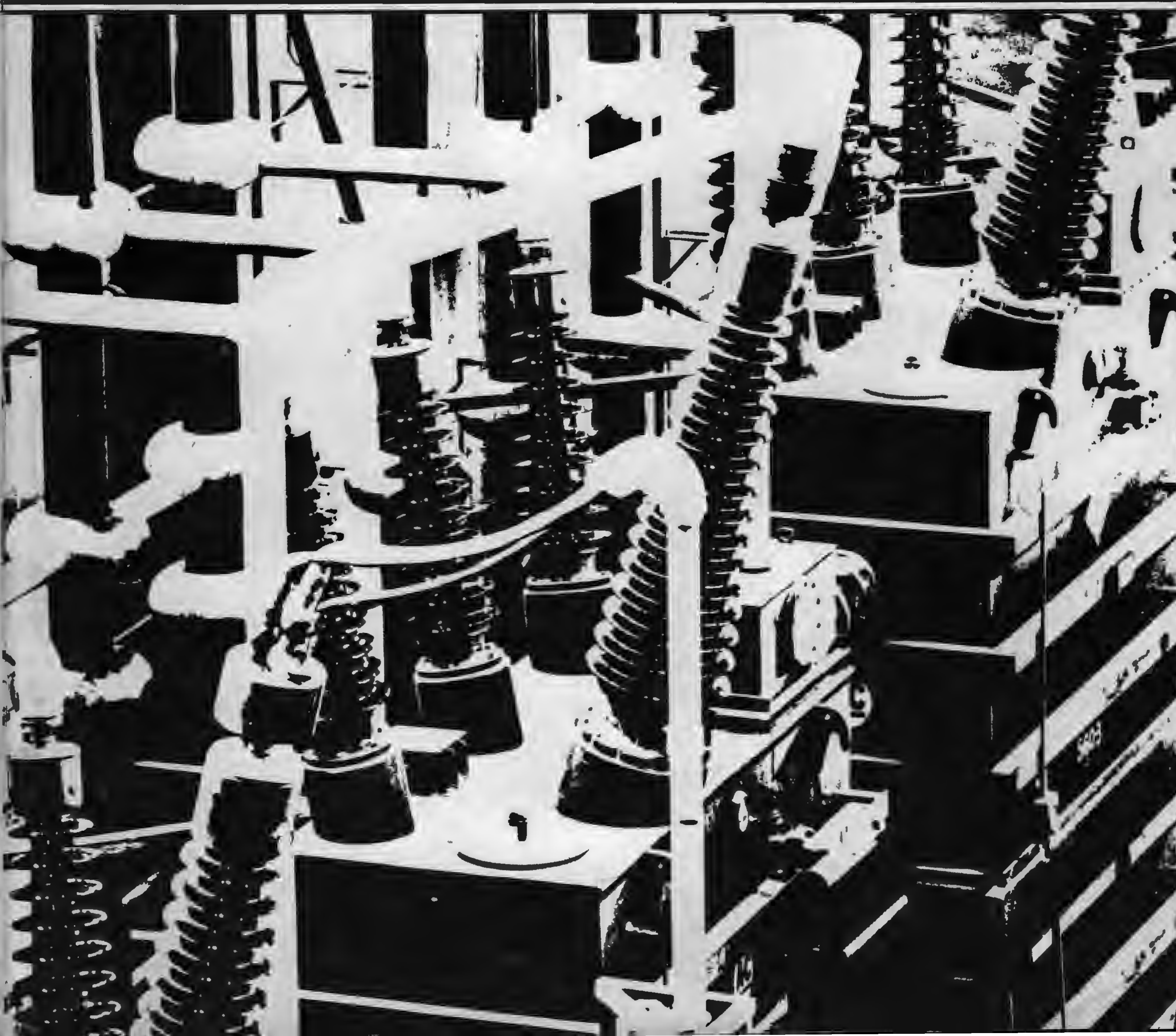
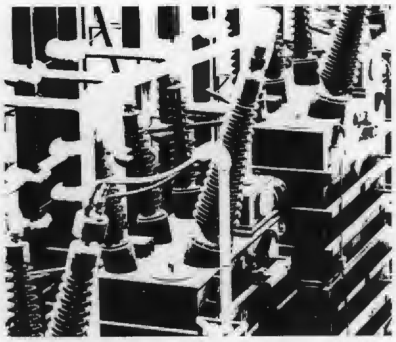
Review

SUMMER 1968

OAK RIDGE NATIONAL LABORATORY





THE COVER: Symbolic of the blinding energy of the sun are the giant transformers that supply the 600 keV, one-ampere ion beams in ORNL's search for controlled thermonuclear fusion. For an account of a new approach to the problem, read "Toward Fusion," page 1.

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Review

OAK RIDGE NATIONAL LABORATORY

VOLUME 2, NUMBER 1 **SUMMER 1968**

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

Our sun is a thermonuclear reactor. The reproduction of this process on a usable scale, its feasibility still in question, is the objective of research now going on in laboratories in England, France, Germany and U.S.S.R. as well as the U.S. This article describes the latest attack on the problem at ORNL.

Toward Fusion: The Target Plasma Program

BY ARTHUR A. SNELL

THE RECENT emergence of a "target plasma program" as a central theme in the Thermonuclear Division's effort to control fusion involves a combination of a variety of new knowledge about plasmas and new techniques in superconductivity. One way to summarize the situation is to describe the main apparatus that is being built, the IMP experiment (Injection into Microwave Plasma), to see its various ingredients, together with the function and necessity of each, and to inspect their interplay.

The concept of the experiment follows the injection-accumulation tradition at Oak Ridge. In our classical DCX-1 experiment we took advantage of the efficiency of direct-current acceleration to heat the ions (the equivalent of a billion degrees is easy this way), and the resulting beam was poured through a magnetic trap where a fraction of the particles was held because we injected molecular ions (H_2^+) and dissociated some of them into atomic ions (H^+) within the magnetic field that was provided to contain the experimental plasma. Electrons automatically gathered to neutralize the charge of the positive ions, and so we had a plasma containing very hot ions and cool electrons. Only a rather tenuous plasma was achieved in this way, having about 10^9 fast ions per cubic centimeter, and although this was about as much as was accomplished in beam-injection experiments elsewhere, it fell far short of the approximately 10^{14} fast ions per cubic centimeter that will be needed as a minimum for some future fusion reactor. We reached an understanding of the instability that prevented further build-up of the plasma density, and this understanding has now joined with other new knowledge to suggest a new start. DCX-1 is being discontinued and is replaced by the Target Plasma Program, and we feel that with this new approach we have a much better chance than before for substantial progress toward the goal of 10^{14} fast ions per cubic centimeter. We will be extremely lucky, however, if we can make the entire jump of a factor of 10^5 in density in the

Arthur H. Snell has been in nuclear energy work since "before the beginning". As early as 1941 he was associated with a group at the University of Chicago working on a neutron diffusion project that tested neutron absorption in graphite. Snell then turned his attention to the delayed neutrons, and the work of his group led to a quantitative understanding of the role of these particles in easing the control of chain reaction. At the time, Fermi was alleged to have remarked, "Thank God for the delayed neutrons." In 1942, when the Metallurgical Laboratory of the Manhattan Project was established at Chicago, the Snell group became part of the new organization, and made fast-neutron measurements of weapons interest using the first five tons of uranium metal that formed the heart of the famous Chicago Pile called CP-1. Snell came to Oak Ridge in 1944, where in 1950 he showed that the neutron is radioactive. He became Director of the Physics Division in 1948, and an Assistant Laboratory Director in 1957, and has served in that capacity until the present, with an overlapping period in which he acted also as Director of the Thermonuclear Division. Canadian-born, he was educated at the University of Toronto and McGill University, where he received his doctorate.

one program. In a matter of this degree of difficulty, a partial success (say to 10^{12}) would be sufficient for a modest degree of restrained jubilation, because we would then start to gain experience in steady-state plasmas in a new regime of densities.

To lapse into the jargon for a moment: The IMP experiment is one of neutral particle injection with directional and energy spread, using a target plasma in a magnetic well, the target plasma being created by electron cyclotron heating, and trapping being accomplished by charge exchange of the injected hot neutrals with the cold ions of the target plasma. The hot electrons serve to stabilize longitudinal waves in the plasma by Landau damping.

What does all this mean?

Before enlarging, let me say that much Oak Ridge National Laboratory experience has gone into IMP. The electron cyclotron plasmas were invented here by R. A. Dandl and associates. G. G. Kelley and his group have been prominent in the generation of ion and neutral beams, and C. F. Barnett's group has furnished basic cross sections necessary for that development. J. R. McNally pointed out the efficiency of trapping by charge exchange (a key factor), and G. E. Guest and his colleagues have been leaders in the theory of the stabilization by hot electrons. Finally, the synthesis into a coherent program has been accomplished by Guest, H. Postma and N. H. Lazar, extending an original calculation by Dandl.

The magnetic well is a good place to start. It is a magnetic configuration in which the field increases in absolute strength as one goes outward in any direction from the center. Thus, if plasma tries to escape in a bubble-like fashion, it encounters increasing opposition as it departs from its equilibrium position; that is, more and more work must be done in displacing magnetic field if a plasma hump tries to move outward. The IMP configuration follows one originally used by the Russian physicist Ioffe. It's an elaboration of the so-called mirror geometry (Figure 1) made necessary because around the middle region of the plasma the magnetic field between the two mirror coils *de*creases as one goes outward in radius, so that if a plasma bulge were to start, it wouldn't be inhibited but, on the contrary, would grow. To counteract this, IMP will have four longitudinal current-carrying conductors

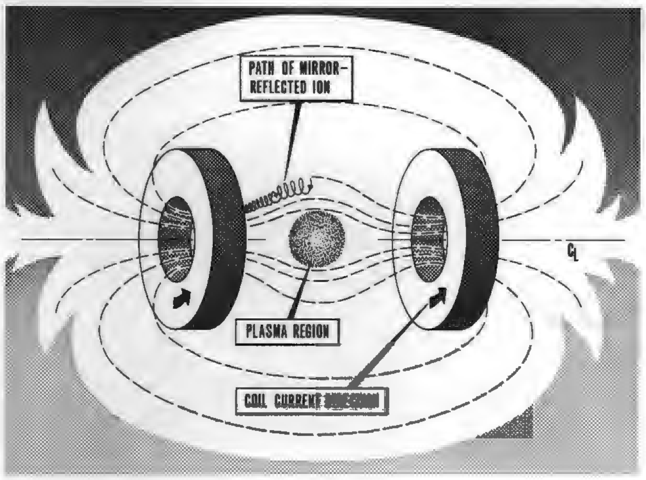


Figure 1

(Figure 2). Each of these conductors carries a heavy current, with a resulting magnetic field *around* the conductor. True, the direction of this field is at right angles to that of the mirror coils, but that doesn't matter at this stage of our description. Now if plasma starts to move from the center of the cage it is stopped—longitudinally because it approaches the higher field at the mirror coils, and radially because it approaches the Ioffe bars and feels increasingly the magnetic field around them. From the current directions shown in Figure 2, it's evident that the Ioffe bars could be closed at the ends into elongated coils as indicated by the dotted lines. When there are four such coils, as in IMP, they are called quadrupole coils, although their straight segments may still be called Ioffe bars.

Let's admit at this point that magnetic wells are a pain in the neck. They are tremendously demanding of electric power, the magnetic forces are large in some regions and act in oblique directions, accessibility is limited because the Ioffe bars have to be so large that there's little space between them,

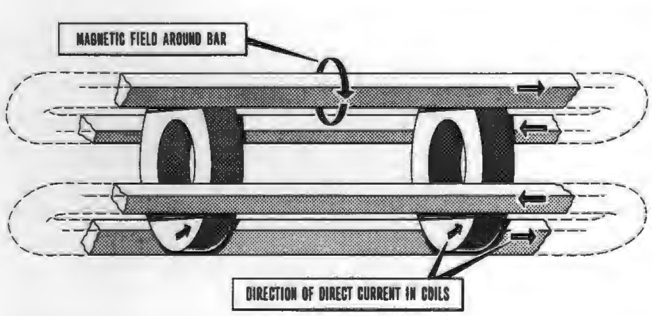


Figure 2

and quantitative interpretation of measurements is complicated because symmetries have been lost. The shape of the plasma is squeezed into wedges at the ends, one wedge being at 90° to the other as if you rolled a piece of paper into a hollow cylinder and then pinched one end vertically and the other horizontally (Figure 3).

We now come to an important point: in a magnetic well of this kind, the magnetic lines of force emerge from the plasma region. True, they rejoin somewhere outside as in Figure 1, but somewhere also they must pass through a vacuum wall or coil supports. Contrast with the "closed" geometry of coils arranged in a circle as in Figure 4. The lines

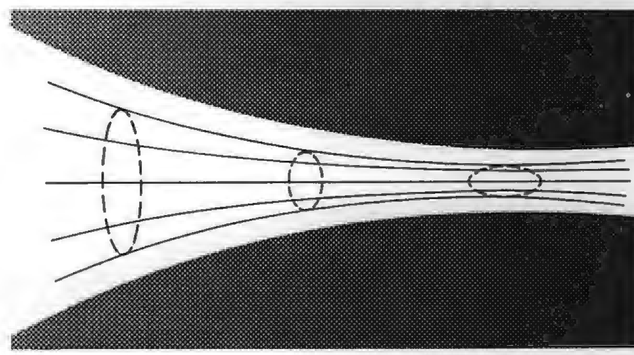


Figure 3

of force here are circular and endless, and need not intersect any wall if the vacuum vessel is a toroidal tube threading the coils.

