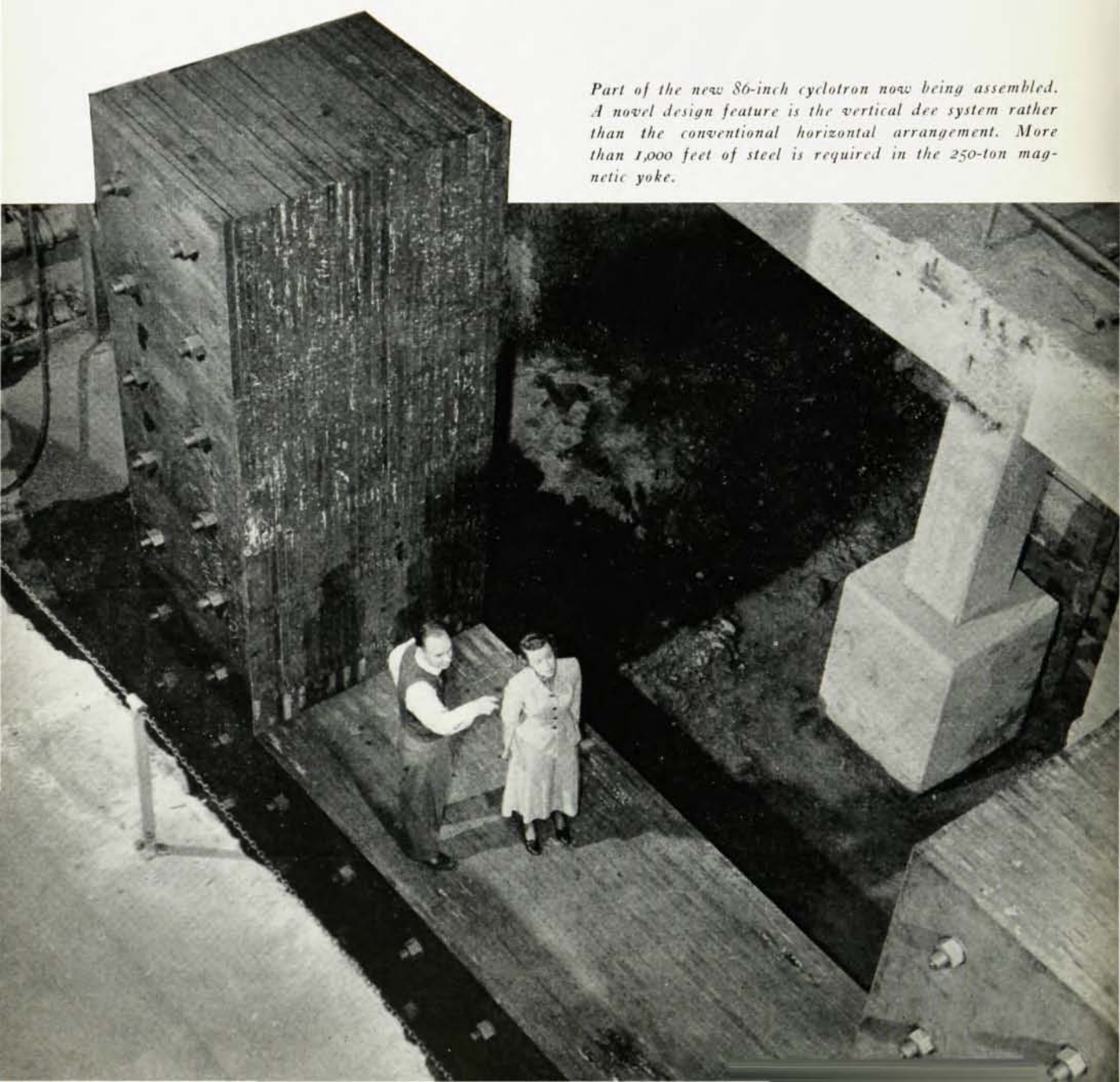


These remarks on the role of physics and of physicists in current nuclear energy development are based on an address given at the banquet of the American Physical Society in Oak Ridge on March 17, 1950.

