Review

SPRING 1971

OAK RIDGE NATIONAL LABORATORY

THE COVER: The superb tooling, jewelry finishing, and minute-tolerance machine work of the ORNL shops is shown in this array of random parts, from cogwheels to grommets. The story of this exceptional machine shop complex is told by Bob Farnham in the article beginning on opposite page.

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OAK RIDGE NATIONAL LABORATORY

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OAK RIDGE NATIONAL LABORATORY
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UNION CARBIDE

Bob Farnham, head of the fabrication department in the Plant and Equipment Division, has been with the Laboratory since 1948, shortly after receiving his degree in mechanical engineering from the University of Tennessee. In the following article about the machine shops over which he has had supervision for nearly 20 years, he fails to conceal the pride he feels in their versatility, ingenuity, and reputation for dependable competence.

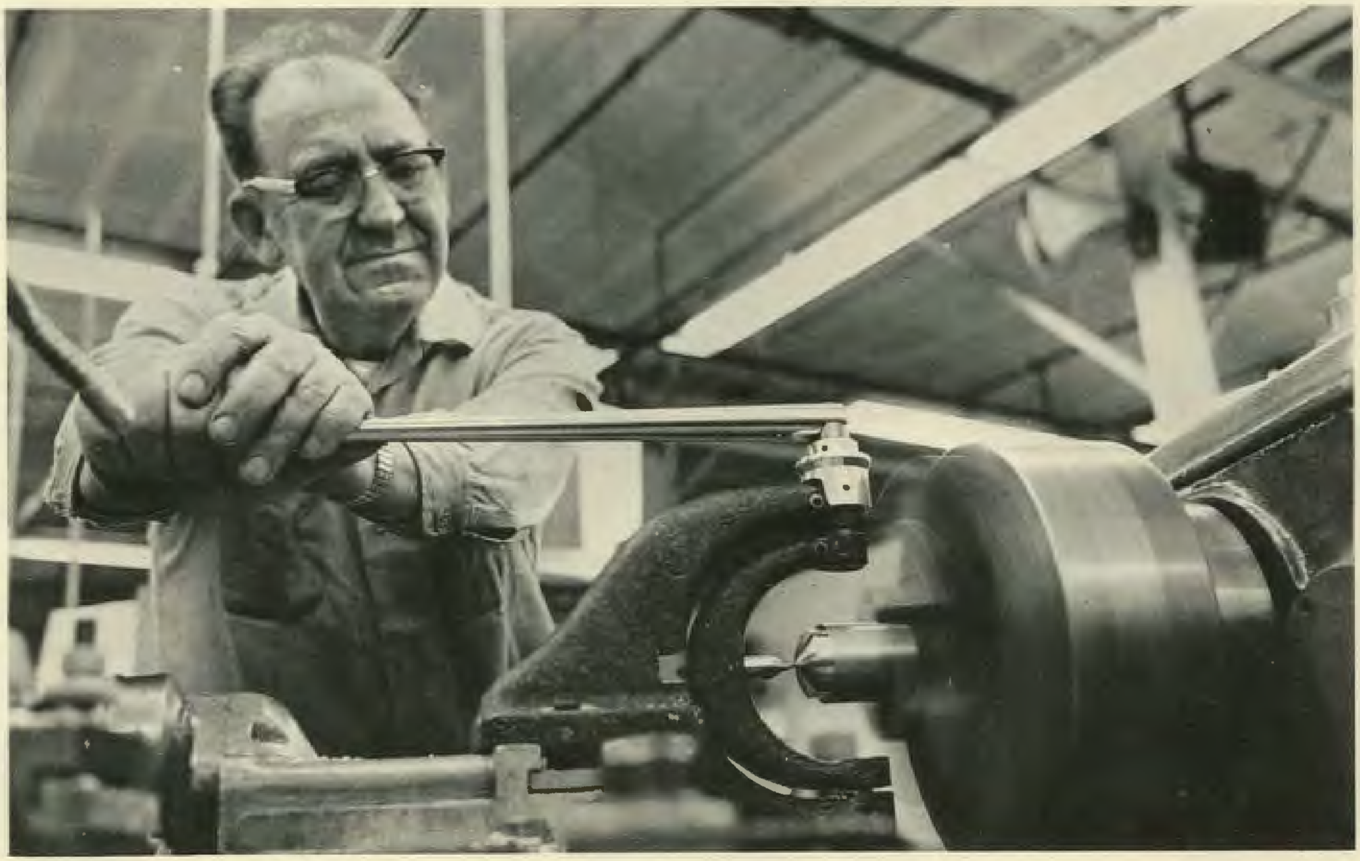
ORNL's Research Shops

YES, THAT NAME FITS ORNL's shop facilities, one of the most interesting and challenging shop operations in the world. The research shops are spotted throughout the Laboratory to fill the highly specialized needs in its overall research structure. Smart theory confirmed by successful experiment performed with suitable hardware leads to scientific progress. New ideas often call for unique or modified hardware. And that is where research shops come in.

Background

In the early days, as each division in the Laboratory organized itself, it included some sort of small research shop. As the research effort increased and diversified, scientists needed relief from the administrative details of shop operation. A committee was formed that decided on the establishment of a Research Shops Department that would operate all the small shops and in

Carl R. Evans, recently retired from Plant and Equipment Division, turns an external radius while making hemispheres on a lathe in the 3024 shop.



addition establish a large central one to increase the total capability. Paul Kofmehl and Earl Longendorfer were the experienced professionals who came to ORNL and accomplished that task in 1947. Continuing growth of the Laboratory brought about expansion of the shops. The Department name was changed to Central Machine Shops, and in 1959 the machine shops and general craft shops were combined into the present Fabrication Department, operating within the Plant and Equipment Division.

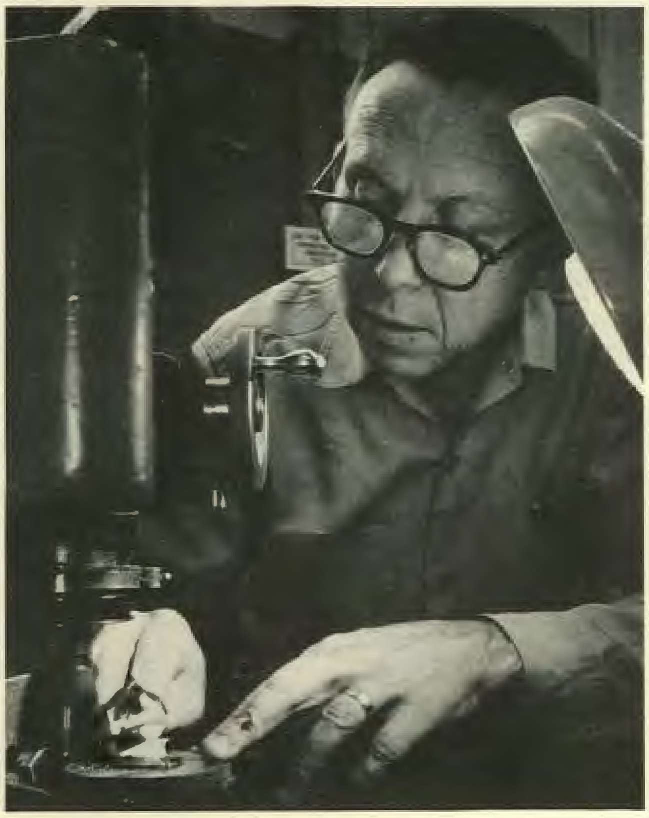
The Prime Ingredient

Since the first X-10 research divisions were mapped out on the mud of plant construction, the skilled craftsman has made his contribution to every major successful experiment, beginning with criticality of the Graphite Reactor. The variety of experimental hardware demands is enormous in a large and diversified research laboratory. That makes ingenuity the first name of the game in research shop work. The heart of shop capability is the skilled craftsman, who guides his tools and equipment to transform materials into geometric and useful works of art. Today hundreds of man-years of shop craft skills go to back up ORNL research — a tremendous inventory of competence established through experience, training, and self-development of the craftsmen. This inventory is, moreover, augmented by experienced Department supervisors and engineers, by frequent technical assistance from other Laboratory departments and divisions, and by assistance from other AEC and industrial installations.

The Constant Challenge of Change

Today's technology is far advanced from 1943. Preparation for tomorrow's requirements started yesterday and won't stop.

Ever wonder why knobs on machines always give the proper instructions? People like Plant and Equipment Division's D. J. Nelson custom make knobs with the proper instructions — whether it's "push," "pull," an arrow, a radiation symbol, or whatever. Here Nelson operates an engraving machine in the 3024 shop.



ORNL research and development work has changed since the day it began, it is changing today, and will continue changing so long as progress of the Laboratory continues to pace the increase of scientific knowledge. In almost every case, expansion of research requires an adjustment in the research support effort. So it is that the key combinations of men, machines, materials, methods, and money continually vary in research shop work.

Flexibility is as essential as breathing. The small experiment may require only that a craftsman be available to the researcher who conceived an idea, plans the experiment to prove it, and tells that craftsman what to make or do for him. By contrast the major experiment or project may require several groups of men in separate crafts with assistance from technical and supervisory personnel in the shops. Here the scientist has decided what needs to be done, but has turned the job over to design engineers and others to complete the details. In either case the basic measure of shop flexibility is found in the individual craftsman. He must be well grounded in a breadth of knowledge and ability for his craft. That is the major tool within his grasp for every job. It is his adaptability that enables his shop to meet the next requirement — large, small, easy, or difficult.

New materials are a never ending challenge in the shop. The best way for cutting, forming, or joining each new metal, ceramic, or plastic is a search goal several times each year. New or revised methods and processes often contribute to a success with a new material, as well as being economic goals within themselves. More stringent product requirements are applied to familiar materials and methods also. New types of equipment and improved models regularly require evaluation based on present and anticipated research hardware needs.

This commitment to meet the constant challenge of change is shown in the wide use made of many industrial, technical, scientific, and managerial periodicals and books. Training efforts and equipment acquisitions also contribute. The effort pays off each time a new job requirement is satisfied.