Here we have the two great topological classes of plasma containment devices, the open-ended systems and the closed systems. Each has its prob-

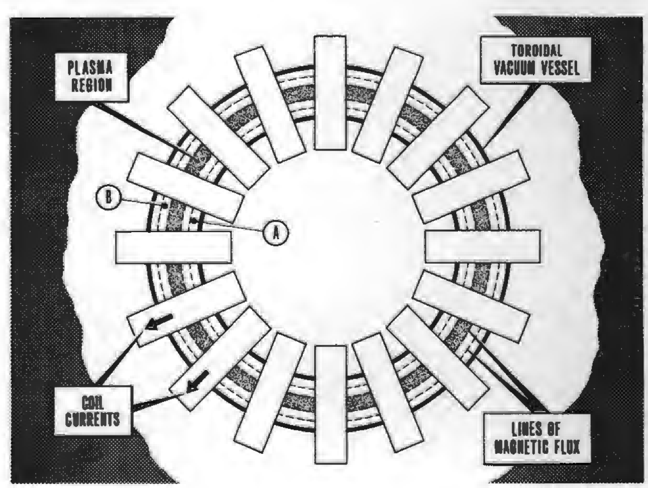


Figure 4

lems. Many of the problems of the closed systems stem basically from the fact that the magnetic field on the inside of the torus (at A) is stronger than at the outside (at B). This gives rise to a family of compensating schemes which – bless them – we don't have to go into here. The open-ended systems' difficulties arise from the fact that although orbiting electrons and ions are trapped between mirrors (being reflected in helical paths between the simple mirror coils in Figure 1 or undergoing much more complicated patterns in the case of Figure 2), nevertheless any particle that is flung by a collision or otherwise into a direction almost parallel with a line of force will have its helix so stretched out that it will pass through the mirror coil or between Ioffe bars, and strike a wall somewhere. Directionally there is, accordingly, a "loss cone" of up to, say, 30° half-angle within which individual plasma particles will sail out of the system. The effects of this loss cone have been extensively studied at Oak Ridge and we shall return to them later.

In summary, the magnetic well contains most ions and electrons and it stabilizes against the grossest kind of plasma loss, but it is leaky along the magnetic lines of force.

We now pass to a second feature of the IMP System – the target plasma. The purpose is to aid in the trapping of hot ions such as eventually will make the fusion reactions when they collide. The old Oak Ridge carbon arc was a target plasma, trapping by dissociating hot injected H_2^+ ions to trapped H^+ ions. IMP, however, uses a target plasma generated by electron cyclotron heating, and under modern concepts it has distinct advantages.

Imagine a cylindrical copper box, with gridded ends, interposed between the coils of Figure 2, and let a few kilowatts of microwave power be admitted into the box through one or more wave guides. The box in IMP will be about 20 cm in diameter, and the wavelength of the microwaves will initially be 0.8 cm. Now turn on the two mirror coils, without the quadrupole coils, and adjust the pressure in the system to about 10^{-5} torr. The field is non-uniform over the volume of the box, and as the mirror coil current is increased, in regions near the ends let the field reach 9000 gauss. The electric fields of the microwaves will accelerate electrons, pulling some from the neutral gas atoms, and when 9000 gauss is reached, the period of the orbiting electrons will match the oscillation period of the microwaves. This is the condition of electron cyclotron resonance, and when it is reached the electrons *really* get hot!

NOT EXACTLY A TOY

A model of the proposed IMP experiment is subjected to pre-construction study. The Ioffee bars make it look like a miniature tank. The larger model is full scale.

They ionize the gas further, but the heavier ions do not get into cyclotron resonance with the microwaves, so they stay at most only warm (that is, with energies of only a few electron volts, and individually soon are lost through the loss cone).

This is the electron cyclotron plasma: hot electrons with a temperature equivalent of about 100,000 ev, and warm ions at perhaps 5 – 10 ev, the electron density being about 10^{12} per cubic centimeter, and the ion density being necessarily equal to that for charge neutrality. Surprisingly enough the electron cyclotron plasma is stable between the mirror coils despite the lack of a magnetic well; the stability comes from the pressure of 10^{-5} torr, which is sufficient to give good electrical conductivity along the magnetic lines of force (the loss cone again!) to the metal ends of the box. When Dandl reduces the pressure to 10^{-6} torr, instability results, marked by gobs of the hot electrons striking the internal walls and generating x rays in bursts strong enough to be dangerous even through 3 inches of lead shielding.

When the conductivity is good, however, charge clusters such as are produced by too many electrons at one region or too few in another are neutralized before they can do any harm because there are plenty of electrons to run to or from the conducting end wall of the box.

The pressure of 10^{-5} torr is too high for IMP purposes, so now we start to raise the current in the quadrupole coils. Gradually the stabilization due to the quadrupole coils replaces that due to conductivity to the ends, and the pressure finally can be reduced to 5×10^{-7} torr without producing bursts of x rays; this is a pressure low enough for IMP purposes.

Why is 10^{-5} torr too high a pressure? The answer lies in atomic processes that introduce another controlling factor into the IMP design. Too many neutral atoms cannot be permitted within a fusion plasma because in an atomic collision a bound electron can easily transfer itself from (say) a neutral deuterium gas atom to a hot trapped deuterium ion. The process is called "charge exchange," and in our example it goes like this:

$$D^\circ \text{ (cold)} + D^+ \text{ (hot)} \longrightarrow D^+ \text{ (cold)} + D^\circ \text{ (hot)}.$$

This is an efficient process, with a cross section of order 10^{-15} square centimeter, because at the moment of collision the fast-moving electron would just as soon be in orbit about the new D^+ nucleus as about the old D^+ nucleus. Anyway, you've lost thereby the energy investment you had in the hot D^+ ion, for the hot D° feels no restraint from the magnetic field and immediately flies straight into a wall. The D^+ (cold) is comparatively worthless, and in fact it will probably soon vanish through the loss cone. Clearly you cannot afford much charge-exchange loss of your hot ions, and it is fortunate that a pressure reduction to the modest requirement of 5×10^{-7} torr will bring this loss under control. Note also that as the target plasma gets more dense, as is expected when 5.5 mm microwaves are used in a 20 kilogauss field as will later be possible in IMP, then neutrals that try to enter the plasma will have to escape ionization by the hot electrons in order to penetrate far, so the interior region will be "burned out" of neutrals. This is an aspect of the final planned performance of IMP.

Thus we now have a stabilized target plasma with hot electrons and warm ions (let's stick to D^+), and sufficiently few neutrals outside and inside of the plasma. We are now ready to introduce the hot ions. This is done by injecting them as neutral atoms, partly because a beam of neutral D° atoms will cross a magnetic field, so the odd directions of the lateral field of the magnetic well will not affect the flight of the beam. The trapping takes place by reverse use of the charge-exchange reaction described above; you now have *hot* D° in the beam and *cold* D^+ in the target plasma. Upon charge exchange, you have *hot* D^+, trapped. You've turned the efficiency of the charge-exchange reaction to your advantage, and since you have already provided that there are not many *cold* D°'s within the plasma, your hot D^+'s will stick around for a while.

Generation of an adequate beam of 20 kev D°'s in itself poses technical problems, but they have been pretty well worked out in Russia, England, and California as well as in Oak Ridge. About 6×10^{17} atoms per second (equivalent to 100 ma) are required to be collimated within a very few degrees,

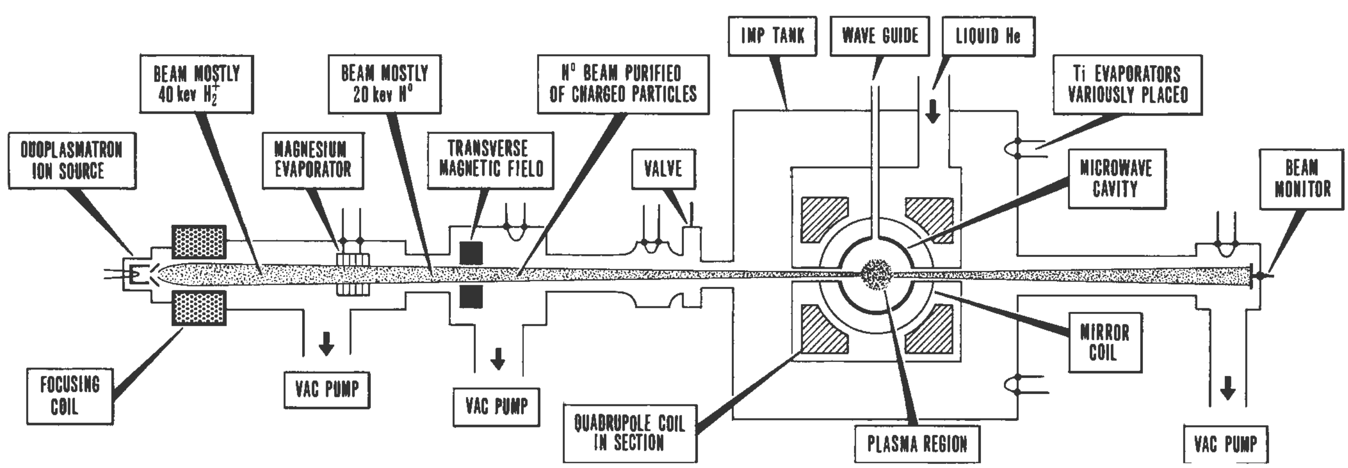


Figure 5

and made to pass through an entrance aperture perhaps 1¼ inches in diameter as they enter the magnetic well region of IMP. At Oak Ridge, the beam train looks something like Figure 5.

First there is a duoplasmation ion source such as has been developed at Sukhumi on the Black Sea and at Oak Ridge, but it is modified for the preferential production of H_2^+ ions. These ions are accelerated to 40 kev and focused into a nearly parallel beam. The beam passes through a cell containing magnesium vapor. Here collisions with magnesium atoms produce almost entirely two neutral H° atoms from each entering H_2^+; any remaining charged particles are swept aside by a magnet, and the neutral beam (containing perhaps a few H_2°) traverses the target plasma. About 1% of the atoms are ionized and trapped (a relatively high percentage as these things go) and the remainder of the beam goes on to a burial chamber where continuously evaporating titanium absorbs it entirely without return of the neutralized gas. Safeguards have to be provided against the entry into the magnetic well of magnesium vapor from the left or titanium from the right—until the burned-out condition is achieved.

Such an H° beam has all particles near one velocity, and all one's instincts tell one that that's wrong. What is needed is a "natural" distribution, like the Maxwellian spread of velocities of the molecules in a hot gas. Figure 6 shows the difference.

The danger is that monokinetic trapped H^+ particles can release free energy by slumping down into the more "natural" Maxwellian spread, and the energy thus made available, probably in a spasmodic process, can produce localized electric fields thereby producing internal instabilities ("microinstabilities") that are not controllable by the magnetic well. Particle and plasma loss would result.

The straightforward way of anticipating this trouble is to inject with the velocity spread previously built into the beam, or else (California) to inject several beams with different velocities such as would approximate the Maxwellian. At Oak Ridge, the first alternative is being followed for the time being; the accelerating voltage of the H_2^+ ions, and with it the current in the focusing coils, is modulated with a period which is short compared with the mean storage time of a trapped ion in the magnetic well. Forty percent in energy spread of the injected atoms is thereby introduced, and the stabilizing effect of this treatment has already been observed.

