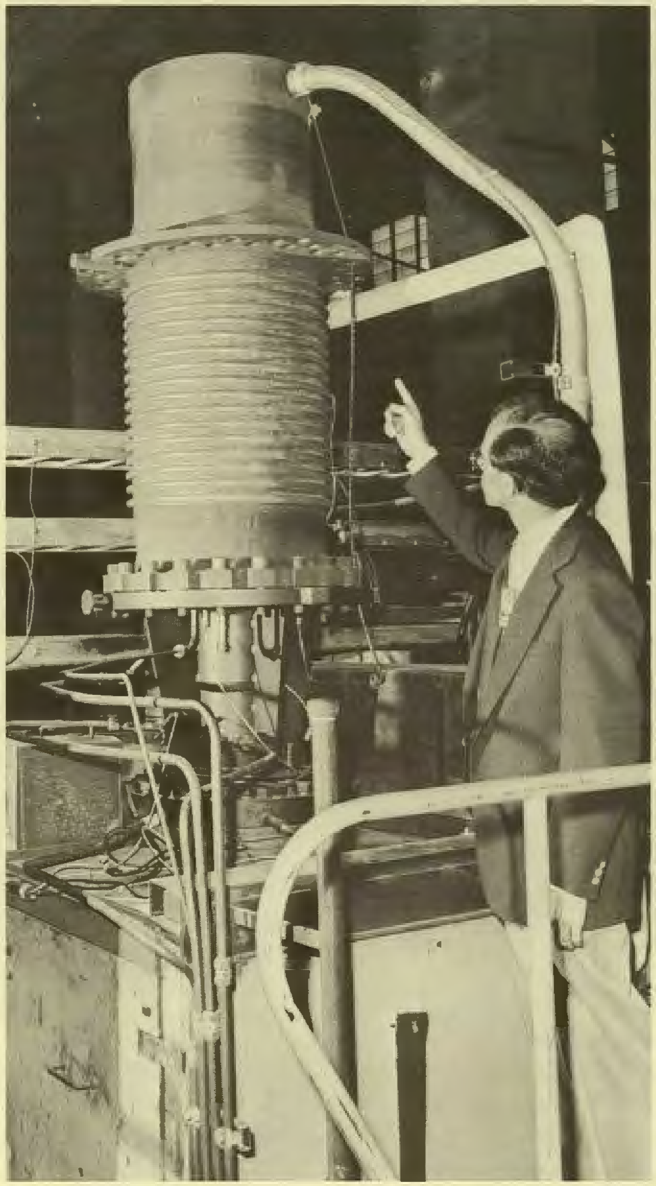
Because fission products are circulated in the primary system of a molten-salt reactor and transported to some auxiliary systems, special procedures and equipment will be needed for the repair or replacement of equipment. The maintenance philosophy used previously at ORNL will form the basis for the maintenance of MSBRs, although the new technology will involve larger components, higher radiation levels, and probably more extensive contamination than we have dealt with before.

Much can be done in the design and layout to facilitate maintenance, although most of the maintenance development effort will have to be directed to perfecting the tools and procedures needed for a particular application.

Environmental Safety

The major uncertainty with regard to environmental effects is how to limit the rate at which tritium enters the steam system, from whence it is released to the environment. Tritium is a special problem because of its high rate of production [2400 Ci/day in a 1000-Mw(e) MSBR] from lithium in the fuel salt and because it readily diffuses through metals at MSBR temperatures. We have estimated that an excessive amount (790 Ci/day) could reach the steam system if measures are not taken to block its passage. Fortunately, several ways of drastically reducing escape by this route appear possible. In particular, oxide films, which can be formed on the steam side of steam-generator tubes, appear to impede the passage of tritium by several orders of magnitude. Limiting tritium release to within present AEC guidelines for light-water-cooled reactors appears possible, but demonstration under realistic conditions is needed.

Dick Engel points to the pump, encased in refrigerant coils, that moves the coolant salt in the test loop at Y-12. Another loop, to contain an analogy of the fuel salt, is being built nearby.