In addition to learning about the new methods, materials, equipment, and changing requirements, the craftsman must translate his knowledge into satisfactory practices. Only then can the advantage accrue to the Laboratory. This means that training is a job never completed. Much of the training of craft, technical, and supervisory shop personnel is self-development. A good many craftsmen use the Company educational assistance program. Much of it is acquired on the job. Classes and audiovisual materials have periodic use, many in informal sessions. More formal training efforts include the apprentice program and welder certification. The apprentice instructors and craft committee members are almost entirely persons with extensive practical experience and proven capability in craft work or engineering. Course material is revised or added to keep pace with changes in shop work. Guidance, coordination, and supervision assistance in the apprentice training is supplied by the Personnel Development and Systems Department. One of the most recent additions to the studies for machinist apprentices is a basic physics course. The welding technologists maintain contact with the Welding Laboratory in the Metals and Ceramics Division, do independent development and qualification work on new welding procedures, and train

Precision welding at the 7012 Central Mechanical Shops. Hugh Binkley, Plant and Equipment Division, welds a pipe section to a Type 316 stainless steel bellows for a VOG Filter Box assembly.

welders to certification on ORNL welding procedures. One welding engineer from the Metals and Ceramics Division is on loan full time to the shops for technical assistance in welding equipment, process, and procedure development.

Shop Technology

The foundation of shop technology is the tremendous fund of craftsmanship brought to bear on the requirements for cutting, forming, shaping, and joining all materials. The glassblowers, work analysts, and welding technologists add to that foundation; and the supervisors, designers, and engineers add to the structure. Since 1943 the enhancement of technological know-how has come also from association with the scientific, technical, and administrative personnel in other departments and divisions of the Laboratory. Individual, group, and cooperative efforts toward increasing this shop technology are recognized as continuing essentials for meeting the research support needs of tomorrow.

Other Services

Few members of the research staff have occasion to see more than a fraction of the research shop facilities; and even if they did, the resources beyond the in-house work force and equipment would not be evident. Urgent research schedules can demand more shop work than the work force can do, or a particular job may require a size or type of equipment we do not have. The Department meets such needs by coordinating the necessary assistance from other AEC installation shops or vendor shops.

Other services available include development of experimental apparatus, consultation on materials selection, and consultation on weld joint design. Value analysis is a term familiar to every shop supervisor, and each is encouraged to apply it whenever applicable to the advantage of the Laboratory.

Some advertising man once wrote, "A taste of precision is like a sip of fine wine." Both are attractive to many people, yet overindulgence is expensive and wasteful. Shop craftsmen are proud to split hairs for accuracy when needed. They do not, however, waste valuable time in exceeding specified precision because that is uneconomical. One related cost in shop work is fine finishing: nonessential beautification of work finishes is discouraged in the shops because of cost. Still there are many small parts that require a fine finish or polishing. Such parts have intrinsic beauty that has a tremendous appeal for many people over the rugged utility of the larger forms and rougher textures. Good craftsmen think and talk quality of workmanship and accuracy more than job appearance, but the feeling each exhibits for his work usually indicates true artistic involvement also. Perhaps "pride in craftsmanship" is the way it is best phrased.

How It Is

Scientific research and development doesn't originate in shops, but the hardware for it does. Research hardware that is commercially available can be very good. Most of it is probably adequate for routine investigations. A research shop can

To position a crystal in a cryostat the proper equipment is a goniometer such as the one R. E. Hopper assembles here in the shop at 3025.

seldom compete with the market price of standard research equipment. However, demands for unique equipment or improvement of the standard types call for the custom job best achieved in a research shop.

There is good basis for relying on the synergism of efforts toward common success. A craftsman who understands the need for, and function of, the thing he makes usually relates it to his practical background and experience. Sometimes he can spot an overlooked detail requirement or otherwise contribute toward improving the end result. Most craftsmen are pleased when it is possible to help in that way, and they do it willingly when communication is established. A recent instance of good communications and helpful results is the NASA support on lunar sample tools and containers. Design engineers, supervisors, and craftsmen worked successfully as a team on tough jobs with a short schedule. Another example is the Metals and Ceramics Division's fundamental improvements on the famed Kratky x-ray camera. Still a third is the expansion of the capabilities of the electron microscope in the Isotopes Division.

While the knowledge of a good job well done is basic satisfaction to the craftsman and his supervisor, it is really the variety in the ORNL shop work that holds the special appeal. It's a good bet you wouldn't get much of an argument on that from any of the craftsmen in the Laboratory's research shops.

To drill a deep hole in a large metal part, W. A. Baker employs a long bit in the radial drill press.

BOOKS

The User's Guide to the Protection of the Environment, by Paul Swatek. Ballantine Books (1970). 312 pages with index, $1.25, paperback.

(Reviewed by D. J. Rose, director of Long-Range Planning.)

WANT TO KNOW WHAT TO USE against mosquitoes, without upsetting God's earth too badly? Want to know which laundry detergents have low phosphate? Want to have a thousand useful facts about living a little more elegantly, a lot less pollutingly, also more economically, all for a buck and a quarter, plus tax? Paul Swatek can help you.

Friends of the Earth, a non-profit that tries to do what its name suggests, has tied up with Ballantine Books, Inc., to turn out a number of useful environmental books. No shrill crying and wailing here, or holier-than-thou hand-wringing and alarm-viewing. This book gives lots of material in sensible, readable, even entertaining form; I have seen much in it that I know to be correct, and very little that I know to be in error.

Swatek brings together material from U.S. Department of Agriculture Surveys, from the ACS monthly *Environmental Science and Technology*, from many other places, and lays it out under 14 headings, which range from shelter to managing waste, with many in between. He endorses a principle of thoughtful frugality, which appeals to my Scottish nature. Far from taking the line of eco-freaks or neo-Luddites who want to turn off all pesticides and stop everyone else's cars, he tells us which pesticides do the best job and least unwanted damage — malathion for chiggers, chlordane for termites — and which cars give the best gasoline mileage. He also suggests how to get the most out of what you do use, at simpler levels: use paper straws for your soft drinks instead of plastic ones, or don't use straws at all; buy the drink itself in a returnable bottle, not in an environmentally expensive aluminum can; remember to return the bottle. All this saves money, too.

Packaging is a big problem. Paper and paper products make up nearly 50% by weight of municipal refuse, and over half of that is packaging material. Do you need your loaf of empty-calorie bread in a plastic bag inside another paper bag? The French put better bread *au naturel* in their shopping baskets.

Some things are better done in the old-fashioned way: old cloth for dusters, hanging up the clothes to dry instead of putting them in an electric dryer, as examples, but as Swatek points out, many new ways are truly better too: peas, cut corn, orange juice, and many other perishable foods are usually better and environmentally less costly when purchased frozen than fresh; this is so because of the real and indirect costs of shipping, special containers, etc., required for the fresh things.

Buy the book: this is a free commercial. But there is more to all this than money, or economy, or "stopping pollution," or the narrow aims. If we can stop walking all over our neighbors, maybe we won't trip on our own shoelaces so much.

A Peril and a Hope: The Scientists' Movement in America, 1945—47, by Alice Kimball Smith. M.I.T. Press, Cambridge (1971). 388 pages + index (paperback), $3.95.

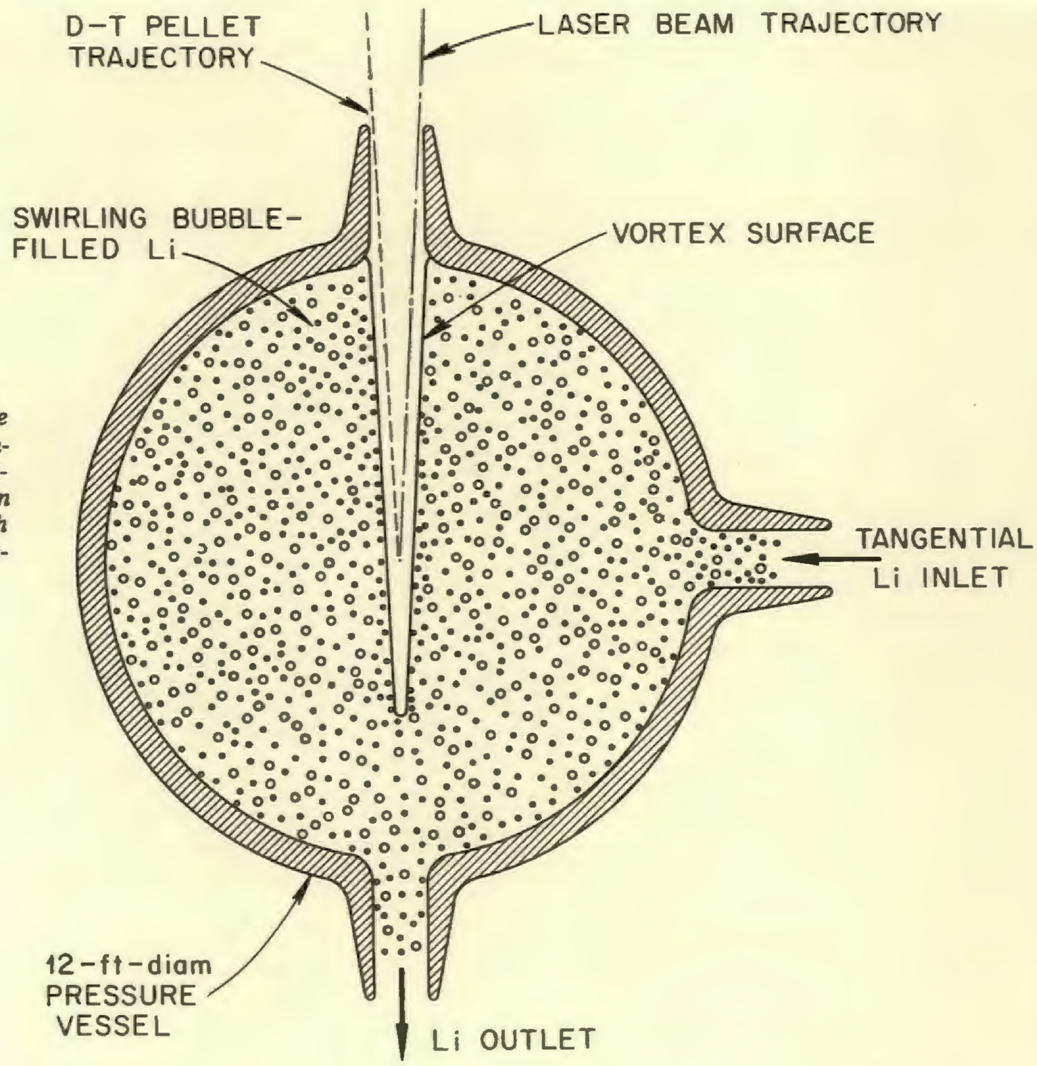
THERE IS BOUND TO BE INTEREST in this reissue of Mrs. Smith's document, in condensed form, originally published by the University of Chicago Press in 1965. For the dozen or so Oak Ridgers still at ORNL who are mentioned in the book, it will evoke strong memories of those days following the war's end when the country's nuclear scientists joined in an intensive involvement with politics. Its relevance to the current theme of technological assessment and today's movement toward increased communication between the natural and social scientists is undoubtedly the reason for its resurrection. It marks the point in time when "science became politically interesting, and scientists became interested in politics," to quote Joseph H. Rush, physicist at Clinton Laboratories and activist in Association of Oak Ridge Scientists (AORS), in 1947. *—B. L.*

A little spin-off from the research on controlled thermonuclear fusion is recounted here in a staff-written article on an almost portable fusion-driven power generator being looked into by Art Fraas, associate director of the Reactor Division. Based on an idea born of early development of fusion reactor trigger devices, the work has minimal funding, but shows enough promise of feasibility not to be ignored. Fraas (left) goes over some of the paper work with M. E. "Mack" Lackey, engineer carrying out the project's hydraulic tests.

the BLASCON
a new approach to fusion power

ALTHOUGH NUCLEAR FISSION OFFERS THE CLEANEST source of economical energy yet envisaged, the construction of nuclear power plants has been seriously delayed in some sectors by controversies over the acceptable amount of radioactivity that can be released to the environment.

