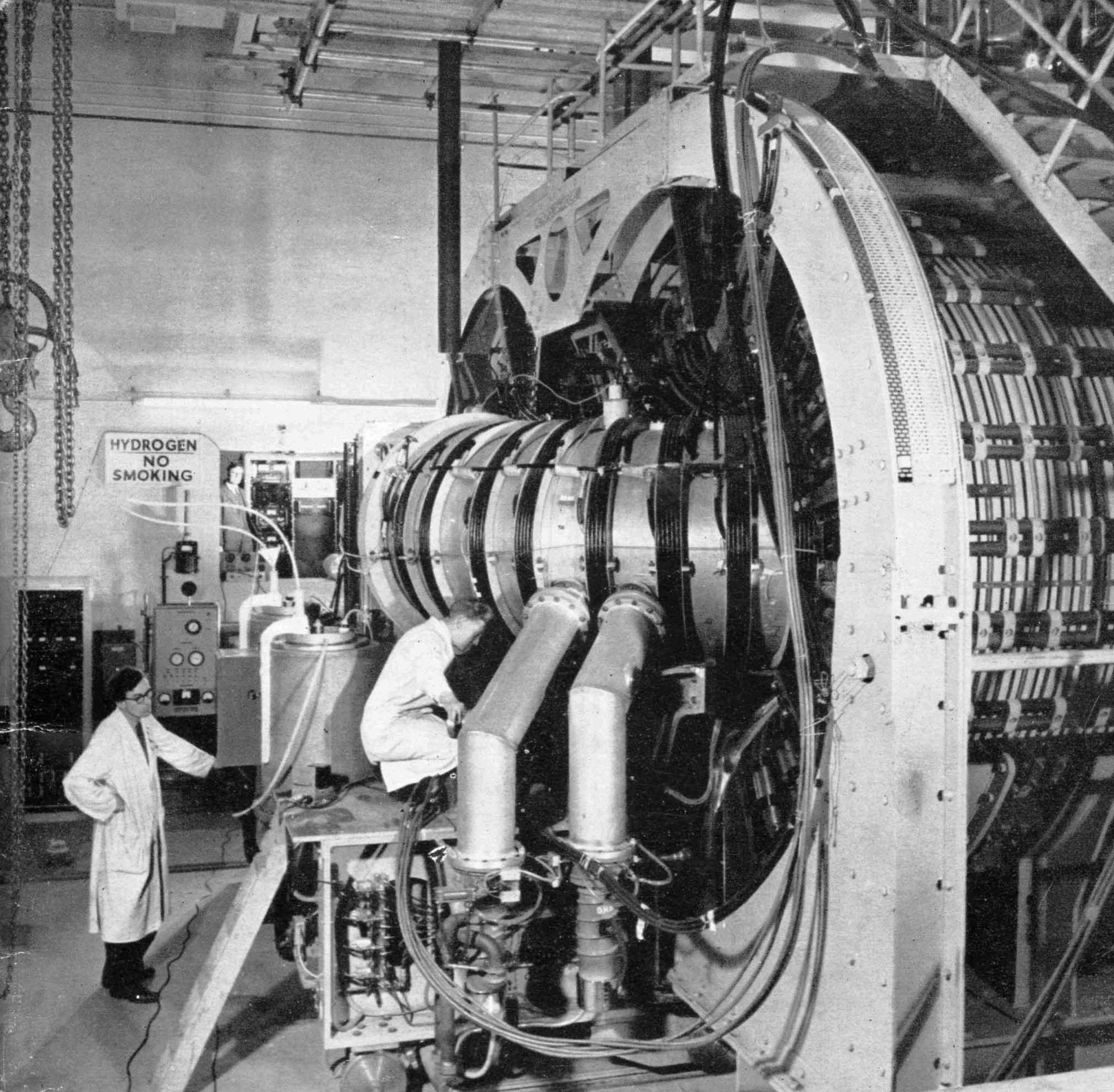
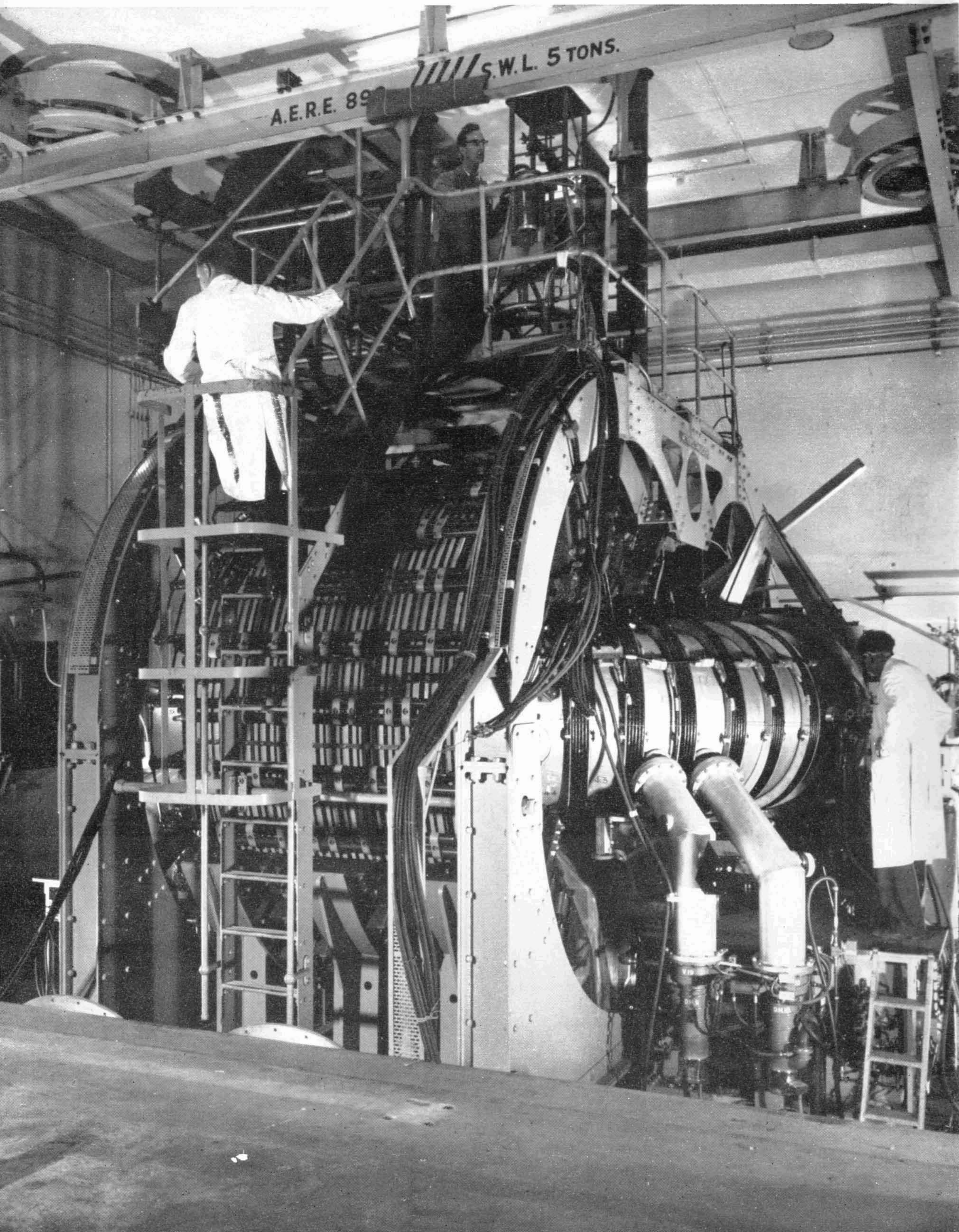


FACTS ABOUT ZETA

United Kingdom Atomic Energy Authority



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Introduction

The operation of present atomic power reactors — such as Calder Hall — is based on the fission (or splitting) of heavy atoms, such as those of uranium.