The situation with regard to kinetics and nuclear safety is unique because of the circulating fuel. The kinetic behavior of molten-salt reactors is now well understood and predictable, and there is ample basis for being confident that there is essentially no probability of a damaging nuclear excursion. Of the potential sources of reactivity, the one that will require the most study is hideout of fissile material, but conditions that would permit it can be safely avoided.

The afterheat situation is also unique. The major heat source in an MSBR is incorporated in a large mass of fuel salt, which can be transferred into a reliably cooled vessel (the drain tank) under any accident condition. On the whole, afterheat promises to be less of a problem in MSBRs than in other reactors, and the dilute heat source lessens concern about any possible meltdown situation. However, reliable cooling must be provided for those components and systems in which fission products are held or deposited.

The design-basis accident in an MSBR is a rupture in the fuel system that quickly spills the entire fuel inventory. Containment of the radioactivity in this event is the chief safety consideration for an MSBR. The containment must be tight, but the behavior of the spilled salt and its fission products is predictable, and designing to handle a spill safely appears to be straightforward. Further, iodine and strontium, two of the most hazardous fission products, remain in the salt as stable compounds.

Future Objectives

During the next several years, the major objectives of the ORNL program will be to accomplish the following:

A modified Hastelloy N or an alternative material will be selected and/or developed that is compatible with fuel salt, resistant to radiation damage, and immune to attack by tellurium. Its compatibility with fuel salt will be demonstrated with out-of-pile forced convection loops and in-pile capsule experiments. Means for providing adequate resistance to radiation damage will be developed if not already present, and commercial production of the alloy will be demonstrated. The mechanical property data needed for code qualification of the material for the MSR primary system will be acquired.

A method of preventing the passage of tritium into the steam system will be demonstrated under reactor conditions.

The complete processing system will be demonstrated, including the materials of construction, in an integrated nonradioactive system.

Systems that are unique to molten-salt reactors, such as the process for stripping xenon from the fuel salt and the off-gas and cleanup systems for the coolant salt, will be developed.

Graphite elements suitable for the MSBR will be obtained in sizes and quantities that assure that a commercial production capability exists, and their radiation behavior will be confirmed. Methods for sealing graphite to exclude xenon will continue to be explored.

On-line diagnostic devices, both chemical and instrumental, will be purchased or developed and demonstrated on loops, processing experiments, and mock-ups.

In addition to these tasks, we will perform safety studies of MSBRs, carry on a small design and analysis effort, continue fundamental chemistry investigations, and carry out some other activities at a low level in order to achieve a balanced program.

Summary

The objective of developing breeder reactors is a reliable and abundant source of energy through efficient use of our uranium and thorium resources. Molten-salt breeder reactors have attributes of fuel utilization, economics, and safety that make them well suited to this objective. The highly successful operation of the Molten-Salt Reactor Experiment, as well as developments in chemical processes that have allowed an important simplification in the breeder concept, provide support for our belief that these reactors can be successfully developed. Because they differ in many aspects from solid-fuel reactors, MSBRs provide good insurance for the nation's energy supply in case major obstacles are encountered by other concepts. In addition, the ability of the molten-salt reactor to be started up as a breeder or operated economically as a converter on plutonium, ^{235}U, or ^{233}U makes it particularly suitable as a companion for other types of reactors in a balanced fuel economy. We believe that a strongly motivated and adequately funded program can lead to molten-salt breeder reactors that can play a major role in providing for our future energy needs. Reactivation of the AEC's program, the proposal for a major industrial program, and the growing interest abroad provide the ingredients for the effort that is needed.

Staff quote:

"What Englishman in 1590 would have predicted that the energy crisis that occurred at that time would result in an energy crisis in 1974? In the late 1500's, at least in England, wood became scarce. Wood was the principal fuel and the principal material of construction for buildings, tools, machinery—almost everything. In their search for a new fuel, they turned to coal, which had not been used much because the water that seeped into the mines made mining difficult. Many patents were granted for pumps and other devices to remove the water, using both human and horsepower. Then, almost exactly 200 years ago, James Watt patented his perfected steam engine, merely for the purpose of replacing the horses at the mine pumps....

"And so the answer to the question in the title of my talk is, 'No, nuclear energy is not a panacea.' It is merely a way of moving from the present crisis along what I hope will be a fruitful pathway to our next crisis, whatever and whenever that may be."—Richard N. Lyon, Energy Division, in a talk entitled "Nuclear Energy, a Panacea?" given at Wesleyan College in Macon, Georgia, early this year.

