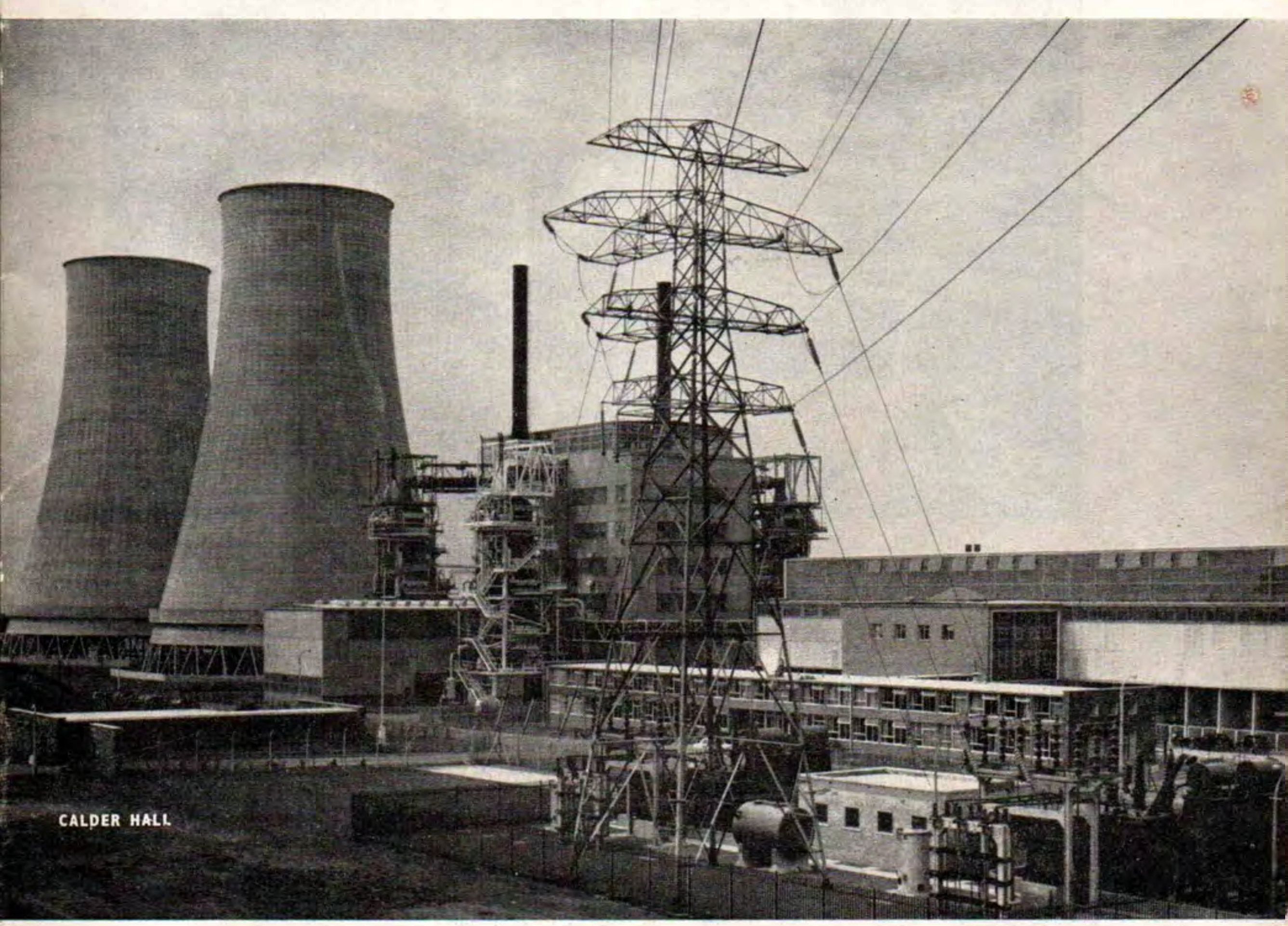
THE A.B.C. OF ATOMIC ENERGY

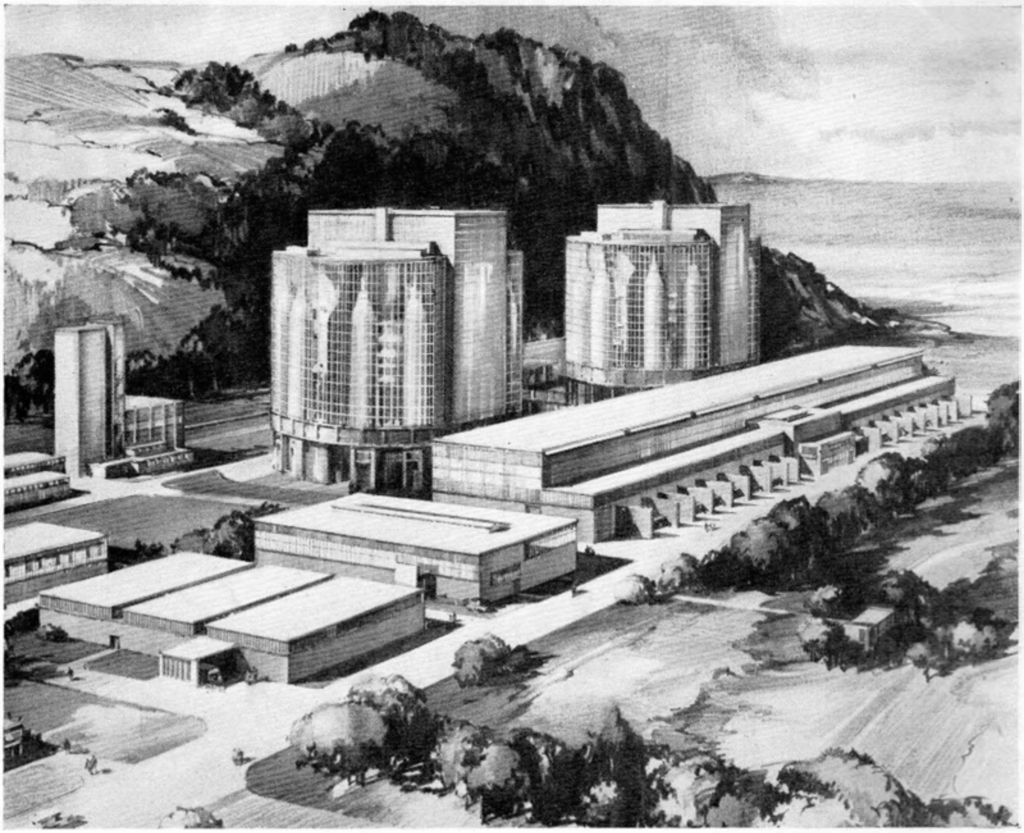


by SIR CHRISTOPHER HINTON, F.R.S.,

formerly Managing Director of the Industrial Group

of the U.K. Atomic Energy Authority

BBC



Atomic Power for the World

With several twin-reactor power stations under construction Britain's nuclear power programme has reached an advanced stage. This station, which will have an installed capacity of 360 MW, is being built by the G.E.C. at Hunterston, near Glasgow, for the South of Scotland Electricity Board.

The General Electric Company Limited of England has immense resources in men and materials and is prepared to build nuclear power stations anywhere in the world. In its Atomic Energy Laboratories, scientists and engineers are constantly engaged upon research and development work on every aspect of atomic energy for peaceful purposes.

G.E.C. *Atomic Energy Division*

THE GENERAL ELECTRIC CO. LTD, MAGNET HOUSE, KINGSWAY, LONDON, W.C.2

A264

THE A.B.C. OF ATOMIC ENERGY

by

Sir Christopher Hinton F.R.S.

Edited by

JOHN DIXON AND PHILIP DALY

Illustrator: J. P. FARTHING

Price

One Shilling and Threepence

1958

THE BRITISH BROADCASTING CORPORATION

ZETA

was

built by

METROPOLITAN-VICKERS

The Zero Energy Thermo-Nuclear Assembly with which the Atomic Energy Research Establishment, Harwell achieved temperatures up to 5,000,000°C on the 30th August, 1957, was built by Metropolitan-Vickers. They also collaborated in the design of this equipment which was the first to produce temperatures of this order.

METROPOLITAN-VICKERS
ELECTRICAL CO LTD · TRAFFORD PARK · MANCHESTER 17

An A.E.I. Company

LEADING ELECTRICAL PROGRESS

TGA/AZ801

Foreword

by Sir Christopher Hinton

ATOMIC ENERGY is new; it need not be mysterious. There is no greater mystery about it than there is about any other source of power. It is, however, the most important thing that has happened in this century and wisely used can be of immense benefit to mankind. It is, therefore, the duty of everyone to try to understand it and get some grasp of the problems and difficulties that are involved. Only in this way will the fear of anything 'atomic' be lessened.

These were the motives that persuaded me to accept an invitation from the External Services of the B B C to broadcast a series of seven talks entitled 'The A B C of Atomic Energy' on which this book is based.* The object of the series and of this book is to explain in the simplest possible terms what atomic energy is and how we can get electricity from it. No scientific knowledge is assumed on the part of the reader.

I am, after all, an engineer not a scientist, and when I was first appointed Managing Director of the Industrial Group of the United Kingdom Atomic Energy Authority, I knew nothing about nuclear physics. Before I could design and build the atomic energy factories, which included Calder Hall, I had to sit at the feet of a nuclear physicist and have the principles, stripped of all jargon, explained to me. My daughter who was then still at school asked me to give a talk on atomic energy to the girls. It was in this way that the lecture which I later called 'Atomic Energy Made Easy' originated. This lecture, modified and improved, was then adapted for radio by John Dixon of the Atomic Energy Authority, and Philip Daly of the B B C, and a talk on Fusion was added. The result of their work forms the basis of this book.

Many scientists will say that I have over-simplified the subject, but I think it is better to have a simplified picture than no picture at all.

* The talks were broadcast in English in the BBC's General Overseas Service, in London Calling, Asia, and London Calling Europe, and in other languages in the BBC External Services which are transmitted on many wavelengths in forty-one languages (*for Overseas and European Services see page 38.*)

Times and details of the European Services are in the weekly magazines LONDON CALLING EUROPE *and* HIER SPRICHT LONDON. *Information about the BBC broadcasts beyond Europe are in the weekly airmail journal* LONDON CALLING. *For copies and subscription forms: BBC, 35 Marylebone High Street, London W.1.*

INTRODUCTION

In a conventional power station we burn coal or oil to boil water which produces steam: the steam turns the blades of a turbine rather like the wind turns the sails of a wind-mill: the turbine drives large dynamos which in turn produce electricity. In an atomic power station exactly the same thing happens except that instead of boiling water by burning coal or oil we boil it by using some of the energy locked up inside the atom. This is the only difference. Instead of the conventional furnace in which coal is burnt we have an atomic furnace, called a reactor, in which we generate heat by splitting atoms.

You would not expect me to explain how we get heat by burning coal because it is an everyday experience. We are all so accustomed to it that we accept it and use it without any explanation, and so it is with anything we are used to. But when something lies outside our common experience we can only get a grasp of it by understanding exactly how it happens. Now the means by which we are able to get heat from atoms are very far from being common experience, and so to understand exactly how we do it we have to start at the very beginning and examine the atom itself.