With the apparatus called ZETA Harwell scientists are exploring the possibility of producing power from the fusion (or joining) of light atoms, such as those of hydrogen.

ZETA is a ring-shaped metal tube like a motor tyre. Within it a gas known as deuterium (or heavy hydrogen) has been heated electrically to a temperature of 5 million degrees Centigrade. This is one third of the temperature at the centre of the sun.

Neutrons resulting from fusion of atoms in ZETA have been observed. But it is not yet possible to establish with absolute certainty that they result from a true thermonuclear reaction. Fusion can take place from causes other than heat and further experiments at even higher temperatures will be necessary before the results so far obtained can be confirmed. Sir John Cockcroft has expressed a personal view that he is '90 per cent certain' that a thermonuclear reaction has been achieved.

The significance of ZETA to the 'man in the street' is that heavy hydrogen can be extracted from ordinary water. This means that if it is eventually possible to construct a fusion power-station operating on heavy hydrogen, mankind will possess — in the oceans of the world — a virtually inexhaustible source of fuel.

Many major problems have to be solved before this goal is reached. The most optimistic estimate of the time needed before a practicable 'fusion station' can be constructed is ten years; and it may take as long as fifty years. Sir John Cockcroft has given his estimate as 'twenty plus'.

A statement by Sir John Cockcroft

Speaking to the Press at Harwell on 23rd January, 1958, Sir John Cockcroft, O.M., F.R.S., Member for Scientific Research of the United Kingdom Atomic Energy Authority, said:

Twenty-five years ago we discovered in the Cavendish Laboratory that nuclei of heavy hydrogen speeded up by high voltage could join with or fuse together with other nuclei of heavy hydrogen to form helium of mass 3, producing neutrons and energy in the process.

We know that processes of this kind provide the energy and heat of the stars. Our sun has a central temperature of about 15 million degrees and at this temperature, nuclei of light elements can move about so fast that fusion reaction can occur.

It has long been the ambition of scientists to emulate the stars and to produce in the laboratory temperatures so high that useful energy can be produced from fusion reactors.

The objective of Stage 1 of our work was to produce temperatures of about 5 million degrees for a sufficient time for fusion reactions to be produced in deuterium gas at low pressure. During the course of this work a series of tori of increasing size have been built culminating in ZETA. Using ZETA, Dr Thonemann and his colleagues have achieved their first objectives of about 5 million degrees for times of a few thousandths of a second, and these have been repeated at intervals of 10 seconds many thousands of times.

I consider that to have achieved temperatures which are a third of those at the centre of the sun and to hold them for so long, is a remarkable scientific achievement, and I have no doubt that within a year ZETA, with some modifications, will far surpass the sun's central temperature.

When the temperature in ZETA reaches 2 million degrees, a few neutrons are produced and these increase three hundredfold as temperatures of 5 million degrees are approached, until about a million are produced in each pulse. This is about the rate of increase and the number we would expect from heavy hydrogen nuclei moving about with the random motion corresponding to these temperatures. We know, however, that heavy hydrogen nuclei could be speeded up by other mechanisms than being part of a hot gas. Strong electrical fields can be produced in such electric discharges and these could produce high speed deuterons. So we are not yet certain that all the neutrons come from a true thermonuclear process, and so experiments are going on to settle this.

At the present time the energy produced in the fusion reaction is only about a million millionth of the energy input. This is why we call ZETA a zero-energy thermonuclear assembly.

We intend to increase the current circulating in ZETA by the provision of more condensers; the temperatures should then rise substantially. If and when we reach a temperature of 25 million degrees the number of neutrons per pulse should increase at least ten thousand times. Even then, however, the amount of energy produced in ZETA would be small compared with the energy input.

In order to break even, we will have to produce temperatures of about 300 million degrees in deuterium gas and above 40 million degrees in a mixture of deuterium and tritium. So while we are experimenting with ZETA, improving it and studying its performance, we will be designing and building its successor which will aim at achieving the break-even point.

We will have many problems to face in this second stage. New methods may have to be devised to heat the gas to higher temperatures and new techniques will be required to measure the temperatures. Even if all goes well and we meet no road blocks we would still have the further engineering problem of designing and constructing a prototype of a practical and economic thermonuclear power station. This would be Stage 3 and after that there would be Stage 4, commercial application.

The Perhapsatron work in the United States together with the results obtained by AEI and our work with ZETA enable us for the first time to see the effect of the size of the apparatus on performance. This is one of the ways in which a collaborative effort helps. If we examine the performance of the three tori of increasing size, this provides us with a good guide for our future line of development and the conditions required to increase the time during which the high temperatures persist. Long containment times are as important as high temperatures for practical results and one of our objectives for the future will be to achieve much longer containment times as well as 'break-even' temperatures. The performance of ZETA has encouraged us to believe that this will be possible.

The results obtained with ZETA

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 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.

On 12th August 1957, a large experimental apparatus for studying the controlled release of energy from the thermonuclear reactions was started up at the Atomic Energy Research Establishment, Harwell. On 30th August 1957 this apparatus was first operated under conditions that produced nuclear reactions; neutrons emitted in these reactions were observed when deuterium gas was heated electrically to temperatures in the region from 2 to 5 million degrees Centigrade. The hot gas was isolated from the walls for periods of 2 to 5 thousandths of a second. The heating process was repeated every 10 seconds. The high temperatures achieved, together with 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 much longer times (perhaps several seconds) are 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.

The source of the observed neutrons has not yet been definitely established. There are good reasons to think that they come from thermonuclear reactions, but they could also come from other reactions such as collision 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 discharge.

Opposite: The Control Panel of ZETA

In the ZETA apparatus the number of neutrons produced by each pulse of energy as the current was doubled was roughly that which might be expected from a thermonuclear reaction at the measured temperatures. These temperatures have been definitely established.

*

As the Atomic Energy Authority have stated in their last two annual reports, research has been in progress for some years to investigate the possibility of producing energy in a controlled manner from thermonuclear reactions. Over two years ago design began of a large installation for this work and in August 1957 the apparatus, which is called ZETA (for zero-energy thermonuclear assembly) started up, with the results described above. The reaction being studied in ZETA is that in which deuterons (nuclei of the heavy hydrogen isotope deuterium) collide with one another and fuse to form heavier nuclei, releasing energy and some neutrons in the process. For fusion to be possible the deuterons must have enough energy to overcome the initial electrical forces of repulsion between them; this necessitates heating the deuterium gas to temperatures of millions of degrees Centigrade. The hot gas must be kept away from the walls of the container otherwise it falls in temperature.

The principle adopted in ZETA is to pass a large electric current through the deuterium gas. This current sets up an electric discharge in the gas (analogous to the discharge in a neon advertising sign) which heats it and also produces an intense magnetic field around the column of hot gas. This magnetic field causes the discharge to become constricted and hence heated still more. Since it also causes the discharge to wriggle about, this field by itself is not enough to keep the discharge away from the walls. The wriggling has been suppressed by applying an additional steady magnetic field parallel to the axis of the tube.

In ZETA the discharge chamber is a ring-shaped tube or torus of 1 metre bore and 3 metres mean diameter, containing deuterium gas at low pressure. The tube is linked (i.e. encircled over part of its length) by the iron core of a large pulse transformer. A current pulse of electricity is passed into the primary winding of the transformer from a bank of capacitors capable of storing 500,000 joules of energy. This pulse in turn induces a very large unidirectional pulse of current in the gas, which forms a short-circuited secondary for the transformer. Peak currents up to 200,000 amperes have been passed through the ionised gas for periods up to 5 milliseconds. The current pulse is repeated every ten seconds. Emission of neutrons throughout the current pulse is observed regularly in routine operation of ZETA with deuterium; there are up to 3 million neutrons emitted per pulse.