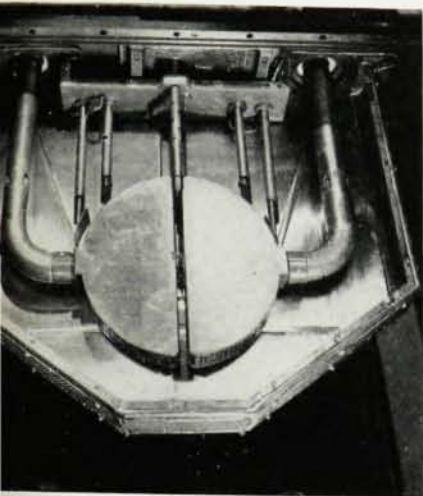
PHYSICS

Part of the new 86-inch cyclotron now being assembled. A novel design feature is the vertical dee system rather than the conventional horizontal arrangement. More than 1,000 feet of steel is required in the 250-ton magnetic yoke.



AT OAK RIDGE

by Alvin M. Weinberg



The 22-inch test cyclotron is being used in the study of problems of ion transport with proton beams up to 2 Mev. The compactness and portability of the dee system facilitates experimental work.

The research effort here in Oak Ridge bears in some measure on almost every phase of the country's atomic energy program. For the laboratory here—unlike the national laboratories at Argonne, Brookhaven, Berkeley, Ames, and Los Alamos—has no single primary function but has many different areas in which it contributes, with about equal emphasis, to the development of atomic energy technology.

The Oak Ridge National Laboratory is large; since the recent merger of the research activities at the electromagnetic plant with those of the original Oak Ridge National Laboratory, nearly 2800 technical and nontechnical people are associated with it. Its activities include, on the applied side, radioactive chemical technology; Oak Ridge National Laboratory was the chemical pilot plant for the Hanford plutonium process. It includes reactor technology; the laboratory is engaged in three separate reactor projects, among which are the materials testing reactor to be built at Arco as a joint project of Ar-

gonne and Oak Ridge, and the nuclear powered aircraft in cooperation with NEPA and NACA. It includes electromagnetic isotope separation research and production of America's isotopes, both radioactive and stable.

The laboratory's facilities, as those of the other national laboratories, are extensive, including the air-cooled graphite chain reactor, many special high level hot chemical and physics-of-solids laboratories, a nuclear binding energy, high voltage laboratory operated cooperatively with NEPA (which when completed will include a Cockcroft-Walton and two Van de Graaff generators), and a vertical, twenty million volt proton cyclotron which it is expected will be in operation by early fall of this year.

Alvin M. Weinberg, Research Director of the Oak Ridge National Laboratory, joined the Manhattan Project in January, 1942, for what he thought would be a six months stint. He had been working at the University of Chicago in biophysics. Shortly after beginning work at the Metallurgical Laboratory at Chicago, he visited the laboratory at Oak Ridge, moving there for permanent work in May, 1945. He was made acting director of the physics division in July, 1947 and full-time director on March 1st of this year.

In support of the applied technology program, Oak Ridge, like the other AEC laboratories, carries out a heavy basic research program which covers the whole gamut of nuclear science from mathematics through physics, chemistry, and on to biology. Parts of this basic program the laboratory carries out in cooperation with the Oak Ridge Institute of Nuclear Studies, an educational agency which represents twenty-nine Southern universities; this cooperation takes the form of research participation at the laboratory by Southern faculty members, traveling seminars by Oak Ridge staff members in the South, summer symposia on scientific subjects, and so on. All this is in furtherance of the intention of the Atomic Energy Commission to have Oak Ridge become an integral piece of the scientific life of the South.