Take A Number.....

BY V. R. R. UPPULURI

POWER OF POWERS

Every power of 25 ends in 25 ($25^2 = 625$, $25^3 = 15{,}625$, etc.), and every power of 76 ends in 76 ($76^2 = 5{,}776$, $76^3 = 438{,}976$, etc.). How can it be established that there are no other such two-digit numbers?

Similarly, every power of 376 ends in 376 ($376^2 = 141{,}376$, $376^3 = 53{,}157{,}376$, etc.), and every power of 625 ends in 625 ($625^2 = 390{,}625$, $625^3 = 244{,}140{,}625$, etc.). How can it be established that there are no other such three-digit numbers?

However, it can be easily seen that if the square of an n-digit number ends in the same n digits, the same is true for every higher power.

FACTORIALS

The product of the first n natural numbers is called the factorial of n and is denoted by $n!$; e.g., $4! = 1 \times 2 \times 3 \times 4 = 24$. It is interesting to note that there are only four positive integers with the property that each one is equal to the sum of the factorials of the digits that represent it (in the decimal system). Three of them are 1, 2, and 40,585. Clearly $1 = 1!$, $2 = 2!$, and $40{,}585 = 4! + 0! + 5! + 8! + 5! = 24 + 1 + 120 + 40{,}320 + 120$. The fourth number (which is in the hundreds) can be easily found. Though there are no rigorous proofs available, one can convince himself of this fact.

Jim McGuffey earned his degree in metallurgical engineering at Penn State. He came to Oak Ridge in 1944 with the Special Engineering Detachment of the army to work at the K-25 plant. He says that in the next 18 years he racked up half a million miles supervising the inspection forces that were monitoring the heavy equipment installed in the gaseous diffusion plants here, at Paducah, and at Portsmouth. When the High Flux Isotope Reactor Project cranked up, he transferred to ORNL as a project metallurgist in the Metals and Ceramics Division, on assignment to the Reactor Division, and he has been involved in the design, construction, and operation of the HFIR. He is at present Superintendent of Inspection Engineering, directing a staff that assists Engineering on capital projects and the operating divisions on safety inspections of existing facilities. Recently Inspection Engineering came in for a singular honor, and Jim tells about it here.

ORNL's Inspectors General

By J. R. McGUFFEY

ONCE IN A WHILE everything works right the first time. On several occasions in Inspection Engineering, we have had the good fortune to share with project personnel the treat of watching first-of-a-kind equipment start up and operate with no surprises.

The department's engineers and inspectors have contributed their expertise to many project directors during the design, construction, and installation of major Laboratory facilities. We're a unique adjunct to Lab Services that is staff to all of ORNL. Our forte is people who specialize in keeping abreast of new fabrication and inspection practices, and our commitment is to help the senior researcher get his dream into useful experimental hardware.

We have many roles in helping to ensure the reliability and safety of sophisticated research devices and systems. The work may range from simply answering technical questions by phone to being an integral part of a team that starts with the conceptual design and stays with the project though construction and periodic in-service inspection. In broad terms, our work falls into three categories: technical support during assembly of major capital equipment projects, inspections and examinations of test equipment and operating facilities, and special

The author watches R. D. Scofield using an ultrasonic testing device on a pair of 10-inch steel plates joined with an electroslag weld. He is pretesting the material for laminar flaws, prior to examining the weld itself.

assignments for the Laboratory safety program.

ASME's Code

One illustration of our technical duties involved the recent coordination by Inspection Engineering of about 40 engineers and supervisors to obtain approval for the Laboratory to design, fabricate, and install pressure vessels and nuclear components in accordance with the ASME Boiler and Pressure Vessel Code. The American Society of Mechanical Engineers now requires manufacturers of pressure-containing components to operate under a very tough, albeit realistic, quality assurance system called a Controlled Manufacturing Program. The AEC had asked ORNL to obtain certificates of authorization and the appropriate Code Symbol stamps from the society so that our shop and field practices would be comparable with those required of the commercial sector of the nuclear industry.