Many scientists and engineers, including some at ORNL, believe that there may be an answer to the energy dilemma in nuclear fusion. Although not yet shown to be feasible, if controlled fusion were to become a reality it would overcome many of the obstacles now facing fission reactors. Since the fusion process itself is dependent on the power input, any event that caused a power shutdown would automatically shut off a thermonuclear reactor, a phenomenon that constitutes a built-in safety device. Another advantage to fusion is that its operation would create, by way of volatile radioactive waste, the less hazardous tritium, which



The principle underlying the blascon is that when an intense laser beam hits a deuterium-tritium ice pellet within a spherical vessel filled with liquid lithium, a fusion reaction will occur.

can subsequently be burned in the reactor. All of these safety features add up to a power center that could be considered to be a good neighbor.

Besides tritium, the fusion reactor would use as fuel the very plentiful deuterium. This isotope of hydrogen abounds in the oceans and throughout the solar system; the need for tritium as a fuel can be met by bombarding either deuterium or lithium with neutrons. Lithium, though of no extensive commercial value, and consequently not mined in abundance, is believed to be plentiful in the earth's crust. It is relatively inexpensive to mine.

The most widely publicized studies of plasma containment have concentrated on concepts involving huge machines that would serve large communities but be impossible for such purposes as motorized sea or land transportation or space travel. The Russian Tokamak and the U.S. ORMAK and Scyllac and Stellarator, enormous as they are, are but models of the vast containment devices ultimately envisaged for practicable control.

Now, a small amount of money is going into a new concept of plasma research, one based on studies of the past ten years in high-peak power, using pulsed lasers.

If an intense, focused laser beam is directed at a frozen pellet of deuterium-tritium, absorption of the incident radiation may result in ion temperatures high enough to induce thermonuclear reactions and ignite the D-T pellet. Art Fraas, associate director of the Reactor Division, has evolved a conceptual design for a 12-foot-diameter spherical reactor based on this approach, and is currently investigating its feasibility in cooperation with M. J. Lubin of the University of Rochester, where the concept is also under study. Jointly, the two are working with a fusion reactor model dubbed by

Mock-up of vessel in 9201-3, showing the central vortex that must be sustained, at the same time maintaining a bubble content in the surrounding liquid. Mock-up is with water, in plastic, about the size of a backyard soap kettle.

Thermonuclear Division Director Herm Postma the "blascon."

Historically it was consideration of this process as a means for igniting the plasma in a large thermonuclear reactor that led, in March 1969, to the idea that the explosions might be contained in a properly designed pressure vessel, and that a reactor power output of perhaps 200 Mw(t) might be sustained by exploding the pellets at perhaps 10-second intervals. The kind of laser needed for success in this project has not yet been developed, but work is under way in other laboratories on a beam of suitable properties. These include: (1) an extremely high power, some 1000 times as strong as the most powerful laser now in use; (2) extremely high efficiency, at least 10%; (3) an extremely fine focus; and (4) a very short pulse duration — of the order of 10^{-10} second. Lasers vary widely in these characteristics, but Fraas thinks success hinges on a combination of all four.

A final condition for success is that the energy from the blast be absorbed in such a way as to yield useful and economical power. For the blascon fusion system to operate, the fusion energy output has to be at least a hundred times the amount of energy input required for the laser beam. This would put the minimum energy output for a workable system equivalent to several hundred pounds of TNT. Absorption of this amount of energy would, under normal circumstances, be impractical, as it would require a vessel with walls of unmanageable thickness. Fraas believes, however, that a wall thickness of only a few inches can be used if the blast wave can be cushioned by filling the liquid surrounding it with a suspension of fine bubbles.

Making use of the detonation studies done in the Civil Defense Project by C. V. Chester and Lawrence Dresner, he has been conducting research on the amount of stress a pressure vessel for a laser-ignited fusion reactor would have to withstand if the D-T pellet is ignited in the center of a molten lithium whirlpool. The trick is to introduce fine bubbles to the extent of about 5% of the volume into the swirling liquid while maintaining the proper liquid throughflow rate, and at the same time a long, fairly immobile vortex.

If this can be done, some preliminary tests with strain gages on a plastic model indicate that the wall thickness of a 12-foot-diameter spherical vessel could be reduced from a theoretical 30 inches to between three and six inches. Today it is not practicable to build a steel pressure vessel with a wall thickness of much more than 12 inches, not to mention the prohibitive cost. A six-inch-thick vessel, on the other hand, is readily fabricable and its cost would be relatively low.

Fraas has filled his Plexiglas blascon model with swirling water to simulate the molten lithium. Water, in addition to its obvious advantages, actually resembles liquid lithium in its hydrodynamic behavior. Results of his experiment are not yet conclusive, but Fraas and other ORNL researchers are at this point optimistic about the outcome.

They believe there is a good chance that the laser laboratories will be successful in producing a laser with the necessary characteristics to ignite D-T pellets. If the problems can be solved, a fusion reactor can be built in power capacities as small as 20 Mw (around 30,000 hp) electric output. Such devices would be suitable for use on ships and spacecraft, and conceivably could even be used to electrify railroads and supply power for high-energy-content storage batteries for automobiles.

AMW COMMENTS

ON BETS: TECHNOLOGICAL AND SOCIAL

For the past 20 years I have had great fun (and have made a little money) betting on long-range technological and social developments. I almost never bet more than $1 unless I know the other fellow is independently wealthy, in which case I have gone up to $20. The bets usually run from five to 25 years. I keep a bet record in my much-prized GE daily calendar, and each January I meticulously transfer my bets from the preceding book to the new one.

By and large, I've been rather successful in my bets. My strategy is simple: I bet pessimistically *on the future of technology, and* optimistically *on the future of the world. Now this will no doubt strike most people as being the reverse of common sense; yet I think there is a certain logic to my position, a logic supported by the money I've made by following this strategy.*

Let me show how my betting works. Take controlled thermonuclear energy, for example. At the 1955 Geneva Conference, Homi Bhabha declared that within 20 years controlled thermonuclear energy would be shown to be feasible. I bet him $20 (he was independently wealthy) that he was wrong. Unfortunately, Dr. Bhabha was killed in a plane crash before the 20 years elapsed; but in the meantime I was able to contract a dozen or so other, shorter term bets on the same subject with many fusion enthusiasts — Harry Smyth, John Cockcroft, Ed Shipley, Bennett Lewis, and others. These bets, each for $1, run until the end of 1971; I'm sure I'll collect about $12 by then. I have some longer term bets on fusion that will be decided by 1980, though I confess that, with the current enthusiasm about controlled fusion, I may lose some of these.

Here are some I've won: a 1960 bet that the nuclear rocket wouldn't fly by 1969; a 1968 bet that fossils would not be found on the moon by 1970; a 1967 bet that the Soviet 600-Mw(e) fast breeder would not be running by 1971; and a 1965 bet *that brackish water would not be desalted for as little as 30 cents per 1000 gallons by 1971.*

There is one place where my pessimism about technology didn't work. I had bet many dollar bills that we wouldn't get to the moon by 1970. As I watched Neil Armstrong and Buzz Aldrin walk on the moon, I made out a dozen $1 checks which I mailed the next morning.

My optimism on the state of the world hinges around the nuclear deterrent. I have made quite a few dollars betting that World War III would not occur by such and such a date; right now I have several active ones going setting the date past 1973, 1975, even 1985. And I've even ventured a dollar on the proposition that by 1975 no more than six nations will possess nuclear weapons. This one may be a little shaky since five countries admit to possessing them right now.

How do I explain my success at betting pessimistically on technological progress? I think it has to do with a certain hypnosis that the extraordinary wartime success in nuclear energy imposed on the technical community. Many of us sometimes forget that fission is a miracle, and that miracles don't necessarily repeat themselves. Because the bombs and reactors worked doesn't mean that everything else is going to work.

But there is perhaps a subtler reason why I've done so well with my betting. In this era of Big Science, especially with budgets tightening, big technological projects are necessarily in competition with each other. If one isn't enthusiastic about one's own project, no one else is likely to be enthusiastic about it: the other fellow has his own pet way of curing cancer or building a breeder. Such a situation is ready-made for honest overenthusiasm—and, in betting the way I do, I simply count on this overenthusiasm. No matter what date an enthusiast gives, I merely add a few years and collect my dollar bills; I never bet that something is impossible.

Why, then, was I so wrong about the man on the moon? Here I confess to falling into another common error — going too far in underestimating the other fellow's chances of success in a technology in which one is not expert. But, altogether, my system works surprisingly well.

As for my success in betting optimistically on man's future, I am merely assuming that people, by and large, are rational. The monstrous irrationalities mankind falls into are not the result of purposeful knavery so much as shortsightedness. Of the irrational futures threatening mankind, thermonuclear war probably remains the most worrisome. Everyone realizes the big nuclear war is insanity. All I am doing in betting against nuclear war is making the assumption that the people in charge of pressing buttons are, and will continue to be, sane. So far I've won money this way.