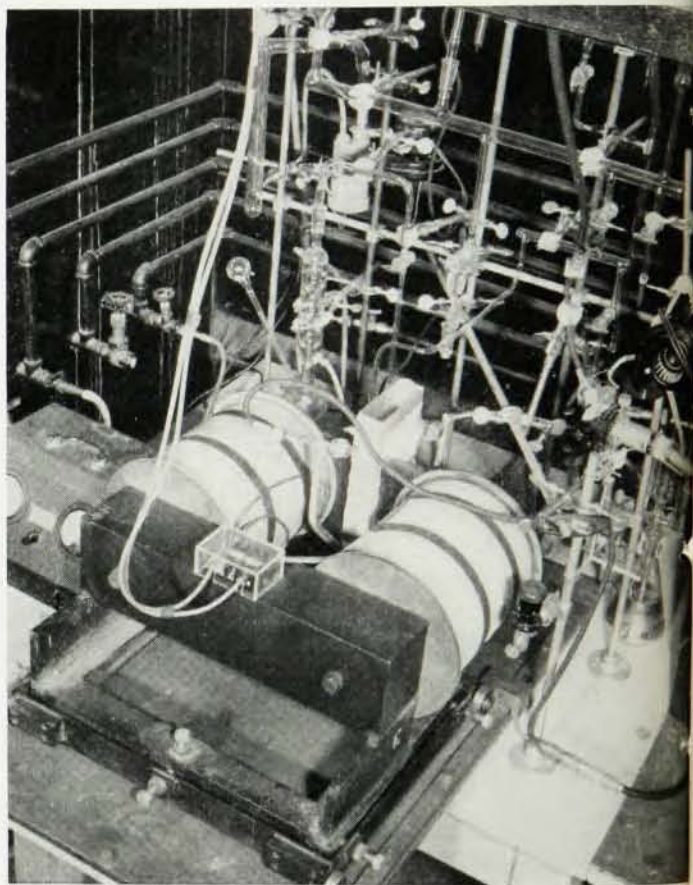
Reactor Problems

In a scientific effort of such magnitude and character as that of the Oak Ridge National Laboratory, or equally, the Atomic Energy Commission itself, the role of physics and of physicists has been a central one. During the war all of the processes for procuring either uranium-235 or plutonium—the electromagnetic, the gaseous diffusion, the thermal diffusion, and the transmutation of uranium-238 into plutonium—were based on physical principles which were made large scale successes by happy interchange between physicists and chemists on the one hand, and engineers on the other.

At the present stage in atomic energy development, at least in that part which has to do with development of reactors for useful mechanical energy, the role of the physicist is in some respects less central than during the war, in others it is more central. On the war's \$64 question—will the chain reaction be self-sustaining, and if yes, how large will the system be—the physicists hit the jack pot. Nowadays such questions as the critical size of a chain reactor, which was a major issue during the war days when uranium-235 was nonexistent, have been put aside as secondary, since it is relatively easy to measure critical masses directly. On the other hand the extremely important question, is it possible to produce more fissionable material than is consumed, that is, is breeding a practical possibility, is still a vital issue and one which calls for the cleverest kind of nuclear experimentation and theorizing. To answer this basic question it is use-