Don Trauger and Mansell Ramsey assigned Inspection Engineering the task of directing an ad hoc committee to prepare the administrative control manual, a procedures manual, and a system to implement these controls. Jim Robinson, Ken Klindt, Bob Farnham, Bill Ferguson, Bill Graves, and I worked intermittently for a year to tailor divisional responsibilities, relationships, and procedures to meet with the rules laid down by the ASME Code. Before it was over, some 100 engineers, supervisors, and inspectors had provided input in the way of design, fabrication, procurement, purchasing, quality assurance, and inspection. The result was a beautiful and workable system for performing and controlling all of the critical activities required in the construction of high-quality pressure-containing equipment at the Laboratory. The ASME wisely requires the manufacturer to prove the adequacy of the system by actual demonstration. Pete Helms, of the Reactor Division, arranged to have the 2500-psi blowdown heat transfer pressurizer fabricated in ORNL shops so we could show the ASME our compliance with its Controlled Manufacturing Program.

Our demonstration took place early this year at the Laboratory in the presence of an ASME survey team who fully approved both the administrative controls and the demonstration. Very few companies are approved on the first survey, so it was a banner event for all of us. ORNL now is formally authorized to construct and install equipment in accordance with Section VIII, Divisions 1 and 2, and Section III of the ASME Code, and to imprint the appropriate Code Symbol stamp on the equipment nameplate. This program also provides a base for performing work in accordance with the added requirements of the AEC RDT Standards. Thus the Laboratory has a close-knit team to design, assemble, and install a broad spectrum of future research facilities with predictable competence.

Some History

Before describing our other functions I'd like to tell you how this special department came into being. Back in the late fifties, when the Laboratory was designing and assembling, concurrently, the Homogeneous Reactor Experiment, the Oak Ridge Research Reactor, and the Tower Shielding Facility, the director of the Lab at that time, Clarence Larson, established Inspection Engineering under the late Ed Miller. The new department was charged with assuming the responsibilities of an independent inspection agency during the construction of research reactors, pilot plants, and test loops that were at that time beyond the state of the art. Miller recruited personnel from other divisions and hired experienced supervisors and inspectors from local contractors engaged in construction in the Oak Ridge area. Only Don AuBuchon and Ernie Childress of the initial force are still active in the department. Miller was superintendent until his death in 1970, when I succeeded to the job.

At any given moment during the period when the HRT, *Glen Bowden is radiographing a weld in an intermediate-level radioactive liquid waste line.*

MSRE, HFIR, TRU, and EGCR projects were at their peak activity, over half the cadre could be found on travel status, riding the low-flying DC-3s, -4s, and -6s through all kinds of weather to conduct surveillance at hundreds of vendors' shops. Christmas party conversations featured many colorful stories of flight experiences. One classic involved the inspector who, in his zeal to do his thing, rushed off the plane with his bag in hand, hurried through the terminal, and charged into a waiting bus. By the time he realized it was a school bus, he was well into the country west of Philadelphia, picking up elementary school children.

These men logged hours in the shops that encompassed second shifts and weekends, representing the designers and the project directors. ORNL by necessity has always purchased nuclear equipment to stringent job specifications. Those fabricators just entering the nuclear field often failed to appreciate our technical requirements. Thus it was necessary for our field men to teach the latest inspection techniques, to explain the reason for them, and above all to coerce the manufacturer into full compliance with the contract.

On the HFIR project, members of the Inspection Engineering staff were assigned to the Reactor Division during the design to become thoroughly familiar with the critical features of the reactor. These and other inspectors then assisted the project engineers in following the actual fabrication and installation of all the primary coolant system and the core components. Another group worked with ORNL metallurgists in perfecting nondestructive examination equipment and techniques for production examination of the high-performance fuel plates and cores.

Nondestructive Examination

Our long suit technically is nondestructive examination for imperfections in R and D equipment that may affect its functioning. Several of our engineers and inspectors are highly qualified in such inspection technologies as ultrasonics, radiography, magnetic particle technique, liquid penetrant application, and helium leak detection. These examinations are conducted on new materials of construction and on welds in vessels and piping systems made by the Plant and Equipment Division shop personnel or by local field contractors. Our inspectors also monitor nondestructive tests performed by vendors at outside material and vessel manufacturing plants.