For proper randomization, the atoms should be injected with a spread also in direction. This looks relatively simple, because a little obliqueness of the injection direction relative to the axis of the magnetic trap will lead to such contorted orbits of

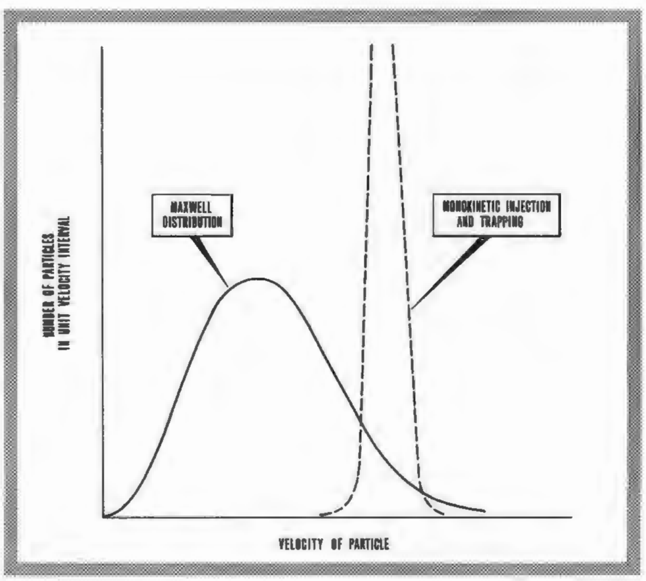
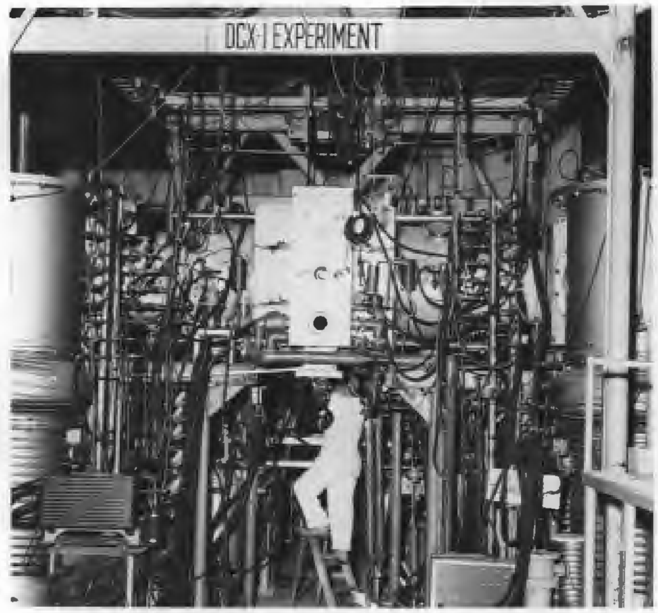


Figure 6

THIS HAS TO GO

The old Direct Current Experiment No. 1 is being dismantled to make way for new technology. In its place in Building 9201-2 will be the target plasma program described here.



the ions within the magnetic well that directions should be well randomized.

Let us return now for a moment to the expected loss-cone instabilities. The loss of individual particles along directions close to the course of magnetic field lines that leave the open-ended systems is a preferential thing, affecting mainly the ions of low energy because their probability of undergoing scattering collisions is greater than that of the more energetic ions. The result is that the lower end of the Maxwellian distribution will be depopulated, and then the spasmodic readjustments into the more "natural" distribution can be expected, probably with micro-instabilities and loss of plasma. In this respect it might be noted that the target plasma may have an ameliorating effect because it contributes a population of "warm" ions at the low-velocity end of the ion distribution. Apparently a continuous throughput of cold-to-warm ions is to be expected in open-ended systems.

The stability analysis that Guest and his theoretical colleagues have supplied for IMP shows among other things the stabilizing influence of the warm-ion population. The analysis is idealized in that it refers to an infinite homogeneous plasma, but nevertheless it serves as a guide to the regimes that may be stable and those that may be unstable. Such analyses are couched in wave language; instability is indicated if the amplitude grows. In the present case it is convenient to treat separately the waves that would move parallel with the magnetic field and the waves that move across the field. (The latter usually means azimuthal waves, as if a knobby plasma were rotating.) Figure 7 is a result of the calculations of the plasma theoreticians and it shows the theoretical stability boundary for cross-field waves with the proportion of warm to hot ions and the total plasma density as the variables. In the target plasma alone, before injection, the warm/hot ratio is large (in fact, infinite); therefore, after starting injection you would drop into this diagram from above, and you wouldn't have to traverse the unstable region.

The analysis for waves travelling parallel to the magnetic field lines also shows regions of instability, but there are wide paths of stability between them. Here a usefulness of the hot electrons has emerged. If the particles in a plasma have velocities almost matching that of the waves, the particles can sap energy out of the wave. This is called Landau damping. Many of our hot, orbiting electrons in the target plasma will have sufficient

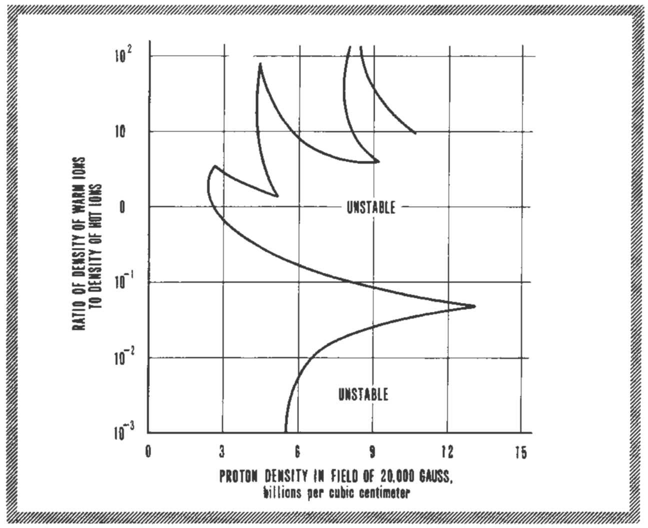


Figure 7

longitudinal velocity in their helical paths to provide this kind of damping. The primary result is that the wavelength associated with the longitudinal instability is increased, and if the plasma is relatively short, a secondary result is that the wavelength can no longer fit into the apparatus, so the instability cannot develop. Thus the microwave-heated electrons are expected to stabilize one class of otherwise damaging instabilities.

We have now all the ingredients for plasma buildup. The magnetic well contains and stabilizes against the grossest kind of plasma loss, the neutral beam furnishes the hot ions, and the target plasma has the quadruple role of serving as the trapping medium, relieving the loss-cone situation somewhat by furnishing ions at the low end of the Maxwellian distribution, discouraging longitudinal waves by Landau damping through the action of its hot electrons, and (eventually) burning out the neutrals from the interior. If everything works according to plan, how far will IMP take us? Calculations suggest that the plasma should build up to a density of about 10^{12} particles per cc and what happens after that depends upon the loss-cone instabilities. At that density, they should be open to experimental investigation, which would be rewarding in view of the substantial amount of theoretical study that has already been given them. A hopeful indication would seem to be coming from the compression experiment called 2X at Livermore, when plasma in the 10^{12} density range appears to be relatively stable in a magnetic well qualitatively like that of IMP, although the experiment, being intermittent, *Painstaking precision took several weeks to wind the two mirror coils with the paper-wrapped conductor. The coils have now shown that they can generate a magnetic field of 66 kilogauss.*

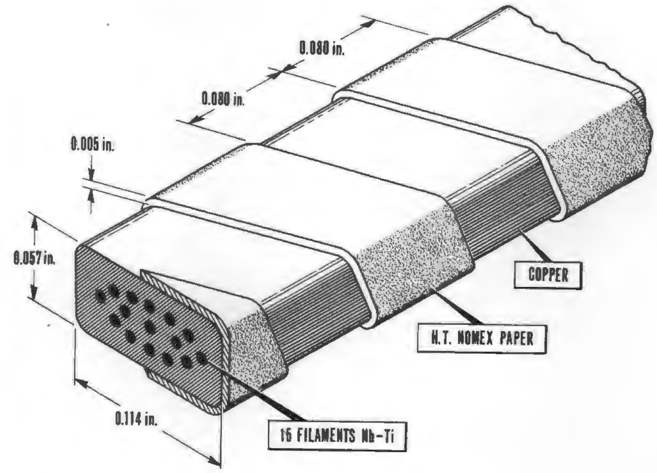


Figure 8

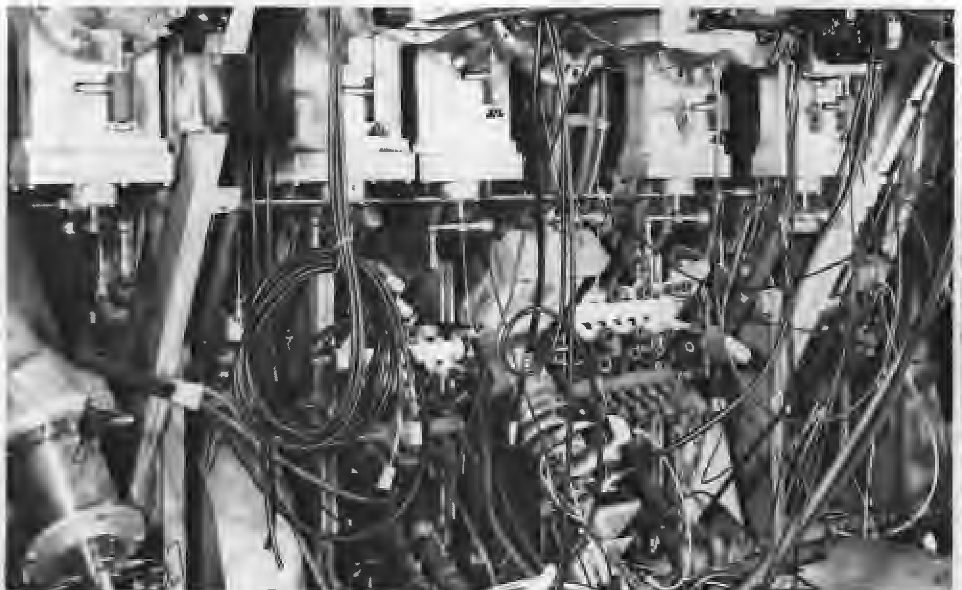
tests confinement for times not longer than a millisecond. Speaking from the 10^9 per cc density level, where we are now, a *steady-state* hot plasma at 10^{12} per cc would be a highly interesting subject to have in any laboratory, and we hope that IMP will provide it.

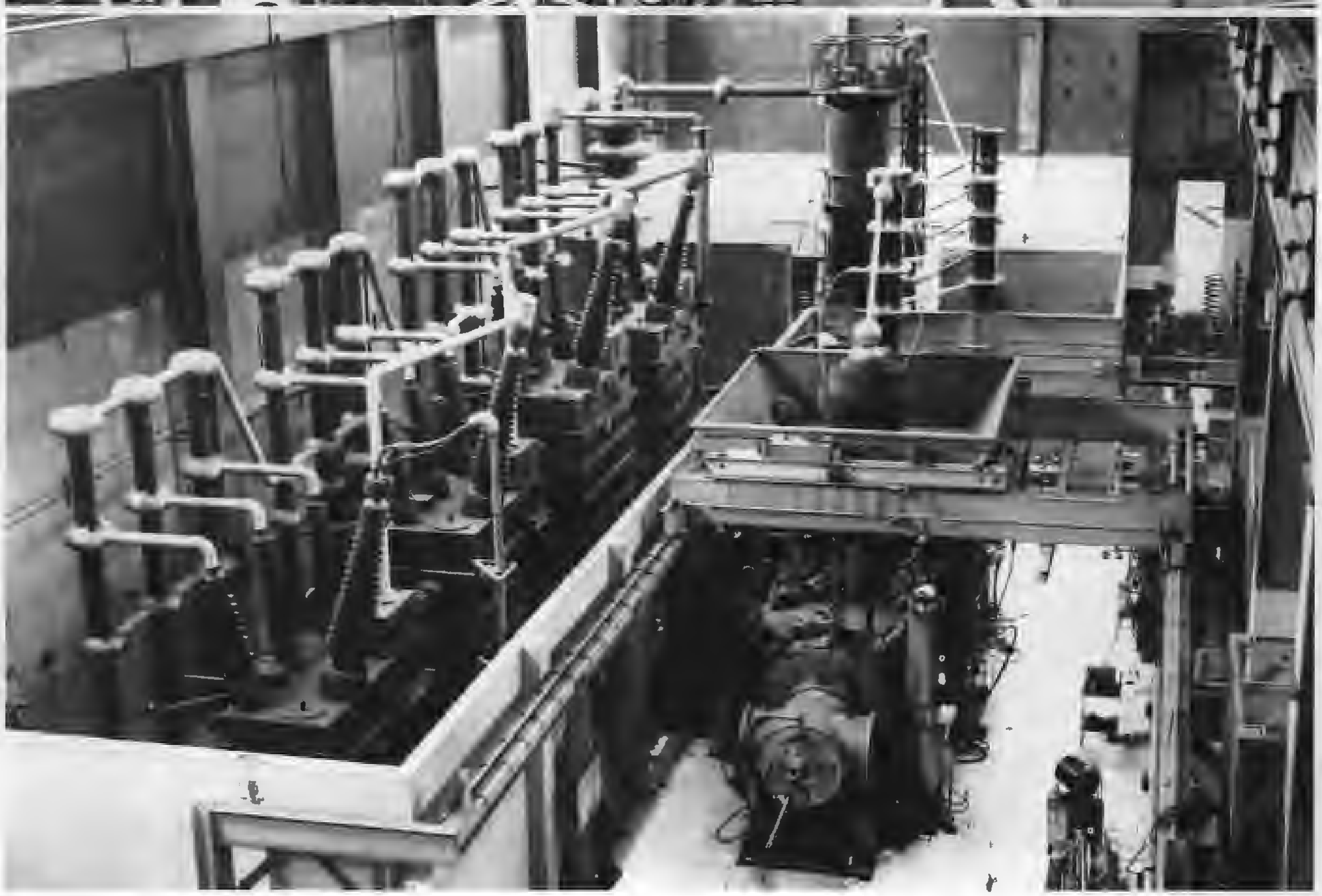
Any discussion of IMP would be incomplete without some reference to the engineering problems that it poses. Most of them center around the magnetic coils—especially the quadrupole coils. If copper coils were used, 23 megawatts of dc power would be required, and the electrical leads and water headers would take so much space that it would be hard to get the beam and microwave guides into the system, not to speak of the plasma measuring equipment. The coils would be tricky, in that close clearances and high water flow would be essential. The use of superconductors seems to be the safer choice, and to this end W. F. Gauster and his colleagues have been pioneering in calculations and tests. The problem is that superconducting technology is so young that even the choice of conductor is a matter of research, and there exists no practical experience with superconducting coil combinations other than simple, circular coaxial ones. Furthermore, space and cost requirements in IMP are such that the coil design must be carefully optimized.