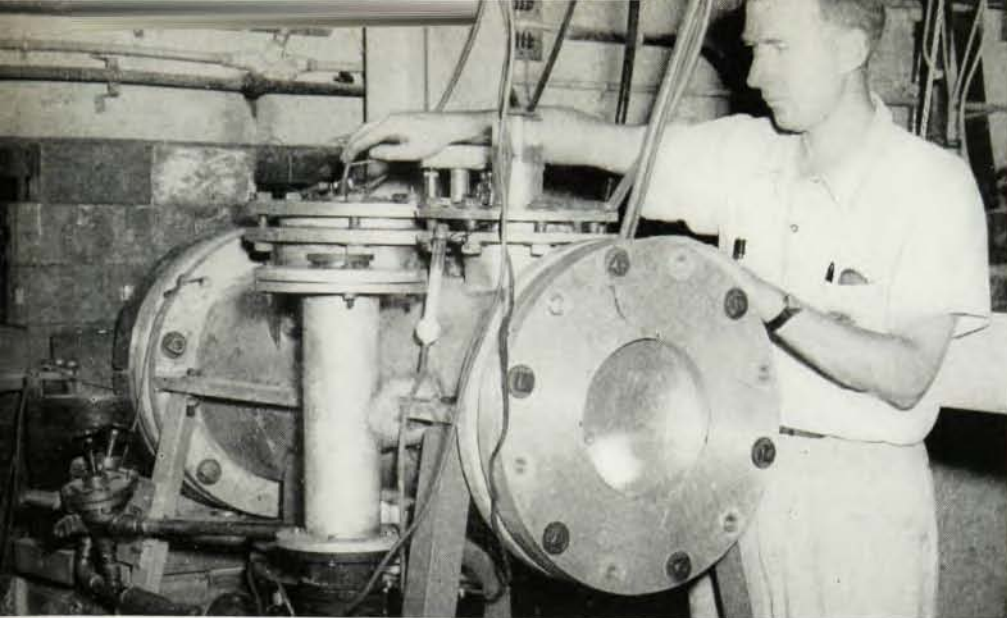
For studying the radioactivity of the neutron, a beam of neutrons is taken from a hole in the concrete shield of the Oak Ridge reactor (background) and is passed through the horizontal evacuated tank where the decay products are counted. The "bull's-eye" on the end of the tank is the thin aluminum window through which the beam emerges to be caught finally in a heavy boron-laden, lead-shielded beam-catcher ten feet away.

Apparatus for studying the hyperfine structure of a methyl iodide-129 from which the nuclear magnetic moment of iodine-129 was calculated.



ful to know the neutron properties not only of the fissionable isotopes (the fission cross sections, number of neutrons per fission, and how these numbers vary with energy) but also the neutron properties of elements which might appear in a reactor either as fission products or as structural materials.

A second major reactor problem, and one which



is of particular concern to Oak Ridge, is whether a reactor can be built light enough to fly. This involves the problem of reducing the weight of the radiation shield to manageable proportions. A nuclear reactor shield must ward off both gamma rays and neutrons. This gamma ray interaction with matter is calculable with good accuracy. But the production of gamma rays by inelastic neutron scattering or by neutron capture, and the neutron scattering cross sections of the nuclei contained in a shield, can hardly be calculated. They require extensive differential neutron measurements both with chain reactors and with accelerators.