NDE is a highly innovative and fast-growing technology. In the pursuit of excellence in this field, our inspectors have undergone comprehensive training programs in the latest techniques. Many are now qualified to do advanced development work and monitor the examinations being performed in the most modern material supplier mills and fabrication shops. To be effective, the field inspector must be fully knowledgeable and versatile in all of the practices currently employed by industry.

For three years our NDE experts have been involved in the Heavy Section Steel Technology program in the Reactor Division under Grady Whitman and his staff. Ernie Childress has performed surveillance of heavy plate fabrication, welding development, and the construction of the intermediate test vessels. Ken Klindt, Steve Baker, Bob Scofield, and Ron Pope have developed advanced ultrasonic techniques to determine the depth of intentional cracks put in the test vessels. They also have devised methods for monitoring the rate of crack propagation when the vessels are pressurized to failure. This technology will soon be extended to the LOCA-ECC (Loss of Coolant Accident–Emergency Core Coolant) Thermal Shock Experiment under the direction of R. D. Cheverton.

Not everything that we inspect is massive. O. J. Smith's crew routinely radiographs the fine wires and welds in thermocouples for the Instrumentation and Controls Division and performs radiography and helium leak tests on a host of experimental fuel pins, spheres, and in-pile capsules for the Metals and Ceramics Division. His men also ultrasonically search for imperfections as small as 0.003 in. in thin-wall tubing.

In-Service Inspection

As the numerous Laboratory facilities went into operation, part of the emphasis shifted to the inspection of the equipment in service during scheduled outages. Inspection of operating equipment is less glamorous than representing the Laboratory on the road, but there is satisfaction in keeping ORNL out of the headlines. Our job is keeping an eye on over 950 pressure vessels and steam boilers and their associated relief devices to ensure against unwelcome surprises. J. D. Fultz and his crew of boiler inspectors periodically examine these vessels with many forms of nondestructive equipment to evaluate whether operating conditions—fatigue, creep, overpressure, erosion, corrosion, or malfunction of the safety devices—may have lowered the safety factor to a possible failure point.

The in-place inspection and testing of 1450 high-efficiency particulate filter systems and 28 iodine charcoal adsorber banks is another safety-related function of the department. J. J. Smith and Ron Pope and their crews have received wide acclaim for the development of inspection practices for these vitally important filter units in ORNL's radioactive facilities. These inspectors also check out all gas mask canisters and soon will be periodically evaluating several hundred self-contained breathing devices in line with new national codes and standards.

Some 450 cranes and hoists and 26 personnel elevators are inspected and load-tested by O. J. Smith's crew. Every sling made at the Plant and Equipment Division riggers' loft is proof-tested and then periodically examined to sort out any defective units. These men also perform an eddy-current inspection of the guy cables at the Tower Shielding Facility every five years. This is one of the more spectacular jobs, involving as it does affixing the equipment to the guy cables at the tops of the 325-foot towers. A new assignment is evaluating the rigging used to tie down radioactive material shipping casks on over-the-road trailers.

One significant feature of all these inspections is the large number of personal contacts required. We're like the August fog—our inspection staff covers the entire valley every day and deals with hundreds of individuals as every inspection or test is cleared with those responsible for the equipment. The majority of the experimenters, operators, or maintenance people are highly cooperative and have planned for our coming via the computerized inspection schedule. A few are indifferent, but occasionally an inspector must confront an individual who is coping with a particularly difficult day, in a situation in which no small amount of diplomacy is required. Those in charge of each facility are immediately told of any condition that might affect safety, and all results are

In the test bay of Building 2000, Bob Scofield demonstrates a method of ultrasonic testing of metal tubing immersed in water.

reported by monthly and quarterly computer printouts.

These inspections, coupled with care and attention by the operators and maintenance personnel, have played a vital part in the Laboratory's excellent safety record.

Special Inspection Activities

Recently, we've taken on some challenging projects. One concerns vacuum boxes. The implosion, several years ago, of a glass viewing window in a vacuum box, while not resulting in injury to the operating personnel, brought attention to the need for a safety criterion for such windows. At the request of Ted Arehart and Bob Affel, Inspection Engineering searched for but couldn't find an established basis for window design, so Jim Robinson developed a rational design approach and confirmed its validity by actual tests. An audit of the laboratories revealed that there were over 900 windows in 350 vacuum boxes; one-third of these did not meet the design criteria, so new windows were ordered and installed. We now, with the help of the experimenters and safety officers, survey every window annually in search of any change that might render it hazardous.