What about the other catastrophe that faces mankind — the social disintegration of the world as the population reaches 10 or 15 billion, say by the middle of the next century? I haven't made any bets on this one; yet, if I found someone who I thought would pay off to my great grandchildren, I'd probably bet that the world 100 years from now won't be as miserable a place as all of us fear it might be. This is what much of what we're doing is all about — trying to create a technological base which will enable the billions who come after us to live in some human dignity. I couldn't possibly *bet against our ultimate success in this basic task!*

Alvin M. Weinberg

Clint Fuller, who brings us this account of the UT-OR Biomedical Graduate School of which he is one of the architects as well as its charter director, received his bachelor's degree at Brown University, his master's from Amherst, and his Ph.D. from Stanford. He came to Tennessee and his present position in 1966 from the faculty of Dartmouth Medical School, where he had served as professor of microbiology as well as chairman of the department. During his career he has gathered experience in radiation biology at both Lawrence Radiation Laboratory and at Brookhaven, and served one year as a National Science Foundation Senior Postdoctoral Fellow at Oxford. When he leaves next fall for a faculty post at the University of Massachusetts at Amherst, he will have spent five years at the Laboratory building and getting into operation an educational experiment that can now be seen to be highly successful and productive.

THE CAMPUS IN 9207

By CLINTON FULLER

THERE IS AN APOCRYPHAL STORY about the origin of the idea of developing a full-time graduate school of the University of Tennessee at Oak Ridge. When Mary Bunting, president of Radcliffe College, was appointed to the Atomic Energy Commission by President Johnson, she undertook a tour of the national laboratories and, in a lighter social moment with ORNL Director Alvin Weinberg, accused him of running a national laboratory that was the "eunuch of science." Here he was, she said, sitting around directing all this talent and utilizing the production of scientists from all over the world, and doing absolutely nothing about reproducing the species. No matter how mythical this story may be, it does indeed appear to offer a sound reason for initiating, in 1965, the University's Biomedical Graduate School in Oak Ridge.

Actually nothing as complex as graduate education gets started so simply. Long discussions were held among Biology Division Director Alexander Hollaender, UT President Andy Holt, and such national figures as Commission Chairman Glen Seaborg, National Institutes of Health's James Shannon, and Office of Science and Technology's Donald Hornig. As a result, a group that included Jim Liverman, Howie Adler, and representatives of both the administration and biology departments of UT then sat down together for a year of planning. They decided early that the school was to be a joint operation of the University and ORNL that would (*a*) guarantee the academic prerogatives of the University of awarding graduate degrees and (*b*) in no way threaten the major research prerogatives of the Laboratory. With the approval of the UT board of trustees and a

Prof. Mayo Uziel lectures for a course he teaches with Prof. Waldo Cohn. Clockwise around the table, from left: Chuck Stiles, Pat McClintock, Maurice Cohen, Cohn, Gene LeClerc, Rick Krogsrud, and Janice Longstreth.

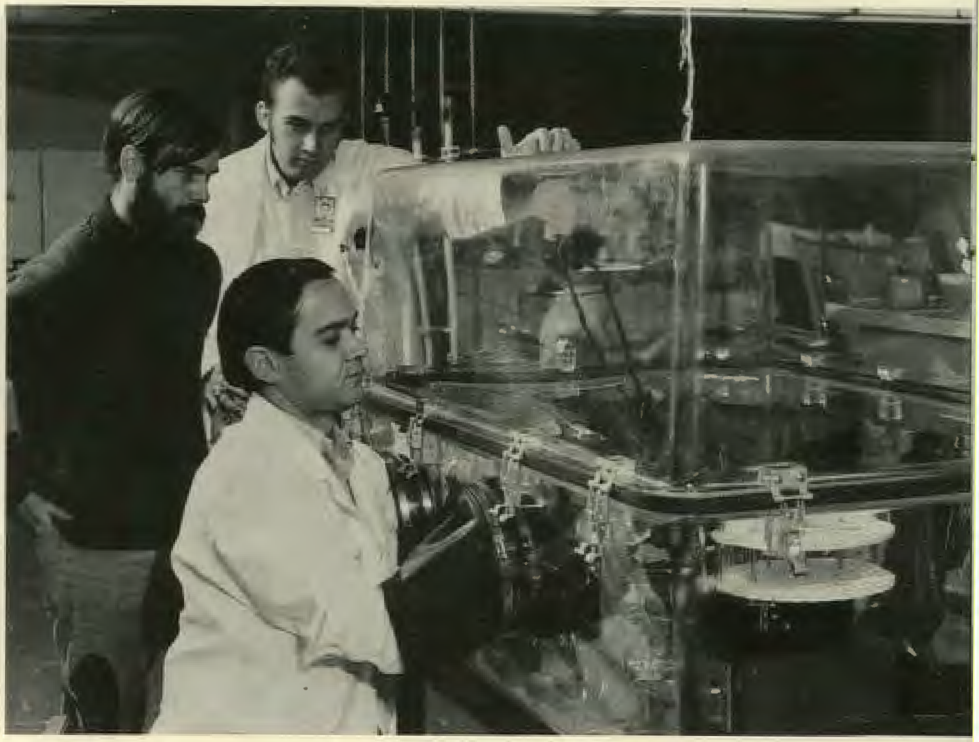
magnanimous gift from Union Carbide, a director was appointed in late 1966, and classes began in the fall of 1967 with seven students and the tremendous goodwill of all who had been involved. Since that time the school has grown and flourished so that it currently serves over 30 full-time Ph.D. candidates and close to that number of postdoctoral trainees, plus a full-time faculty of five UT professors, an administrative staff of four, and is proudly anticipating the graduation of its first six or seven students in 1971.

Why Here?

The interest of local and national leaders in science and education has been mentioned. They proposed that the outstanding facilities and talents of the federally supported research institutions be more fully organized for graduate education. A school for the biomedical sciences was therefore established under the joint auspices of the University of Tennessee and ORNL's Biology Division. The school, which is the first of its kind in the U.S., is housed in Biology's Building 9207 and makes use of the division's staff and extensive research facilities, as well as the staffs of other Laboratory divisions, for the educational program. The school offers an individualized program for full-time graduate study leading to a Ph.D. degree in the biomedical sciences awarded by the University of Tennessee. Postdoctoral training is also provided and positions are available for those who have Ph.D., M.D., D.V.M., or D.D.S. degrees. In such a way, the school makes available to applicants across the nation the talent, experience, and staff of one of the world's largest research institutions, bringing the most advanced research methods and technology directly into the mainstream of full-time graduate study in the life sciences.

Among the school's prime functions is the enhancement of the graduate effort in the southeastern United States. There would have been little point in placing such a school in Boston, Chicago, or Berkeley because of the already strong graduate programs saturating those parts of the country. The southeastern U.S. has lagged behind in education in all areas, but graduate education has been in particularly bad shape. In a recent study by the National Academy of Sciences, the states of Tennessee, Alabama, Mississippi, and Kentucky have had the poorest record in training Ph.D.s, bringing outside Ph.D.s into the area, and retaining those that they did produce. Therefore, the implementation of such a program by a large and

Prof. Franklin D. Hamilton makes a point.



Prof. Frank Gaertner instructs incoming students McClintock (1.) and Rick Welch on the use of a clean box in an anaerobic biochemistry experiment as a part of the lab rotation courses offered to first-year students.

growing state university with the full support and facilities of the national laboratory seemed to be an efficient, practical way to help overcome some educational hurdles in the Southeast.

In addition, a school of this kind is not to be competitive with other growing graduate educational efforts in the Southeast, and particularly those of the state university. There are special things that can obviously be done better at national laboratories than at universities, and, although the school has a strong multidisciplinary approach toward the biomedical sciences as its educational base, the areas of specialization, which include basic biology and medicine, will also include scientific endeavors that could not be carried on easily in a Southern university without huge investments of facilities, people, and money. For instance, the mammalian genetics facility in the Biology Division is probably one of the largest in the world. The need for training individuals to work in mammalian genetics, what with the pressing problems of population, disease, and related matters all over the world, has become critical, and yet this facility was not being used in any purposeful way for the training of such individuals. Two of the first Ph.D. candidates to be coming out of this program will be produced by Liane and Bill Russell and their world-renowned genetics groups. Other students, it is hoped, will be going the same route, and this certainly could be one of the world centers for the production of Ph.D.s in the area of mammalian genetics.

Multidisciplinary approaches toward other critical areas, where forces within the Biology Division can be marshaled in a unique manner, will obviously contribute to the national professional effort in a way that many universities cannot do so well. Therefore, not only does the Biomedical Graduate School add to the excellence of education in the Southeast and at the University of Tennessee, but it is additive in terms of scientific output as well.

Structure and Philosophy

In 1946 Alexander Hollaender set up the Biology Division of Oak Ridge National Laboratory. It has since grown to be one of the largest biomedical research institutes in the world. He had before him a primary mission, which was to look into the effects of the newly created hazards of radiation on man.

With great prescience, and the realization that this was not a simple engineering problem, he seeded the division with sound, basic, multidisciplinary scientists as well as people who could more directly apply their findings to the long-range

Cynthia Warner confers with LeClerc in her office, typical of those provided all the students.

Ray Fenwick and Ron Sheehy operate a scintillation spectrometer in Prof. Roy Curtiss's laboratory.

mission. He very wisely decided not to compartmentalize the effort. Therefore, as an educator coming into the situation to establish a full-time educational program, I was confronted with what can only be described as a great amorphous mass of scientific excellence. How does one build a cohesive educational training program on a diverse and unstructured entity? That was the challenge, and the solution turned out to be not as difficult as it had at first seemed. As a matter of fact, it was a great opportunity to be free of departmental lines of established university programs where, in order to move into multidisciplinary areas, one must cross over rigid administrative barriers.

I decided to put together a program that would embody a core of basic biomedical sciences regardless of the area of specialization or the eventual mission of the student at the termination of his training. This core, which is made up of genetics, cell biology, biochemistry, mammalian physiology, and biophysics, is the in-depth experience of the students in their first year. Again, because of the lack of structure and the lack of the day-to-day regimentation of the university system, we didn't have to meet in scheduled classes at 9:00 Monday, Wednesday, and Friday and worry about conflicts. Therefore, the didactic part of the course was grouped in the early part of the week to allow the students to spend at least 50% of their time in uninterrupted research.