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.

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 300 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 that 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.

The work on ZETA has been done in the General Physics Division at Harwell which is under the direction of Mr D. W. Fry. The group responsible for the work has been led by Dr P. C. Thonemann and senior members concerned with ZETA have been Mr R. Carruthers and Mr R. S. Pease, with Mr J. T. D. Mitchell of the Engineering Division, and Dr W. B. Thompson of the Theoretical Physics Division (Dr Thompson is a Canadian). Dr Thonemann's interest in thermonuclear reactions goes back to his undergraduate days at the University of Melbourne, Australia, and he has been actively engaged in research in gas discharge physics for over ten years, first at the Clarendon Laboratory Oxford, and since 1951 at Harwell. The principal contractors for construction were Metropolitan-Vickers Electrical Co. Ltd (who also collaborated in the design), British Insulated Callender's Cables Ltd and Telcon Ltd.

Research work in the field of controlled thermonuclear reactions is also being carried out at the AEI Research Laboratory (Director Dr T. E. Allibone) on behalf of the Atomic Energy Authority and with the advice of Sir George Thomson. Experimental work was started at Imperial College by Sir George Thomson in 1947. It was moved to the AEI Laboratory in 1951. The senior members of staff engaged are Mr D. R. Chick and Dr A. A. Ware.

Full collaboration in the CTR field of research was established with the USAEC in October 1956.

Questions and answers on ZETA

Q What did ZETA cost?

A ZETA cost about £300,000.

Q How many people have worked on the ZETA project?

A About fifty professional scientists and engineers have been directly engaged.

Q *What are the next steps in this field of research?*

A The current circulating in ZETA is to be increased by the provision of more condensers; it is hoped this will increase the temperature to 25 million degrees Centigrade. Even at this temperature the amount of energy produced will be small compared with the amount of energy put in.

To break even (i.e. to produce an amount of energy equal to the energy put in) it will be necessary to obtain temperatures of over 300 million degrees, in deuterium, or above 40 million degrees, in deuterium and tritium ('super heavy' hydrogen). While experiments continue with ZETA, Harwell will design and build its successor — ZETA II — which will aim at achieving the break-even point. This should take about four years. Stage III would be work leading to the construction of a prototype of a practical and economic thermonuclear power station. Stage IV will be commercial application.

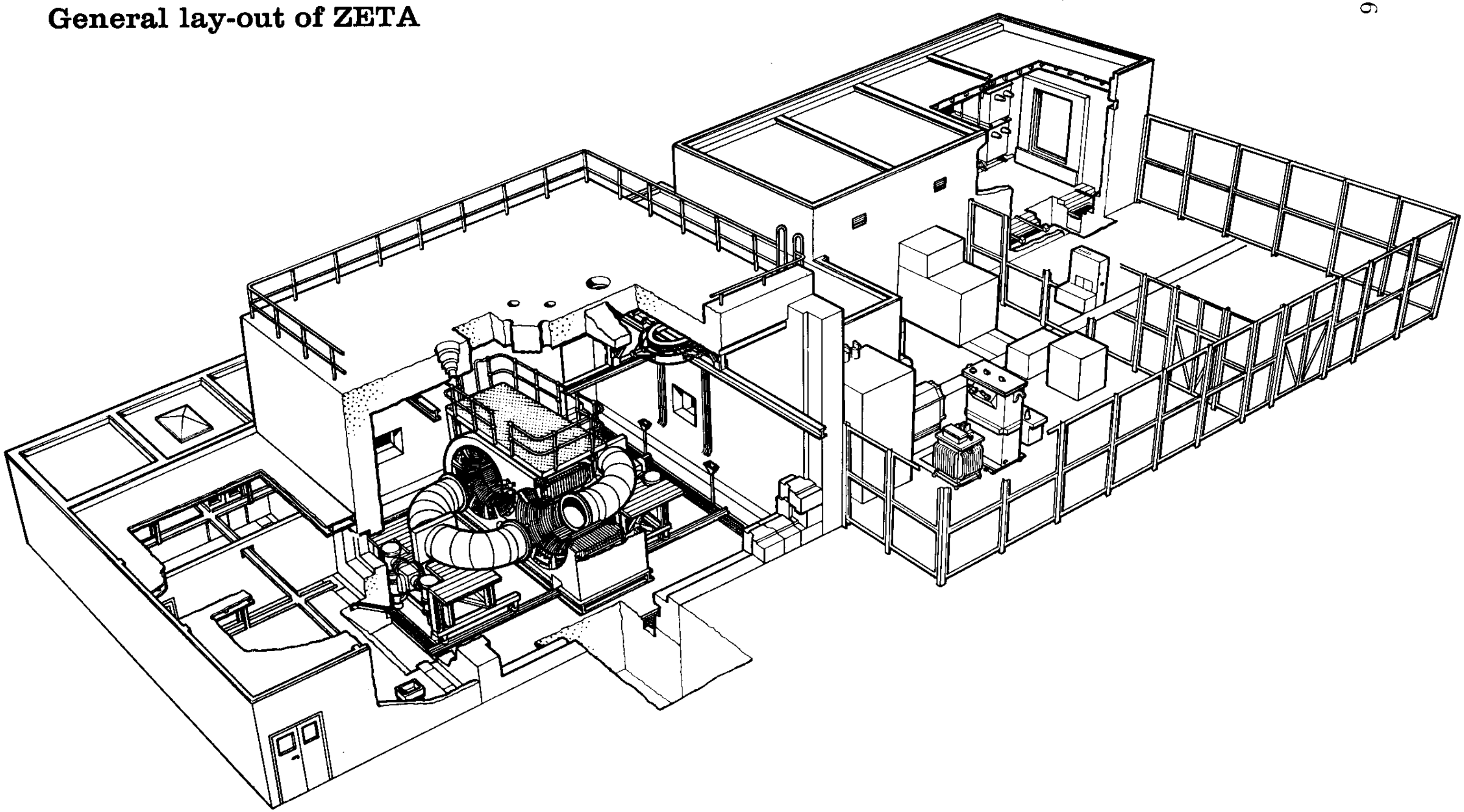
Q If it proves ultimately possible to build fusion reactors which will generate electricity economically, what will be the long-term significance of this development?

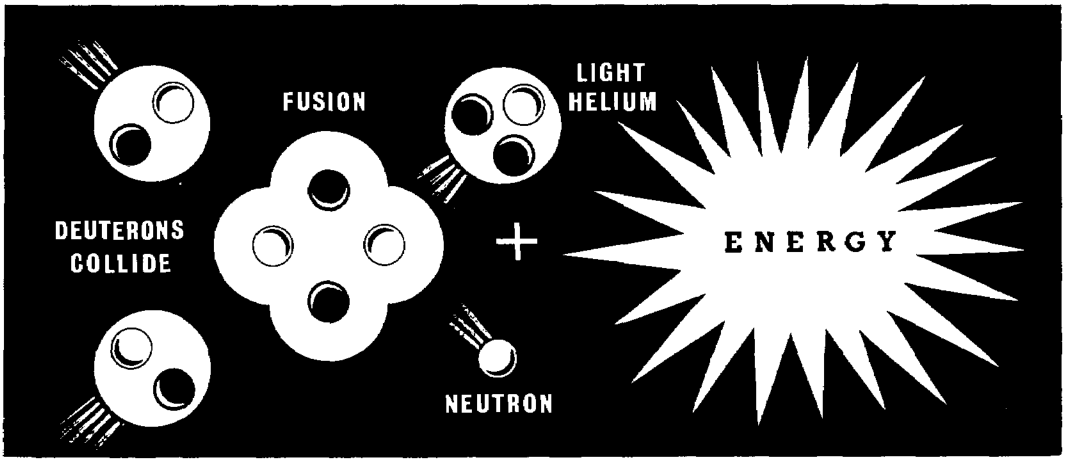
A ZETA's long-term significance is that, if commercial fusion reactors can be built, a virtually inexhaustible source of fuel will be available for economic development throughout the world.