Another big project has been the in-service inspection of all of the major equipment and piping in the operating research reactors. It is one thing to inspect conventional fired and unfired pressure vessels and piping; it is something else again to conduct these examinations under radiation conditions. Ken Klindt has assumed the task of working closely with Operations to develop a long-range program, to purchase or build the special and remote tooling, and to direct the actual inspections. One cir-

Staff quote:

"Although it is trivial to say that 'it's good to get away for a while,' we in fact found this to be the case, and the more important observation is that we did not really realize that we needed to get away until we did. I think Oak Ridge has a special problem, first, because it is a small community with a relatively small number of stimuli, and second, because the Laboratory has a very stable labor force which for historical reasons is now beginning to have a high average age. In short, it is easy to get into a rut and not to know it. I firmly believe that an arrangement which approximates the traditional sabbatical leave concept could be of substantial benefit to the Laboratory. Furthermore, I think that it is not enough to assist individuals who are themselves seeking temporary outside situations. I think the Laboratory should actively encourage this sort of activity. I realize that these ideas are not original and have been the subject of much discussion in the past several years. Nevertheless, I have been so impressed by our own experience, that I think it is worthwhile to add one more voice to the argument."— Charles M. Jones, Physics Division, discussing his year's assignment to the Institut für Experimentelle Kernphysik, in Karlsruhe, Germany, July 1971 to July 1972.

cumstance that complicates the work is that the reactors were designed and installed before national in-service inspection requirements were established.

To illustrate the effectiveness of this ongoing program, an ultrasonic technique was perfected a few years ago to permit examination of the studs and nuts used to attach the top and bottom heads to the shell of the HFIR primary pressure vessel. In-place examination of the studs during a scheduled outage revealed that one-third of the top head studs had incipient stress corrosion cracks at the root of the threads where they contact the nuts. A few top head nuts also had shallow radial cracks. The accuracy of the in-place ultrasonic findings was confirmed by bench ultrasonic and liquid penetrant examinations and metallographic studies. Finding these incipient cracks before the strength of the parts was materially reduced allowed time to fabricate replacements before emergency shutdown became necessary.

The remote inspection of the HFIR shell and nozzles is going to tax our expertise. Underwater television inspection coupled with new ultrasonic methods and equipment developed on the HSST program will be used to search for flaws in the weld overlay, the base metal, and all accessible welds in the coming years.

Future Activities

Al Boch and Bob Hill have advised us that we will be called upon to assist in all of the new energy research and development programs. We look forward to the challenges that will be involved in the surveillance of the field installation of waste handling systems, the installation of the massive vertical pressure vessel for the heavy-ion accelerator, new ORMAK equipment, and the several Reactor Division test loops. We hope to be able to supply engineering input, fabrication and inspection expertise, and good judgment at the right time to those requesting our services, without jeopardizing the current safety-related programs. We will probably soon find that once more our staff is spread out among Oak Ridge, New York, and California at 9 AM on any given morning.

LAB ANECDOTE

By HERBERT POMERANCE

"Let us establish a scholarly tradition at ORNL."

When Research Director Alvin Weinberg said this in 1950, reactor technology was hardly eight years old, the third reactor school had begun, and he had taught in all three of them. It was another 15 years before ORNL gave up its teaching role in reactor physics and engineering.

The first school was informal. It comprised the seminars and conferences and teaching programs held during wartime at the Metallurgical Laboratory in Chicago. At the same time there was a Project Handbook, CL-697, in 12 chapters (5 typed volumes) that was in many ways the basis of the first commercial "Nuclear Engineering Handbook" edited by Harold Etherington and published in 1958.