Indeed, the training apprentice system and tutorial approach can be achieved more easily and realistically in this non-structured environment than in most university programs. A student is plunged in depth into a research laboratory for a period of at least three months, not just to learn the techniques of a particular area of science, but to learn how to approach and carry out research in certain areas. A student who has had a good training in cell biology may go into a biochemistry lab his first quarter, a genetics lab his second quarter, and perhaps a cancer and virus lab for his third quarter, thereby getting a diversity of technical experience as well as seeing how different areas of the biomedical sciences are approached. During his first summer, or fourth quarter, a student is given an option to go back into one of these labs and take a closer look at some subject he may have become interested in. In most cases the student will choose this as his thesis lab. By the start of the second year of his work, then, he may already have had an in-depth experience of over six months in his thesis area. Much to our surprise, two things have happened. First of all, many of the students have changed their minds about what they thought they wanted to do in science; and secondly, because of the full research experience early in their graduate career, the time it usually takes to get a Ph.D. has been considerably reduced. Regardless of their background before coming, many of our students will finish their Ph.D.s in three and a half to four years, far faster than the average for biological sciences.

Staff and Facilities

From the very beginning it was clear that, whereas there was a vast array of talent for teaching and training students in the laboratories, this was a comprehensive, full-time educational program and needed full-time educators to coordinate it. Therefore, in addition to the director, a full-time faculty of the University of Tennessee has been put together to guide the educational aspects of the program. These comprise, among other services, course planning, student advising, and managing qualifying exams. As a member of this staff, as well as director, I manage to teach a little upon occasion in spite of my administrative and managerial responsibilities, and still find it the most challenging part of my operation. A new associate director and professor, Roy Curtiss, has recently joined the full-time faculty of the University. Roy has the true multidisciplinary approach toward problems of science in our society. He not only has wide interests in the area of biology, he is senior editor of the section on genetics in the *Journal of Bacteriology* and serves as well on the Oak Ridge city council. In addition to these wide responsibilities, his main role in the school is the coordination of the teaching efforts of its vast, amorphous staff in order to make sure that the various subjects in the curricula are properly taught and that the staff of the Biology Division is fully attuned to the needs and desires of the students. Donald Olins, who is an associate professor of biomedical sciences and teaches courses in physical chemistry of macromolecules, has been coordinating the laboratory experience for all the students. He comes from the only analogous institution in the country, the Rockefeller University in New York City, and is well aware of the special needs of students and the special opportunities and limitations of establishing graduate education at a research institute. A more recent arrival is Frank Gaertner, who received his Ph.D. at Purdue and spent some time on the research staff of the University of California San Diego at La Jolla. Gaertner, who specializes in subcellular organization and control mechanisms, has one of the most challenging responsibilities of the coordinated educational efforts of the school. Besides his own research and teaching in biochemistry, he is in charge of what can best be described as a required course for all entering students in scientific communications.

In these days, science not communicated is science not done, and the public as well as other scientists face a real communications problem. Many scientists are not trained as effectively as they should be to carry out these responsibilities. Therefore Gaertner, with the aid of John Gilbert, who has nine years' experience in the scientific editorial office, teaches a course that involves the analysis, presentation, and writing of science effectively.

In January 1971 the fifth full-time staff member was appointed. Franklin Hamilton, in addition to his research and teaching activities in the school, will have the challenging job of coordinating new graduate and undergraduate programs with the predominantly black liberal arts colleges in the Southeast: a new project and area of development for the school.

The Gown in the Town

One of the key factors in making a coordinated, comprehensive group of this education operation was the housing of students in Oak Ridge. Oak Ridge is very much a family-oriented, spread-out town, and students can feel the isolation more acutely than in an urban or academic environment. The University of Tennessee very wisely purchased eight adjacent E-type buildings and had them converted into comfortable apartments plus, with more financial help from Union Carbide, a student recreational center. Here, with 30 dwelling units, the students indeed have their own community in Oak Ridge, and a whole new generation of citizens contributing to that and the larger community is the happy result. Their participation in Oak Ridge affairs is by now common knowledge. Gary Dunn, one of our mammalian geneticists, participates regularly in the Playhouse programs; Harvey Bank has been active in environmental problems and is president of EACOR, the town's environmental action committee; there are many other cases of student involvement. Perhaps, as well, one of the greatest contributions the school has made to the community is the input of student wives. Many of them have assumed teaching, business, medical, and social responsibilities in the town. All in all, the benefits of having this new, cohesive generation in Oak Ridge are patent.

Looking Ahead

There is a current hysterical reaction and self-perpetuating propaganda campaign going on around the country regarding overproduction of Ph.D.s. Members of our faculty have had to prepare themselves with answers to the question, "Why are you building and developing new graduate education ventures that will simply flood the market further and dilute the jobs that are becoming more and more difficult to get?"

First of all, even though it may be realistic for the next year or two in terms of job security, such an outlook is a short-range view that could prove to be a real disservice to the future technological and sociological development of this country. Good people from good programs will always be needed. For instance, of the six or seven Ph.D.s that will be produced this year, all have jobs at distinguished institutions: Dale Graham: Biology Department, California Institute of Technology; Kenneth Roozen: Microbiology Department, Washington University Medical School, Saint Louis; Gary Dunn: Genetics Department, University of Edinburgh, Scotland; Ann Olson: Biochemistry Department, McGill University Medical School, Montreal; Stephen Fairfield: Roche Institute of Molecular Biology, Nutley, New Jersey; Gerald Price: Cancer Institute, University of Toronto.

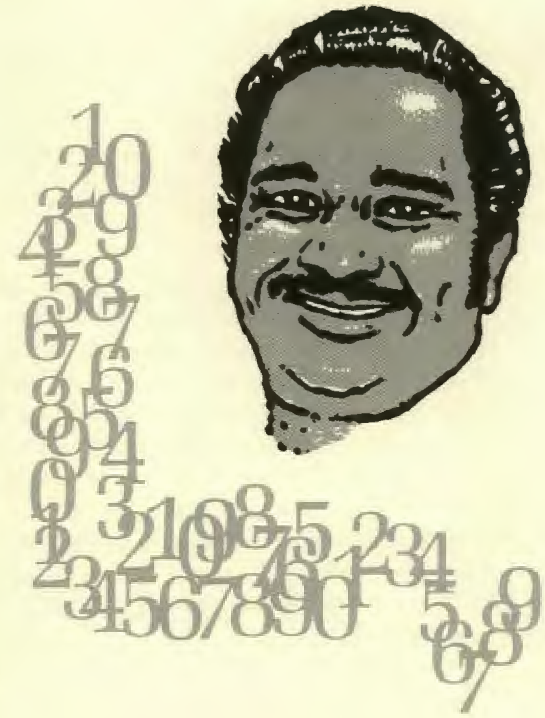
We hope that with the broadening postdoctoral training many of these outstanding new scientists will come back to teach and participate in science in the Southeast. Also, the current job shortage reflects federal cutbacks and the state of our economy. Granted that in times of recession or even depression, jobs are difficult to come by: are we thereby compelled to plan the future with a perpetual recession or depression in mind? Of course jobs and technology are going to expand if we hope to keep this country going. Figures are available to show that the rate of expansion of college graduates has been going on steadily since World War II, and according to the projected figures from the Office of Education for the next decade, the rate will not diminish. By 1980 we will be graduating 11.5 million bachelor-degree candidates. Unless we lower standards and dilute quality, the need for increased numbers of teachers is obvious. So the message to graduate students is, "Hang in there, kids; you are going to be in demand before long." And it is quite clear what we are doing to the supply for these needs in the near future if we hearken to the current cries: we are in danger of cutting it off in the face of ultimate demand. As fellowships disappear, the incentive for graduate education will disappear, and we are going to become very short of people. Added to the need for teachers will be the demand for technologists and scientifically trained people in all fields, from sociology to biochemistry, to cope with our population increase, as well as the insults we are effecting on our planetary environment.

What, to be more specific, are the needs of our particular region of the country, a region that has been educationally as well as economically and industrially deprived compared with the rest of the U.S.? Here the percentage increases will be even greater than they are projected nationally. For instance, of the 111 predominantly black liberal arts colleges in the country, approximately 100 of them are in the Southeast. These schools have not gotten the equal break with the increase in funding to educational institutions through science and research over the past 15 years. Yet more and more blacks are seeking higher education, and they offer a reservoir of talent in the areas of science and education that is relatively untapped. As these schools grow, and they are growing in proportion to the relative slowdown in some of the more established institutions, we will have available more and more talent and people who are currently in demand to teach in the Southeast and throughout the rest of the country as well. There is no oversupply of black scientists or teachers. They are very much in demand all over the country as the realization finally dawns of the great potential in this minority group. Therefore, a program has been set up under Professor Hamilton to begin to implement and utilize the latent talents of several of these schools in at least a small way.

There is a need for scientists in the future and a need to develop and train them in ways that are more meaningful to society. The short-term shortage of need will disappear. We must not overreact and cut off the supply of talent and then have to overreact again to catch up. A steady-on policy is called for as well as new approaches. Perhaps the University of Tennessee—Oak Ridge Graduate School of Biomedical Sciences at Oak Ridge can help maintain that steady policy and offer some new approaches to training scientists that will have new concepts and ideas in attacking the problems ahead.

Take A Number.....

BY V. R. R. UPPULURI



An Additive Characterization of Primes

Take a natural number, and see how many odd divisors it has. Then count the number of ways the same integer can be expressed as a sum of two or more consecutive positive integers. Interestingly enough, these are equal. For instance, take 15. The odd divisors of 15 are 3, 5, 15; and so the number of odd divisors of 15 is 3. There are exactly 3 ways of expressing 15 as a sum of two or more consecutive positive integers given by $7 + 8 = 4 + 5 + 6 = 1 + 2 + 3 + 4 + 5$. It can be proved that the number of odd divisors of n is exactly equal to the number of ways of expressing n as a sum of two or more consecutive positive integers.

Consequently, any number which is a power of 2 cannot be expressed as a sum of two or more consecutive positive integers. For example, take $16 = 2^4$; no matter how hard one tries, 16 cannot be expressed as a sum of two or more consecutive positive integers, because 2^4 does not have any odd divisors.

It is well known that the prime numbers (above 2) are all odd, and any prime has exactly one odd divisor. The first few prime numbers are given by 3, 5, 7, 11, 13, 17, 19, 23, 29, 31. We can see that for each prime there is exactly one way of expressing it as a sum of two consecutive numbers, such as $31 = 15 + 16$. This can be used as a defining relation to generate primes; but it is not clear whether this is a better way of generating primes on digital computers.