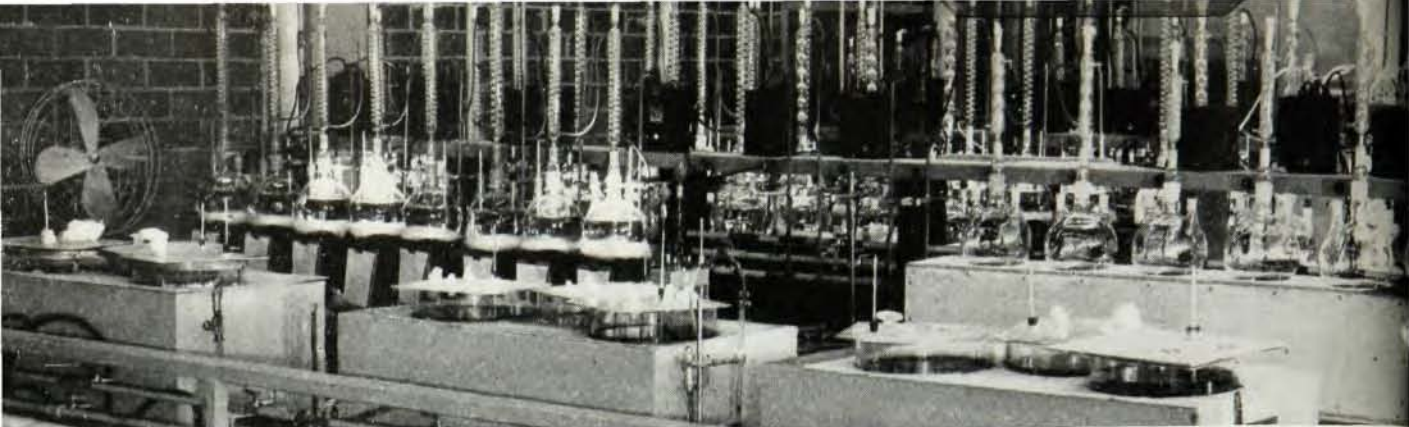
Thus the present day reactor problems of neutron economy and shield weight both require knowledge of the properties of many nuclei in the binding energy region. It has been implied, I suppose for this reason, by some eminent authorities that binding energy nuclear physics is engineering, but this can surely not be the case if by engineering one means only application of fundamental principles which are already well known. Thus the interest in binding energy nuclear physics which has been demanded by the atomic energy program has to some extent at least given impetus to the rediscovery of the magic numbers in nuclear physics, and the very serious and not entirely unsuccessful attempts to construct an aufbauprinzip for the isotopes.

At the Oak Ridge National Laboratory there has been, as part of the general "neutron economy drive", a program for measurement of the thermal neutron cross sections of all the isotopes to five percent accuracy. The method used has been to oscillate the unknown element back and forth in the

chain reactor. The amplitude of the resulting AC neutron depression signal is a measure of the absorption cross section; spurious effects due to neutron scattering are eliminated by a judicious phasing of the recording apparatus. In this way the thermal cross sections of 70 of the elements have been measured, and in all two dozen separated isotope absorption cross sections have been determined to date. One striking and technologically important discovery was that zirconium 90—an isotope containing 50 neutrons and 40 protons (this being doubly magic since 50 and 40 are both magic in some degree)—has a particularly low cross section. This is especially important since zirconium combines very excellent metallurgical properties with its small neutron absorption cross section and is therefore a very important material for the reactor engineer. It illustrates the importance of magic numbers and nuclear theory even from the technological viewpoint.

Radiation Damage

A second area of physics which is pursued both in Oak Ridge and other AEC establishments because it is directly relevant to the design of advanced chain reactors is the rather new subject of radiation damage physics. That ionizing radiation affects macroscopic properties of crystalline solids was well known long before a nuclear chain reaction had been established. The discoloration of glass x-ray tubes and the production of F-centers in alkali halides by x-rays have been subjects for study since the beginning of the century.



Corrosion laboratory showing corrosion test units.

Not so well known, however, are the curious effects which heavy ionizing particles have on the mechanical, thermal, and electrical properties of metals and nonmetals, although as early as 1945 Andrade reported that the creep rate of cadmium was increased by alpha particle bombardment. Graphite atoms inside a chain reactor can receive as much as 570 Kev energy from a 2 Mev neutron with which they suffer collision. In the process of slowing down, such graphite atoms can lose energy either by ionizing the neighboring carbon atoms, or by colliding elastically with their neighbors. Energy loss of ionization is most likely at the beginning of the range, where the velocity of the carbon atom is large compared to the velocity of the K electrons in the orbits, while energy loss by bumping is more likely at the end of the range where the velocity is less than the electron velocity. Should the energy transferred in such a bumping collision exceed the energy of binding of the atom in the crystal lattice, a dislocation will occur. Depending on the rate of annealing, it is to be expected that a solid crystalline material placed in an intense chain-reacting pile will suffer damage to its crystals, and that this damage might be roughly similar to what one expects from cold working of metals.