It is easy to get a short sample of the modern "hard" superconductors to carry a large current in a magnetic field, but when you wind the same material into a coil it "degrades," and fails to carry as much current. The reasons for the degradation are not really understood, but nevertheless the engineering can proceed by winding small coils and testing them by energizing them in opposition, as they hang cross-wise in liquid helium in one of the high-field solenoids of the Magnet Laboratory. Such an arrangement mocks up the forces, the heat transfer, and the squeeze on insulation that are to be expected in IMP. The tests are most illuminating; one observation, for example, is that the amount of current that you can get into the superconducting coil depends upon the rate at which you build up the current.

Another tantalizing thing is that at the highest fields the coils don't degrade, and the current-carrying capacity is satisfactory. But how then can coils be brought up by themselves, without the external solenoid, until their own field is sufficient to get them beyond the region of degradation? The conductor chosen for the mirror coils of IMP is shown in Figure 8. It consists of 15 strands of NbTi alloy imbedded in a copper matrix measuring about $\frac{1}{8}''$ by $\frac{1}{16}''$ in cross section. The copper is neces-

The machinery that is contrived to achieve thermonuclear reactions is wondrous and complex.





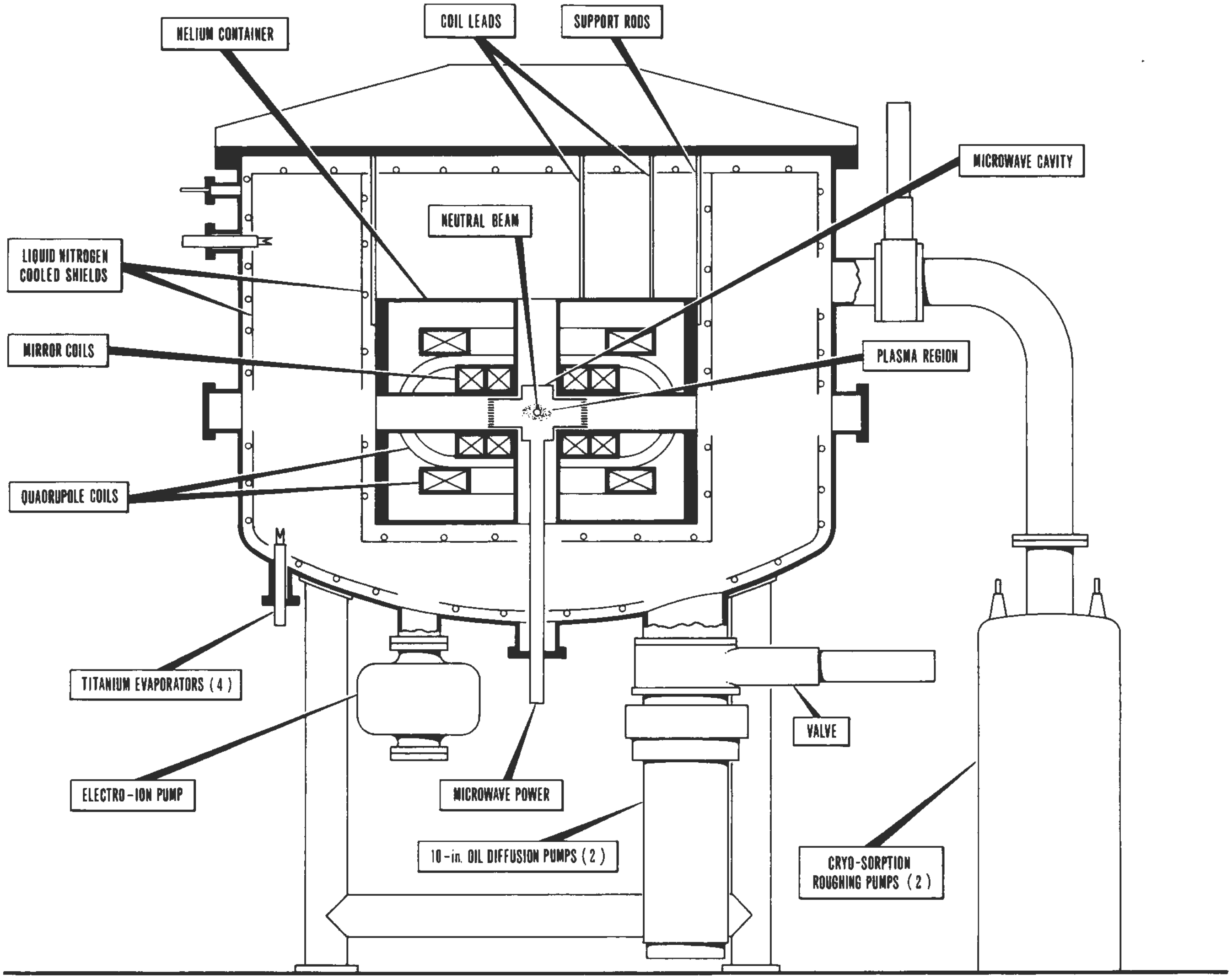


Figure 9

sary for "stabilization;" that is, to save the coil in the event that some region warms itself above the superconducting temperature, causing the whole energy stored in the magnetic field suddenly to appear as heat, starting at that spot. A spaced, spiral wrap of insulation is provided to let the liquid helium penetrate between the wires.

What then will the total IMP look like? A line drawing is given in Figure 9. At the center is the hot plasma at a billion degrees more or less, with the neutral beam passing through it. A few inches away is the copper microwave cavity, water-cooled to dispose of the 10 to 100 kw of microwave power that enters it through the wave guides. Then there is a barrier at 77°K (liquid nitrogen), and outside of that the liquid helium tanks containing the coils, at 4°K. All of this hangs in an outer vacuum tank, itself provided with a liquid nitrogen cooled liner and several titanium evaporation units for vacuum purposes. Outside of this, and not shown in the drawing, an x-ray shield of lead at least three inches thick will be required. The neutral beam line, the plasma instrumentation, the microwave power equipment and the vacuum pumps will comprise a forest of external equipment.

IMP is not a large piece of apparatus. The vacuum tank is seven feet in diameter. In its small volume, it will nevertheless epitomize the most advanced aspects of experimental plasma physics and modern electrical technology.

John A. Swartout left his position as Deputy Director of the Laboratory in 1964 to become Assistant General Manager for Reactors with the U. S. Atomic Energy Commission. Two years later, he moved to New York to become a member of the staff of Union Carbide Corp., where he is now Director of Technology. He has been engaged in nuclear energy research and development since early 1943, when he joined the Metallurgical Laboratory at the University of Chicago. He received his Ph.D. in physical chemistry from Northwestern University, and his work at ORNL focussed principally on the chemical problems in reactor development.

Critical Chemical Problems in the Development of Nuclear Reactors

By John A. Swartout

IN RETROSPECT the program for the development of nuclear reactors into practical, useful devices has been in several respects the technical *tour de force* of mankind. In duration and magnitude it ranks among the major undertakings of history; it continues today after twenty-five years with no reduction in tempo and with annual expenditures by our government alone approaching one-half billion dollars. The total annual expenditures by the governments and private institutions of the world can only be approximated but figures well into the billions can be compiled quite readily.

"The nuclear power reactor . . . may well produce . . . a far-reaching revolution, increasing the welfare of more people than were affected by the industrial revolution of the last century."

Longevity and gross input of man's ingenuity and brawn are indices which alone place this massive effort in the company of the pyramids of Egypt, the cathedrals of the Middle Ages and the space program of today. The distinguishing characteristic is the impact, which already has been exerted or is promised for the future, on man's way of life and his well-being by the products of this technical development. Few other single technologies have had so broad an influence on man in changing his tactics and strategies of war, in expanding his knowledge and in increasing the energy available to him. Although not yet comparing with the impact of the introduction of the steam engine, the nuclear power reactor with its prospect of providing unlimited, low-cost energy may well produce a more far-reaching revolution, increasing the welfare of more people than were affected by the industrial revolution of the last century.

Moving closer to the subject, the development of reactors of increasingly sophisticated design for specific purposes such as for nuclear research, production of fissionable nuclides or of the transplutonium elements, for production of energy for naval propulsion or central station power has been possible only by combining the expertise of a multitude trained in almost all fields of science and engineering. The necessity for, and the outstanding success of, this interdisciplinary attack may be illustrated by innumerable case histories of the courses leading to the solutions of specific problems. The discovery and subsequent development of the cladding material for the fuel elements of water-cooled reactors, upon which essentially all of our present nuclear power economy is based, constitute one of the more clearcut as well as significant examples. The discovery came with the measurement by Herbert Pomerance, now in the Solid State Division, of the neutron cross-section of pure zirconium in the pile-oscillator of the X-10 Graphite Reactor and the indictment of the high cross-section hafnium, which occurs with zirconium in nature, as the source of previous, misleading high values. The transformation of a promising laboratory metal with interesting nuclear properties to a practical material for reactor usage followed with:

- the development at Oak Ridge of a simple, inexpensive solvent extraction separation of hafnium from zirconium;
- the scale-up of the iodide process for producing "crystal bar" zirconium at the Westinghouse Bettis Laboratory;
- the development of the Zircaloy series of alloys, also at Bettis, in which tin and traces of iron, chromium and nickel were incorporated to improve physical properties and resistance to corrosion by high temperature water;
- the development of metallurgical procedures for fabricating the desired structures, plate and extruded tubing;
- the establishment of the environmental conditions required to prevent the well-known "crud" formation during exposure of Zircaloy to water at reactor operating conditions;
- and finally, the conversion of procedures and processes from the relatively primitive and expensive to the engineered lines producing an accepted commercial product at costs which have contributed to the amazing reduction in the cost of nuclear power over the past few years.

Thus, in supplying this one essential reactor component, contributions from physicists, chemists, metallurgists, engineers and production specialists intermingled. It is typical of the complex, interdisciplinary technology of reactor development that, except in very fine detail, classification of problems by discipline is not very meaningful as well as not very important.

With this disclaimer, I would now like to discuss some of the more critical problems of reactor development which have, at least, a significant chemical content. In so doing I intend to concentrate on the present, with reference to research of the past 25 years, in illustration of how reactors reached their present status. Even then, the subject is so varied and extensive that a limitation to topics most familiar to the author has been required. As will be noted and might be anticipated, the source material is weighted heavily in favor of Oak Ridge National Laboratory for the same reason. The objective is to describe a few critical problems, on whose solution the course of reactor development as we see it today depends, and thus demonstrate the continuing role of chemistry in reactor development.

Reactor Types and the Fate of Early Contenders

Although the variety and number of reactor systems under development have diminished markedly during the past few years, the surviving competitors still represent radically different technologies.

Research Reactors. As the requirements of nuclear research have demanded higher and higher neutron fluxes, the choice of reactor has narrowed to refined versions of the Materials Testing Reactor, the first of the postwar high performance reactors. This class, capable of producing fluxes as high as 5×10^{15} neutrons per square centimeter, is represented by, among others, ORNL's 100 megawatt, High Flux Isotope Reactor. Successful operation has provided proof of the solution of anticipated problems, and it now seems safe to conclude that there are no remaining critical chemical problems associated with the normal operation of these superperformance research reactors.

Power Reactors. For reasons unique to each system, several types of reactor power systems which looked promising a decade or so ago have been dropped from the developmental program in the United States. Some encountered formidable technical obstacles; others became less and less attractive as the simplicity, reliability and acceptance by the power industry of the water-cooled reactors were demonstrated and as the economics of these improved steadily.

Among former contenders were:

- the sodium-cooled, graphite moderated system, a prototype of which was built and operated as the Hallam (Nebraska) Reactor;
- the aqueous homogeneous reactors represented by ORNL's uranyl sulfate solution fuel and Los Alamos' uranyl phosphate;
- the liquid metal reactor, actively pursued at Brookhaven, which was to be fueled and cooled by a solution of uranium in bismuth, and which progressed to joint industry-Brookhaven design and component testing for an experimental unit before discontinuance;
- the heavy water moderated reactor, both in its heavy water cooled and organic cooled versions (although the heavy water reactors continue as the system of choice by the Canadian power program);
- variants of other systems such as the spectral-shift version of the water-cooled reactors sponsored by Babcock and Wilcox, the BeO-moderated reactor, the short-lived Pennsylvania Advanced Reactor program at Westinghouse based on a slurry or suspension version of the aqueous homogeneous reactor, and the clad fuel version of the gas-cooled reactors, cooled by helium and moderated by graphite (represented in Oak Ridge by the ill-fated Experimental Gas Cooled Reactor);
- several special purpose systems such as the reactors aimed at aircraft propulsion (General Electric's air-cooled, direct-cycle system; Pratt and Whitney's liquid metal cooled and ORNL's molten salt systems) and some of the compact units directed toward supplying small amounts of power in remote or inaccessible regions such as the SNAP-50 descendant of Pratt and Whitney's aircraft reactor—all of them complex, highly sophisticated technical systems intended to meet extremely difficult power requirements for the fulfillment of specific military or space missions.