A famous conjecture attributed to Goldbach (1742) states that every number (greater than 2) is the sum of two primes. Now that we have an additive characterization of primes, does it shed light on this conjecture which still remains neither proved nor disproved?

A Property of 30

Many of us know that a prime number is a positive whole number which cannot be written as the product of two smaller factors. Neither 10 nor 21 is a prime number. But $10 = 2 \times 5$ and $21 = 3 \times 7$ have no divisor that is common to them both. Such numbers are said to be "relatively prime." The numbers 6 and 10 are not relatively prime since they have the common divisor 2.

Among all the numbers from 1 to 8, the numbers 2, 4, 5, 7, 8 are relatively prime to 9. Though 2, 4, 8 are relatively prime to 9, they are not prime numbers. Of all the numbers from 1 to 17 the numbers relatively prime to 18 are given by 5, 7, 11, 13, 17, and they are all prime numbers. This property of 18 is also shared by the numbers 3, 4, 6, 8, 12, 18, 24, 30.

The interesting fact is that 30 is the largest number that has this property that all the numbers less than it and relatively prime to it are all prime numbers.

to the editor:

THERE ARE ALL TOO FEW accounts of scientific research which are written in a direct, personal manner and Ellison Taylor's story "The Great Polywater Doodle" (*ORNL Review* Winter issue this year) is one of the delightful exceptions. It is good because it honestly conveys the kind of thoughts that go through every scientist's head when he is competitively involved in an important problem whose resolution is unknown. A sense of frustration and righteousness pervades Taylor's article, and this has not been uncommon among workers on polywater. It is also not surprising that he resorts to *Time* magazine-type adjectives such as "unimpressive" or "extraordinarily poor" to characterize believers' work while those on Taylor's side are "carefully done" and "superbly reported."

Since I and my institution (and Taylor's Ph.D. alma mater) come in for heavy derision, I obviously want to round out his story a bit and also try to put in one or two objective reference points. In the winter of 1969 when Dr. Weinberg visited Princeton (in connection with an American Chemical Society address which I had arranged as president of the local section), I mentioned to him that one of our Chemistry Department seniors was working on polywater on his own initiative, and I also noted that one of our young chemistry instructors had gotten a group of 15 freshman quite excited about scientific exploration by turning them loose on a real research problem that used equipment within their understanding. But I was entirely unaware of Ellison's experiments, and there certainly was no "snide remark that the trouble was we were too uptight about it."

In contrast to the emotions expressed, I am surprised at Ellison's rendering of our scientific effort, and a brief description of it is in order. I and my graduate student, Peter Kollman, devised a model for polywater based on semiempirical calculations that consistently interrelated and accounted for all of the 20-odd different experiments which had been reported, and this led us to an initial belief in its existence. Included were calculations on the wall effect which showed a fall-off with distance over a number of atomic layers, thereby invalidating Taylor's single-layer, poisoned catalyst hypothesis. We spelled this out in our paper for the *Journal of Colloid and Interface Science,* Lehigh Symposium issue, in the written answers to questions, in oral discussion, and in private telephone conversations, and thus I don't believe I "avoided his criticism by not believing in polywater any longer." It may be interesting to note that my present disbelief in polywater does not arise from the experiments noted by Taylor, because the various people who have claimed to disprove it strongly disagree among themselves. On the other hand, at least three results have arisen since our initial model was put forth that make a new water allotrope untenable: (*a*) High-accuracy *a priori* calculations on the detailed type of bonding we had postulated showed them to be of considerably higher energy than normal hydrogen bonds, destroying the model which had seemed to uniquely correlate the data and explain the phenomena. (*b*) A new measurement reported by Deryagin indicating a molecular weight of approximately 180. This is also inconsistent with our original model. (*c*) The failure of Lippincott and others to reproduce the Raman spectra.

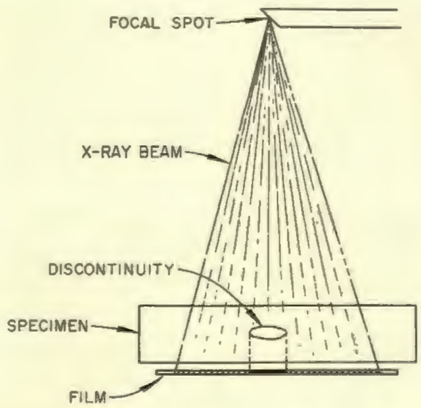
Finally, I wish to clearly state my respect for Ellison Taylor's numerous and important scientific accomplishments — he has made significant contributions to chemical problems related to isotope separation and to radiation kinetics. He ushered in a new era in chemical physics as the first to carry out molecular beam scattering experiments, and this field has now become a large and central area of chemical research. It is also clear from the volume of good research which has emanated from the ORNL Chemistry Division that he is a first-class administrator. With these credentials it is hard to forgive the one serious sin he has committed in his polywater article: Throughout the entire piece he maintains a haughty and imperious presumption that any new phenomenon such as polywater could not possibly exist. Science is being challenged today more than ever before, and no scientist at Oak Ridge or anywhere else can afford that kind of attitude.

Leland C. Allen
Professor of Chemistry
Princeton University

ORNL's traditional concern with the properties of materials as they undergo changes during their use in highly radioactive environments has resulted in one of the most sophisticated non-destructive test development laboratories in the world. The current head of this laboratory is Bob McClung, who can take much of the credit for its excellence. McClung is a member of the American Society for Metals, and past president and current chairman of the board of directors for the American Society for Nondestructive Testing. He is active as well in the American Welding Society and the American Society for Testing and Materials. In 1962 he received the Coolidge Award of the American Society for Nondestructive Testing. He has provided the *Review* with a comprehensive look at the latest developments in his field.

NDT: A State-of-the-Art Report

By R. W. McCLUNG

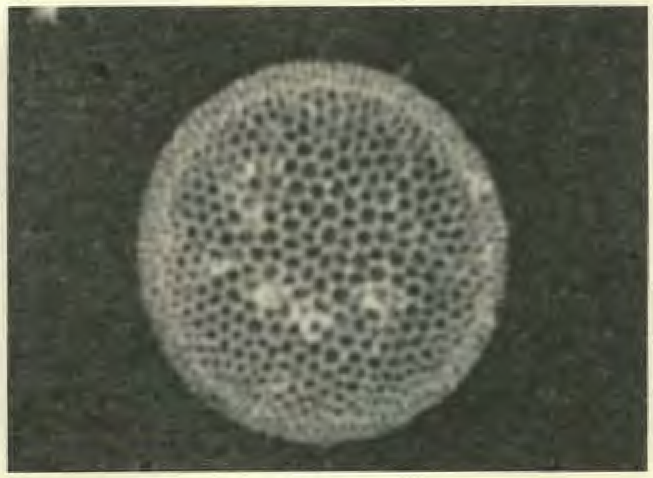


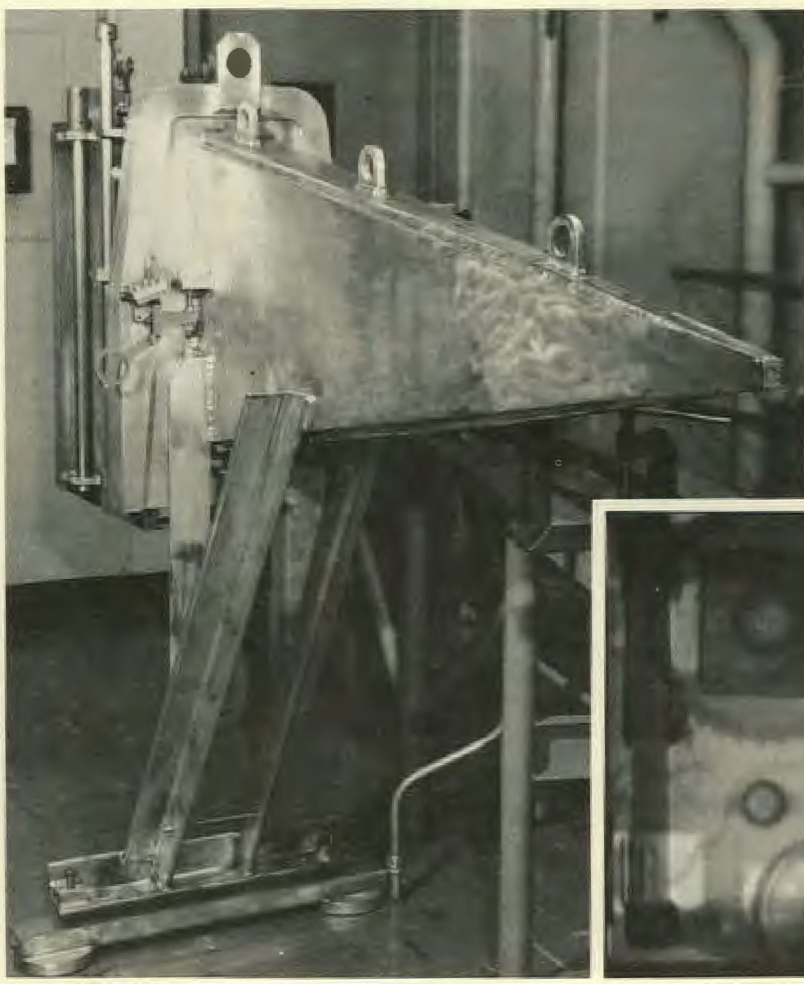
NDT: PENETRATING RADIATION *Such penetrating radiation as x rays or neutrons, when directed through a specimen of material under study onto film, can detect differences in thickness, density, and chemical composition.*

NDT: PENETRATING RADIATION *Radiograph of dogwood blooms. Note the sensitivity to the veins in the petals and the change in contrast when petals overlap. Print was made with special, low-voltage x-ray techniques developed for the examination of thin, lightweight materials like aluminum, graphite, and beryllium. (See also the American Beauty roses on back cover.)*

NDT: PENETRATING RADIATION *Radiograph of a tomato seed, using low-voltage x rays combined with high-resolution photographic emulsion, then optically enlarged. This technique is in regular use to evaluate microspheres of nuclear fuel being studied for gas cooled reactors.*

NDT: PENETRATING RADIATION *A diatom (microscopic unicellular organism in algae) radiographed by the same technique as the tomato seed, only enlarged 500×. Details as small as a micron can be observed with the microradiographic technique.*