Direct evidence of damage has been obtained by S. Siegel and D. S. Billington at the laboratory. An ordered and a disordered sample of copper-gold alloy was exposed to an integrated fast neutron flux. The electrical resistance of the ordered material after irradiation was found to increase by more than half while the resistance of the originally disordered copper-gold sample remained unchanged. An x-ray diffraction pattern taken before and after the irradiation gave unmistakable evidence of severe disordering of the originally ordered system.

In general, work done to date at this laboratory and elsewhere indicates that neutron irradiation in-

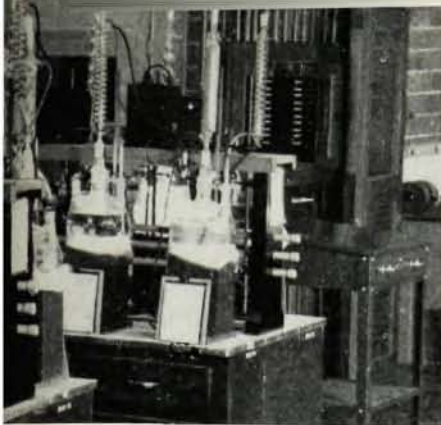
creases the thermal and electrical resistance and the hardness of most metals; and in some cases it can cause easily measurable dimensional changes.

The irradiation of germanium semiconductors produces effects which are particularly interesting. The semiconducting properties of a semiconductor are determined by so few impurity atoms that even relatively mild irradiation can have drastic effects. Thus an irradiation of a few hours in the Oak Ridge pile changes an n-type germanium semiconductor into a p-type. In the course of the irradiation the germanium goes through a maximum resistance corresponding to its being an almost intrinsic semiconductor.

The sequence of events when an n-type germanium semiconductor has been irradiated has been interpreted crudely as follows: the displaced germanium atoms act as acceptors which neutralize more and more of the impurity conduction electrons until all such n-type levels are neutralized. At this time there are no electrons in the forbidden band, and the germanium has maximum resistance. Further production of acceptor levels in the forbidden band makes the germanium a semiconductor again, but of p- rather than n-type.

Chain Reactor

Thus far I have written of those fields of physics which are pursued at Oak Ridge, and at the other atomic energy laboratories, because they are rather directly applicable to the advance of reactor technology. To summarize, these include neutron physics in the binding energy region pursued because of interest in breeding where neutron economy is important, and in mobile power reactors, where shield weight is important; and radiation damage physics, pursued because in any chain reactor radiation damage occurs. I turn now to a somewhat different func-



tion which physicists perform at the AEC laboratories, the scientific exploitation of the unique experimental facilities (mainly the chain reactor) available only at atomic energy installations. The Atomic Energy Commission believes that the scientific exploitation of these unique apparatuses is and rightly should be a responsibility that must be carried by the national laboratories.

A nuclear chain reactor is a source of neutron flux spread rather uniformly in a logarithmic energy scale from about 2 Mev down to thermal, with a few neutrons straggling on out to 20 Mev or more. Thus the reactor can be used for experiments which study neutrons themselves, or which study their interaction with matter, or which study the properties of materials which become radioactive after neutron bombardment.

Among the studies of the intrinsic properties of neutrons performed with chain reactors there are, in particular, the measurement of the neutron magnetic moment at Argonne, and the detection of the radioactive decay of the neutron at Oak Ridge and Chalk River. There are long shot experiments on elementary properties of neutrons which are being planned: it is proposed by a group from Harvard to try this summer to deflect a neutron beam from the Oak Ridge reactor in an inhomogeneous electric field and thus demonstrate whether or not a neutron has an electric dipole moment; and there have been under way, both at Chalk River and at Oak Ridge, attempts to find whether neutrons decay into negative protons.