The second school started up in September 1946 when Eugene Wigner began his year as research director of Clinton Laboratories (now ORNL) and was joined by Fred Seitz to establish the Training School. The building was a two-story wooden structure, set on a concrete pad that had stored nitric and hydrofluoric acids used in the wartime separation of uranium and plutonium. The students were established scientists and engineers from industry, from government, from within the lab, and from Monsanto Chemical Company, which operated the Lab for the Manhattan District of the Army Engineers and which organized its own Power Pile Division. (When the Atomic Energy Commission took over from the Army Engineers in 1947, they also changed the word from pile to reactor.) The faculty were principally old-timers in the project, half of them still in their twenties. After Kay Kayser's popular radio program, the school was dubbed the Klinch Kollege of Knuclear Knowledge.

The scholarly tradition didn't give rise to many books, although many were proposed. Harry Soodak (now of City College New York), who lectured, and E. C. Campbell (now of North Dakota State University), who took notes, published a book entitled "Elementary Pile Theory." The material was not elementary, but the declassification guide permitted publication of elementary pile theory, and who wants to argue with a declassification guide? The other good works from the school were not in hard cover but in soft cover: reports and compilations of lecture notes, feasibility studies, reactor designs, neutron measurements. Capt. H. G. Rickover and a half dozen naval officers reported copiously and used their training to consider the design of a nuclear Navy. Clark Goodman of M.I.T. organized courses on his return to teaching there that were published as the second edition of "The Science and Engineering of Nuclear Power." Fred Seitz returned to the University of Illinois in 1947; today he is president of Rockefeller University.

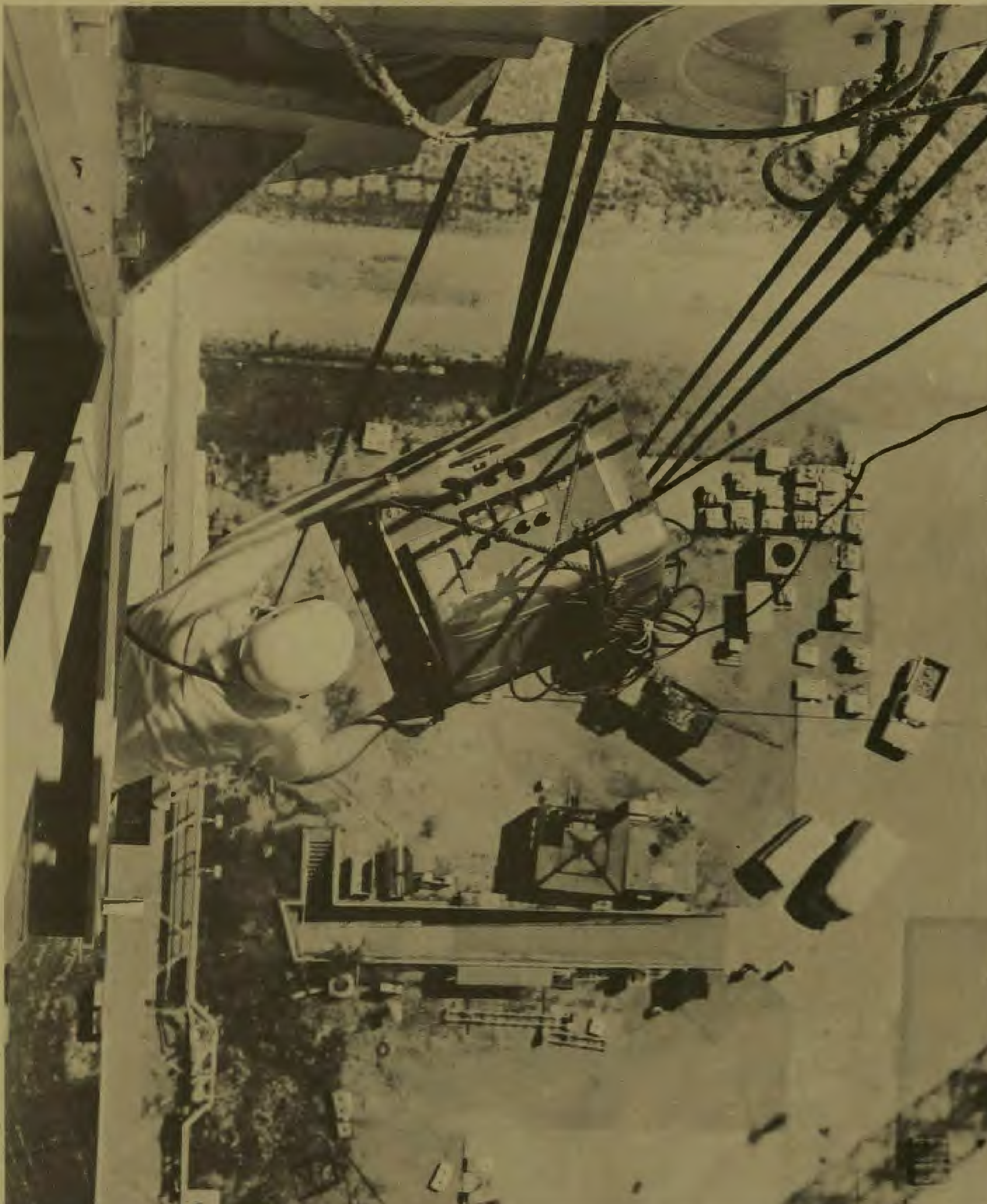
It was two and a half years later that the third school began in an abandoned cafeteria near the West Portal. The push for the school came from Capt. Rickover, who lamented the dispersion of the old Training School group and who needed nuclear design engineers for the nuclear Navy; he later attained the rank of rear admiral for his success with the Navy.