Associated with the systems in this lengthy list of reactor "has-beens" was considerable research in virgin territories, including the determination of the properties and behavior of materials under a wide range of conditions. Fortunately much of this technology, acquired at an appreciable fraction of the total bill for these discontinued projects amounting to well over a billion dollars, has been applicable to some of the surviving reactor systems.

Let us turn now to these survivors, the types of reactors on which the Atomic Energy Commission and the power industry are now concentrating. Since so few reactor types remain as serious contenders for production of electrical power, categorization by relative efficiency of usage of nuclear fuel provides as good a basis for discussion as any. These categories conform with the two major divisions of the AEC's civilian reactor program: burner or low conversion reactors, and advanced converters and breeders. Chemical as well as other problems may then be considered which affect the basic requirements of operability, economy and safety of each system.

"A . . . demonstration that fast reactors will operate as breeders to produce economically competitive power, and do so safely, has yet to be made."

Burner or Low-Conversion Reactors

The world-wide emergence of nuclear power as a major producer of electricity is based primarily on the satisfactory performance and competitive economics, demonstrated or projected, of two types of systems: the water-moderated and cooled reactors fueled with a slightly enriched uranium; and the graphite-moderated, gas-cooled reactors fueled with natural or slightly enriched uranium. The first are represented by the pressurized water and boiling water reactors which now dominate the commercial nuclear power market in the United States; the latter by the clad fuel, gas-cooled reactors which have been adopted by the British and the French. The venture by the United States into the "low-performance" gas-cooled reactor field ended with the demise of the Experimental Gas Cooled Reactor and has been superseded by the development of more efficient unclad-fuel gas cooled reactors to be discussed under Advanced Converters.

The successful commercial operation of both the water cooled and gas cooled "burners" is *a priori* evidence that the chemical problems encountered in the development of these were satisfactorily solved. The current, very favorable economic competitiveness of these systems with fossil fuel power sources likewise demonstrates that the processes and procedures for production of fuels and materials, for corrosion control and for retention of radioactive by-products are sufficiently cheap as well as effective. Thus, it is safe to conclude that the technology required for operability and competitive economy of the "burners" is well in hand. However, economic competitiveness can be very transitory, and the necessity for reducing fuel costs by development of simpler and cheaper methods of making fuel elements, of extending fuel lifetime, of recycling plutonium is typical of the problem faced by most established industries.

The chemical aspects of some of the uncertainties about the safety of nuclear installations will be considered under Reactor Safety.

Advanced Converter Reactors

Of the three types of so-called advanced converter reactors scheduled as recently as two years ago by the Atomic Energy Commission for systematic development through the construction and operation of large prototype power units, one survives as such today. The seed-and-blanket modification of the pressurized water system progressed as far as contract negotiation for construction of a large unit in California. The inability of the fuel elements to endure for the time required by fuel cycle economics forced cancellation of the prototype and sent the project back to the laboratory.

Thus, the plan to fill the anticipated gap between the "burners" and the breeders by advanced converters depends today on the High Temperature Gas Cooled Reactor. The potentially greater efficiency of the HTGCR compared with the water reactors or the gas-cooled "burners" derives from the higher coolant and steam temperatures (and therefore higher thermal efficiency), and from the higher conversion ratio. The expected attainment of this performance, indeed the practicability of the concept, has resulted from the spectacular discovery of the coated particle fuels, combined with the use of helium under pressure as reactor coolant. Parasitic neutron loss is appreciably reduced; limitations on operating temperature imposed by the chemical reactions between coolants and the cladding and graphite are removed, as are temperature limitations set by the reduction in strength of cladding metals.

Coated Particle Fuel. Typical particles consist of a spherical core of uranium dioxide or carbide, about 400 μ in diameter, surrounded by a coating of pyrolytic carbon, about 100 μ in thickness. The carbon coating serves the same functions as the metallic cladding of fuels, i.e., protection of the fuel from chemical attack by the coolant or impurities therein and prevention of the escape of fission products into the coolant. In practice, the particulate fuel may be embedded in the center of a graphite ball, as in the German AVR, packed in tubes within a graphite rod, or arranged in other geometries to suit specific reactor designs.

Since the initial demonstration of the utility of the carbon coating, extensive developmental programs have been conducted at Battelle Memorial Institute, Minnesota Mining and Manufacturing Company, General Atomic, ORNL, Union Carbide Corporation and others. The literature on the subject is by now voluminous, as perusal of a few recent publications will indicate. The development of a satisfactory composite fuel particle has entailed studies of:

the chemical and physical properties of uranium and thorium compounds at temperatures up to 2000°C;

reactions of these with carbon;

long-term radiation effects including the chemical effects of accumulated fission products;

procedures for the preparation of the spheres;

the physical and chemical stability of various types of carbon layers and their effectiveness in retaining fission products;

methods for depositing carbon on the spherical cores;

reactions with, and control of, impurities in the coolant.

As a result of this research, it is now possible to specify and produce coated particles which appear to meet the requirements of the HTGCR. The following are pertinent characteristics:

Core: Of the two compounds most thoroughly studied and which would satisfy requirements, uranium dioxide has advantages over the carbide. The oxide particles do not flow after high burn-up nor does the oxide diffuse into the carbon coating at higher temperature. The cost of manufacturing oxide particles should be lower. Reaction between the oxide and carbon coating does not take place when the CO is retained by the coating.

Pyrolytic Carbon Coat: The properties of the carbon, which is deposited by pyrolyzing methane or acetylene in a fluidized bed, are critical. Based on the behavior of single, double and triple layers, a carefully tailored duplex coating appears to be the choice.

Although coated particle fuels look extremely promising, work continues in order to see that the essential criteria, of adequate fission product retention and resistance to impurities, be met.

In a complex set of hardware of the size of a full-scale reactor plant, it is inevitable that impurities will be introduced into the re-circulating helium coolant originating from gases adsorbed on structural materials and graphite and from leakage into the circuit, for example from the secondary water system. Establishment of permissable impurity limits and criteria for clean-up processes is dependent on detailed knowledge of the reactions and their rates, between steam, for example, and graphite and the coated particles. Variables being studied include temperature, partial pressure of steam, type of graphite, type of coatings, degree of irradiation and catalytic effects of fission products. Also of concern are the effects of such reactions on the release of fission products from the coated fuel and the transport of these through the system.

This abbreviated discussion has overly simplified a complex subject, single aspects of which have been topics for full-fledged symposia. Although the outlook for successful use of coated particles in HTGCR's is very encouraging, work continues to provide data for design of a reactor the operation of which will validate the research.

Breeder Reactors

Fast Breeders. Of the two paths to breeding – the fast system operating on the ^{238}U-^{239}Pu cycle, and the thermal on the ^{232}Th-^{233}U cycle – by far the greater developmental emphasis has been placed on the former. A continuous, active and fruitful program has existed at Argonne National Laboratory for almost twenty years. The high points of its history are well known, marked as it has been by operation in 1951 of the first reactor of any type to produce electrical power, the Experimental Breeder Reactor I, the demonstration of the feasibility of breeding, and the operation of EBR II.

Of the possible combinations of nuclear fuels and coolants which might be put together in a mechanical device constituting a fast breeder power system, the peculiar nuclear requirements of the fast system pointed at an early date to the use of clad-metallic fuel elements cooled by liquid sodium. The development, both in this country and abroad, concentrated on this line until emphasis was shifted in the United States to ceramic fuels, prompted mainly by uncertainties about the long-term stability of metallic elements. Secondary studies continue on alternate types such as steam-cooled fast reactors and on a variety of fuel materials.

This article is based on a talk given by the author to the American Chemical Society last fall.

In recent years the programs sponsored by both Government and industry in this country have expanded greatly to include also the Battelle Northwest Laboratory, North American, General Electric, Westinghouse, General Atomic, BNL, ORNL and others. A research effort of such duration, scope and magnitude has obviously tackled all recognized problems in considerable detail. Successful operation of experimental fast power units such as the EBR I, EBR II and the Dounreay Fast Reactor provides evidence that the technology necessary for operation exists, despite adverse experience with the Fermi Reactor. A corresponding demonstration that fast reactors will operate as breeders to produce economically competitive power, and do so safely, has yet to be made. These requirements of breeding, economic competitiveness and safety, are the sources of the major remaining problems.

Thus, as a major factor of power cost, the cost of fuel depends on fuel element lifetime and fuel recycle cost. A goal of >10 atom percent burn-up appears compatible with estimated fuel recycle costs. The development of a fuel element which will withstand the radiation exposures and composition changes corresponding to such a burn-up in liquid sodium at temperatures approaching 1000°C. is a truly interdisciplinary task. Involved in the case of oxide fuels, for example, are questions of the radiation damage to the oxide and to metal cladding, control of dimensional changes and damage, optimum stoichiometry of the oxide, reactions between oxide and/or accumulated fission products and the cladding, reactions between sodium and the cladding and oxide, reactions with carbon and oxide impurities in the sodium, control of impurities, and optimization of cladding composition to satisfy the many demands on it. All these and more have been investigated. The next obvious step is proof of the adequacy of solutions already found and the relative merits of fuel and cladding compositions in a power breeder environment.

Thermal Breeders. For these as for the fast breeders, the choice of reactor class which offered greatest likelihood of accomplishing breeding was dictated by basic nuclear and reactor physics. In this case the lower number of neutrons produced per neutrons absorbed (2.28) for ^{233}U at thermal energies leaves few neutrons for any other than the primary fission and thorium capture reactions. The overwhelming importance of very low neutron losses gives the fluid fuel reactors inherent advantages, such as:

- the absence of neutron absorbing structural materials within the reactor core;
- the potential ability to reduce loss to fission products by continuous extraction of these from the circulating liquid fuel;
- similarly the potential ability to extract continuously the intermediate product ^{233}Pa and thus reduce the double loss of neutrons and ^{233}U;
- the absence, in some types, of neutron absorbing mechanical control devices;
- and in the aqueous systems the use of heavy water as solvent, moderator and coolant.

Attractive as these "chemists'" reactors appear in principle, the chemists have met with small success until recently in converting promise to reality. The core of a high power, high temperature nuclear reactor can be an extremely hostile environment for a chemical system, as early proponents well recognized. As a note of historical interest, we might recall that the first proposal after World War II for a high-flux research reactor came from the chemists at the Clinton Engineer Works. They investigated for some months an aqueous homogeneous reactor for this purpose until it became apparent that a high-flux research reactor would be required to demonstrate the feasibility of a homogeneous system and efforts were switched to what became the Materials Testing Reactor.

The fate of the programs to develop the aqueous and liquid bismuth solution fueled reactors has already been recounted. The surviving liquid fuel system, based on molten salt fuels (an outgrowth of the project to apply a molten salt reactor to aircraft propulsion), shows encouraging signs of escaping a similar fate.

The Molten Salt Reactor Experiment has now been in operation at Oak Ridge National Laboratory over the past year with remarkable freedom from technical difficulty.* However, some of the, as yet, incompletely resolved uncertainties can be pointed out. Additional information required to produce a

*The history and results of the fifteen year program of chemical research and development have been summarized recently by Warren R. Grimes (ORNL TM-1853; June 6, 1967).

prototype breeder includes:

- a more detailed knowledge of the behavior of oxides and of oxide and hydroxide ions in the proposed breeder salt;
- a sounder technical basis for selection of a secondary coolant: although the $NaF\text{-}BF_3$ system offers promising physical properties, more must be known about its compatibility with structural alloys, about its phase behavior including the effect of oxides and the corresponding data for alternate systems;
- extension of the knowledge of radiation effects up to the exposures expected in full-scale breeder reactors, and determination of fission product behavior at the concentrations that would exist in breeders;
- knowledge of the chemistry of protactinium in the fluoride salt systems: particularly of reactions pertinent to the extraction of Pa such as the reduction with Th metal;
- and the improvement of production processes for the fluoride salts, improved analytical control procedures including in-line techniques, and, in general, the type of development required in the transition from a pilot plant to a competitive commercial system.

Nuclear Safety

The vast expansion of the nuclear power industry during the past two years has increased the emphasis on research and development related to reactor safety on at least two counts: first, the magnitude of the expansion *per se* and the trend toward larger and larger units with which there has been little or no experience; and second, the desire to realize the economic advantage of locating power installations as close as possible to the major customers, i.e., in metropolitan areas. In the case of the water-cooled reactors, a large fraction of the studies is aimed at assessing the mechanical integrity of the very large pressure vessels and piping circuits now being constructed and establishing design criteria to assure safety over the operational history of the units. Major chemical questions concern reactions between fuel, cladding and water, under abnormal operating conditions, resulting in high fuel element temperature and fuel melting. Of particular significance are 1) anticipating the behavior of the fission products during such possible accidental reactions and 2) evaluation of methods for containing fission products released from the reactor primary system. With the goal of simulating, insofar as possible, conditions of a large reactor installation, the studies have progressed from the laboratory to engineered devices or mock-ups, such as the transient excursion reactor (TREAT), at ANL, the loss of fluid test reactor (LOFT) at Idaho, and mock-ups of containment systems in which the characteristics of released fission products and their transport are determined.

