News of Science

Thermonuclear Reactions

On 24 January the U.S. Atomic Energy Commission and the United Kingdom Atomic Energy Authority released statements and technical reports about recent work in the field of controlled thermonuclear reactions. The most important results obtained so far are (i) the confinement of deuterium plasma at temperatures of 2 to 6 million degrees centigrade for periods ranging from about 1 microsecond to about 5 milliseconds and (ii) the production of up to 100 million neutrons, some of which may result from the fusion of deuterons (deuterium nuclei), during time periods of similar length.

Technical reports. Technical reports on the results achieved in both the United States and Great Britain were published in the 24 January issue of *Nature*. Research scientists in both countries have been working with deuterium gas contained at low pressure (0.4 to 6×10^{-4} millimeters of mercury) in "pinch" tubes of various shapes and sizes. A large electric current (10^5 to 10^6 amperes) is passed through the gas. The current heats the gas and produces a strong magnetic field around the column of hot gas. The magnetic field constricts, or "pinches," the gas discharge to a smaller diameter within the tube, away from the walls, and thus causes further heating of the gas. The magnetic field created by the current also causes the discharge, or "pinch," to wriggle about in the tube; hence, by itself, the field does not prevent the pinch from touching the walls of the tube. Means for minimizing the wriggling of the pinch, or stabilizing it—among them is the application of a magnetic field parallel to the axis of the tube—have been devised.

If the temperature of the pinch is high enough, deuterons collide violently and repeatedly. Most of the collisions result in exchange of energy between one deuteron and another. About half of the remaining collisions produce helium nuclei, energy, and neutrons; the other half produce protons, tritons, energy, and neutrons. The hotter and more confined the pinch, the more frequent the collisions between nuclei, and the more the likelihood of producing a thermonuclear reaction.

In the British experiments, temperatures up to about 5 million degrees centigrade have been produced for periods of 2000 to 5000 microseconds by current pulses of up to 200,000 amperes lasting about the same period; up to 3 million neutrons per current pulse have been observed. In the experiments in the United States, temperatures up to 6 million degrees have been produced for periods of a few microseconds by current pulses of up to 1 million amperes lasting a few microseconds; from 10,000 to 100 million neutrons per current pulse have been observed.

Although neutrons have been detected in the experiments, their source has not been established. In commenting on the source of the neutrons, the British release stated: "There are good reasons to think that they [the neutrons] come from thermonuclear reactions, but they could also come from other reactions such as collisions of deuterons with the walls of the vessel, or from bombardment of stationary ions by deuterons accelerated by internal electric fields produced in some forms of unstable discharges."

The AEC statement reported: "The great majority of the neutrons come from the hot ionized gas. The character and timing of the signals in the neutron detectors, and other physical measurements, encourage the view that the fraction of the neutrons which arise from unwanted voltages due to the instability in the gas or to collisions with the walls and the electrodes, is relatively small."

Strauss' comments. In his commentary on the technical reports, Lewis L. Strauss, chairman of the U.S. Atomic Energy Commission, said: "As I stated on December 18, and as is borne out in the scientific papers released today, both we and the British have succeeded in producing and maintaining quite high temperatures in a plasma of light nuclei, and the containment of such a plasma for brief but nevertheless appreciable lengths of time. But today's reports make it clear that much longer containment must be obtained and much higher temperatures reached.

"Two main conditions are necessary for the attainment of power-producing thermonuclear reactions. First, heavy hydrogen must be brought to a temperature of at least 100 million degrees centigrade. Second, the atomic nuclei in this hot gas must be held together for an appreciable time.

"When the temperature reaches several million degrees centigrade—a result reached in both United States and British laboratories—neutrons are emitted in quantity. However, at such a temperature far below 100 million degrees it is a delicate and difficult matter to distinguish the neutrons produced by fusion from those arising from other processes which are not of particular interest for controlled thermonuclear reactions. Today's reports *suggest* the achievement of neutrons from thermonuclear reactions, but their mode of origin must be positively established. This can be done only by experiments as I have previously noted. Such experiments are continuing in both the United States and the United Kingdom.

"The progress achieved by scientists and engineers associated with the commission's Sherwood program is promising and encouraging and today's reports strengthen confidence which I have had for many years that the difficulties in the way of controlled fusion will eventually be overcome.

"We are making important progress, but the problems are formidable and it will be a matter of years before we will be able to build and operate commercial reactors utilizing the deuterium of the oceans, thus to produce electrical power and provide a source of energy sufficient for man's expanding needs for ages to come.