The Training School staffed many industries. Sam Untermyer talked General Electric into the boiling-water reactor route. John Simpson managed the Westinghouse nuclear effort and became a vice-president there. Louis Roddis is now president of Consolidated Edison, former ANS president, and co-author of the article on Nuclear Energy in Marks Mechanical Engineering Handbook. H. G. MacPherson of Carbide research later returned to ORNL to be deputy director. John Menke and Gale Young formed Nuclear Development Associates, an important engineering firm.

The Training School building itself was a victim of the nuclear age. Nowadays all nuclear process buildings must have double containment as a protection from accidental spills, but when the pilot plant in Building 3019 still had single containment it sent some alpha-active materials downwind onto the roof of the Training School. That roof had to be cut up and given proper burial. The site of acid storage, then the site of the school, is once again a roofless site for storage of hazardous chemicals.

GRADUATES OF THE KLINCH KOLLEGE FOR KNUCLEAR KNOWLEDGE

First Row, l. to r.: J. R. Menke (Kelley Corp.), L. A. Matheson (Dow Chemical Co.), K. O. Donelian (Kellex Corp.), S. Siegel (Westinghouse), F. Seitz (Carnegie Tech.), E. C. Campbell (Princeton Univ.), A. V. Masket (Naval Research Lab.), N. M. Smith, Jr. (Kellex Corp.). *Second row:* J. J. Markham (formerly Brown Univ.), G. A. Morton (R.C.A. Labs.), D. E. Hull (Carbide & Carbon), J. W. Kent (California Res. Corp.), L. D. Roberts (General Electric), D. J. Crowley (Socony-Vacuum Labs.), W. L. Davidson (B. F. Goodrich Co.). *Third row:* F. C. Vonder Lage (formerly U.S. Navy), A. P. Weber (Kellex Corp.), H. C. Ott (Rensselaer Poly. Inst.), H. G. MacPherson (National Carbon Co.), W. I. Thompson (Standard Oil Dev. Co.), J. E. Hill (Westinghouse), R. C. Mason (Westinghouse). *Back row:* P. J. Bendt (General Motors), L. I. Eisenbud (formerly McLaughlin Carr Associates), H. M. Clark (Rensselaer Poly. Inst.), S. Lawroski (Esso Laboratories), J. J. Grebe (Dow Chemical Co.), J. I. Hoover, E. P. Blizard (Navy Dept.). *Trainees not appearing in picture:* E. B. Ashcraft (Westinghouse), R. M. Boarts (Univ. of Tenn.), J. H. Buck (Socony-Vacuum Labs.), L. P. Hunter (Westinghouse), S. M. MacNeille (Eastman Kodak), R. F. Newton (Purdue Univ.), W. H. Yanko (Monsanto).



Al Holloway attaches an eddy-current monitor at the top of Tower Shielding Facility's guy wires, 325 feet off the ground. The monitor will then work its way down the wire, inspecting all the way. *(See article p. 23)*