This makes it possible to contemplate a continued increase in standards of living which would otherwise — 200 or 300 years from now — have to level out or even slip back. It should, however, be borne in mind that practical applications of fusion for electricity development are not likely to be attained for ten, twenty or even fifty years.

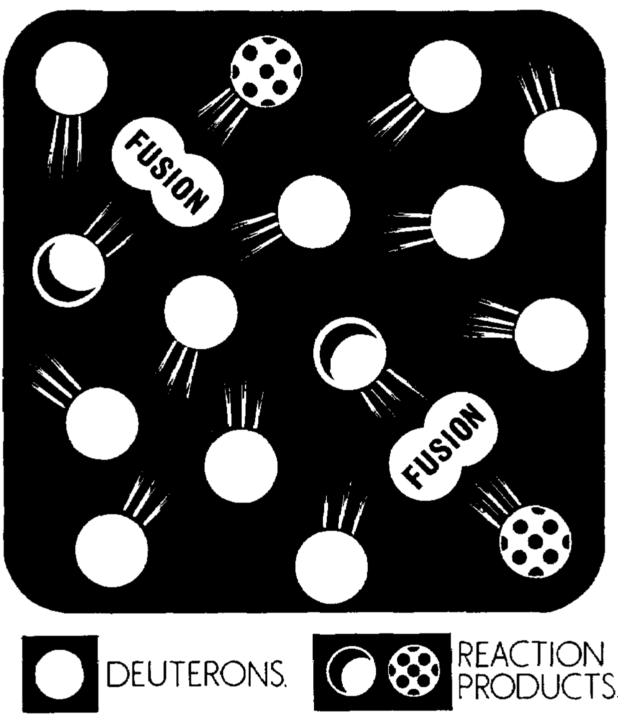
It is not necessarily true that 'fusion electricity' will be cheap. The fuel will be in abundant supply; but it must be extracted from water; and no one, at this stage, can assess what the capital costs of a plant producing power on a commercial scale would be. Therefore it is not possible to hazard any estimate of what the overall costs will be. The present researches are unlikely to have any effect on the UK nuclear power programme or on UK uranium requirements for at least twenty years. Development of fusion reactors does not necessarily mean that (even after twenty years) uranium will no longer be used in fission reactors (of the Calder Hall type). It may well be economic to plan for a combination of the two.

General lay-out of ZETA





Fusion reactions: $D + D - He_3 + n + 3.23$ MeV



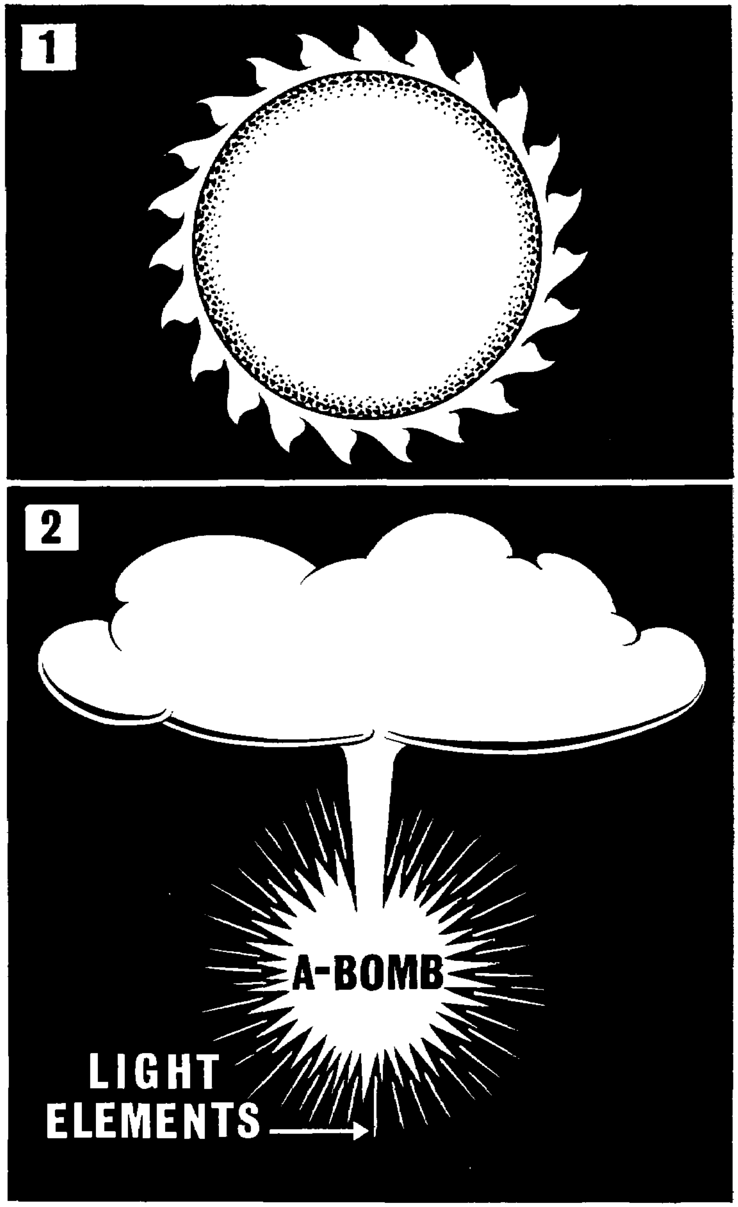
Thermonuclear reactions:

If deuterium gas were heated to a temperature of several million degrees Centigrade, fusion reactions would occur due to thermal collisions between deuterons. This is termed a thermonuclear reaction.

Thermonuclear reactions in our experience are:

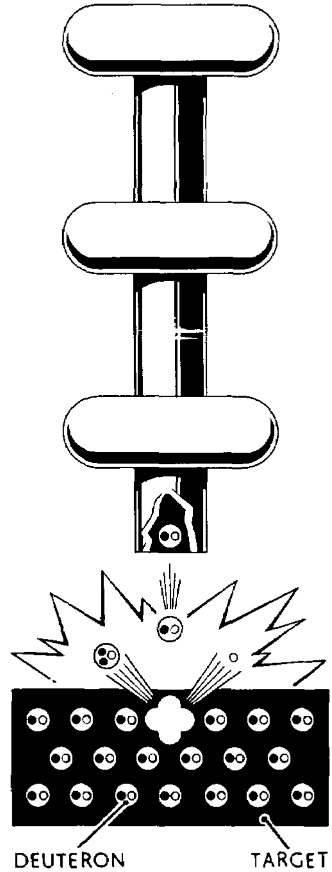
(*1*) The Sun: *hydrogen-helium by slow fusion process at 20 million degrees Centigrade.*

(*2*) The H-bomb: *fusion produced in deuterium and other light elements by high temperature ofatomic bomb.*



To obtain useful power from fusion the reaction must first be controlled

Fusion reactions *can be produced by bombarding deuterons with fast beams of deuterons from an accelerator. This is not an efficient way of releasing the energy of the reaction.*



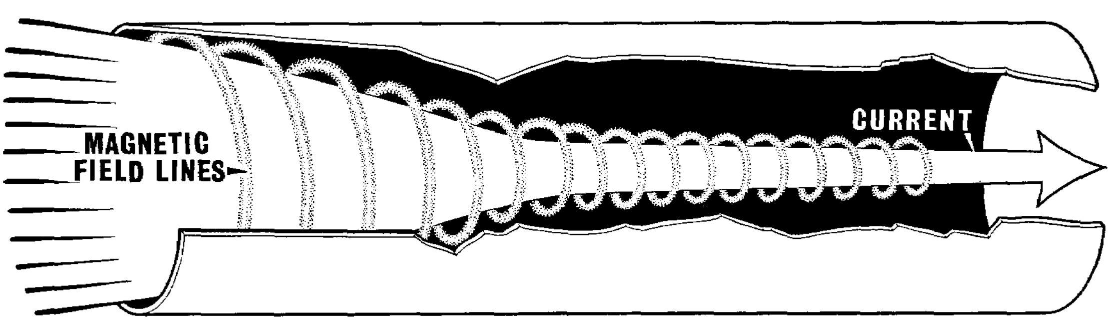
Preliminary work:

the Harwell thermonuclear project uses the method of passing an electric current through deuterium gas. This heats the gas, which is confined to the centre of the tube by the 'pinch effect'.