THE ATOM

When I was at school, I was taught that everything was made up of tiny little particles called molecules, and that these, in their turn, were made up of even smaller particles called atoms. You could take two or more atoms and build them up into a single molecule and you could, by suitable means, break a molecule down into the separate atoms forming it, but that, we were taught, was as far as you could go. You could not break atoms into anything smaller; they were the ultimate particles of matter and we used to regard them rather as being tiny, solid balls. But even at the time when I was being taught this at school, which is quite a number of years ago, the scientists had got a pretty good idea that this conception of the atom was quite wrong.

Today, far from regarding an atom as a tiny, solid ball, scientists believe that it is much more like a very small solar system, made up in very much the same way as the solar system in which we live. You can think of the atom as being an entire solar system with the sun in the centre and the planets circling around it. Corresponding to the sun in the centre is a collection of particles which we call the *nucleus*. Circling round the nucleus as planets circle round the sun are other particles which we call *electrons*. They move in orbits just as the Earth, Jupiter, Mars, and other planets do in our own solar system.

Now before we go any further, I think we should get some idea of the size of these atomic solar systems. Let us suppose that we have an atom and a football side by side. If we magnify them both at the same rate we find that by the time the atom is as big as the football, the football is as big as the earth. In fact, an average sized atom is as much smaller than a football as a football is smaller than the earth.

And remember that here I am talking about the size of the orbit of the outermost electron or planet. The nucleus itself, the sun, is far, far smaller, so now let us magnify the atom still further, until the nucleus becomes as big as a football. We now find that the outer electrons are something like rifle bullets flying round and round the football a few miles away from it. All the intervening space is completely empty. In fact, atoms contain nearly as much empty space as the solar system in which we live.

At first sight it is difficult to understand how hard matter, the wall or the floor of your house, can be made up of particles which consist of so much empty space. The reason is the enormous speed at which the electrons travel round their orbits.

Let me give you a comparison. When the wheel of a bicycle is stationary you can put your hand through the gaps between the spokes and come to no harm. If, however, you are foolish enough to try the same thing when the wheel is spinning you will find to your cost that the wheel does not appear to have any gaps, it is virtually a solid disc. In reality, of course, the gaps are still there.

In the same way when an aeroplane propellor is rotating at speed it appears to be as solid as a wall. Now the tip of the aeroplane propellor is moving at a speed which is a mere imperceptible crawl compared to the speed of the electrons in their orbits round the nucleus, and this is why the atom is able to appear so solid.

Now it is possible, by using suitable timing gear, to shoot machine gun bullets through the gaps between the blades of a propellor while it is rotating because the bullets are travelling at such high speeds. In exactly the same way, some atomic particles move so fast that they can pass through this barrier of circling electrons which seems so solid to us.

This fact, that atomic particles can pass through the barrier of the circling electrons, is important, as we shall see later. In fact, if the particles could not get through the electrons to the central nucleus the energy locked up there could not be released. We could not split the atom.

I have dealt so far with the planets in our atomic solar system; now let us have a look at the sun in the centre, the nucleus. This we find is made up of two kinds of particles, one we call a *proton*, the other a *neutron*.

These two particles, the proton and the neutron, together with the circling electron, are the only three particles we shall meet. They make up all the different atoms that exist—your body, your home, everything.

There is one important fact about these particles which I have not yet mentioned. The protons in the centre of the atom and the electrons circling around them both carry electric charges. These charges are just like the charges you can produce by rubbing the top of your fountain pen on your sleeve. Every schoolboy has amused himself doing this and then picking up scraps of paper on the end of the pen. The reason why this trick works is that in the rubbing an electric charge is produced on the pen. We call this a negative charge. But the rubbing also produces an electric charge on the sleeve. This balances the charge on the pen and so we call it a positive charge.

In the same way the electron, like the pen, carries a negative electric charge and the proton, like the sleeve, has a balancing positive charge. The third kind of particle, the neutron, is as its name implies, neutral. It carries no electric charge at all.

Now generally speaking, objects are not electrified, and it is therefore fair to conclude that the individual atoms making them up are not electrified either. This means that in each atom the negative charges on the electrons must balance the positive charges on the protons, and this in turn means that the number of protons in the central nucleus must equal the number of electrons circling around it. If there are six of one there must be half a dozen of the other.

The number of protons, however, varies in different atoms, and it is this variation which gives us different elements such as silver, gold, iron, and oxygen. Each element has its characteristic number of protons, ranging from hydrogen with 1, helium with 2, and so on up to the biggest atom found in nature, uranium, which has 92 protons and, of course, 92 electrons to balance them.

Quite often we find there are atoms with the same number of protons but a differing number of neutrons. These atoms all belong to the same substance, the same chemical element, because they all have the same number of protons, but they differ in weight due to the varying number of neutrons. These atoms we call *isotopes.* You can think of isotopes as brothers and sisters—they all have the same family name—but they differ in weight.

Although reference to isotopes has only recently become commonplace, isotopes themselves are not something new arising from atomic energy. Certainly atomic energy has created a lot of artificial isotopes, but many ordinary elements in nature consist of mixtures of isotopes. An atom of iron, for example, always contains 26 protons in its nucleus, otherwise it would not be iron, but while some atoms of iron contain 28 neutrons others may have 30, 31, or even 32 neutrons.

CHEMICAL AND NUCLEAR REACTIONS

Let us now see what happens to atoms when they take part in reactions. Take first a well-known chemical reaction, burning coal.

Coal consists largely of carbon atoms, and when we burn coal one atom of carbon links up with two atoms of oxygen from the air to form a molecule of carbon dioxide (*figure 1*). The central nucleus of each atom in the molecule remains separate, distinct, and unchanged. The linking is done by the electrons. Instead of each electron circling just round its own nucleus as in the three separate atoms, they weave a complicated pattern round all three and bind them into a single molecule. It is like a parcel containing three boxes tied up with string. The string holds the boxes together but their contents remain separate, distinct, and unchanged. In the molecule the electrons do the job of the string, and the contents of each box represent the protons and neutrons in each nucleus. That may explain what happens, but what about the heat from our coal which, of course, is what we are after when we burn it? Where does that come from? Well, heat is one form of energy—and there are several other forms—which can be interchanged. When you apply the brakes on a bicycle you find the brakes get hot. What you have done is to transform energy of movement into heat.

Every atom contains a certain amount of energy. Part of it is electric energy due to its electric charges, and part of it is energy of movement—because the electrons are moving at high speed. The total amount of energy is called the 'energy content of the atom'. In the same way the molecule which is produced by joining together the atoms also has an energy content. But the interesting and important thing is that if we work it out we find that the energy content of the molecule we finish up with in this chemical reaction is less than the total energy content of the three separate atoms we started with. Now since energy cannot be

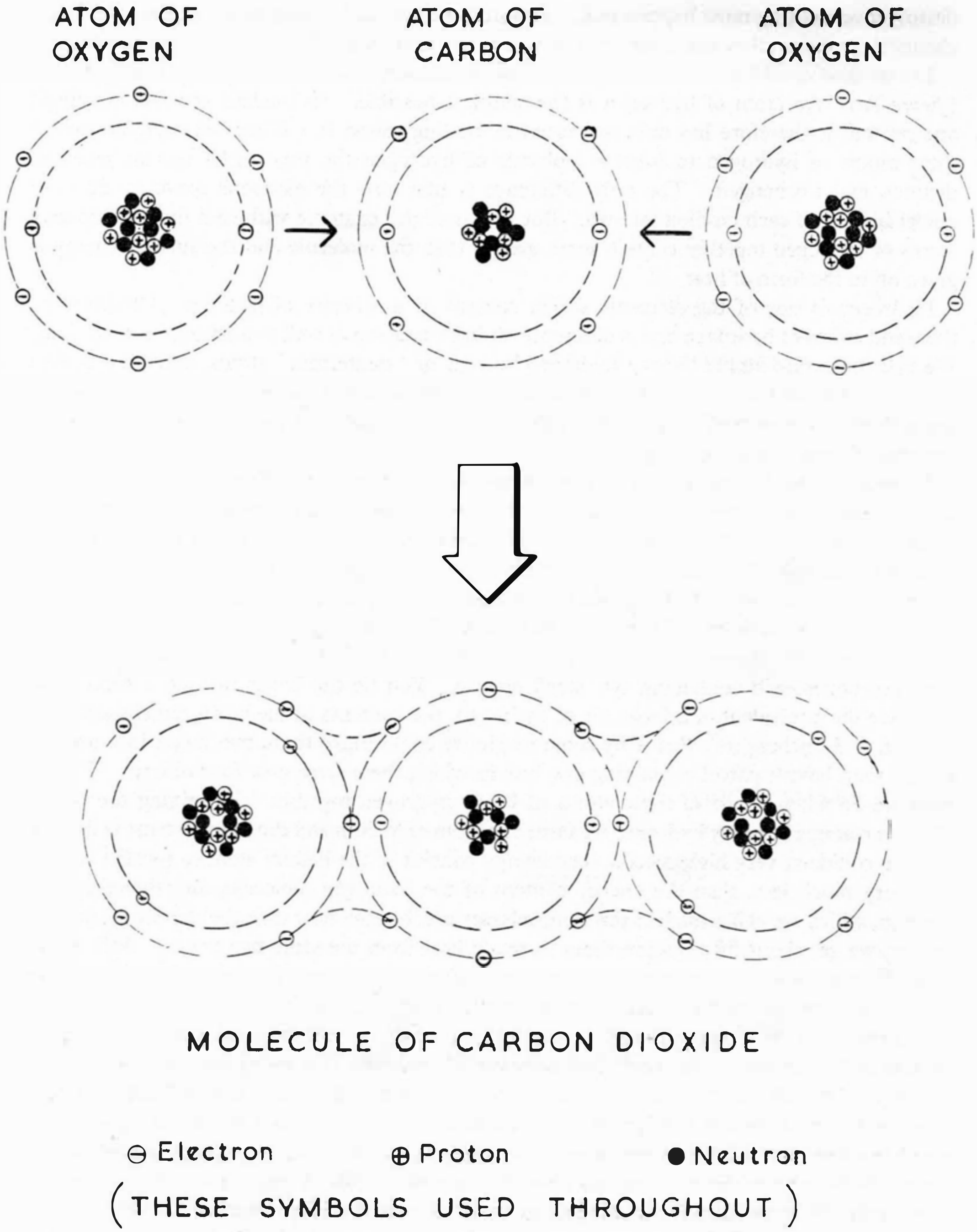

ATOM OF OXYGEN
ATOM OF CARBON
ATOM OF OXYGEN
MOLECULE OF CARBON DIOXIDE
⊖ Electron
⊕ Proton
● Neutron
(THESE SYMBOLS USED THROUGHOUT)

FIGURE 1

destroyed something must happen to it. It is in fact converted to heat which is given out as the chemical reaction takes place, and this is where the heat comes from when we burn coal.

Let us now consider an even simpler chemical reaction, this time using atoms of hydrogen (*figure 2a*). An atom of hydrogen is the simplest possible. Its nucleus consists merely of one proton, it therefore has only one electron circling round it. When we combine two of these atoms of hydrogen to form a molecule of hydrogen the two nuclei remain separate, distinct, and unchanged. The only difference is that now the electrons move round both nuclei instead of each circling its own. But just as in our example with coal the two separate atoms of hydrogen together contain more energy than the molecule and the surplus energy is given off in the form of heat.