"It appears that years of intensive work will probably be required to develop a laboratory thermonuclear device which would yield more energy than it consumes. And after that, it will require more years to develop a full-scale power producer. Therefore, the controlled thermonuclear program will not interfere with the current development and construction of reactors to produce electricity from nuclear fission.

"However, the results of our research in the fusion process are sufficiently encouraging and the ultimate rewards are so great as to justify the necessary expenditures of money, time and talent."

British comments. The statement issued by the United Kingdom Atomic Energy Authority commented: "Research at Harwell with the latest apparatus has led British scientists to the conclusion that control of thermonuclear reactions for electricity generation may well be a possibility for the future, though its practical application is still a long way off.

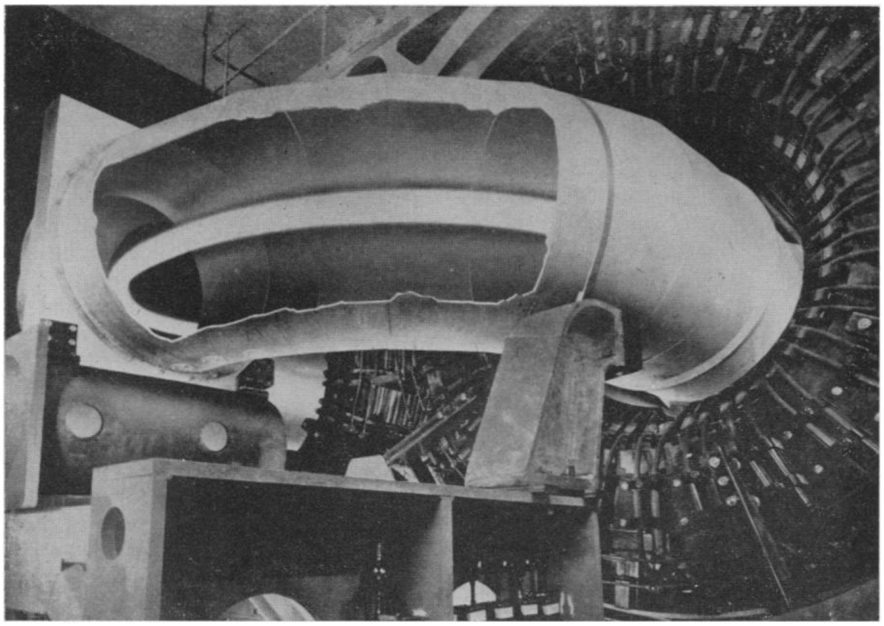

Diagram of Zeta (Zero-energy thermonuclear assembly) with cutaway view of the torus, and, on the right, the transformer. The white strip in the center of the torus is the pinch of hot plasma. [British Information Services]

"The operation of present atomic power reactors is based on the fission (or splitting) of atoms. The possibility now being explored is the harnessing of power from the fusion (or joining) of atoms, which provides the heat for the stars.

"Results obtained from the Harwell apparatus Zeta [Zero-energy thermonuclear assembly] suggest that 'thermonuclear neutrons' have been obtained, but further experiments will be necessary before this can be proved conclusively. Temperatures reached in this apparatus have been as high as 5 million degrees centigrade, higher than the measured surface temperatures of any star.

"Many major problems have still to be solved before its practical application can be seriously considered, and the work must be expected to remain in the research stage for many years yet. If it proves ultimately possible to construct a power station operating on the fusion of deuterium, the oceans of the world will provide a virtually inexhaustible source of fuel . . . .

"In order to obtain a net gain in energy from the reaction it would be necessary to heat deuterium gas to temperatures in the region of 100 million degrees centigrade, and to maintain it at this temperature long enough for the nuclear energy released to exceed the energy needed to heat the fuel and lost by radiation. Lower temperatures would suffice for a deuterium-tritium mixture. The high temperatures achieved in Zeta, and the relatively long duration for which the hot gas has been isolated from the tube walls, are the most important experimental results obtained so far. Whilst a much longer time (perhaps several seconds) is required for a useful power output, there appears to be no fundamental reason why these longer times, together with much higher temperatures, cannot be achieved.

"There are, however, many major problems still to be solved before its practical application can be seriously considered, and the work must be expected to remain in the research stage for many years yet."

Zero-energy thermonuclear assembly (*Zeta*). The British results have been obtained with two toroidal pinch tubes, Zeta and Sceptre III. Zeta was first operated on 12 August 1957 at the Atomic Energy Research Establishment, Harwell. Work with Zeta was described in an article in *Nature* by P. C. Thonemann, R. Carruthers, D. W. Fry, R. S. Pease, G. N. Harding, S. A. Ramsden, E. P. Butt, E. McWhirter, D. J. Lees, A. Dellis, S. Ward, and A. Gibson.