(a) Current initially fills tube.

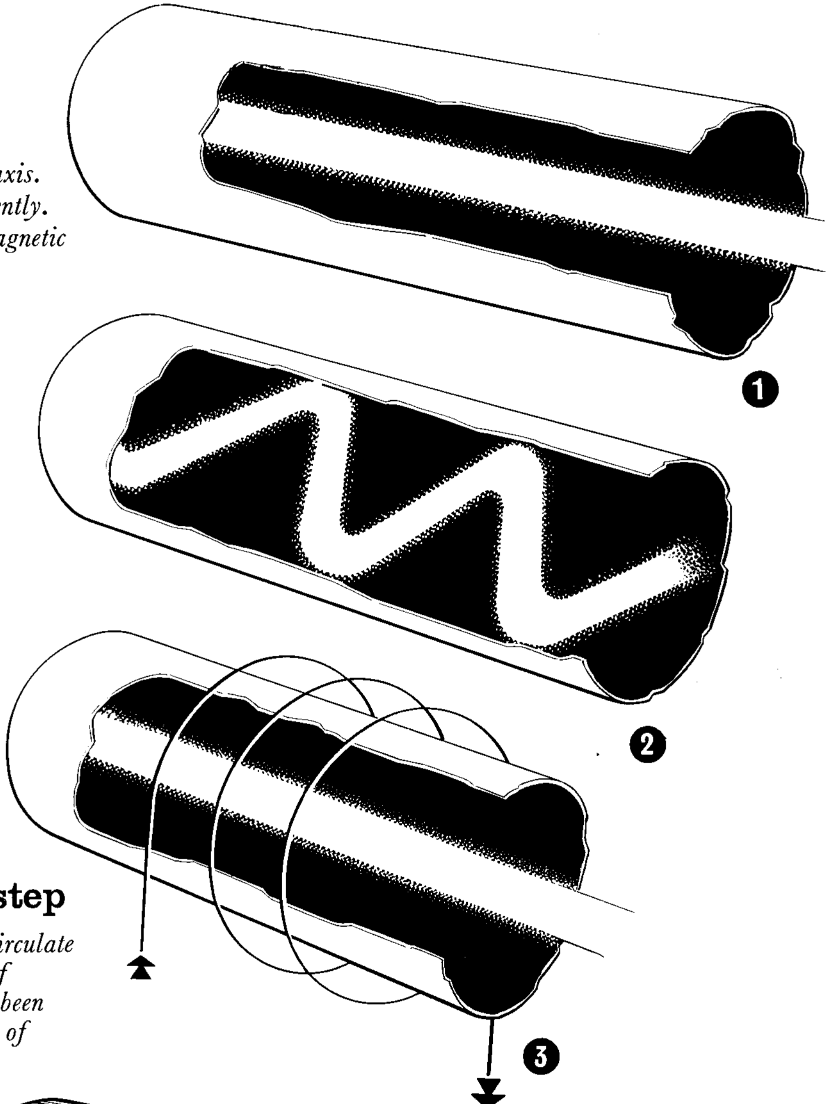
(b) Current draws hot gas into thin filament away from walls.

Currents of up to 80,000 amperes and temperatures of over 140,000 degrees Centigrade were obtained in preliminary apparatus.



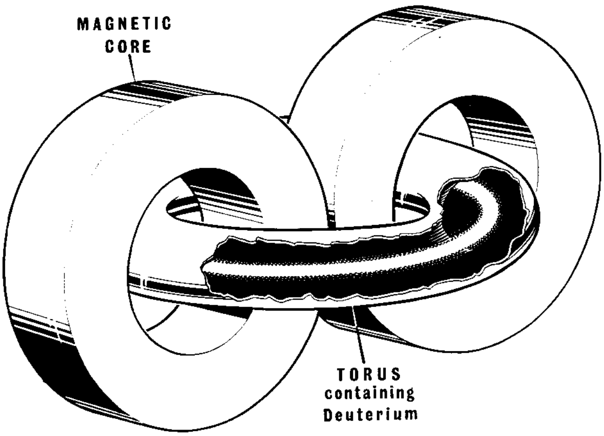
Principal difficulty : 'The Wriggle'

Ideal case: *Current straight down axis.*
Actual case: *Current wriggles violently.*
Solution: *Stabilization by axial magnetic field.*