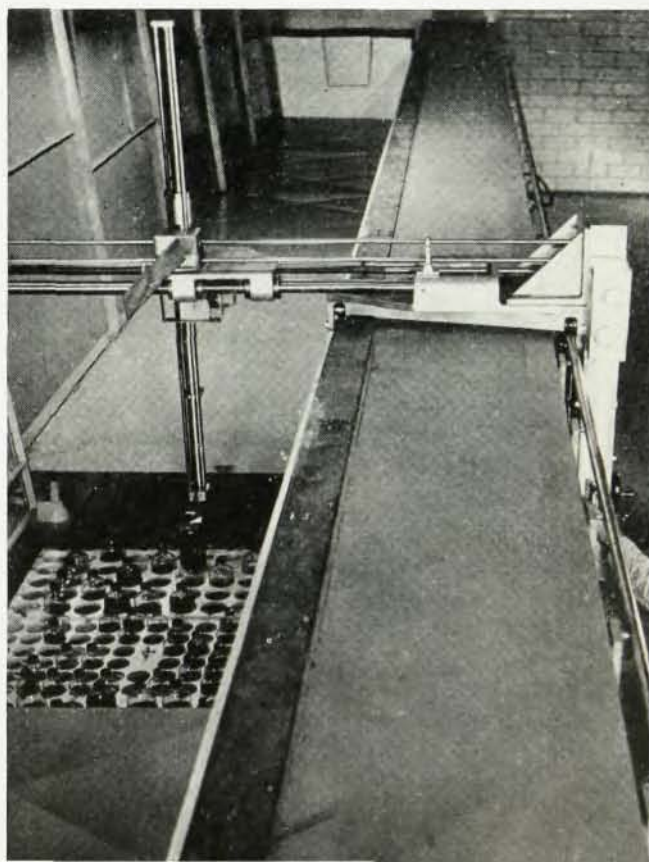
It is not perfectly obvious why a neutron in a vacuum could not decay into a positron and a negative proton rather than into a negatron and a positive proton. To test this remote possibility is relatively simple once the neutron decay apparatus has been set up. In the Oak Ridge arrangement a beam of neutrons enters a vacuum tank, and the decay

products, proton and electron, are caught, in delayed coincidence, in a multiplier and proportional counter respectively. The magnitude of the delay between positive and negative particle pulse, being a measure of the time of flight, identifies the positive decay product as a proton in the regular decay experiment. Now if the neutron were to decay into a negative proton and positive electron, delayed coincidences should also be found when the polarity of the apparatus is reversed. Attempts to detect such delayed coincidences at Oak Ridge have to date met with no success. This is, of course, not too surprising. To date the evidence is strong that neutrons do not decay into negative protons.

Neutron Diffraction

I turn now to the extremely interesting and fruitful work on neutron diffraction which has been going on at Oak Ridge and other chain reactor laboratories. That neutron diffraction would supplement ordinary x-ray and electron diffraction in the study of hydrogen bearing crystals, or in fact any crystals in which very heavy and very light elements are present, had been recognized very early.

The radioisotope storage barricade. The sectional lids, opened and closed by remote control, regulate air flow to maintain safe working conditions in the building.



In a sense such structural studies represent an extension of known techniques and known results. However, an entirely new sort of magnetic crystallography, based on the fact that because of its magnetic moment a neutron is scattered differently by magnetic ions oriented parallel or antiparallel to the neutron spin axis, has recently been demonstrated in the beautiful experimental work on neutron diffraction in antiferromagnets reported by C. G. Shull.

The work in neutron diffraction is directed toward two entirely different goals. One is the specifically nuclear information to be obtained from neutron diffraction measurements. For example, it has been determined by analysis of neutron diffraction crystal structure factors that only ten percent of the elements scatter with change in phase of the scattered neutron near 0° while ninety percent of the elements scatter with change in phase near 180° . Again, from the neutron patterns of such hydrogen bearing crystals as sodium hydride or potassium hydride it is possible to determine the amplitude of the coherent scattering in hydrogen, and from this the range of the n-p force in the triplet state. This number, as found at Oak Ridge by neutron diffraction, is 1.6×10^{-13} , in good agreement with the value found at Los Alamos by scattering in ortho- and parahydrogen and a little smaller than the value found at Argonne from total reflection of neutrons.