In brief, these are aimed at providing answers to the basic problems of reactor safety:

1. definition of the actual radioactive source strength as a function of accident parameters, involving measurement of the fraction of each radioactive specie evolved during melting or reaction of the fuel;
2. the nature of transported species and the mechanisms of transport to permit design of effective removal processes;
3. and scaling relationships to permit application of data from small-scale or simple experiments and mock-ups to actual power reactors.

Safety of the newer reactor types (high temperature gas-cooled fast breeders, and thermal breeders) concerns the same basic questions but with unique combinations of possible chemical reactants for each. Thus, reactions of uranium compounds and metallic alloys with sodium, steam and graphite, sodium and air, molten fluoride salts and air and the behavior of fission products during such reactions are receiving attention. Although of a highly applied nature, much of this research entails basic studies of the kinetics of complex reactions, the identification of transitory chemical species, and the development of techniques and devices for experimentation in exotic environments.

Conclusion

This discussion has concentrated on the problems associated with the development of nuclear reactors for generation of electrical power. Left untouched have been the equally challenging applications to rocket propulsion; to compact sources of power for space, under sea and remote terrestrial locations; and to such uses of large blocks of energy as desalting sea water. The examples of chemical researches involved in the progress of nuclear power to its present status, and those still requiring answers suffice, I believe, to illustrate that the chemist is still an essential member of the interdisciplinary team developing nuclear reactors.

Science for Nonscientists

By W. W. Grigorieff

IN THE last 25 years the scientific and technological progress of the society in which we live has been extraordinarily rapid. The discovery of nuclear fission and the resulting practical applications are fast changing our way of life. Yet the understanding of science by the general public has been left far behind, and this gap, moreover, continues to widen.

The instructional programs developed some two decades ago by Oak Ridge Associated Universities (Oak Ridge Institute of Nuclear Studies at that time) in cooperation with Oak Ridge National Laboratory were primarily designed for university faculty, for graduate students and for research scientists. Subsequently, they were broadened to include undergraduate college science students, secondary school teachers and pupils and, in some cases, certain groups of the general public. One of the interesting developments was the science lecture demonstration program carried on by ORAU as a part of the U. S. Atomic Energy Commission's international exhibits program. The first ORAU model classroom for science teaching in Buenos Aires in December, 1960, was an immediate success with the Argentinian teachers and high school students. The program, now in its eighth year, has been in 24 different countries.

The results we were able to achieve in a number of foreign countries with audiences which differed

Wladimir W. Grigorieff, born to a Russian tea importer in Hangkow, China, raised by an English governess and educated in Switzerland and the U.S., can be said to have learned very early the art of communicating across boundaries, both regional and cultural. As Assistant to the Executive Director for Special Projects at Oak Ridge Assocated Universities, he has exercised this ability by organizing, over a period of years, some half-dozen seminars in which the scientific disciplines indigenous to Oak Ridge can engage in a colloquy with such disparate professions as sociology, philosophy, world politics and theology. That such an interdisciplinary communication is needed has been acknowledged widely since the C. P. Snow controversy nine years ago. Grigorieff, among the first to see the possibilities inherent in the Oak Ridge facilities, was responsible for developing the series of conferences described here. He graduated in Chemical Engineering at Swiss Federal University in Zurich, and received his doctorate in Organic Chemistry at the University of Chicago. He came to Oak Ridge in 1953 to head the University Relations Division at ORAU (then Oak Ridge Institute for Nuclear Studies) from the University of Arkansas, where he was Director of the Institute of Science and Technology.

widely in the extent of their scientific training and in general background training led us to question, "Shouldn't we initiate a program designed to develop an understanding of science by academic audiences not trained or versed in science?"

The First Summer Institute (1963)

In 1962 we proposed a further expansion of these activities by formulating a program for university faculty members from the social sciences and humanities, with the stated purpose of increasing their awareness and understanding of natural sciences and their appreciation of the impact of science and technology on modern society. The first such program was a six-week institute on science for nonscientists to be held in Oak Ridge in the summer of 1963.

In planning this summer institute we had to answer a number of questions: Should we attempt to teach science to nonscientists, or should we only talk to them about science? How much science could we expect a nonscientist to know? How should the group be selected: by academic discipline? by geography? by faculty rank? by age? or by some criterion yet to be determined? It appeared improbable to us that we could teach science to nonscientists in a short six-week period; rather, we decided that talking about science was the most fruitful approach.

The response to the announcement of the 1963 summer institute was unexpectedly large and diverse; 290 applicants had to be evaluated for the selection of the 30 who were invited to participate.

The 30 invitees, all of whom accepted, represented the fields of political science, English, history, philosophy, economics, art, classics, psychology and anthropology. The program followed the central theme of "The History Of Science." There were lectures on varied aspects of scientific history: Babylonian mathematics, history of Greek science and mathematics, physics in the nineteenth century, biology and biological thought, the history of the concept of force and of thermodynamics, and the history of technology.

Besides the formal lectures there was a "process of science" series designed to deepen participants' knowledge and understanding of science in the making, consisting of (1) visits to specific laboratories of Oak Ridge National Laboratory to supplement the lectures by Oak Ridge scientists on experiments in which they had been or were currently engaged; and (2) seminars directed by the participants themselves.

Several institutions sent observers to the institute, and in each case a further cooperative relationship resulted between the observer or his organiza-

Literally buckets of applications arrive in response to the announcement of each conference. Here Grigorieff and his assistant, Bernice Gulley, tackle the job of preliminary screening of the hundreds of applicants to the 1968 Clergymen's Conference.

tion and ORAU. Some of these positive results were: (1) The Carnegie Endowment for International Peace supported several subsequent institutes; (2) Miss Claire Nader, a political scientist from Columbia University, joined the ORAU staff for a one-year appointment and was instrumental in the organization and conduct of the 1964 summer conference before assuming her present position at ORNL; (3) the National Science Foundation provided partial support for several subsequent activities; and (4) the American Foundation for Continuing Education provided the leadership of William J. Trainor to our April, 1965, pilot institute.

The 1963 institute was successful, but it had some weaknesses, partially identifiable at its conclusion, and certainly more distinct when viewed five years later with the additional experience of other summer institutes, two foreign ventures, and the various other, shorter conferences. We learned that:

- Six weeks is too long a period for a program designed to convey an "awareness" of science to a group of academic faculty members.
- The rigid schedule of lectures, discussion periods, seminars and laboratory visits, left the participants too little free time for informal discussion and thinking.
- The presence of wives and, in a number of cases, whole families limited the opportunities for extracurricular contacts between participants.
- The 15 volumes of advance reading material which was sent to each participant only a month before his arrival in Oak Ridge proved to be too much for him to assimilate in so short a time.
- The extensive bibliography and a "special" reserve library set aside for the participants missed the mark and were sparsely used, perhaps because of a too heavy daily schedule.

The Second Summer Conference (1964)

"Science and Contemporary Social Problems" in the summer of 1964 was fortunate in having as its chairman Professor Norwood Russell Hanson,* a member of the Department of Philosophy of Yale University. He was assisted by a staff consisting of Robert Cohen, Professor of Physics, Boston University; Lewis Nelson, Director of University Relations, ORNL; R. Christian Anderson of Brookhaven; and Miss Nader at that time of ORAU.

This month-long conference was ably designed to provide an opportunity for a "conversation" among the 30 humanists and scientists who were selected to participate. It is in this conversational atmosphere that we find the main difference between the 1964 institute and its predecessor.

The second conference was conceived by its staff and its chairman as a kind of "three-part fugue" consisting of the main themes: (a) The conceptual structure of modern science as learned from the ORNL machines, the history of recent science and its logic and philosophy, problems in methodology, history of ideas, philosophy of physics, etc.; (b) the organizational complexity of modern science; and (c) the

*Deceased 1967.

implications and effects of "big science" on the other aspects of our lives, as viewed by the artists, the social critics, and moralists.

The stated intentions of the conference were to "minimize lecturing" and to "maximize discussion and interchange," with the hoped-for end results of: (a) a deeper understanding of scientific pursuits by nonscientists; (b) a greater awareness, by scientists, social scientists, and individuals in the humanities, of the relationship of science and technology to society's intellectual and practical pursuits; and (c) a developing and tutored perception of the contribution of natural sciences, the social sciences, and the humanities to the comprehension and solution of multi-faceted modern problems in which science is recognized as one element among many to be considered.

A very serious and conscientious effort was made to bring the participants into closer contact with the scientific activities and day-by-day life of the Oak Ridge community, most particularly that of ORNL.

In order to eliminate the too-rigid teacher-learner pattern encountered in 1963, each of the participants was asked to offer a prepared presentation in the morning session with some discussion immediately thereafter; the afternoon session was reserved for a formal discussion of the morning presentation. This made the 30-day conference essentially independent of "visiting" lecturers, since the "student body" was in some ways its own faculty, with Prof. Hanson and his staff functioning as regulators of discussions. The dozen or so other lecturers included several Oak Ridgers and the specially invited out-of-town experts.

In an effort to prevent overorganization and to promote spontaneity in discussions, only the morning lectures and the afternoon "counter-lectures" were formally scheduled; however, every day was taken up in this way, with the result that some participants felt the lack of free discussion time.

One lesson we learned is that standardized format should be avoided: either "two lectures per morning" or "15 minutes per lecture discussion" becomes tiresome if repeated day in and day out for four weeks.

There is little doubt that the 1964 conference did produce an excellent forum for a stimulating set of discussions by a group of scholars, and it did provide a discourse between representatives of natural sciences, the social sciences and the humanities, about social and intellectual questions of common concern to the participants.

Herceg Novi Conference (1964)

An unexpected spinoff of this program occurred in the fall of 1964 as a ten-day conference on "Science and Technology and Their Impact on Society" at Herceg Novi, Yugoslavia, sponsored jointly by the Federal Nuclear Energy Commission of Yugoslavia and ORAU. Drawing on our Oak Ridge experience, the program consisted of lectures on science as well as on implications of science. Among the highlights of the U. S. contributers: ORAU Director W. G. Pollard lectured on the "Genetic Code," while Paul Gross, Emeritus Professor of Chemistry at Duke University, addressed himself to "Science Policy," and A. M. Weinberg covered, among a variety of subjects, the nuclear power revolution.

The idea for such a conference had sprung up spontaneously during a formal visit I made in May, 1963, to Federal Nuclear Energy Commission headquarters in Belgrade. A mid-morning ceremonial coffee period led to the following exchange:

Question: What's new in Oak Ridge?

Answer: Plans for a conference on science for nonscientists.

Question: Why don't we do one in Yugoslavia?

Answer: Why not?

By the end of the day, the FNEC was committed to the idea and had assigned financial resources for the conference; our embassy experts viewed the proposed venture with interest and an approving eye. Funding of the U. S. delegation to the proposed conference was secured by the Bureau of Cultural Affairs of the Department of State in less than 30 days after the original laconic dialogue in Belgrade.

Weinberg participated enthusiastically in the conference; his article in *International Science and Technology* (February 1965) gives an excellent description, from which the following quote is most pertinent:

"I am convinced that conferences such as this, between scientists and humanists of the two societies, are much in the interest of both. Since there is no alternative to peace in today's world, we must set about resolving our differences. Certain differences between Yugoslavia and the West are much smaller than we could have imagined a dozen years ago. One feels this when one sees the many Yugoslavian-made Fiats on the roads; the New York *Herald Tribune* for sale in the kiosks in Zagreb; Pan-Am's operation (under contract) of the magnificent Zagreb Intercontinental-Esplanade Hotel. Yet doctrinal differences do remain. Insofar as conferences like the

At the party on the last night, ORNL Director A. M. Weinberg teaches the Herceg Novi participants of 1964 the intricacies of the Virginia Reel, a dance that proved to be so popular it was revived by the 1966 conference.

one in Herceg Novi smoke out these differences in doctrine, and discuss them in the light of the world of 1964, not the world of 1864, we have made progress toward keeping our troubled world from blowing itself up. Science is a good horse on whose back we can ride into a territory generally avoided when we meet our colleagues from the East—the philosophic bases of the two contemporary social systems.

"Ours will be one world indeed when the two societies can discuss dispassionately not only a neutral subject, like science, on which all can agree, but a nonneutral subject, like the philosophic basis for communism, on which we don't agree. The Herceg Novi conference was a good start in this direction. I hope there will be more such dialogues. They will be small but important steps in our climb toward a more tolerable and stable world."