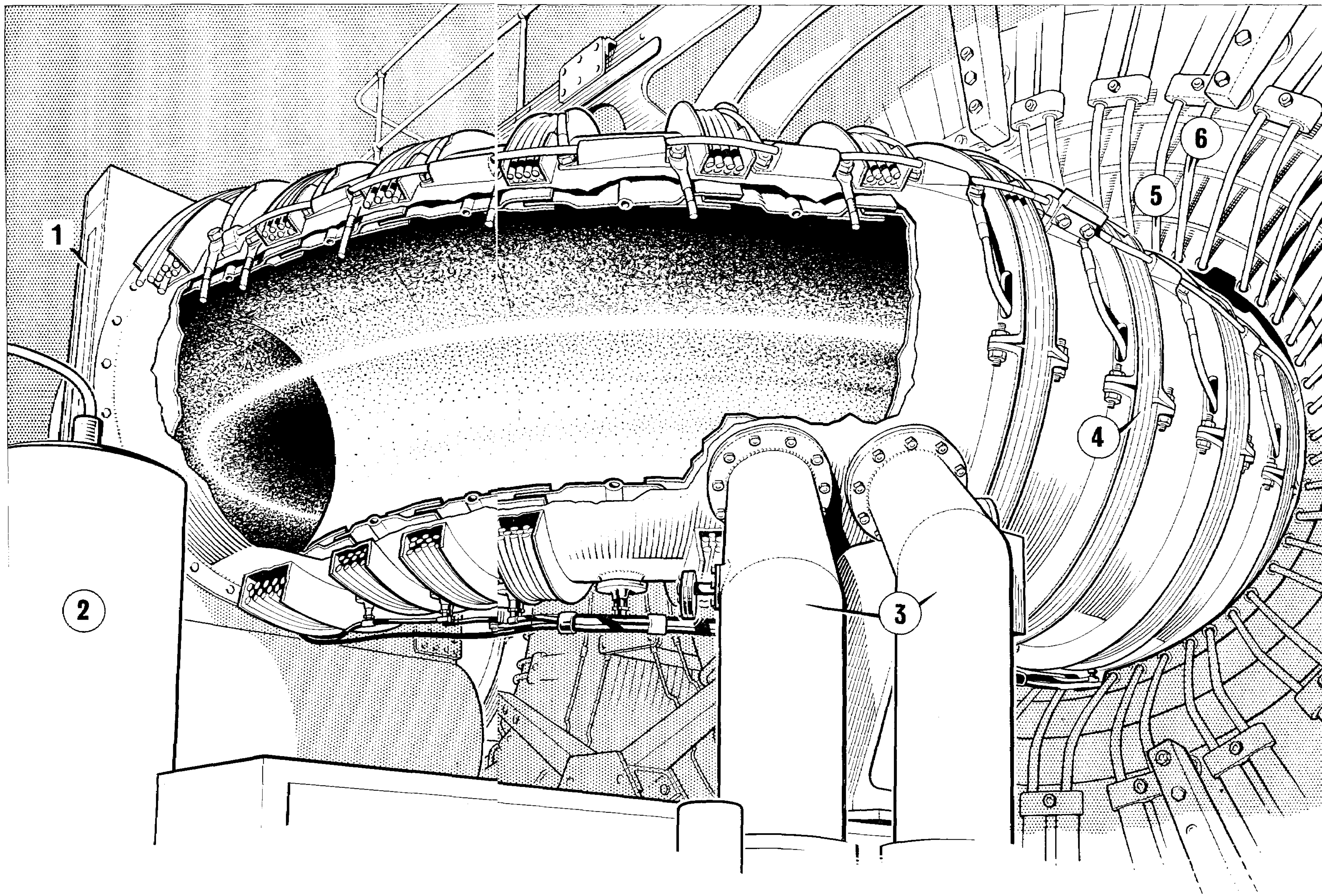


ZETA was the next step

Currents of up to 200,000 amps circulate in a closed 'torus'. Temperatures of 5,000,000 degrees Centigrade have been measured. Neutrons from the fusion of deuterium nuclei have been detected.



Cutaway diagram of ZETA showing thermonuclear flame



(1) *Viewing window.*

(2) *Cold trap.*

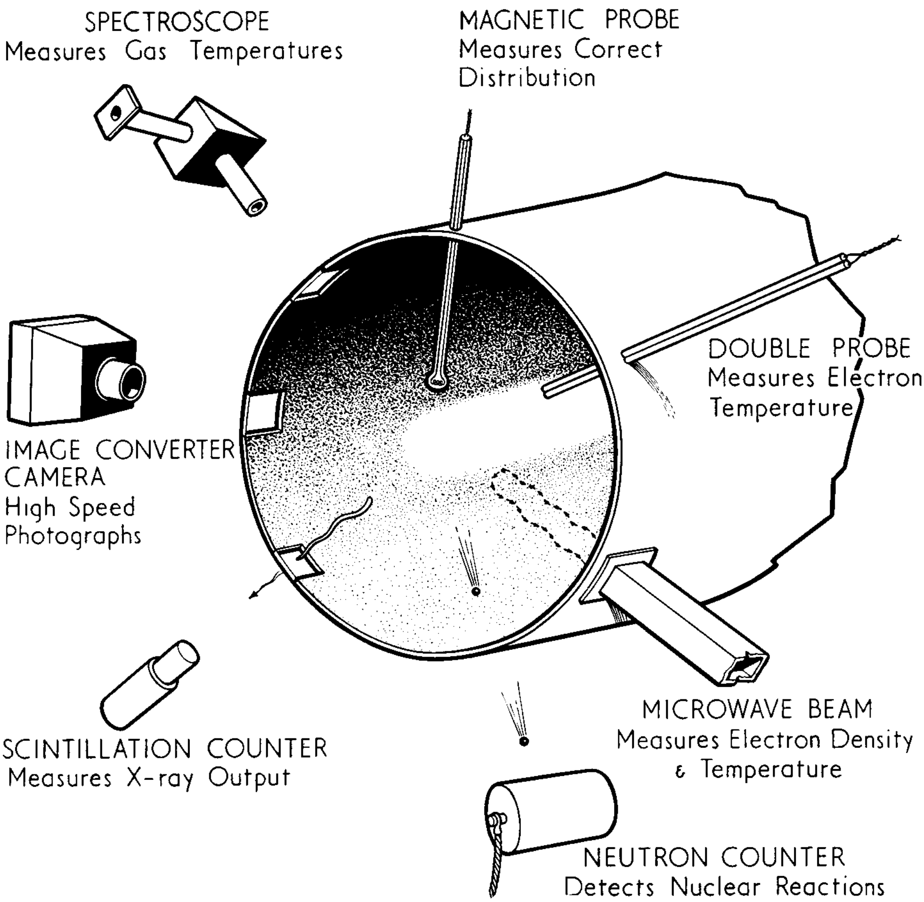
(3) *Vacuum pump.*

(4) *Axial field windings.*

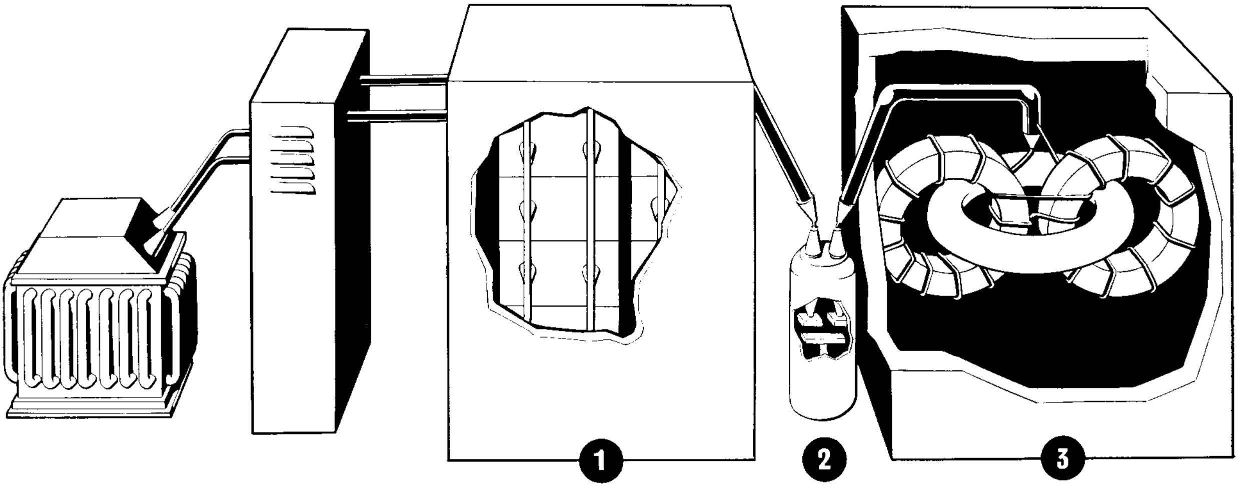
(5) *Pulse windings.*

(6) *Bias windings.*

Techniques for studying the gas discharge

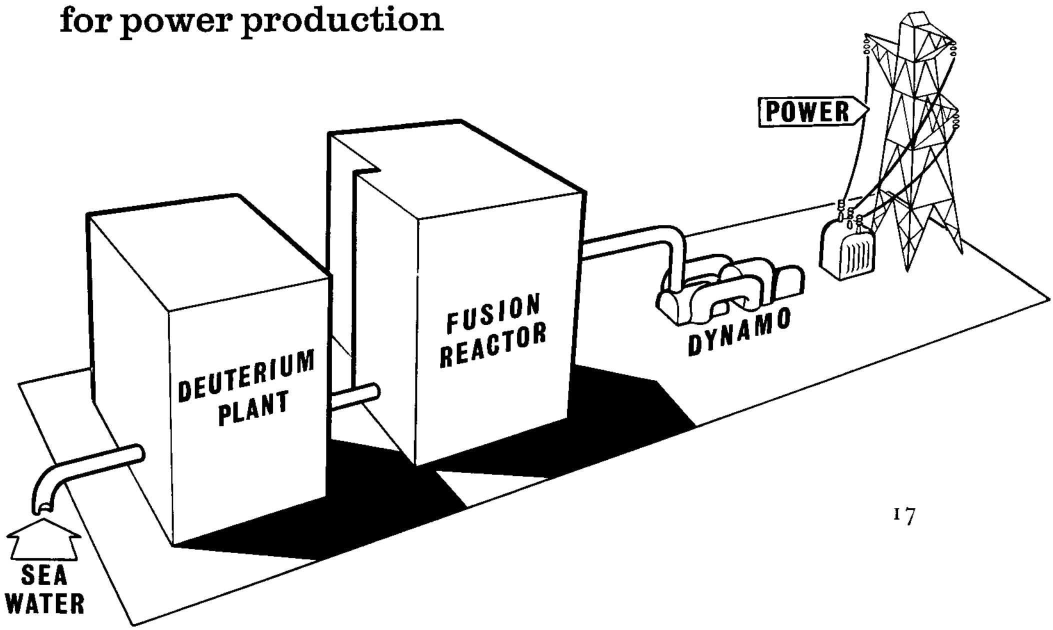


The operation of ZETA



(1) Condenser bank charges up to 25 Kv in 10 seconds, storing 500,000 joules energy.
(2) Switch closes.
(3) Condenser bank discharges its energy into transformer in 3 milliseconds.