Hydrogen is one of the elements which consists of a mixture of isotopes. Of every six thousand atoms of hydrogen one is different. It has a neutron as well as a proton in its nucleus. We call these rare atoms ' heavy hydrogen ' atoms or ' deuterium ' atoms, and they behave chemically like all the others. Two of them will combine to form a molecule (*figure 2b*)—and again there is a release of energy when this happens, and again the nuclei in the molecule are separate, distinct, and unchanged.

If, however, we can make two of these heavy hydrogen atoms collide at very high speed then it is possible for the nuclei themselves to combine together for a moment and then break up again (*figure 2c*). The original nuclei have been transformed into a new nucleus and an escaping neutron. This nucleus now contains *two* protons and one neutron, so by definition it is no longer hydrogen. In fact, instead of a molecule of hydrogen we have an atom of helium which has three particles in its nucleus and we are left with a spare escaping neutron.

Let us go back to our example of the boxes made into a parcel. Imagine this time you have two boxes each containing two small objects. You tie the boxes up into a parcel and you have the equivalent of a molecule of hydrogen, the contents of the boxes remain separate, distinct, and unchanged. But if by some magic we could make these two boxes into one we should then have a parcel containing one box in which there were now four objects. This is what we do when we drive these atoms of heavy hydrogen together. By mixing the nuclei of the two atoms of heavy hydrogen we form one atom of helium and the magic we use is forcing them to collide at very high speed. The energy content of the helium atom so formed is even less, very much less, than the energy content of the hydrogen molecule, and therefore this reaction, which we call a nuclear reaction, releases much more heat than the chemical reaction. In fact, we get about fifty million times as much heat from the same two atoms. And this is generally true of all nuclear reactions, namely, that from the same quantity of matter we get millions of times more heat than from an average chemical reaction.

Unfortunately, it is very difficult to make this type of nuclear reaction work. The atoms have to collide at very high speed, and one way of achieving this speed is to raise their temperature. After all, you have to heat coal to start it burning. But while coal will begin to burn at a few hundred degrees centigrade, these nuclear reactions in which the nuclei join or fuse together—what we call *fusion* reactions—only begin to work at several million degrees centigrade. Now to start the reaction and control it is a very difficult and expensive process, and many years of research will be needed to make it commercially practicable. However, a great deal of work has already been done in several countries and in particular our scientists at Harwell have achieved promising results. I shall deal more fully with this fusion reaction later.

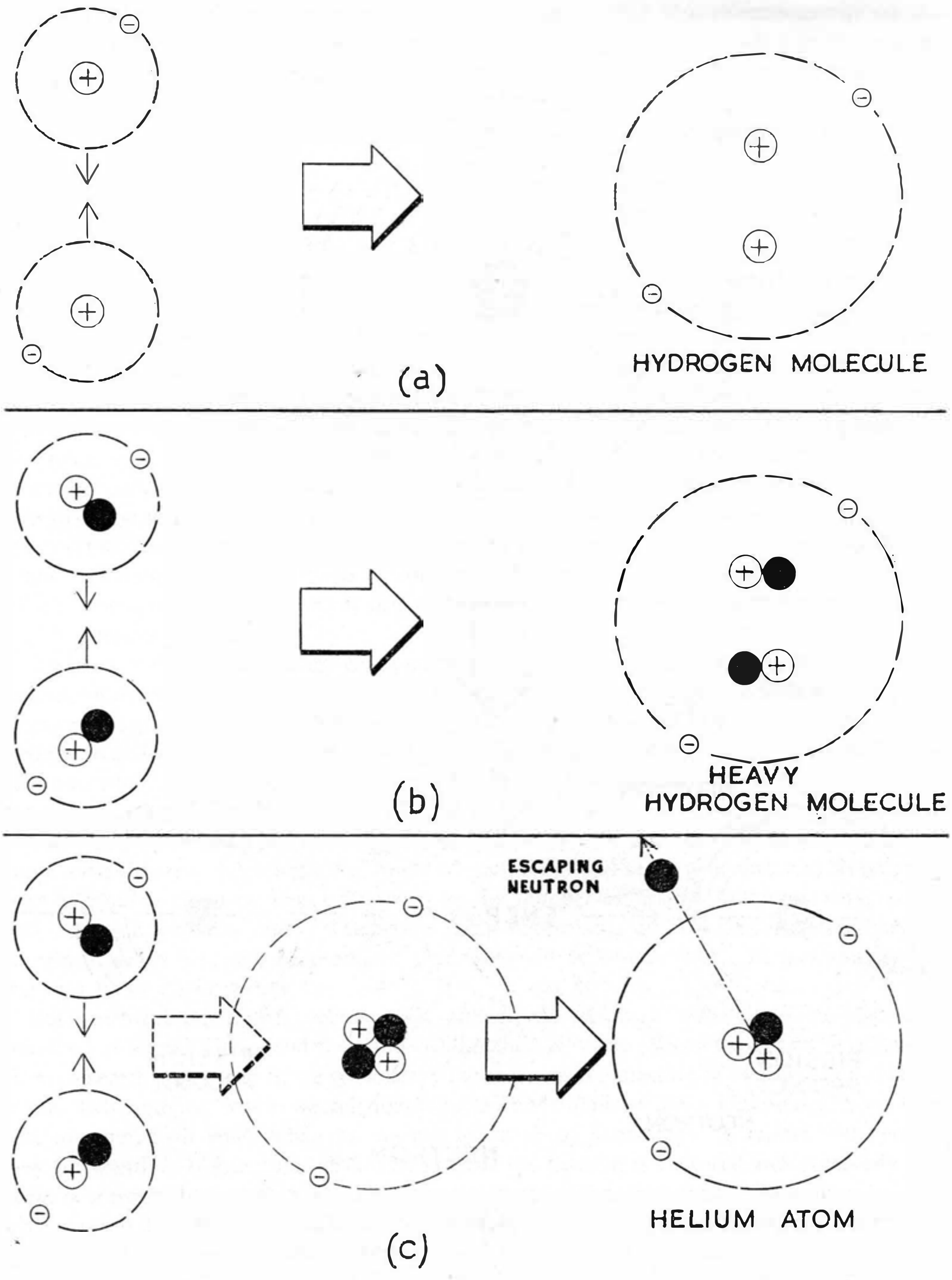
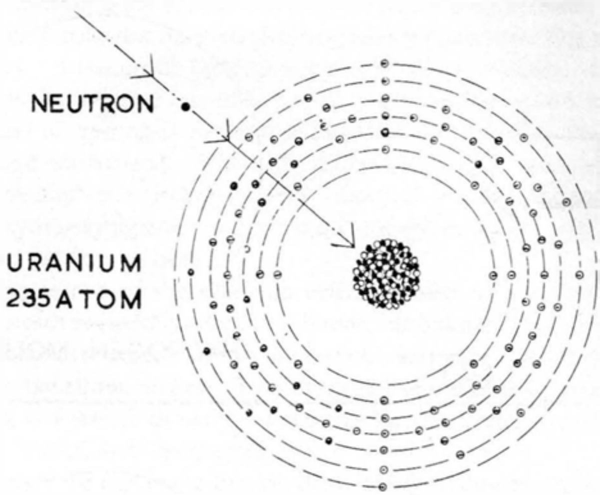
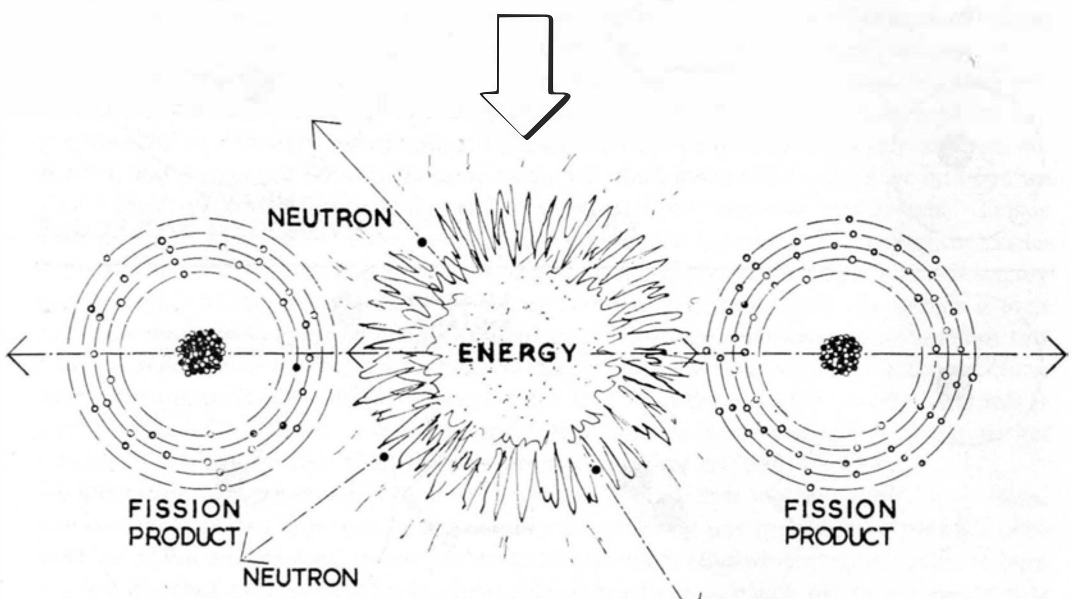

HYDROGEN MOLECULE
(a)
HEAVY
HYDROGEN MOLECULE
(b)
ESCAPING
NEUTRON
HELIUM ATOM
(c)

FIGURE 2


NEUTRON
URANIUM
235 ATOM

(a)


NEUTRON
ENERGY
FISSION
PRODUCT
NEUTRON
NEUTRON
FISSION
PRODUCT

(b)

FIGURE 3

Fortunately there is another type of nuclear reaction, which also releases energy on this enormous scale, and which will work at ordinary temperatures. We call it a *fission* reaction because it consists not of joining atoms together but of splitting very heavy atoms apart. Fission merely means splitting.

URANIUM

Of all the different types of atom which occur in nature, there is only one with which we can carry out the fission process, and this one is an isotope of uranium. Like all uranium atoms its nucleus contains 92 protons, and it also contains 143 neutrons making a total of 235 particles. So it is called, in scientists' shorthand, uranium 235. This is a very big and complex nucleus and if a stray neutron succeeds in penetrating the barrier of the circling electrons (*figure 3a*) the nucleus is so unstable that it breaks into two pieces—two smaller nuclei. These two pieces are called the fission products (*figure 3b*). Also their combined energy content is much less than the energy content of the original uranium atom, and the surplus energy is again given off as heat. This surplus energy drives the fission products apart at enormous speeds. They very quickly lose their speed by colliding with the surrounding atoms, and their energy of movement is converted to heat, just as happens when you apply the brakes on a bicycle and the brakes get hot.

There is one other important effect of this fission reaction. Besides the big pieces, the fission products, separate neutrons shoot out of the splitting nucleus. Sometimes only one neutron escapes, sometimes there are two and sometimes three. On the average we get about two and a half neutrons from every fission, although, of course, there is no such thing as half a neutron. Remember we started all this off with one neutron and we now have two or three new ones.

The importance of these new neutrons is that in a lump of uranium 235 they can split still more atoms thereby releasing more heat and producing still more neutrons, and so on in an ever expanding chain reaction. In this way the number of fissions builds up very rapidly and each one produces heat. The whole thing happens so quickly that in a fraction of a second so much heat will be produced that there will be an explosion. In fact, this is what happens in an atomic bomb.