The other aim of neutron diffraction work lies in the realm of solid state physics, the determination of structures, either magnetic or hydrogenlike, in cases which are hardly approachable by ordinary x-ray diffraction. Thus neutron diffraction is a tool in both nuclear and solid state physics. The relevance of these two very different fields of physics here is curiously similar to the juxtaposition of solid state and nuclear physics in the whole reactor technology. Whether nuclear or solid state physics is more important for reactor technology, or to which of these areas neutron diffraction will contribute most heavily, is impolitic to say. My first choice, in spite of my own closer contact with the nuclear side, is that the problems of neutron diffraction will lie more and more in the field of solid physics and the problems of reactor technology in the future will also be based more in solid state physics than in nuclear physics. In this connection I may mention that the essentially inexhaustible field of neutron diffraction will, in my opinion, make chain reactors useful

research instruments long after their contribution to nuclear physics has been completely exploited.

Radiochemistry

I turn now to work that goes on in the measurement of properties of materials rendered radioactive in the chain reactor. The atomic energy laboratories, and particularly Oak Ridge, possess large hot laboratories in which activities produced at pile levels of intensity can be isolated chemically. Using such equipment it has been possible to measure the spin and magnetic moment of radioactive iodine-129, a



At the controls of the mass spectrographs (calutrons) engaged in enrichment of stable isotopes.

long-lived fission product. This work has been done in cooperation with Duke University. Present plans call for the measurement of the shorter lived iodines, I^{131} , I^{133} , and I^{135} , since the spins of such an isoprotonic sequence of iodine isotopes should be of considerable theoretical interest. Because of the short half-lives of later members of this series, it is hardly practical to measure them far from the chain reactor in which they are produced.

Proximity to a chain reactor makes it possible also to study neutron induced radioactive transition of periods too short to otherwise measure. The radiations from a 0.9 second isomeric activity in

lead recently reported by Drs. Campbell and Goodrich is only one of a series of moderately short-lived activities (in the range of a few seconds) which have been discovered with the Oak Ridge reactor.

At the extremes in half-life, very long and very short, considerable progress has been made, although this work on the whole is not specifically tied to chain reactors. Reports have been made on isomeric transitions of half-life of one millionth of a second or less, detected by delayed coincidences, and the shapes of forbidden beta ray spectra (of half-life approximately 10^7 years), measured by use of the scintillation spectrometer. Work such as this is done at the atomic energy laboratories since it is our business to learn as much as we can about the products we sell, radioactive isotopes, and because all phases of nuclear physics, not only nuclear technology, are the business of the Atomic Energy Commission.

I have tried in these remarks to tell you about Oak Ridge and about science in Oak Ridge and I have tried to picture for you how important solid state physics is in nuclear technology, how it may occupy a role in such technology just as important as the role occupied by nuclear physics. In a sense, the solid state physicists, no less than the nuclear physicists, must therefore share in the responsibility for the country's progress in nuclear technology. That this technology is essentially military in the same way that aircraft technology is essentially military is hardly a matter to doubt or wonder at. To those who are responsible for the development of atomic energy, and to whom the necessity for military emphasis is intrinsically no more tasteful than to others without such responsibility, there is this consolation: the military technologies of the past have always achieved fruition beyond estimate in scientific and peaceful endeavors. It is our belief and our hope that the sciences supported by nuclear energy technology, among which are nuclear physics and some phases of solid state physics, will bring forth significant nonmilitary rewards which, in the larger view, will far transcend any supposed taint they may carry by association with instruments of destruction.



Final purification of radioactive iodine-131 is accomplished in this hot cell operated by remote control.