In Zeta the discharge chamber is a torus of aluminum of 1 meter bore and 3 meters mean diameter. The pressure of deuterium is usually about 10^{-4} millimeters of mercury. The plasma in the torus forms the secondary of a large pulse transformer. A pulse of electric current is passed into the primary of the pulse transformer by discharge of a bank of capacitors which stores a maximum of 500,000 joules. This pulse induces a large current in the gas, which is, in effect, the short-circuited secondary of the transformer. Currents up to 187,000 amperes, lasting for 3 to 4 milliseconds, are induced in the gas. The pulse is repeated every 10 seconds. Instabilities in the pinch are suppressed by a magnetic field that is imposed parallel to the pinch and by electric fields produced in the metal walls of the torus by eddy currents. Emission of 1.34 million neutrons per current pulse is reported. The calculated temperature is 4.65 million degrees Kelvin.

The methods of measuring the temperature were described as follows in the British AEA statement: "The temperature of gas discharges may be determined from measurements on the light emitted by the gas atoms, but measurements of this kind in these experiments present problems because, at the temperature of the discharge, the hot deuterium atoms are completely stripped of their electrons, and therefore do not emit a line spectrum. One method of solving this problem is to mix with the deuterium a small quantity of some heavier gas, such as oxygen or nitrogen, the atoms of which are not stripped of all their electrons under these conditions, and to study the spectral lines emitted by this impurity; the random motion of the high-energy impurity atoms which make many collisions with the deuterium atoms and so reach the same energy causes the spectral lines to broaden, owing to the Doppler effect, and the amount of broadening is a measure of the ion energy. Many measurements by this method have indicated temperatures in the region of 2 to 5 million degrees centigrade. Whilst temperatures in this range are required to explain the observed rate of neutron production on the basis of a thermonuclear process, electric fields in the gas arising from instabilities can also accelerate deuterium ions and lead to nuclear reactions. Such a process was described by Academician Kurchatov in his lecture at Harwell in 1956. Therefore it is not altogether certain that the observed neutrons come from a thermonuclear reaction. Experiments are continuing to study the details of the neutron-producing processes."

Sceptre III. Sceptre III is an aluminum torus that has been built at the research laboratories of Associated Electrical Industries Limited, Aldermaston, Berkshire, near Harwell. Work with this apparatus was described in *Nature* by N. L. Allen, T. E. Allibone, D. R. Chick, R. E. Hemmings, T. P. Hughes, S. Kaufman, B. S. Liley, J. Mack, H. T. Miles, R. M. Payne, J. Read, A. A. Ware, J. Wesson, and R. V. Williams. These workers have received advice from Sir George Thomson, who began experimental work in the field at Imperial College in 1947.

The torus of Sceptre III has an internal bore of 30 centimeters and a mean diameter of 115 centimeters. Temperatures of about 4 million degrees Kelvin were attained for a period of a few microseconds. Neutron yields ranged from 1200 to 100,000 per pulse. According to an article by R. K. Plumb in the

New York Times for 25 January, the cost of this apparatus was $28,000, much less than the costs of the apparatus used by the respective government agencies. Plumb also noted that the workers at Associated Electrical Industries are much more optimistic about developing higher temperatures within a reasonably short time than the AEC and the AEA: "... temperatures of ten to twelve million degrees are hoped for in a few months."

Columbus. Five papers by scientists from the United States were published in the 24 January issue of *Nature.* L. C. Bankhardt, R. H. Lovberg, and J. A. Phillips of Los Alamos Scientific Laboratory described measurements made in mid-1956 of the distribution of currents in a linear, pinched discharge in deuterium. The measurements provide a means for determining the effective temperature of the hot gas.

The production of neutrons in a straight pinch apparatus was described by D. C. Hagerman and J. W. Mather, also of Los Alamos. This apparatus, Columbus II, is 30 centimeters long and 10 centimeters in diameter; it began to yield results last summer. Under various conditions the tube can be made to yield between 10 million and 100 million neutrons per pulse, in a time of about 1 microsecond or less.

Tests were made to determine whether most of the neutrons are produced by thermonuclear reactions or whether they are emitted at the electrodes or walls, or from instabilities in the gas. It was found that the neutrons are emitted from the gas and that they come practically uniformly from all parts of the tube.