Nuclear Science and World Politics (1965)

In the spring of 1965, a three-week pilot institute was conducted at ORAU, at the instigation of the Carnegie Endowment for International Peace. It was aimed toward assisting the political scientists involved in international affairs to develop an understanding of the role science plays in today's world, and generally to increase their "scientific literacy."

W. J. Trainor, Jr., of the American Foundation for Continuing Education, directed this novel educational endeavor along lines suggested by E. R. Platig and J. L. Schwartz, who had been the observers sponsored by the Carnegie Endowment at the first Oak Ridge Institute in 1963. Two ORNL physicists, Alex Zucker and Ted Welton, were the major reason for the ultimate success of this endeavor.

The lecturers presented to the participants a 250-year picture of man's knowledge of physics, beginning with Newtonian mechanics and concluding with a lecture on the non-conservation of parity. Lectures in between were on relativity, reactors, the A-bomb and fusion, to name a few. The lectures that were not on physics dealt with the impact and political implications of science.

The pilot institute was a teaching challenge. Since this was our first attempt to teach science, and nuclear physics at that, to nonscientists, we planned carefully to provide an environment conducive to the teaching-learning process. The group of 18 participants was subdivided into groups of three which met on alternating afternoons in "tutorial" sessions.

Care was taken to provide sufficient free time for the participants to absorb the subject, to study, to read and to reflect.

The principal accomplishment of this institute was that the participants learned some science, and believed that this new knowledge was going to be helpful to their future activities.

The 1965 Summer Institute

This four-week institute was directed by Professor Arnold M. Clark of the University of Delaware. The number of presentations which could be characterized as science lectures surpassed the nonscience lectures by a ratio of 3 to 2. The central theme of these lectures was biology, reflecting the field of interest of Dr. Clark.

The principal lecturers and their topics were: R. F. Kimball, Ionizing Radiation and the Cell; W. G. Pollard, The Genetic Code; S. I. Auerbach, Ecological Aspects of Environmental Pollution; C. L. Dunham, Impact of Atomic Energy on the Marshall Islands; W. L. Russell, Radiation and Mammalian Heredity; A. C. Upton, Radiation, Disease, Aging; C. C. Congdon, Organ Transplantation; S. F. Carson, Modern Experimental Biology; R. C. von Borstel, Space Biology; N. G. Anderson, Origin of Life. That these lectures were well understood by most of the nonscience participants is a distinct tribute to the lecturers, who worked hard to present information at a level commensurate to the assimilation potential of their audience. The first week of the conference, lecture-demonstrations on atomic structure, radioactivity, and fission and reactors were given. This was a helpful preparation for the biology lectures.

The theme of the conference could best be stated as "impact of science on higher education" and the impact of the conference on the 23 participating faculty members was appreciable. Representation from the disciplines was distributed as follows: social science, 3; psychology, 1; music, 1; engineering, 1; economics, 4; biology, 3; mathematics, 1; political science, 4; history, 1; philosophy, 1; English, 3.

The participants were particularly interested in the impact of science upon their own fields and were receptive to suggestions that would enable them to widen their perspectives. The Oak Ridge environment, the tours, and the speakers from Oak Ridge National Laboratory comprised, in the words of a participant, "a dramatic and magnificent example of science as a social and humanistic activity."

There developed among the participants of this institute a team spirit, a group identity, and good social intercourse to a degree that had been lacking in earlier conferences.

The conference helped to shake the faculty from its traditional ways of looking at education and to appreciate that problems exist. No remedies were found. It became clear from the discussions that the "humanities" professors lack a common understanding of the role of the humanities in the modern world in which we live.

A very gratifying result of this conference was that some of the participants, even before returning to their campuses, came up with ideas of extending the format and the theme of this conference to similar activities for professors at their own institutions, for deans, for homogeneous groups of faculty members, for secondary school teachers, and a variety of academic audiences. If this were the only outcome, the conference could be considered a success.

In the advance planning stage of the conference, the fourth week was purposely left unscheduled until opening week. This was done in the expectation that self-generated projects might develop and that additional lecturers might be desired. As it developed, the last week was used for a series of panels, which were planned, organized and presented by the participants themselves.

The 1965 institute was an interesting mixture of a "conference" and a "course." The group did not become a conference until the last week; by then it had become closely knit and could interact on "the impact of science on higher education."

This conference, as well as the three-week institute in April, had the services of a rapporteur, who summarized the content lectures and subsequent discussions for immediate reproduction and distribution among the participants. This type of summary-report-précis was found to be an invaluable asset, both to the ongoing conference and to the published proceedings at its conclusion.

Yugoslavian hospitality includes gifts of fresh flowers brought by girls in native costume. Charmed by this gesture at the plush Adriatic resort are Grigorieff and his wife, Lilian.

Herceg Novi II (July, 1966)

The Yugoslavs were anxious to broaden the audience and the participation in a second Herceg Novi conference. A Yugoslav-U.S. bilateral arrangement in 1964 became a truly international forum in 1966 with strong participation from U.S.S.R. and several other East European countries. The Yugoslav organizing committee chose as a subtheme of the "Impact of Science and Technology on Society" a broad discussion of cybernetics.

As the date of the conference approached, news of the program kept filtering through; the U.S.S.R. delegation included two academicians with V. I. Slushkov, one of their leading cyberneticists. The highpoints of our contribution included a first day transatlantic speech by Alvin Weinberg, who was fondly remembered by the 1964 participants, and three separate demonstrations of computer applications. A direct line connecting Professor Joseph Weizenbaum, department of electrical engineering at Massachusetts Institute of Technology, with Project MAC (Multiple-Access Computer) at MIT provided an interesting dialogue between the audience and an imaginary "computer doctor" in Cambridge. A. H. Snell of ORNL presented a sample of machine translation of Russian to English: at the start of his talk, a scientific Russian text was given to the telex-operator, installed at the side of the lectern Snell was using. This was transmitted by Telstar to the Computing Technology Center at Oak Ridge Gaseous Diffusion Plant. After some 30 anxious minutes, Snell's talk was interrupted by the click-click of the Telex sending us a reasonably good English translation. In the meantime, the audience was given the opportunity to request a bibliographic search on any nuclear subject; these questions were sent to Oak Ridge and complete printouts of references in Nuclear Abstracts were received in the lecture hall the next day, a very impressive performance, particularly to the nonscientists in the audience.

Herceg Novi '66 enjoyed the facilities of simultaneous translation during the talks. The bottom picture shows an important part of the picnic that closed the conference.

The Fourth Summer Conference (1967)

Early in 1966, an informal discussion of what type of conferences we should consider led to the suggestion by C. G. Wilder* of ORAU to have an audience of clergymen.

Drawing on our past experiences, we found it relatively easy to formulate the broad outline of such a conference: two weeks' duration, thirty participants, "content lectures," "impact discussions," advance readings, housing, and other parts of what should be in any respectable proposal.

Getting the nod from ORAU Director Pollard and ORNL Director Weinberg was not difficult. Financial support was another problem; before tackling that, however, we wanted to find out how the clerical community would take to the idea. While attending a technical society meeting in New York City, I was fortunate enough to get in touch with Reverend Ralph E. Peterson, who was in charge of Continuing Education at the National Council of Churches. He came down to the hotel for what was supposed to be a short breakfast conversation before another meeting at 9:00. We were still finishing breakfast at 11:00. He was completely captivated with the concept, and assured me that we could count on interest among Protestant clergy. In addition, he made arrangements for a meeting that same afternoon with Rabbi Eugene Weiner, Director of the Herbert H. Lehman Institute of Talmudic Ethics at the Jewish Theological Seminary of America. Rabbi Weiner, too, endorsed the project and assured us of participation by the Jewish community.

The general outline of the program was developed in discussions with an interdenominational national committee of clergymen and a number of Oak Ridgers. It was decided to present the broad spectrum of science, concentrating on nuclear science, and a specific laboratory session of "doing" some science was planned. Pollard agreed to present three substantive science lectures; Weinberg offered to give four seminars; the Special Training Division undertook to conduct a laboratory exercise in determining the half-life of a specific radioisotope. All in all, the response from those Oak Ridgers whom we asked to participate in the project was gratifying.

By early May we had applications from over 250 clergymen for the 30 spots we hoped to fill. Since there were no mailing lists available for our original announcement of the conference, this was an unexpectedly large number. With no precedents and no established criteria for selection, the task of reducing the large number of applicants to 12% fell on the shoulders of the national committee. We were all pleasantly surprised at the end of a very full two-day session in a mid-Manhattan hotel to find that we had selected, with self-assurance and har-

*Deceased 1968.

Participants in the 1967 Science for Clergymen worked hard and with enthusiasm. They represented Baptist, Catholic, Congregational, Jewish, Lutheran, Methodist, Presbyterian and Unitarian denominations.

mony, 30 participants and six alternates. The major criteria, developed in the selection process, were: a minimum educational equivalent of a B.D., a maximum age of 55, and a minimum pastoral experience of five years.

The 30 participants, the six local clergymen and the two clergymen observers turned out to be a well balanced, appreciative and stimulating group, who enjoyed the two-week experience, seemed to learn a lot, and who returned to their parishes well satisfied with what they had learned.

Their response to the lectures, the lab sessions, the breadth of science and the stimulation of Oak Ridge's scientific spirit was all that we had hoped it would be. Some of them commented later that this was one of the most stimulating intellectual activities they had ever experienced. Others were eager to put into practice what they had learned. As to the Oak Ridgers, they seemed to be intrigued by the challenge of explaining science to this type of audience and did this most effectively, lecturing on subjects which ranged from modern biology to civil defense, from the periodic system and atomic theory to the agro-industrial complex. The clergymen were stimulated to active participation in the conference as well as in weekend contributions in local churches: they gave as well as they received.

An intriguing sequel to the 1967 conference for clergymen is the National Science Foundation's preference for supporting one Oak Ridge conference of 90 clergymen instead of three geographically separated conferences for 30 clergymen each; it is scheduled for August 5–16, 1968.

A Five-Year Summary (1963–1967)

The five-year sequence of seminars on science for nonscientists has been successful mainly because it enjoyed the cooperation of Oak Ridge National Laboratory and of a number of Oak Ridge scientists and engineers.

We started in 1963 with an approach that attempted to bring an awareness of science to humanists by emphasizing the history of science, then gradually shifted to "talking" science and even "doing" science, which turned out to be a more valid and valuable approach.

This sequence of conferences has demonstrated that understanding of and acquaintance with science can be successfully imparted to nonscientists; at the start, this took six weeks; subsequently we tried a month, four weeks, three weeks and finally a fortnight, which seems to be the most desirable duration.

We found that the variety and number of disciplines represented in a given group of participants does not seem to be crucial to the success of these conferences; on the contrary, a reasonably homogeneous group (foreign affairs generalists or clergymen) appears to offer a synergetic effect to the learning experience.

A carefully selected and limited amount of advance readings, and the availability of daily summaries by a rapporteur are important aids to the participants' assimilation of the content of lectures and discussions.

At the start of a conference, a certain part of the daily schedule should be left uncommitted so that new activities may be generated or requested by the participants.

Future Oak Ridge seminars on the Impact of Science on Society should be designed as pilot efforts to serve as prototypes for other seminars elsewhere, nationally or internationally. Future audiences might be labor leaders, congressional staff, or professional women!

Lewis Nelson, Director of Education and University Relations at the Laboratory since 1965, is the ORNL representative in the "Sister-Laboratory" arrangement which he describes here. He first came to Oak Ridge as a member of the Fairchild Nuclear Energy for the Propulsion of Aircraft project in 1947 and joined the Laboratory in 1949 as a member of the Mathematics Division staff. In 1950 he became Assistant Director of the Oak Ridge School of Reactor Technology, and served as its Director from 1956 until it was discontinued in 1965. He participated in the establishment at ORNL of the University of Tennessee Graduate School of Biomedical Sciences and the two schools of engineering practice, conducted in cooperation with Massachusetts Institute of Technology and the University of Tennessee. He is the responsible officer for the Laboratory's Exchange Visitor Program in which about 100 visiting scientists participate each year in the work of the Laboratory. He received the Ph.D. degree in Mathematics from the University of California at Berkeley in 1947.

ORNL's Sister Laboratory in Thailand

By Lewis Nelson

THERE IS a tendency among us in the United States to think of the people of Asia as being homogeneous. We call them Asians.

Asia is a geographic entity in the same sense that Europe is, but as in Europe so in Asia the countries of which it consists differ. Thailand, formerly known in the West as Siam, has a common border with Cambodia, but no Thai wants to be mistaken for a Khmer, i.e., a Cambodian. Those two countries have a history of conflict, and relations between them aren't at present cordial. The people of Thailand insist on being Thai, even the few residents of Chinese extraction. Those who came from China or whose ancestors were Chinese, speak Thai and bear Thai names. The principal concession to Chinese influence is in the food served at most of the finest restaurants in Bangkok: although chopsticks are rarely used in Thai homes, they are present in all the restaurants.