Section of a possible fusion reactor for power production

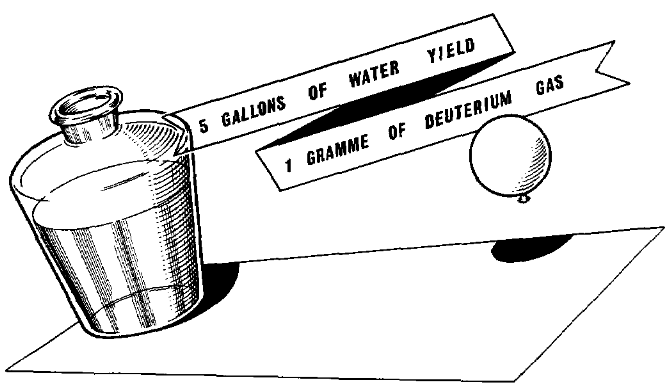


World sources of fuel

- ▲ Coal
- ■ Oil
- ● Uranium
- ▬ Deuterium

Extraction of Deuterium

Present cost of extraction is 2s. per gramme. The energy stored in one gramme of deuterium is equivalent to the energy stored in several tons of coal.



Fuel	Source	How used	Estimated reserves
Coal and oil	Mines and wells	Burned	About 150-250 years
Uranium and Thorium	Extracted from ore	Fission reactor	About 200–300 years (minimum)
Deuterium	Extracted from sea	Fusion reactor	More than 1,000 million years

Glossary *of terms used in thermonuclear research*

CAPACITOR (or condenser): a device which can be used to store electrical energy.

DEUTERIUM (or heavy hydrogen): Ordinary hydrogen is made up of two isotopes: i.e. two different kinds of hydrogen atoms which differ mainly in weight. The heavier isotope, called deuterium, or heavy hydrogen, is present in small proportion only (about one in 5,000).

DEUTERON: The nucleus of a deuterium (or heavy hydrogen) atom: it is formed by stripping the planetary electron from the atom (see also hydrogen ions).

DOPPLER EFFECT: If the atoms of a gas are emitting light in a narrow band of frequencies then the width of the band will increase as the temperature of the gas increases, because the speed of movement of the atoms also increases. This effect, (analogous to the change in the note of an engine whistle when a train passes through a station) is called Doppler 'broadening'. This broadening can be used to calculate the temperature of the emitting gas.

HEAVY HYDROGEN — see deuterium.

HYDROGEN IONS (or heavy hydrogen ions): Ions are atoms which have become charged by gaining or losing planetary electrons. In ZETA atoms lose their electrons and so become positive ions; thus hydrogen and deuterium atoms in the gas discharge lose their single planetary electrons and become positive ions called protons and deuterons respectively. Atoms with more planetary electrons do not lose all their electrons so readily; thus the additive gases used to measure temperature lose some but not all of their electrons.

JOULE: a measure of energy; 500,000 joules are equivalent to about one-tenth of a unit of electricity.

LINE SPECTRUM: Atoms, or ions which still have planetary electrons emit radiation only in very narrow and widely separated frequency bands. These appear when photographed as widely separated narrow black lines; this gives rise to the name 'line spectrum'. Fully ionised atoms (i.e. atoms which have lost all their planetary electrons) do not emit line spectra.

MILLISECOND: One thousandth of a second (10^{-3} sec.).

MICROSECOND: One millionth of a second (10^{-6} sec.).

THERMONUCLEAR NEUTRONS: Neutrons which are emitted from a true thermonuclear reaction.

THERMONUCLEAR REACTION: The atoms of a gas are always in random motion. As the gas is heated up, the speed of this motion increases. Now, for a nuclear fusion reaction to take place the colliding nuclei must possess considerable energy, i.e. be travelling very fast. If a gas is so hot that the speed of random motion in it provides sufficient energy for nuclear fusion to take place, then a thermonuclear reaction is said to take place. Neutrons produced in thermonuclear reactions are called thermonuclear neutrons. One million degrees Centigrade is the lowest temperature at which any measurable number of thermonuclear reactions could be observed.

TRITIUM: (See deuterium). Tritium is a radioactive isotope of hydrogen which has three times the weight of the ordinary hydrogen atom. It is manufactured by bombarding an isotope of lithium with neutrons; it has a half-life of 12¼ years and decays by emitting beta particles (electrons).

ZERO ENERGY: A zero-energy thermonuclear apparatus is one in which the thermonuclear power output is very small (even though the initiating power input is large).

A selected reading list on Thermonuclear Reactions*

1: General articles

BISHOP, A. S. *Controlled fusion.*
Nucleonics, vol. 15, no. 9, pp. 128–130, September, 1957.

BOSTICK, W. H. *Plasmoids.*
Scientific American, vol. 197, no. 4, pp. 87-94, October, 1957

LAWSON, J. D. *Power from nuclear fusion.*
Nature, vol. 180, no. 4590, pp. 780-782, October 19, 1957

LINHART, J. G. *Power from thermonuclear reactions.*
Nuclear Engineering, vol. 2, no. 11, pp. 60-65, February, 1957.

PAULSEN, F. R. *Power from nuclear fusion.*
Atomics & Nuclear Energy, vol. 8, no. 9, pp. 343–346, September, 1957.

REIFFEL, L. *Thermonuclear research the world around.*
Nucleonics, vol. 15, no. 8, pp. 88–89, 117. August, 1957.

SCHULTZ, M. A. *Fusion reactor control.*
Nucleonics, vol. 15, no. 6, pp. 76–79, June, 1957.

SMYTH, H. de W. *Controlled thermonuclear reactions.*
Atomic Energy in Industry, 4th Annual Conference, pp. 27–33, March, 1956.

TELLER, E. *General problems of the controlled thermonuclear process.*
Nuclear Sci. & Eng., vol. 1, no. 4, pp. 313–24, August, 1956.

TELLER, E. *Controlled thermonuclear reactions (Press interview June, 1956).*
Bulletin of the Atomic Scientists, vol. 12, no. 7, pp. 271–272, September, 1956.

THIRRING, H. *Thermonuclear power reactors — are they feasible?*
Atomic Energy in Industry, 4th Annual Conference, pp. 23–26, March, 1956.
Non-weapon potentials of thermonuclear reactions.
Atomic Scientists Journal, vol. 5, no. 4, pp. 227–230, March 1956.

THIRRING, H. *Thermonuclear power reactors.*
Nucleonics, vol. 13, no. 11, pp. 62–66, November, 1955.

*AERE Inf./Bib. 114, compiled by C. S. SABEL
UKAEA Research Group, Atomic Energy Research Establishment, HARWELL
October 1957.

THONEMANN, P. C. *Thermonuclear reactions.*
Nuclear Power, vol. 1, no. IV, pp. 169–172, August, 1956.

THONEMANN, P. C. *Thermonuclear power.*
Financial Times Annual Review of British Industry (in this Atomic Age), 1957, pp. 81–82, July 1, 1957.

US ATOMIC ENERGY COMMISSION.
Press conference of April 1, 1957 attended by USAEC Commissioners etc. Pages 4–17 consider aspects of US controlled thermonuclear research.