But remember this fission process—this splitting and release of heat—only takes place with one kind of uranium atom and this kind is comparatively rare. When we extract uranium ore from the earth and purify it, we get a heavy metal which is a mixture of two kinds of uranium atoms, two isotopes, which we call uranium 235 and uranium 238. Uranium 235 we have just considered—it splits when its nucleus is struck by a neutron. Uranium 238 behaves very differently. If a neutron strikes its nucleus the neutron is captured and eventually that atom is converted to an atom of an artificial element called plutonium. Plutonium behaves like uranium 235—when struck by a neutron its nucleus splits, produces fission products and heat, and releases more neutrons. It is, in fact, an artificial nuclear fuel.

We can now see how we should like our nuclear reactions to carry on inside our reactor. Let us suppose we have a lump of natural uranium and we expose it to neutrons—neve mind where the neutrons come from at the moment, I shall deal with that later. The reaction starts when one of these neutrons strikes an atom of uranium 235 (*figure 4*). The atom splits, fission products are formed, heat is given off, and two or three neutrons shoot out. Let us suppose it is two neutrons from each fission, as I did say that on average 2½ neutrons appear but some are inevitably lost. To keep our reaction going one of these two neutrons must hit another atom of uranium 235 but the other can hit an atom of uranium 238. This does not produce heat, but the uranium 238 atom is converted to plutonium which gives us fresh fuel. If we can carry on like this, using one neutron from each fission to cause a further fission, and the other neutron to convert uranium 238 to plutonium, we get a steady production of heat and a steady production of plutonium. The steady flow of heat is really what we are after as it is this heat which we can use to boil water to raise steam in our nuclear power station. The simultaneous production of plutonium is a fortunate bonus or by-product as we call it. Now all this sounds splendid but there is one big snag. For every atom of uranium that will split and give off heat there are 139 atoms that will not.

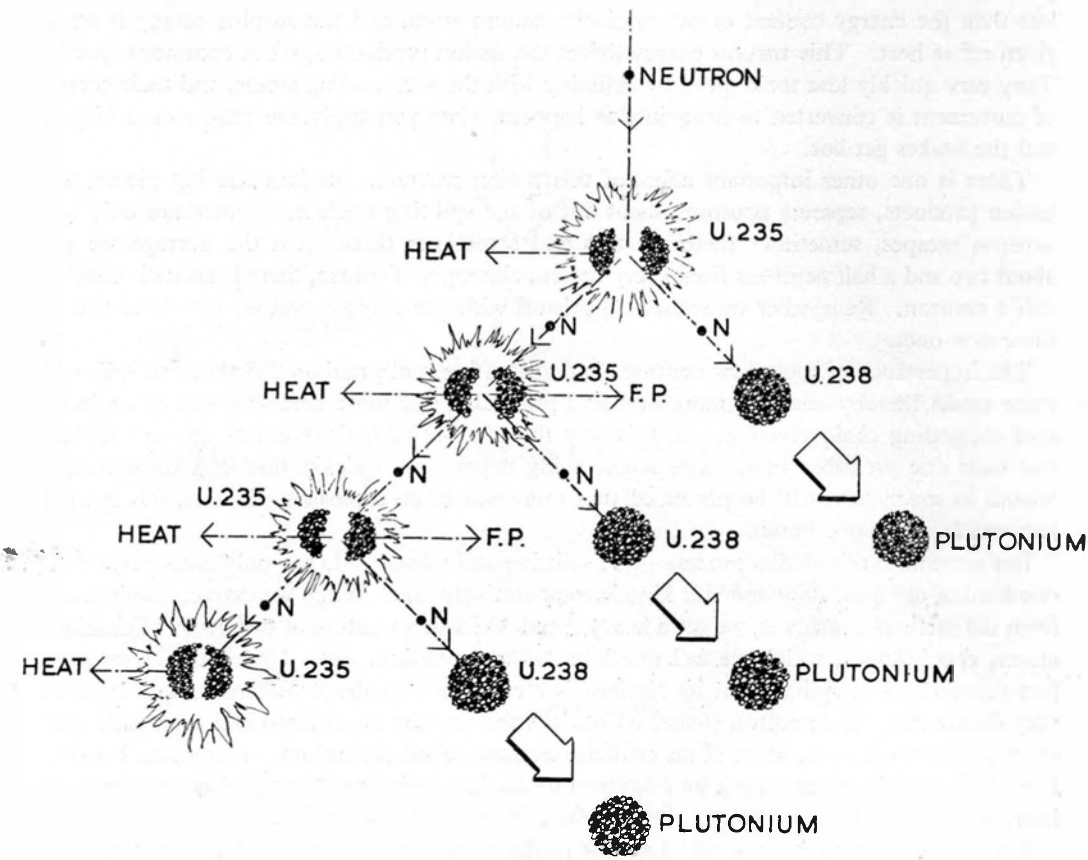
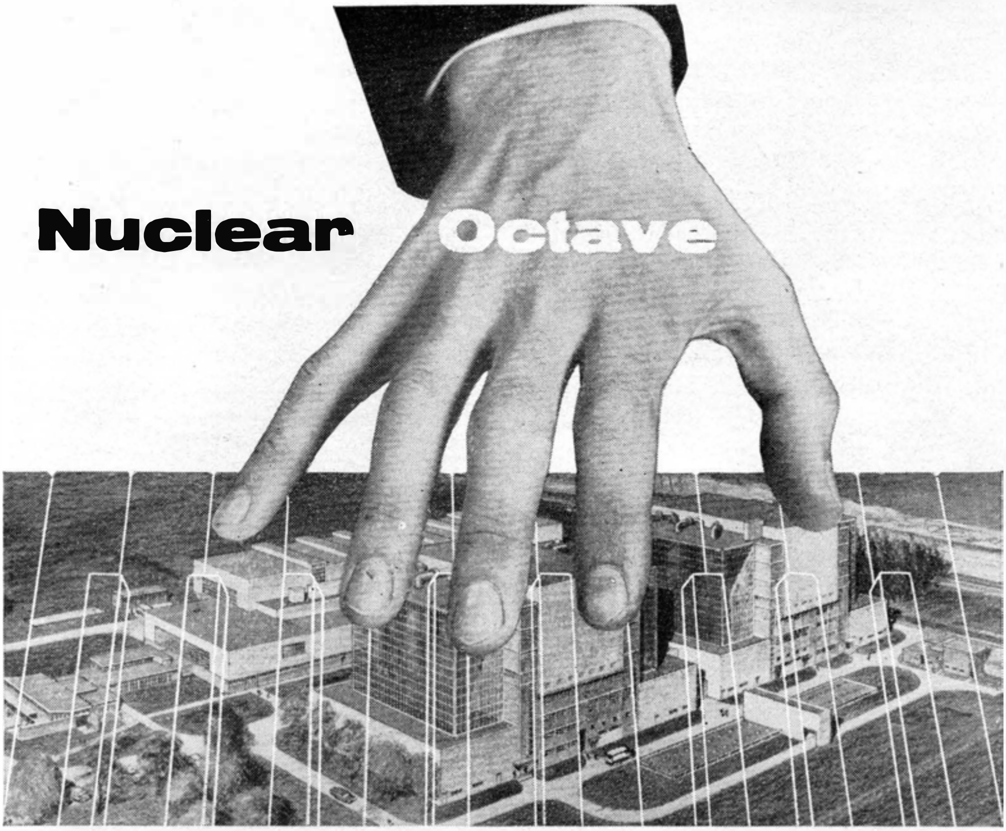


FIGURE 4

Nuclear Octave



Eight specialist companies make up the nuclear octave. Each sounds exactly the right note in terms of its own particular skills and experience.
In combination they form N.P.P.C. which thus has all the resources necessary for the construction of complete nuclear power stations throughout the world.
At Bradwell, Essex, N.P.P.C. are building a new nuclear power station for the Central Electricity Authority, with a guaranteed output of 300 megawatts. This great enterprise is a commercial venture aiding Britain's economy and emphasising her world lead in the practical application of atomic power for peace.

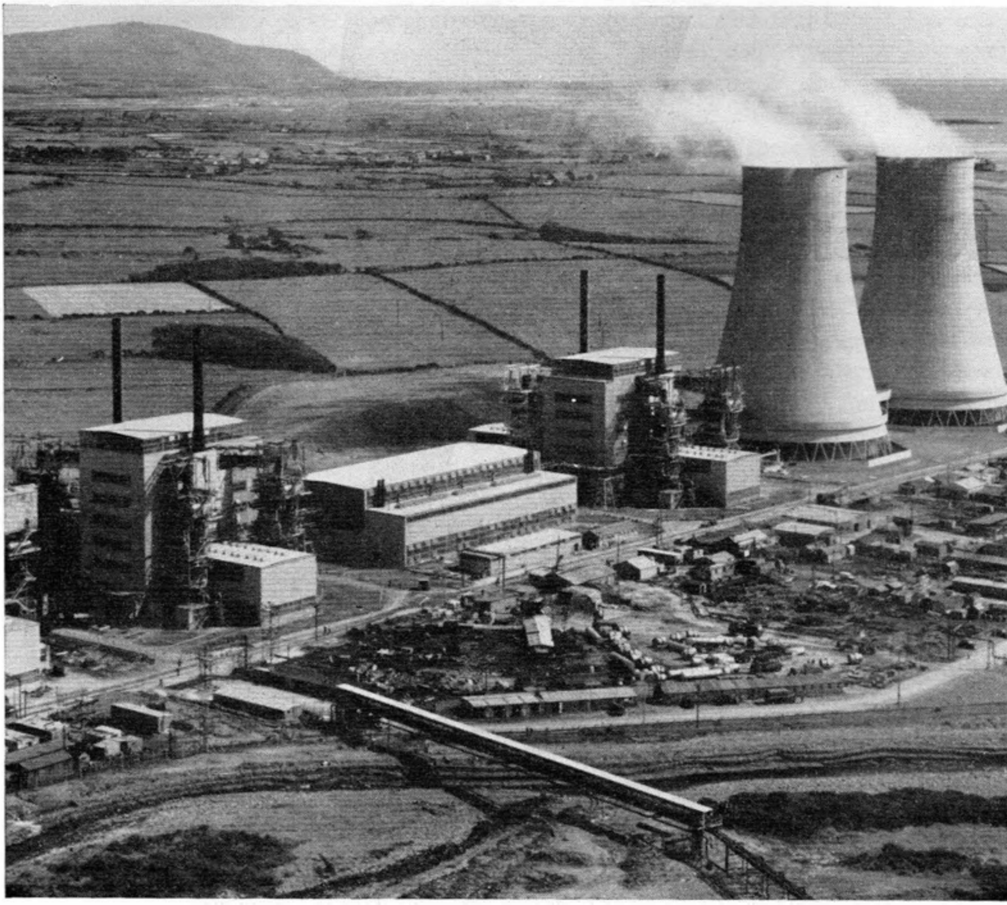
NPPC A Greater Britain through Nuclear Power

THE NUCLEAR POWER PLANT CO LTD

C. A. PARSONS AND COMPANY LIMITED
A. REYROLLE AND COMPANY LIMITED
HEAD WRIGHTSON AND COMPANY LIMITED
SIR ROBERT McALPINE AND SONS LIMITED
WHESSOE LIMITED · STRACHAN AND HENSHAW LIMITED
ALEX FINDLAY AND COMPANY LIMITED
CLARKE CHAPMAN AND COMPANY LIMITED

BOOTHS HALL · KNUTSFORD · CHESHIRE

TGA NP2



CALDER HALL—the world's first full-scale nuclear power station

Unless we can somehow improve the chances of the neutron hitting the rare atoms this ideal chain of events will break down. Just imagine you have a box with one white ball and a hundred and thirty nine coloured balls in it, and you are then asked to shut your eyes and pick out two balls—how often do you think you could pick the white ball unless you had something to help you?