The third paper, by L. C. Burkhardt and R. H. Lovberg, dealt with another straight pinch tube, Columbus S-4. This tube is a porcelain cylinder 5 inches in diameter and 24 inches long. The paper showed that there can be circulating currents in the tube at certain times during the pinch process. Particle energies of 300 electron volts (or temperatures of about 3 million degrees) were attained, in spite of the fact that the tube was operated at voltages below 20 kilovolts. When the tube was started with pressures of 40 microns of mercury, the pressure became 12 atmospheres at the time when the diameter of the current column was smallest, about 6 microseconds after the current started. According to the AEC release, "Perhaps the most significant observation with S-4 is that the field produced by the pinch current is highly reproducible over several half-cycles of the applied voltage."

Perhapsatron. The fourth paper from Los Alamos was written by J. Honsaker, H. Karr, J. Osher, J. Phillips, and J. L. Tuck. It described the production of neutrons from a stabilized pinch in a small doughnut-shaped tube, the Perhapsatron S-3. This tube came into operation in December 1957; it yielded as many as 1 million neutrons per discharge. The main burst of neutrons occurs in a time of about 2 microseconds. Smaller bursts continue to occur for several additional microseconds. The results are felt to be consistent with an effective temperature of about 6 million degrees. There is good evidence that the pinch is well centered while the applied current is high; the amplitude of the undulations of the pinch is about 2 millimeters, which suggests that the discharge is well stabilized.

Two other papers by scientists from the United States were released on 24 January. One, the fifth of the group published in *Nature,* was an analysis of the results obtained by the British workers with Zeta, by Lyman Spitzer, Jr., of Princeton University. The other described the production of neutrons in linear deuterium pinches. It was written by D. A. Anderson, W. R. Baker, S. A. Colgate, H. P. Furth, J. Ise, Jr., R. V. Pyle, and R. E. Wright, of the University of California Radiation Laboratories, Livermore and Berkeley, and was published in the 1 February issue of the *Physical Review.*

Cooperation in research. The British release stated: "Full collaboration in the controlled thermonuclear reactions field was established with the U.S. Atomic Energy Commission in October 1956."

Lewis L. Strauss, chairman of the U.S. Atomic Energy Commission, stated: "After the U.S.-U.K. decision to declassify results of work on controlled thermonuclear reactions (except for certain areas) and following necessary concurrence of the two countries on a revision of the Joint Classification Guide to accomplish this, conferences began with a view to releasing the newly-declassified information as early as possible in 1958. It was agreed that January 24, 1958, was the most convenient date.

"Assertions that U.S. pressure was used to persuade the U.K. authorities to suppress publication of the results of their research are contrary to the fact and have been refuted by Sir Edwin Plowden, chairman of the United Kingdom Atomic Energy Authority, and by me.

"Furthermore, certain comparative observations which have been published in recent weeks about British and U.S. progress in this field will be seen from today's British and U.S. papers to have been not only misleading but lacking in any foundation of fact.

"Today's announcements make it clear that fruitful and promising results have been achieved in the laboratories of both countries but we should not expect early harnessing of fusion for the production of power. In the field of fusion, we are not yet at a point comparable to December 2, 1942, when the first self-sustaining fission reaction was obtained.

"Our research efforts and those of the United Kingdom are at a point where it occurs, periodically, that first one laboratory and then another will make a useful and illuminating advance. This has happened in the past, and no doubt will occur in the future, as our two countries pursue their studies . . . .

"We congratulate the United Kingdom Atomic Energy Authority and its scientists and engineers for the notable advances which they have made. We are happy with the cooperation which we have established with our British friends in this field of science, and we confidently expect it to expand the frontiers of knowledge."

Petition Urging Agreement To Stop Nuclear Tests

Linus Pauling announced on 20 January that 9235 scientists in 44 countries have signed a petition to stop the testing of nuclear bombs by international agreement and that he had presented the petition to the United Nations. The petition bears the names of 36 Nobel laureates, 101 members of the National Academy of Sciences of the United States, 35 Fellows of the Royal Society of London, and 216 members and correspondents of the Academy of Sciences of the U.S.S.R.

A total of 2705 American scientists signed the petition. There were 216 Russian names, 304 from the United Kingdom, 65 from France, and 1141 from Japan.

The petition was prepared by Pauling as an individual scientist and was signed by other scientists as individuals. No organization was involved in the formulation of the petition or in the collection of signatures.

The petition resulted from an address on "Science in the Modern World" given last May at Washington University, St. Louis, Missouri. In the address Pauling discussed the damage that is being done by the testing of nuclear bombs and expressed his conviction that a stop to the testing through international agreement would be an effective first step toward averting a cataclysmic war, and that international problems should be solved not by war, but by the application of man's power to reason, through arbitration, negotiation, international agreements, and international law.