USAEC Press Release on April 1, 1957, 31 pp.

Illustrated write-ups of the above release.
US expands efforts to control fusion process.
Atoms for Peace Digest, vol. 2, no. 25, pp. 8–12, May 18, 1957.

Fusion power — the pace quickens.
Nucleonics, vol. 15, no. 5, p. 108, May, 1957.

Power from fusion. Report on J. D. Lawson's and Sir George Thomson's papers to British Association Meeting in Dublin. September 6, 1957. Electrical Times, vol. 132, no. 3435, pp. 371–373, September 12, 1957.

Thermonuclear power; The search for ideas.
Nucleonics, vol. 14, no. 2, pp. 42–44, February, 1956.

Thermonuclear reactions; The Times Science Review No. 20, pp. 1–2, Summer 1956.

2: References to specific subjects related to thermonuclear reactions

ALLEN, J. E. *An elementary theory of the transient pinched discharge.*
Proc. Phys. Soc. (London) *B*, vol. 70, pp. 24–30, January, 1957.

BURKHARDT, L. C. et al. *Pinch effect.*
Journal of Applied Physics, vol. 28, no. 5, pp. 519–521, May, 1957.

CARRUTHERS, R. & DAVENPORT, P. A. *Observations of the instability of constricted gaseous discharges.*
Proc. Phys. Soc. (London) *B.*, vol. 70, pp. 49–50, January, 1957.

KURCHATOV, I. V. *On the possibility of producing thermonuclear reactions in a gas discharge.*
(Lecture delivered at Harwell on April 25th, 1956).
Atomnaya Energiya, no. 4, pp. 65–75, 1956 (In Russian).
Discovery, vol. 17, no. 6, pp. 227–233, June, 1956.
J. Nuclear Energy, vol. 4, no. 2, part II, pp. 193–202, 1957.
Nucleonics, vol. 14, no. 6, pp. 36–43 and p. 123, June, 1956.

KURCHATOV, I. V. *Controlled thermonuclear reactions* (Pravda *interview May 10, 1956*).
Bulletin of the Atomic Scientists, vol. 12, no. 7, pp. 269–271, Sept., 1956.

LAWSON, J. D. *Some criteria for a power producing thermonuclear reactor.*
Proc. Phys. Soc. (London) *B*, vol. 70, pp. 6–10, January, 1957.

LLEWELLYN-JONES, F. *Ionization and breakdown in gases.*
London, Methuen & Co. Ltd, 1957, 176 pp.

PEASE, R. S. *Equilibrium characteristics of a pinched gas discharge cooled by Bremsstrahlung radiation.*
Proc. Phys. Soc. (London) *B*, vol. 70, pp. 11–23, January, 1957.

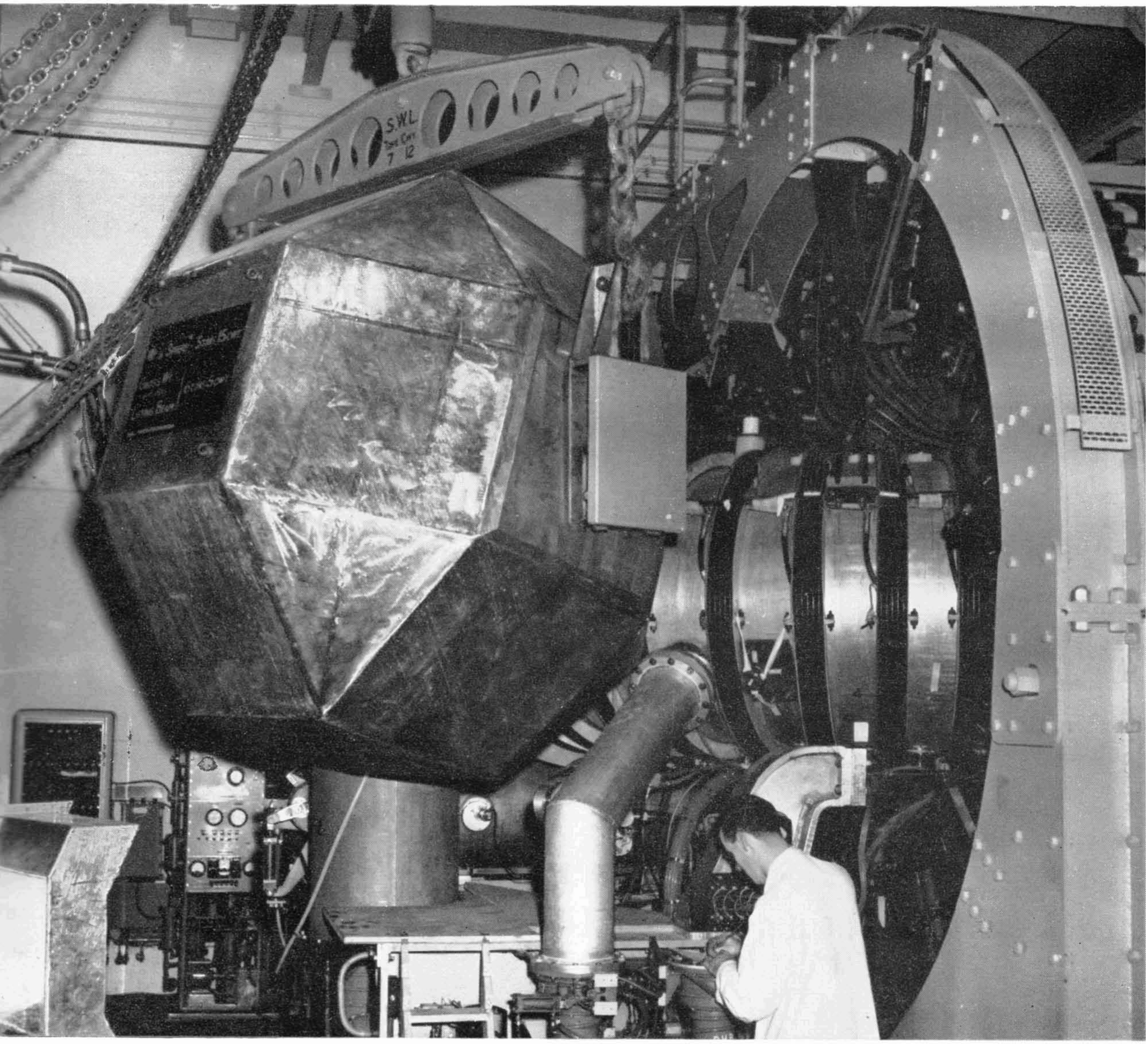
POST, R. F. *Controlled fusion research — an application of the physics of high temperature plasmas.*
Revs. Mod. Phys., vol. 28, pp. 338–62, July, 1956.

SPITZER, L., Jr. *Physics of fully ionized gases.*
New York, Interscience Publishers Inc. 1956, 105 pp.

TAYLER, R. J. *Hydromagnetic instabilities of an ideally conducting fluid.*
Proc. Phys. Soc., *B*, vol. 70, pp. 31–48, January, 1957.

THOMPSON, W. B. *Thermonuclear reaction rates.*
Proc. Phys. Soc. (London), *B*, vol. 70, pp. 1–5, January, 1957.

THOMPSON, W. B. *Thermonuclear power; a theoretical introduction.*
Nature, vol. 179, no. 4566, pp. 886–889, May 4, 1957.



ZETA, showing the aluminium torus as the secondary of a large transformer. The pipes used for pumping the apparatus down to low pressure can be seen together with the coils used for producing the axial magnetic field used to control instability. The large box hanging from a crane is a directional neutron detector used to scan the torus and help determine whether true thermonuclear or stray neutrons are being produced. In the lower left-hand corner can be seen the triple boron trifluoride counters used to integrate the total neutron production per pulse.

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