Similarly we must improve the chances of the neutrons striking the rare atoms of uranium 235, and fortunately there is an easy way of doing this. When the neutrons first shoot out from the splitting atom they are travelling at tremendous speeds, and it has been found that if they can be slowed down sufficiently they are then much more likely to split other atoms of uranium 235 and less likely to be absorbed by the more plentiful atoms of uranium 238. How do we slow them down? We do it by making them bounce about amongst atoms of a substance which is unlikely to capture them. We call the substance a *moderator*, because it moderates the speed of the neutrons. There are various possible moderators, but the one we have used in most of our reactors in Britain is carbon in the form of very pure graphite.

THE REACTOR

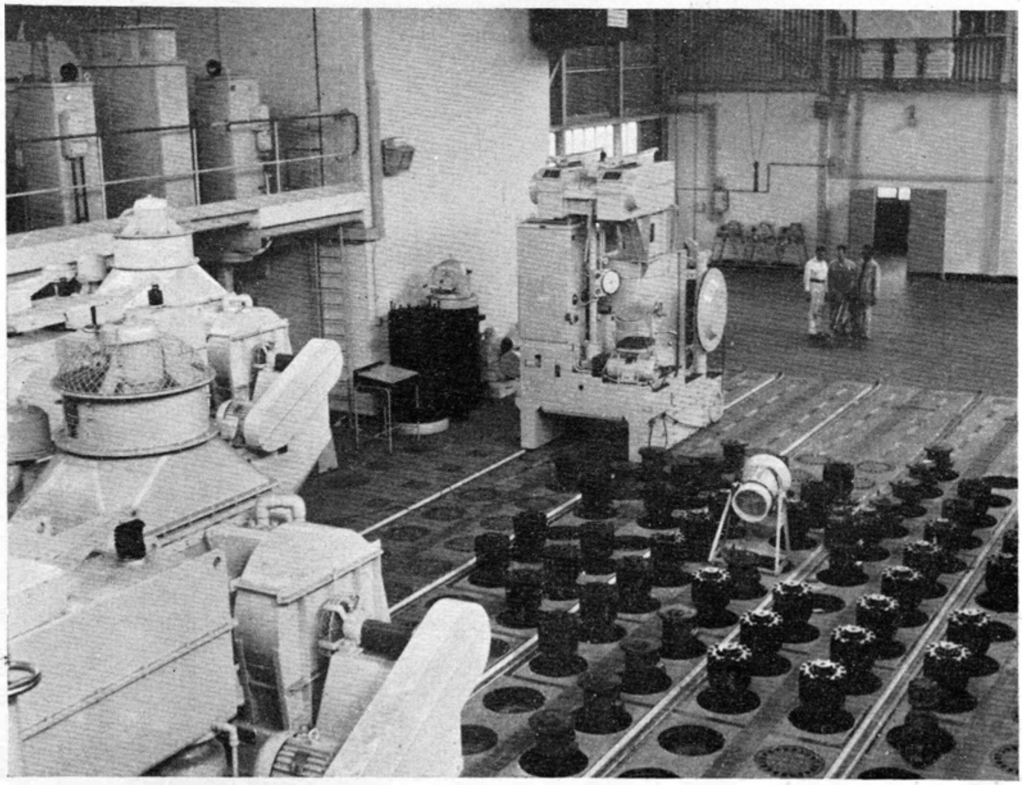
The essential structure of a reactor is a mass of graphite with lumps of uranium spaced regularly in it. In fact the first reactor ever built in 1942 was just that. If the reactor is going to produce heat, we must also provide some means of collecting the heat. We can do this by forcing a gas through the graphite and uranium structure, where it picks up heat from the hot lumps of uranium and we can then use this heated gas to boil water.

Let us now consider what happens to the neutrons. We start with two and a half from each fission, and one of these must cause a further fission if the chain reaction is to continue. Of the rest, some will be captured by atoms of uranium 238, and others by the materials of the reactor. Some will escape altogether. If the graphite and uranium structure, which we call the *core*, is small, so many neutrons will escape that there will not be enough left to keep the chain reaction going. But as the size of the core is increased the proportion which escapes gets less. It is like having a flock of sheep in a pen. If there are only ten sheep in the pen and five of them manage to get out you have lost half your sheep, but if in the pen you have got several hundred sheep then twenty or thirty can escape without making a noticeable difference to the

THE CONTROL ROOM of a Calder Hall reactor size of the flock. In other words as the size of the flock increases the proportion of sheep which escapes gets less. In the same way with our reactor: as the size of the core increases the proportion of neutrons which escapes gets less. When this proportion is low enough to leave just enough neutrons to carry on the chain reaction, we say the core has reached the critical size. Anything smaller, and the reactor will not work at all. Anything bigger will leave us with neutrons to spare.

Imagine you have a pair of scales and on one side you place a pound weight. If you start weighing grains of rice you will find that to start with you can add rice by the handful and there will be no noticeable effect on the scales. But there comes a time when just one more grain is needed to tip the scales. The amount of rice has reached what we call the critical size. If you add still more then obviously you will have enough and some to spare.

A practical reactor must be bigger than the critical size so that there are spare neutrons to enable the fission reaction to build up. But we must not let it build up too far, or the release of heat will be too great—our reactor will get too hot. So we must have some means of controlling the reaction, and we do this by absorbing the spare neutrons when the number of fissions has reached the level we want.



THE WORKING DECK of a Calder Hall reactor showing the top of the charge tubes

The Fairey Aviation Company Limited makes and designs components in heavy-gauge aluminium and steel for industry and the United Kingdom Atomic Energy Authority. It supplied the reactor fuel containers for the Calder Hall Power Station, and has undertåken major contracts for Springfields, Windscale, Capenhurst and Dounreay.

THE FAIREY AVIATION CO. LTD.

HAYES, MIDDX. & STOCKPORT, CHESHIRE

(Member of Atomic Power Constructions Ltd.; one of the five British nuclear energy groups).

Certain substances absorb neutrons very readily, and one of these is a metal called boron which is a glutton for neutrons. Boron can be made into an alloy with steel and if we push rods of boron steel into the core the rods will absorb some of the neutrons and prevent them from splitting uranium 235 atoms. The further we push them in the more neutrons they will absorb, and in this way we can control the level of the reaction, just as we can control the rate at which an ordinary fire burns by pushing a damper into the chimney. If we push the rods in far enough, we can stop the reaction altogether.

It is always wise to have a reliable safety device like a fuse in an electric circuit, to prevent an accident if something goes wrong. In the same way we want to be sure of being able to shut down our reactor in case of need, even if something goes wrong with the control rods. We achieve this by having a similar set of boron steel rods hung above the reactor core, and in an emergency they will fall into the reactor under their own weight and shut it down. One final problem has to be faced. If our reactor is producing heat it will inevitably produce fission products and these are highly radioactive. Something must therefore be done to protect the

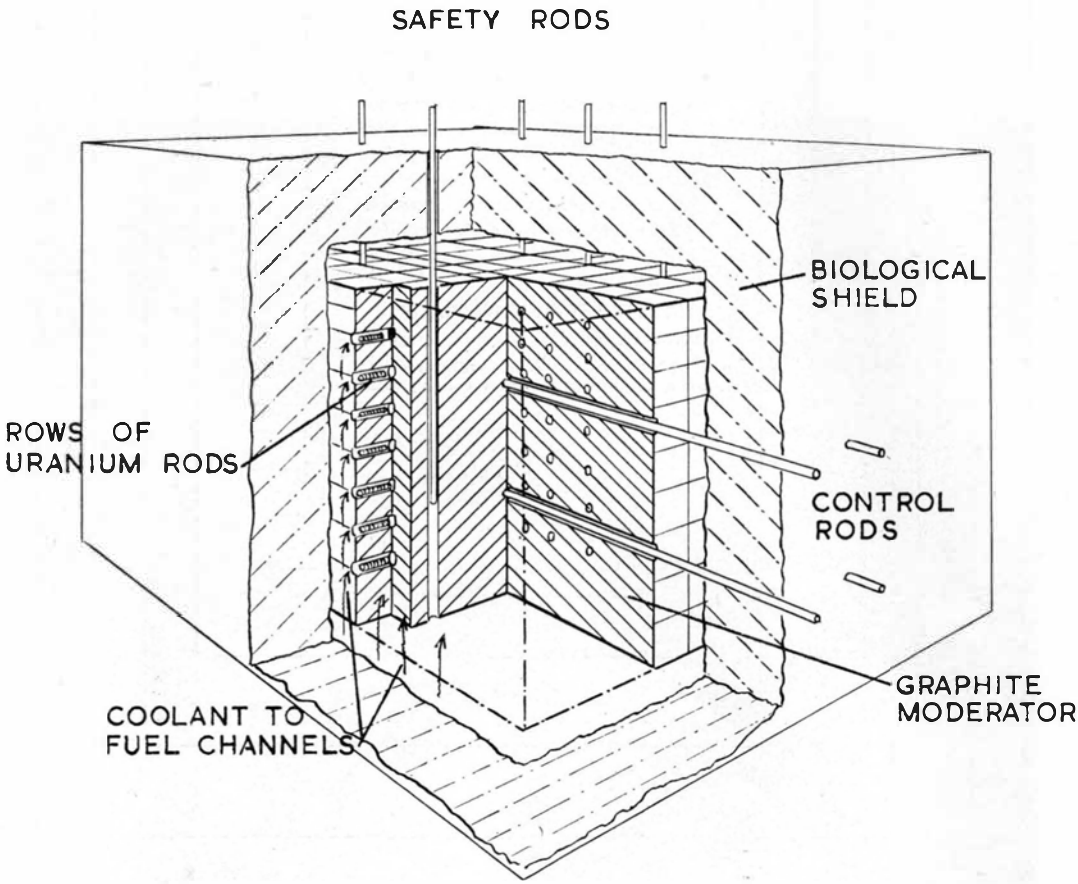


FIGURE 5

men who operate the reactor from too much exposure to this radioactivity. This we do by building a concrete box several feet thick round the reactor. The concrete will absorb sufficient radioactivity to make it biologically safe, and for this reason we call it a biological shield.

Let us now summarize the basic features of a reactor (*figure 5*). On the outside we have the massive concrete box to absorb the radioactivity. Inside this concrete box is our graphite moderator which slows down the neutrons. At regular intervals in the graphite are the lumps of uranium, our nuclear fuel. Now for a variety of reasons you cannot put lumps of uranium into a reactor like you can throw lumps of coal on a fire. You have to make the uranium up into bars and seal the bars in metal containers. This assembly we call the fuel element. As the atoms split in the fuel element the container gets very hot. This is the heat we are after and we collect it by pumping gas past the hot containers and then use the heated gas to boil water. Finally we have our control and safety rods, the control rods to absorb any excess neutrons and so regulate our atomic furnace, and the safety rods to shut it down completely if the need arises.