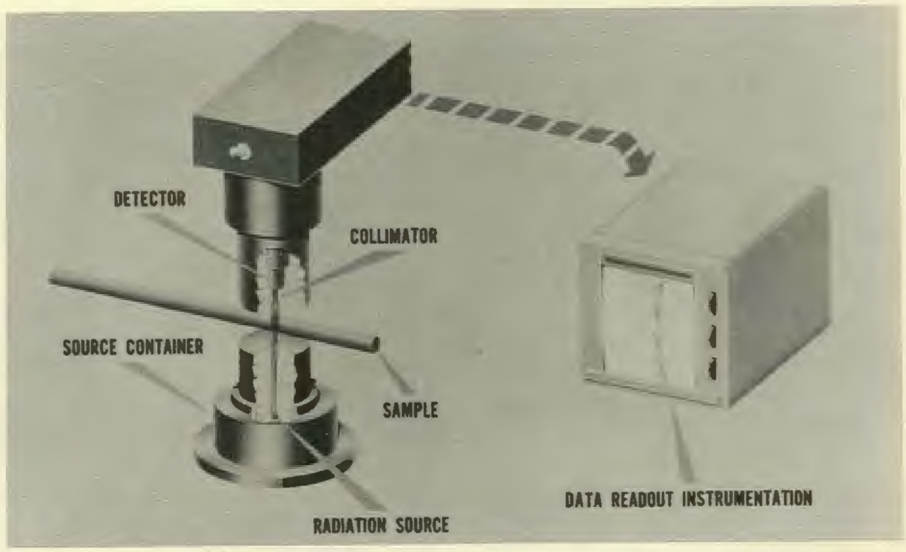


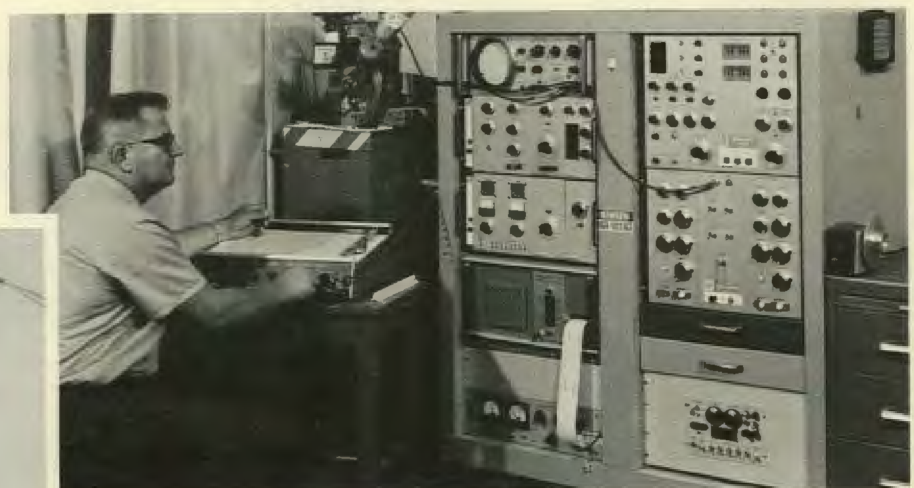


NDT: PENETRATING RADIATION *The neutron camera recently installed at Oak Ridge Reactor. The tapered section is the gas-filled collimator that channels the neutrons from a beam hole near the reactor to the large, rectangular specimen chamber. Detector foils of such materials as indium collect the latent image that results from the varying absorption of neutrons in the specimen. Autoradiography on the activated foil produces such pictures as that of the transistor radio (on the right). Note that neutrons, unlike x rays, detect the plastic parts more readily than the metals.*

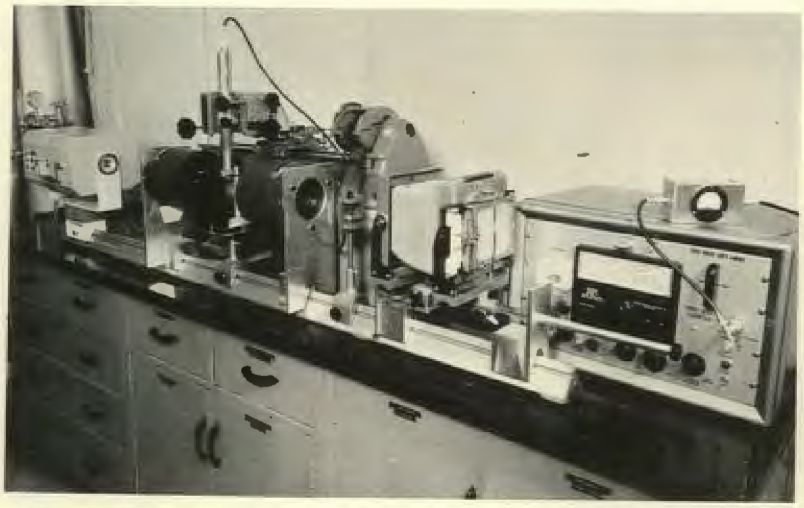
NDT: PENETRATING RADIATION *Neutron radiograph of a frog, again unlike an x-ray picture, as the hydrogen content in the muscles makes them more neutron absorptive than the bones.*

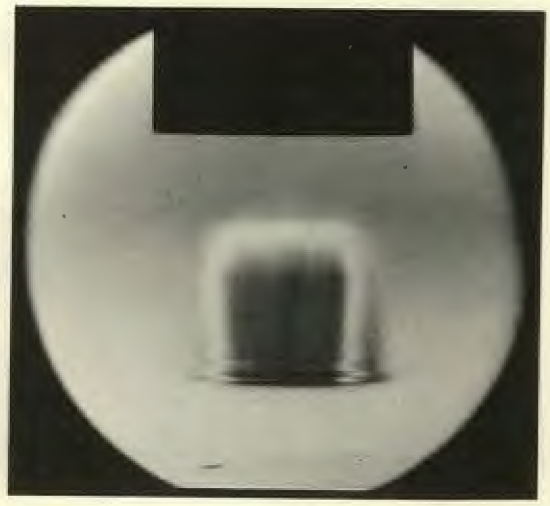
NDT: PENETRATING RADIATION *Thickness, homogeneity, and density can be measured quantitatively by measuring x or gamma rays as they are transmitted in fine collimation through the specimens and then picked up by a detector and converted to an electrical signal for readout on an attached instrument.*





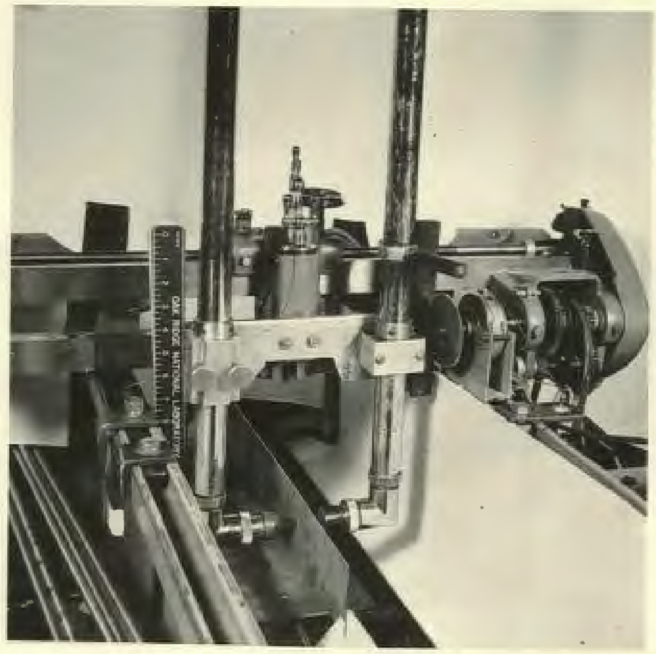
NDT: PENETRATING RADIATION *New techniques are being studied for measuring thickness and alloy content by using x-ray scattering and fluorescent detection. The simple mechanical array (shown in the inset left) includes an isotopic source, and two collimators: one to direct the beam of radiation onto the sample at the desired angle and another to assure that only the desired secondary radiation reaches the detector. Information is picked up by multichannel analyzer, right, which performs spectral analysis on the reflected radiation.*





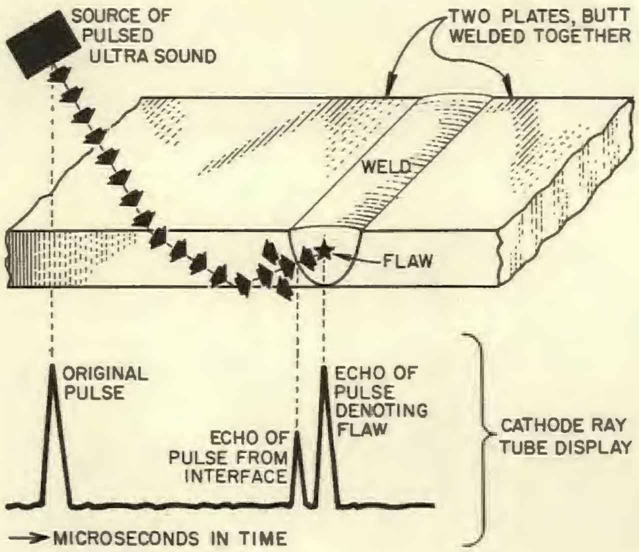
NDT: ULTRASONICS *Ultrasonic (called "supersonic" until the flight industry gave the term its own flavor) energy is also used for nondestructive evaluation of materials. A beam of light is passed through two lenses, between which stands a flat sided container of water. The water is then subjected to a high-frequency pulse of around two megahertz generated by a piezoelectric transducer. Called the "schlieren technique," this process creates optically observable "schlieren," or strata, in the water that can be caught on film by a fast pulse of light, creating the picture upper right.*

NDT: ULTRASONICS *When the schlieren technique is applied to a specimen such as this curve surface of aluminum, the striations in the water interact with the material. In this photograph, a continuous beam of ultrasound (instead of a single pulse) creates a focusing effect in the reflection.*