The area of Thailand is about three quarters that of Texas, and its population, which is increasing by a rate slightly over three percent per year, is nearly 35 million. Of this number, more than two million live in Bangkok, the capital and only large city in Thailand. The per capita income is low and there is grievous poverty, but virtually everyone has enough to eat. The vast bulk of the population dwells on farms which, for the most part, are individually

Every residential building in Thailand has, somewhere on the grounds around it, a spirit house, in which dwell the spirits of the place. These small shrines, some of them quite elaborate, are kept decorated at all times with fresh flowers and talismans. This is the spirit house of the Hotel Arawan.

owned. Rice is the great staple and enough is produced to allow an export of more than a million tons per year. The country exports a number of other commodities, mostly agricultural, accounting for an annual income of about $172 million. There are no major manufacturing industries, but the portion of the gross national product due to agriculture has been decreasing and that by manufacturing has been increasing. The GNP is growing at the rate of about seven percent per year. A brochure compiled by the U. S. Agency for International Development (AID), "Private Enterprise Investment Opportunities in Thailand," lists metal manufacture, chemical industries, pulp and paper industries, food and allied products, textiles, furniture and wood products, tourism and handicrafts.

A famous and popular product of the Thai handicrafts is their silk which is one of the world's most beautiful fabrics. In Bangkok there are shops in which it is displayed and sold and where an amusing sight is the tourists, from the East as well as from the West, making what seems to be the impossible choice of which color or design to buy—one wants far more than his purse will allow even though the price is reasonable. In addition to the uncut cloth, there are shops in which the silk is made into apparel of local design. Here as elsewhere the good taste of the Thai appears.

More than 95% of the Thai are Buddhists and less than one-half of one percent are Christian. The country has never been the colony of any western power and its record of independence is a matter of deep pride to the people. For many centuries its government was an absolute monarchy which persisted until 1932. The King and the royal family are still much revered and remain both a national symbol and the source of legitimacy of the present government. A constitution has been adopted and political power resides in the successors to the group which, in 1963, ended the monarchy by a coup d'état. Field Marshal Thanon Kittickachorn has since that time been the Prime Minister who presides over the Royal Government of Thailand.

A group of U. S. experts in electric power production, under contract with AID, made a comprehensive study of Thailand's present and projected needs for electrical power and reported its findings and recommendations to the Royal Government of Thailand in December, 1966. The document is voluminous and cannot be summarized here, but the opening sentence of the Foreword strikes an optimistic note and gives the flavor of the entire report:

"The Electric Power Study Team believes that its greatest contribution to the future of Thailand—'Land of Freedom'—will be to establish firmly the PHILOSOPHY OF PLENTY as a basic premise for planning the expansion of its electricity supply system."

Because there are no significant deposits of coal and oil in Thailand, power production is by falling water and imported fuels. The study team accordingly considered nuclear power as a part of its recommended construction program of hydro and steam generated electricity. The first nuclear plant in the schedule would be 400 MW, in service by 1977. Two others of the same capacity are contemplated, one to be in service in 1978 and one in 1980.

Virul Mangclaviraj, member of the staff of the Office of Atomic Energy for Peace in Thailand, jots down data from the oscilloscope as Acting Chief Punnamee Punsri and ORNL scientist J. J. Pinajian look on.

The Thai have been alert to the possibilities inherent in atomic energy for a long while; the Thai Atomic Energy for Peace Commission was established in 1954. TAEP is a functional part of the Ministry for National Development and is headed by a Secretary-General, the distinguished Dr. Svasti Srisukh. (In Thailand the family name is given first, hence the Secretary-General is addressed and referred to as Dr. Svasti, pronounced SUE-AHT.) Dr. Svasti holds a degree in biochemistry granted by an English university from which he clandestinely returned to Thailand prior to the end of the Japanese occupation in World War II. The story sometimes told of his return is one of great courage and daring, but when asked about it, he diverts the conversation away from himself.

Thailand has had a U. S. Atomic Energy Commission depository library since 1955. In October, 1962 its research reactor, one megawatt, pool type, built by Curtiss-Wright, attained criticality and has been in operation ever since. A grant of $350,000 for the reactor was made by the U. S. Government to the Royal Government of Thailand, but the Thai have reserved this money for equipment and operating expenses since they preferred that they themselves purchase their reactor. It is located about eight miles north of the center of Bangkok, on the highway leading to the airport, which is a few miles further north. The Office of Atomic Energy for Peace (OAEP) or the Laboratory, as we would call it, employs about seventy people who hold university degrees. Four of them are not unknown at ORNL: Mr. Sungwean Wongmungkorn, Chief of the Isotope Production Division, studied the production of radioisotopes for four months here in the Isotopes Division in 1961. Mr. Krivuthi Sukijbumrung, Deputy Secretary General, and Mr. Vichai Hayodom, Chief of the Radiation Hazards Control Department, attended the 1959–1960 session of the Oak Ridge School of Reactor Technology. Mr. Somchet Tangthieng came to the Instrumentation and Controls Division of ORNL in 1966 where he spent two years on a fellowship granted by the International Atomic Energy Agency (IAEA). During his stay he attended the University of Tennessee, receiving his Master's Degree in electrical engineer-

Pinajian, center, describes the changes needed for isotope production to ORNL colleague W. S. Lyon, Jr., and Deputy Secretary-General Krivuthi Sukijbumrung as they stand at the edge ofthe pool-type reactor.

ing. Divisions of OAEP other than the above mentioned are Reactor Operations and Training, Electronic Instrumentation, Isotope Production, Biological Sciences, Chemistry and Physics.

Thailand became a member of the IAEA in 1957 and has received substantial aid from the Agency in the form of fellowships, grants for the purchase of equipment and in experts sent to Thailand for periods of up to one year.

Under an interagency agreement between AID and AEC the Oak Ridge National Laboratory became a sister-laboratory to the Laboratory in Bangkok. The purpose of this arrangement, which was the first of its kind for ORNL, is to make available to the small laboratory of a developing country some of the experience and sophistication of a large, highly developed U.S. laboratory. In spite of the effort that has been made, the Laboratory in Bangkok has not yet achieved self-sufficiency. It is small and isolated and its scientists and engineers are both inexperienced and underpaid. As its sister-laboratory, ORNL has the obligation and opportunity to try to offset the isolation and inexperience through communication and personal contact between the personnel of the two laboratories. The cost of this is paid by AID, and while AID spends at a rate in excess of $40 million per year in Thailand (and this sum does not include the military assistance given by the U.S.), the portion given to atomic energy is small. One may criticize our Agency for International Development, as indeed is now being done in Congress, but there is nevertheless little reason for encouraging it to fund support in atomic energy in Thailand on a grand scale. A research reactor with associated laboratory does not alone constitute a means for developing an underdeveloped country. Those of us who have gone to Bangkok under the sister-laboratory arrangement sometimes allow ourselves to dream of what could be done with large sums of money, of the kind of research center that could be established there, but the hard truth is that we must count on the effect of a small force acting for a long while; and so also, it seems, must everyone, including the Thai.

The first emissary under the sister-laboratory arrangement, J. J. Pinajian, went to Bangkok in April, 1966; Mrs. Pinajian and their son joined him a little later. The sister-laboratory scheme allows our sending scientists and engineers to Thailand for visits of up to one month in duration, but does not permit us to finance visits by the Thai. An exception in the time limit was made in the initial visit which allowed Pinajian to work in Bangkok for seven months. He was welcomed by the Thai, not only by those in OAEP, but by many in the other institutions of education and research and by many in the Government. The U. S. Embassy in Bangkok also made him welcome and supported him fully and actively. The Embassy has a strong interest in the sister-laboratory, and encourages and assists its staff in all possible ways, which are many. This cooperation has been and remains invaluable to the enterprise.

Since Pinajian had gone to assist the OAEP in its production of radioisotopes and to scout the educational and research activities in Thailand, he visited many people in many institutions during his stay. At times he found himself regarded as expert in areas in which he claims no expertise and in that respect discovered a phenomenon that later visitors from ORNL have also remarked, which is the reaction to a surfeit of experts. Under a variety of auspices, many people who claim to be experts pass through Bangkok (and no doubt through many other cities of Asia), visit the Laboratory, nod their heads sagely or give a talk on some topic of science that no one is prepared to evaluate or question. The genuine expert can be of no help to the Thai unless he is both able and willing (and many are neither) to address himself to their problems in terms of the existing available experience and equipment. It is idle for a visitor to suggest programs of research that are quite beyond the capability of the Laboratory in Bangkok; it is worse than idle when such a program is so esoteric that it is unlikely ever to be of use to Thailand. Yet suggestions of this nature are frequently made by visiting "experts."

Pinajian visited the two major hospitals in Bangkok, Chulalongkorn and Siriraj, and the one in Chiengmai, about 350 miles north, and found that all three regularly use radioisotopes. The hospitals constitute almost the only users. Other institutions could, and if stimulated to do so certainly would, use the isotopes that the OAEP can make and deliver. Although Chulalongkorn University is in Bangkok, there is as yet minimal cooperation between it and the OAEP. The situation seems to be similar to that often observed in the United States: a research center and a nearby university are slow to discover the ways in which collaboration is mutually advantageous. In Bangkok a training program of engineers of the Yanhee Electrical Authority by a cooperative effort of the OAEP and Chulalongkorn University is being undertaken. Its purpose is to prepare the Authority for considering the acquisition of a nuclear power station, for Yanhee understands full well the necessity for thorough orientation of its own engineers into the new technology before negotiating the purchase of a nuclear plant. Conceivably this cooperation between the Laboratory and University can be expanded to the benefit of each.

The Laboratory in Bangkok is virtually on the grounds of the Kasetsart (Agricultural) University at which there is some work going on in plant physiology. Here again one can expect some useful

Lyon and Pinajian stand in the courtyard of the Thai Atomic Energy center with members of the Chemistry, Biology, Health Physics and Isotopes Production Divisions.

cooperation to eventuate. Also nearby are the laboratories of the Applied Scientific Research Corporation, a new and vigorous institution. Because it is new, its leadership is cautiously seeking the kinds of things that it can do for the benefit of the country in the near future and at the same time patiently allowing its staff time and opportunity to grow and to learn. It can best be described as analogous to our National Bureau of Standards. Anyone who has eaten coconut milk ice cream applauds the effort being made by the Corporation's Technological Research Institute to preserve coconut milk and its delicate flavor. However, the research going on there encompasses far more than the preservation of fruit; also under study, to name two, are textiles and fiber technology and construction materials.

Another and very important undertaking in Thailand is the Asian Institute of Technology. It was established in 1959 by the Council of the South-East Asia Treaty Organization in Bangkok as the SEATO Graduate School of Engineering and has since become autonomous. Its purpose remains education and research for the benefit of Southeast Asia. An example of a thesis topic listed by the Institute (and quite possibly not randomly chosen by one who has seen an ancient, overloaded bus racing a train to a crossing) is "Application of Car-Following Theory to Unsteady State Flows . . . Based on the ability of a human eye to detect changes in the mode of operation of a moving object . . ." There seems to be little exchange between the OAEP and the AIT, but here again the potentiality of beneficial cooperation may soon be realized. Both organizations are young and each has its own problems.

In consequence of Pinajian's visit in 1966 and of his return in 1967, the production rate of radioisotopes by the OAEP has significantly increased. However, that is a poor measure of the effect that the sister-laboratory arrangement has had. Others have made visits of one month each to assist either in chemistry, primarily activation analysis, or in reactor operations. All have been graciously received and each has found the Thai eager for assistance. They are a proud people, be it said to their credit, and they are rightly wary of interference in their affairs, which they intend to conduct in their own way. A realization on their part that our purpose is to help and not to dominate seems to have emerged. This is a serious matter because they haven't yet established research programs which can be encouraged and which can respond effectively to the ideas and advice of a scientist or an engineer who visits infrequently and then for only a short time.

A cordial relationship on which to base further cooperation has matured; it is a rare friendship that is born whole. The limitations of each party are understood by the other. We can advise the Thai on maintenance of their reactor system's heat exchanger; we could not supply them with a new one. They have the potential for repairing disabled shim rod control magnets and possess the will to try; we can and do supply small items needed for production of radioisotopes. They can and want to produce the bulk of the isotopes now regularly used in Thailand and desire the ability of making those that may be wanted urgently but infrequently; we can share our expertise and help develop their ingenuity.

At midnight in Oak Ridge it is noon tomorrow in Bangkok; probably the rice stem borer is busy at his destructive work. Curbing that pest may be within the reach of biological control techniques that employ radiation. That would be a spectacular accomplishment, but there are other, less striking ways in which the Thai Office of Atomic Energy for Peace can contribute to the well-being of the people of Thailand. The scientists and engineers of the OAEP can set their sights on modest research goals and their friends at ORNL can help them formulate the programs and achieve the goals. Each member of the sistership believes that persistence will yield a sequence of small achievements which will aggregate in importance, slowly perhaps, yet certainly.

Aerial view of Thailand's Office of Atomic Energy for Peace, situated on the road between Bangkok and the Thailand International Airport, shows the experimental farm in the background. The tall building with the mural on the top storey houses the reactor.

Seated at the control panel of the Thai reactor, Acting Chief Punnamee demonstrates the instrumentation to Deputy Secretary-General Krivuthi and the ORNL scientists.

OAK RIDGE NATIONAL LABORATORY
U.S. ATOMIC ENERGY COMMISSION