Now to deal with a point I mentioned earlier. Where do the neutrons come from to start the whole reaction? Well, they could come from anywhere. Wherever you may be at this moment there are a few stray neutrons flying about you. We could rely on such stray neutrons to start off our reactor, but in addition to these we sometimes put inside the reactor what we call a neutron source, which will give us a steady supply.

RADIOACTIVITY

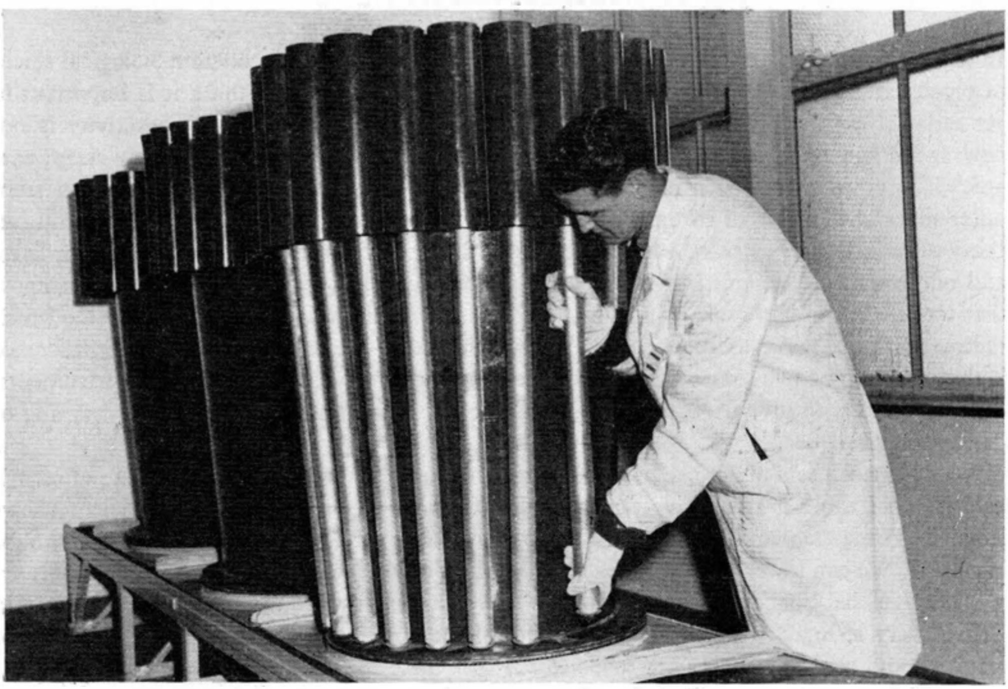
In describing the construction of a reactor I mentioned the need of a concrete biological shield to protect the men operating the reactor from radioactivity. Now I think it is important to get radioactivity and its effects on the human body into perspective. Radioactivity is not new: it did not start with the discovery of uranium nor with the first use of X-rays sixty years ago. There has always been radioactivity everywhere on the earth. Some of it comes from outer space in the form of cosmic rays and some from minerals in the earth's crust. You can think of radioactivity as being something like sunlight, all of us are exposed to it all our lives, and our bodies are designed to accept a certain amount of it without ill effects. You know that too much sun can make you ill and it could even kill you. In the same way too much radioactivity can make us ill, and if we receive sufficient it can also kill us. The difference is that none of our five senses enables us to detect radioactivity, so we have to use instruments, called monitors, to give us warning, just as miners use instruments to give them warning of dangerous gas.

A lot has been said about the possible dangers from the widespread industrial use of atomic energy and I think it most important to realize the true position. We have sufficient knowledge from experience with radiography to know at what level radioactivity begins to be harmful. We can lower this level still more to allow a wide safety margin and then ensure by good design that our atomic power stations will not release more than this safe amount. In Britain very stringent health regulations control the amount of radioactivity which may be released, and constant checks are made to see that these regulations are observed. In fact, I believe that you cannot have a safer job than working on a nuclear reactor.

CALDER HALL

The world's first atomic power station to produce electricity on a commercial scale was built at Calder Hall in the north of England. The design of the reactors is basically the same as I have already described and was developed from earlier reactors of the same type which had been built at Harwell and Windscale. The Harwell reactors GLEEP and BEPO were experimental models; the first large reactors were at Windscale. These were designed to produce plutonium for defence purposes, but of course they produce heat as well, because as we have seen every reactor of this type inevitably produces both heat and plutonium. When we built them around 1949 we did not know enough to run the reactors at a high enough temperature to be able to harness the heat economically, so that what heat was produced just went up the chimney. We realized that this was very wasteful, but a lot of research was needed to enable us to raise the temperature high enough so that we could use the hot gas coming from the reactor to produce steam.

By 1953, when it was decided to build more reactors, this time at Calder Hall, the problems had to some extent been solved and besides using the reactors to make plutonium we were able to use the heat from them to boil water. The steam thus produced drives turbines and the turbines drive alternators, which generate electricity (*figure 6*). Let me remind you of



URANIUM FUEL ELEMENTS being prepared for loading into a reactor at Calder Hall

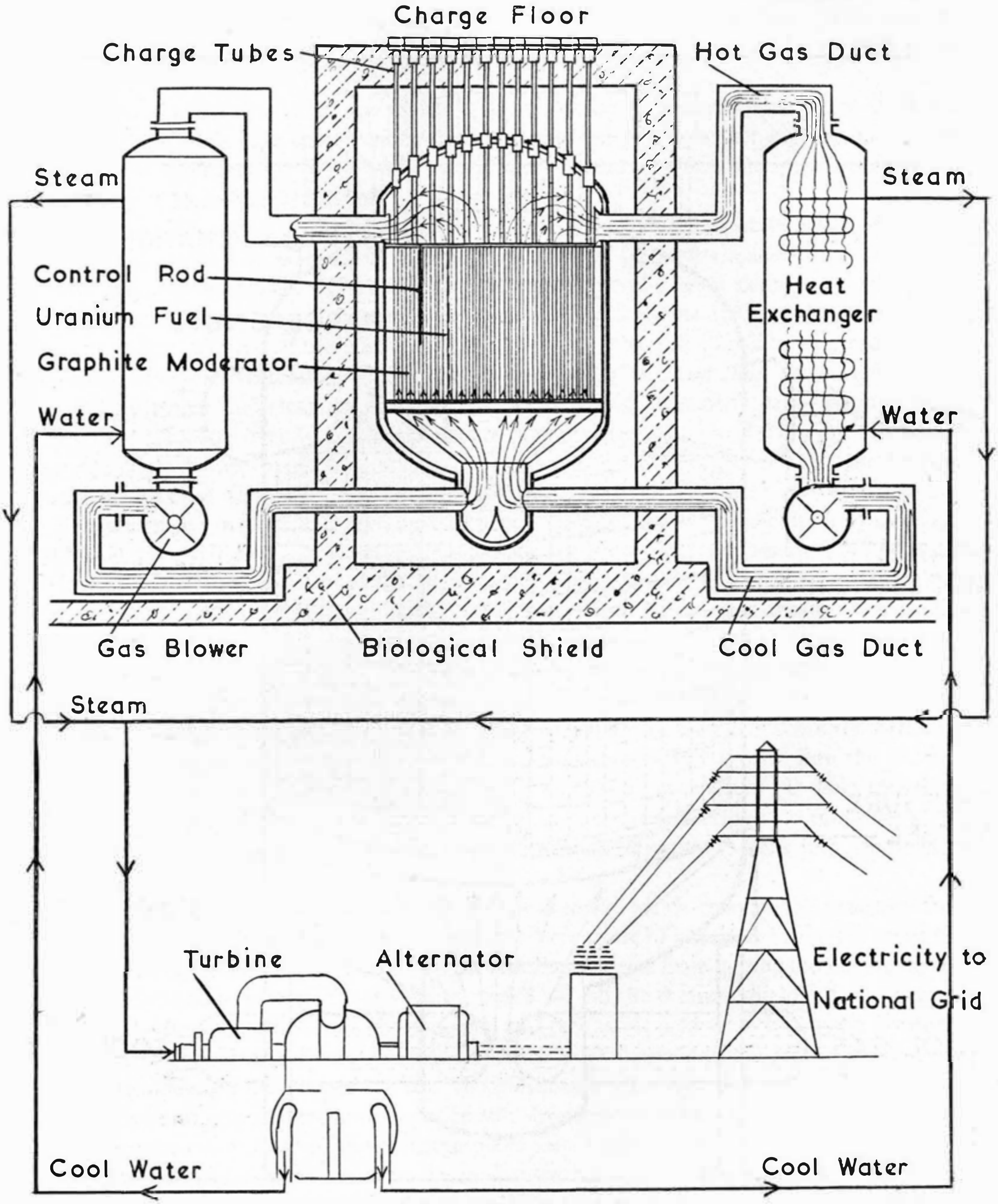

Charge Floor
Charge Tubes
Hot Gas Duct
Steam
Steam
Control Rod
Uranium Fuel
Graphite Moderator
Heat Exchanger
Water
Water
Gas Blower
Biological Shield
Cool Gas Duct
Steam
Turbine
Alternator
Electricity to National Grid
Cool Water
Cool Water