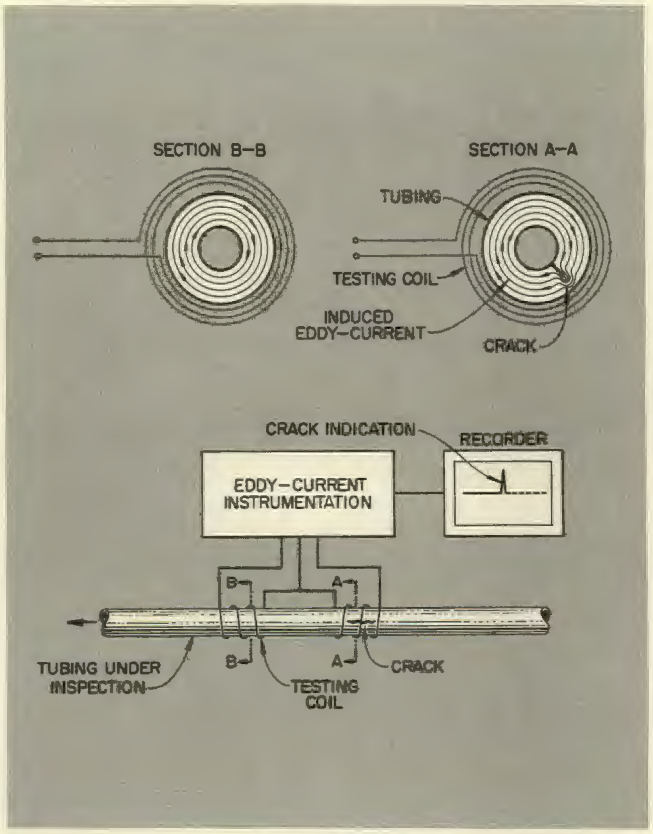
NDT: ULTRASONICS *Another type of ultrasonic nondestructive examination, and one of the simplest, is to pass the sound directly through the specimen and then monitor the intensity. In this mock-up, the piezoelectric transducer at the lower end of the left hand vertical pipe is used to send ultrasound through the fuel plate to monitor the quality of bond between the nuclear core and the cladding. The plate is moved lengthwise through the beam, and if a non-bond area is present it will alter the transmission of ultrasound to the receiver. This can be signaled to appropriate electronic instruments to produce a map of the entire fuel plate, showing areas of non-bond.*

NDT: ULTRASONICS *Pulse-echo techniques are more commonly used in ultrasonic inspection. This illustrates the transmission of a series of pulses from the transducer into a specimen containing a weld. The pulses of ultrasound are reflected by a flaw in the weld, and the echo is detected by the transducer and plotted as shown in the lower part of the figure on a cathode ray tube, permitting information about the relative size and distance of the flaw to be inferred.*

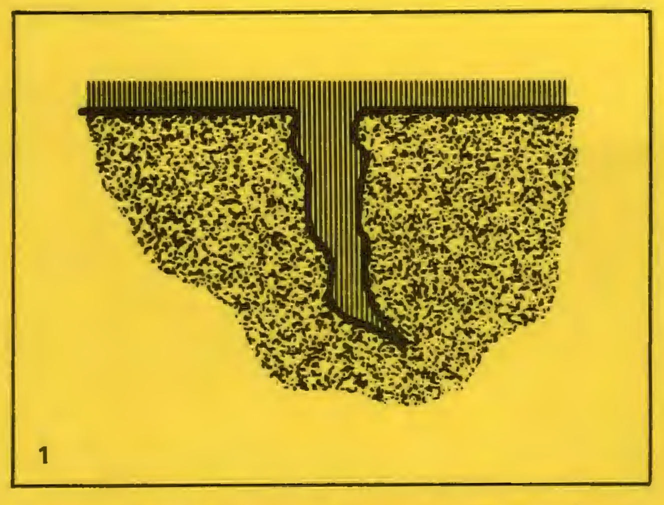


NDT: EDDY CURRENTS *An alternating current passed through a coil of wire will induce the flow of electrical current (eddy currents) in a nearby conductor. The flow of current in the specimen will reveal many of its properties, such as thickness, clad thickness, electrical conductivity and therefore alloy identification or verification, the presence of flaws, etc.*

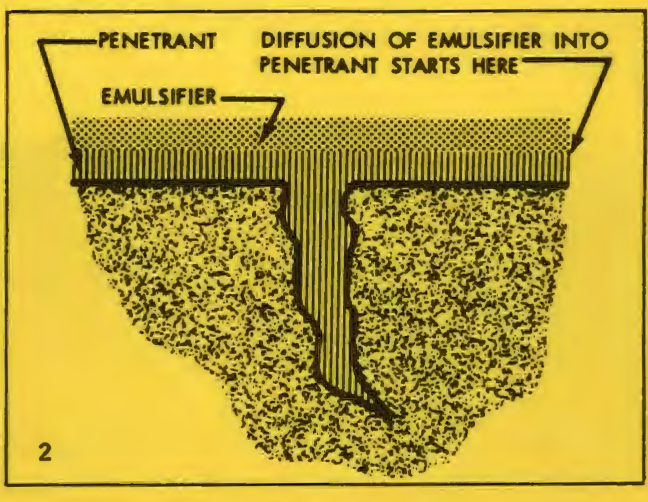
NDT: EDDY CURRENTS *A useful application of eddy currents is for the inspection of tubing. Two cross sections of tubing are shown, with an encircling induction coil and the flow of eddy currents within the tube. The section containing the flaw (below, right) shows a distortion of the current. An inspection system for tubing is diagramed below: two coils are used in a tandem configuration for purposes of comparison. The presence of a flaw in one area under examination will produce a difference in the eddy-current pattern of the two coils. This difference may be displayed and analyzed for interpretation. Eddy-current instruments developed by ORNL's NDT group have now been adopted by industry and are commercially available.*



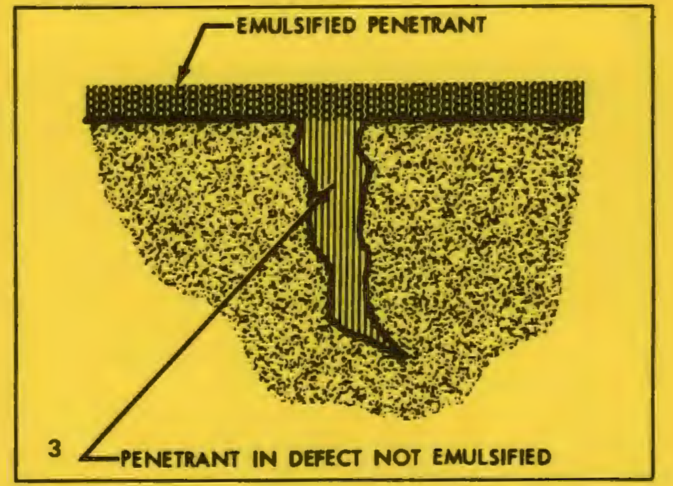
NDT: PENETRANTS *Liquid dye-bearing penetrants are also useful to detect surface flaws. Shown on opposite page is one of the ways in which a fluorescent penetrant is used for this. This method is highly effective for testing the interior wall of a cylindrical specimen.*



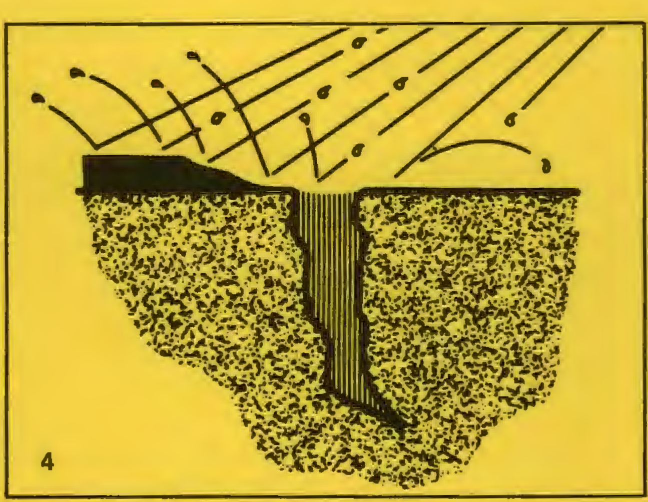
Penetration — Fluorescent Penetrant on Surface Seeps into Crack.



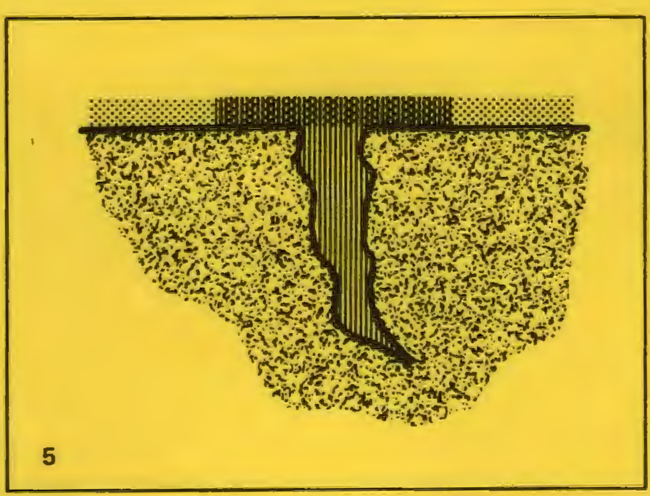
Emulsifier Applied to Penetrant.



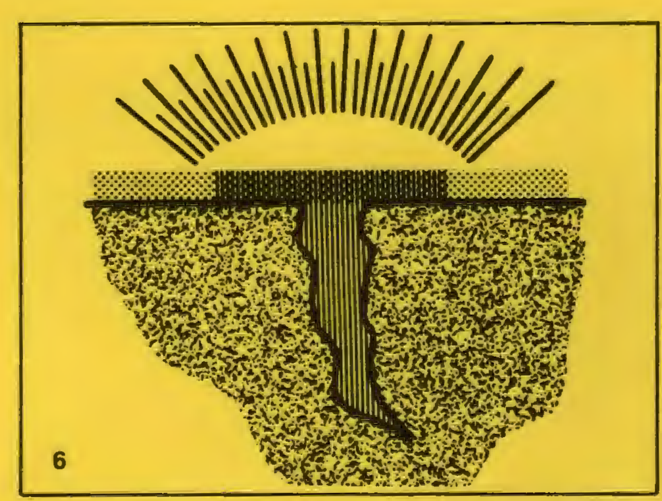
Surface Penetrant is Emulsified.



Water Spray Removes Emulsified Penetrant.



Development — Developer Acts Like a Blotter to Draw Penetrant Out of Cracks.



Inspection — Black Light Causes Penetrant to Glow in Dark.

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Nondestructive Testing (see page 20)