FIGURE 6

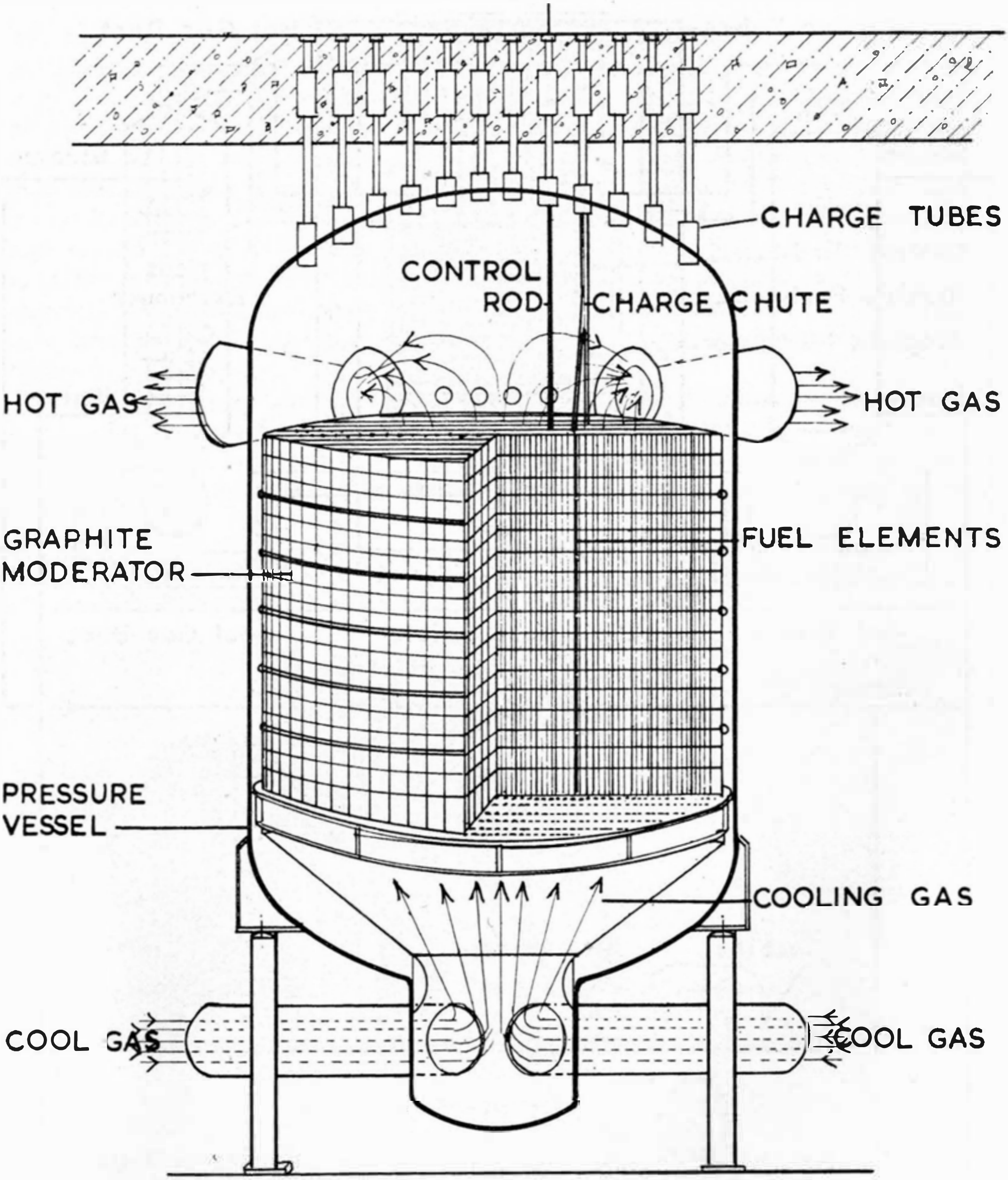

CHARGE TUBES
CONTROL ROD
CHARGE CHUTE
HOT GAS
HOT GAS
GRAPHITE MODERATOR
FUEL ELEMENTS
PRESSURE VESSEL
COOLING GAS
COOL GAS
COOL GAS

FIGURE 7

what I said right at the beginning—the only difference between a nuclear power station and a conventional power station burning coal or oil lies in the source of the heat. The rest—the boilers, the turbines, and the alternators—are all the same, and the electricity which comes out at the end is the same.

As Calder Hall is the prototype of the civil atomic power stations now being built it is worth while to study it in some detail. This will show us how practical engineering requirements led to modifications of the basic design and will also give us some idea of the size and complexity of an industrial reactor.

At Calder Hall (*figure 7*) the moderator is made up from 58,000 separate pieces of graphite into a structure 36 feet across and 27 feet high. Every piece was made to an accuracy of two thousandths of an inch. The channels in which the uranium fuel elements are placed run from top to bottom instead of from side to side and there are some 1,700 of them. Each fuel element consists of a rod of uranium about an inch in diameter and 40 inches long and is sealed in a metal container with spiral fins to help in transferring the heat from the uranium to the gas. Six of these fuel elements are stacked one on top of another in each channel, which means that there are over 10,000 fuel elements in each reactor. To load them into the reactor a charge chute is inserted in the appropriate tube passing through the roof and the fuel elements are lowered down it. They are later extracted in the same way.

The gas we use to carry away the heat is carbon dioxide, and to remove the heat more efficiently we keep the gas circulating under a pressure of 100 pounds per square inch. Because of this pressure we have to surround the graphite core with a steel vessel two inches thick. This pressure vessel has four large pipes leading away from the top and another four leading back into the bottom.

Gas flows up through each of the channels round the fuel elements, collecting the heat as it passes, then flows out through the top pipes to the heat exchangers or boilers. Here the gas loses its heat to water and converts it to steam. By the time the gas reaches the bottom of the heat exchangers it is comparatively cool and it is then pumped back into the pressure vessel through the pipes at the bottom to begin its journey all over again. It flows round and round in this way, collecting heat from the fuel elements and delivering it to the water in the heat exchangers. The speed of flow is so fast that a ton of gas flows back into the pressure vessel every second.

Surrounding the pressure vessel is the biological shield which reduces the radiation from the reactor to a safe level. The walls of the shield are made of reinforced concrete seven feet thick with an eight-foot concrete roof. To prevent the concrete from getting too hot we line the entire inside surface with thick steel plates, which we call the thermal shield. A six-inch gap separates the thermal shield from the concrete, and through it cold air is constantly flowing.

The top of the eight-foot concrete roof forms the working deck of the reactor. From here the fuel elements are loaded into the core thirty feet below through tubes which pass through the concrete and into the pressure vessel itself. In order to reduce the number of openings in the pressure vessel, each of these charge tubes serves sixteen fuel channels.

The position of the control rods in the moderator has been altered from our basic design. Instead of being pushed in and out from the sides, they operate in special vertical channels. These channels are directly beneath the charge tubes which pass through the roof, and this enables us to put a winding mechanism on the top of the tube and hang the control rod from it on a steel cable. The winding mechanism raises or lowers the control rods in the reactor

Too hot to handle

When you are handling highly radio-active material, you have to keep your distance. Here you see how they do it at Harwell.

Materials are examined in hot cells by remote control using pairs of master slave manipulators. These ingenious " hands " are almost human in their movements and sensitivity. Their delicate mechanism, however, needs a special lubricant that will withstand the intense radiation under which it has to work.

Shell had long foreseen the need, for ordinary oils and greases completely break down under radiation. They were the first to study the problem, and in 1957, after 4 years of concentrated research, they introduced the first-ever range of Atomic Power Lubricants, Shell APL Oils and Greases. These are used both at Calder Hall and Harwell, and have already been specified for the new nuclear power station at Bradwell. *They are the only range of fully-proved, radiation-resistant lubricants in the world.*

The moral is that Shell research is supremely applicational. The Shell Research Centre at Thornton is always ready to work with even the most specialised sectors of industry to produce the right oil for the job. If you and your organisation have any major lubrication problem, it pays to get in touch with your local distributor of Shell Industrial Lubricants.

SHELL

LEADERSHIP IN LUBRICATION

core and so enables us to regulate the power level. In an emergency, the control rods fall into the core under their own weight and we do not therefore need a separate set of safety rods.

In addition to all this, the Calder Hall reactors are fitted with elaborate equipment for detecting the occasional fault which may develop in a fuel element and locating the channel containing it. There are also numerous instruments for measuring such things as temperatures, gas pressures, and the number of neutrons at various points. All this information is automatically fed to the reactor control room, where it is displayed on an array of dials and charts. From here one man controls the entire operation of the reactor.

THE BRITISH NUCLEAR POWER PROGRAMME

By 1966 Britain plans to be generating a quarter of its electricity from a chain of nuclear power stations thereby saving the equivalent of nearly twenty million tons of coal a year. These stations will be built by British industrial firms and operated like the conventional stations by various Electricity Authorities. The construction of the first four stations started in 1957 and should be completed by 1961.

These commercial atomic power stations are based on the Calder Hall design, but already many engineering improvements have been made. For example, the temperature of the fuel elements will be higher and the pressure of the heat collecting gas greater. The output from a reactor has been increased so much that a single commercial reactor will produce more electricity than all four of the reactors at Calder Hall put together.

The first commercial atomic power station will produce electricity cheaper than many of the existing conventional ones, and the further advances that can be made with this type of reactor will quickly make them more economical than the best conventional stations. In fact, based on foreseeable developments I estimate that reactors built twenty-five years from now will generate electricity at half the cost of coal-fired stations.

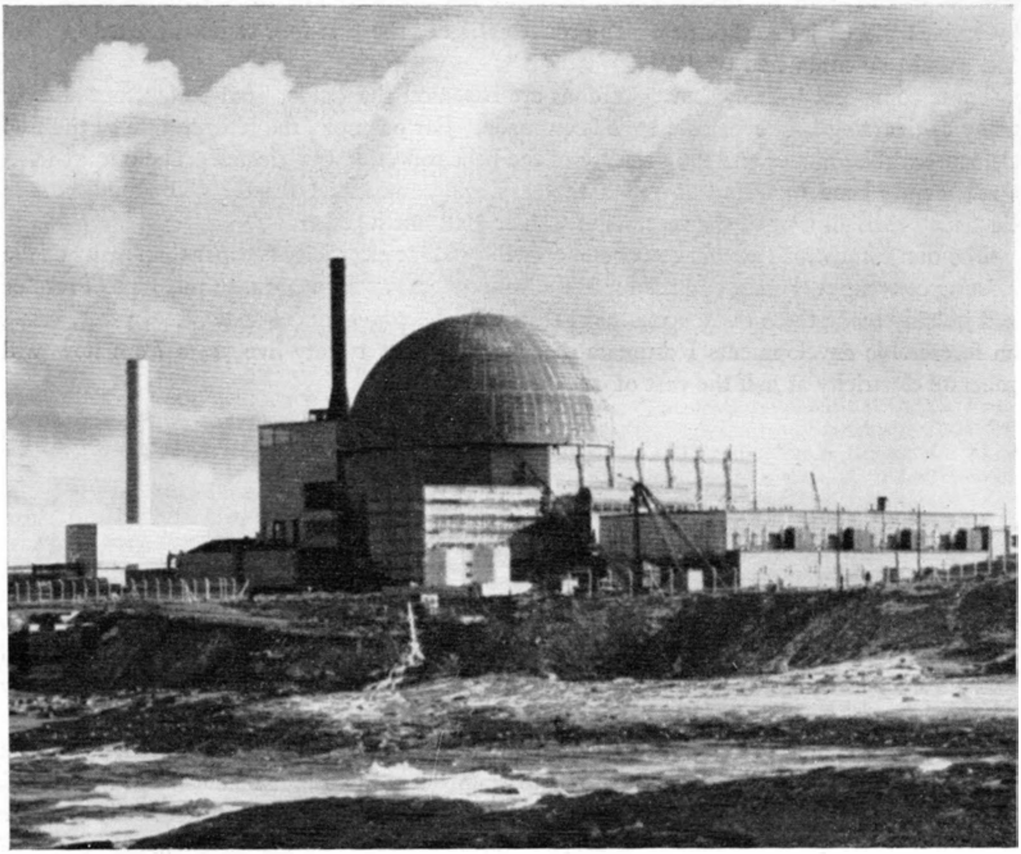
THE DOUNREAY REACTOR

All these atomic power station reactors are producing not only heat but plutonium as well. This inevitable by-product is an artificial nuclear fuel of great value. Every industry tries to find a use for its by-products, so as to reduce the cost of its main product and in the same way we want to find the best means of using this plutonium which is formed in our reactors.

One way, of course, is to mix it with uranium which has lost some of its uranium 235 atoms —the fuel atoms which can be split—so as to restore it to its original standard as a fuel. If, however, you have a highly concentrated fuel, it is generally a bad thing economically to dilute it down: it is far more economical to design a machine which can take advantage of its special properties, and this is what we have done.

At Dounreay in the north of Scotland, we have built a reactor which is designed to work with a very rich fuel like plutonium. The Calder Hall reactors, remember, use uranium as it is extracted from its ore—what we call natural uranium—and less than one per cent of this can act as fuel. Because these fuel atoms—uranium 235—are so few we have to provide a large mass of graphite to slow down the neutrons so as to ensure that a sufficient number of the neutrons do manage to split the rare fuel atoms, and do not get captured instead by the atoms of uranium 238. If all or most of the atoms present are fuel atoms, we do not have to worry about the neutrons being captured, and so we need not provide any moderator to slow them down. This means we can get rid of over a thousand tons of graphite, and put our fuel close together. This makes the core of our reactor very much smaller. Instead of being something like the size of a house, it is now the size of a dustbin.

You will remember that the two and a half neutrons produced on the average each time an atom is split can go one of three ways. One from each fission must cause another atom to split to keep the chain reaction going; some are wasted because they are caught by materials in the reactor and get lost, and the rest are used to convert atoms of uranium 238 to plutonium.



DOUNREAY—showing the sphere housing the fast radar reactor

A MATTER OF NECESSITY

The ever-increasing peaceful exploitation of man's prime source of power, nuclear energy, is no longer the prerogative of any one nation—rather are these achievements the outcome of combined research and development from the most prominent countries of the civilized world. ZETA, with its background of Anglo-American technical liaison, is an outstanding example.

Such progress demands the attention of scientists, research technicians and progressive businessmen throughout International industry, and already such men in 93 countries keep in touch with the latest nuclear advances by reading Britain's foremost journal in its field, *Nuclear Engineering*. Articles by leading authorities cover all phases of world industrial production and utilization of nuclear energy and its by-products in informative illustrated articles, and with frequent pull-out cut-away drawings. Summaries of the most important features are translated into French, German and Spanish.

SUBSCRIPTION RATES

42*s.* ($7.00) *for one year* (12 *issues*). *Single copies* 3*s.* 6*d.*

Send your order for

NUCLEAR ENGINEERING

with remittance to the address below or hand it to your usual supplier

The Subscription Manager

TEMPLE PRESS LIMITED · BOWLING GREEN LANE · LONDON E C 1 · ENGLAND

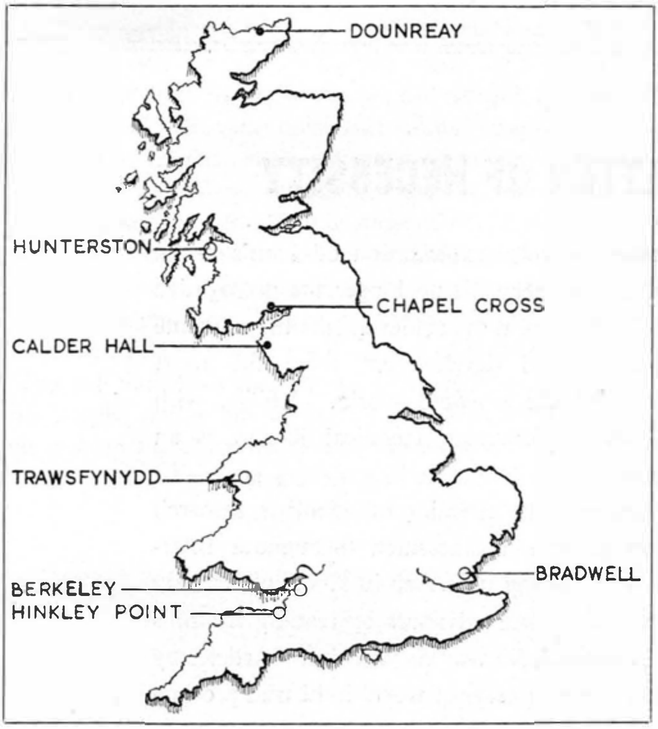


FIGURE 8

Map showing the sites of the Nuclear Reactors for the production of electricity in Britain.

Those marked • are Atomic Energy Authority stations; those marked o belong to Electricity Authorities.

By 1966 Britain plans to generate a quarter of its electricity from nuclear energy.

In this plutonium fuelled reactor, there is much less material in which our neutrons can get lost, so there are more neutrons available to convert atoms of uranium 238 to plutonium. There is, of course, no uranium 238 in the core, so we surround the core with rods of this uranium and these capture the spare neutrons. Of the neutrons produced from each fission one keeps the chain reaction going by splitting another plutonium atom, on average about a quarter of a neutron is lost, leaving one and a quarter neutrons to escape from the core and convert uranium 238 to plutonium. So each time we split a plutonium atom in the core we get one and a quarter new plutonium atoms produced, that is for every four atoms we burn, we get five new ones. In fact, we make new plutonium faster than we burn it. We call this breeding. Also because we do not slow the neutrons down, but use them when they are still travelling fast, it becomes a fast fission reactor. This combined with its ability to breed more new fuel than it burns makes it a *fast fission breeder reactor*.

Now how do we ensure that the spare neutrons do not go on hitting more atoms of plutonium instead of leaving the core and converting the uranium round the outside into fresh fuel? The answer lies in the precise arrangement of the plutonium in the core arrived at by a combination of intricate mathematical calculations and skilful design.

So in this reactor (*figure 9*) we have a core consisting of plutonium fuel elements surrounded by rods of uranium 238. Because the fuel is richer and closer together, the heat produced is much more concentrated than it is in the Calder Hall type of reactor. In fact, it is so concentrated that no gas could remove the heat fast enough, and we have to use a liquid metal. This liquid metal is a mixture of sodium and potassium which looks rather like the mercury

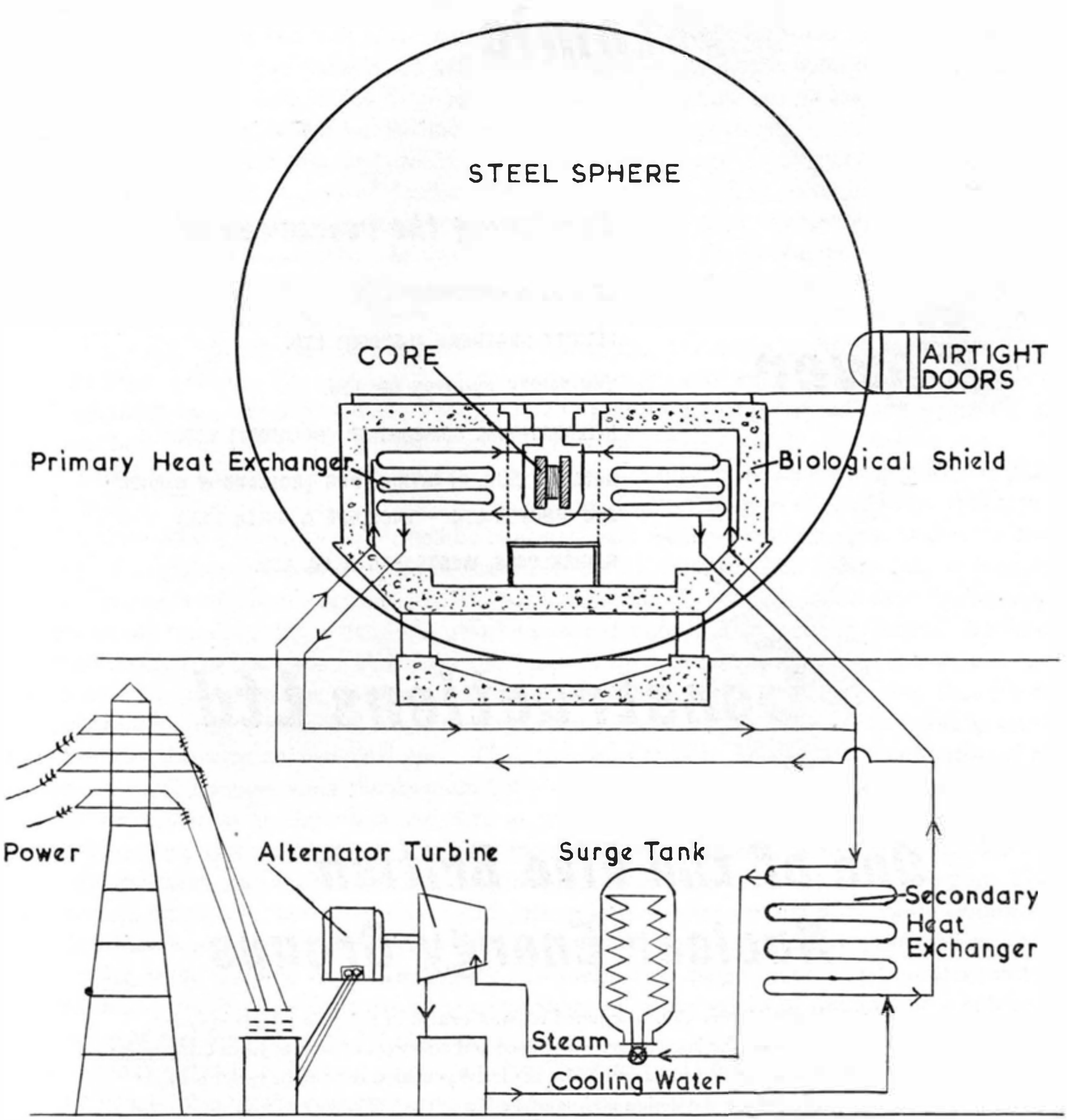

STEEL SPHERE
CORE
AIRTIGHT
DOORS
Primary Heat Exchanger
Biological Shield
Power
Alternator Turbine
Surge Tank
Secondary
Heat
Exchanger
Steam
Cooling Water

FIGURE 9

Atomic Power Constructions Ltd

Combining the resources of

CROMPTON PARKINSON LTD.

ELLIOTT BROTHERS (LONDON) LTD.

THE FAIREY AVIATION CO. LTD.

INTERNATIONAL COMBUSTION (HOLDINGS) LTD.

NUCLEAR CIVIL CONSTRUCTORS (HOLLAND & HANNEN AND CUBITTS LTD · TROLLOPE & COLLS LTD.)

RICHARDSONS, WESTGARTH & CO. LTD.

One of the Five British Nuclear Energy Groups

Atomic Power Constructions Ltd. was formed in December 1956 in order that the knowledge, experience and resources of several great companies, each outstanding in its own field, could be pooled and brought under a single control for the design and construction of nuclear power plants.

Atomic Power Constructions Ltd. is so constituted that it has full technical and executive control of all aspects of nuclear power station development, design and construction. It will accordingly accept overall contractual responsibility for any work undertaken.

ATOMIC POWER CONSTRUCTIONS LTD., 28 THEOBALDS ROAD, LONDON, W.C.1

in a doctor's thermometer. The mixture is pumped through the core of the reactor where it collects heat from the fuel. This heat we use to boil water and produce steam for our turbines just as in the other atomic power stations. Unfortunately, while the liquid metal is collecting the heat it becomes radioactive as well, so we cannot allow it to come outside the biological shield. Also, for various technical reasons, we do not want to take the water inside the biological shield. So in order to transfer the heat from the liquid metal to the water we have to provide a link between the two in the form of a completely separate circuit or loop of this sodium-potassium mixture, which we call the secondary liquid metal circuit.

Round the reactor core, and inside the biological shield, are the primary heat exchangers. They are made up of coils of double tubes, one inside the other. The liquid metal which has been heated in the core flows through the inner tube, while the secondary liquid metal flows through the outer tube. In this way the heat but not the radioactivity is transferred to the secondary liquid metal which we can then bring out through the shield to the secondary heat exchangers or boilers. There it passes its heat to water and produces steam.

The only other feature of the Dounreay reactor that I want to mention is probably the best known of all. Surrounding the reactor, the primary heat exchangers and the shield is a huge metal ball, 135 feet across. That is there to prevent the escape of radioactive material in case there should be a fire, because sodium is very inflammable and burns very fiercely.

I told you that the object of building this fast fission breeder reactor was to burn the plutonium which is inevitably produced in the industrial power stations of the Calder Hall type. But from what I have just said it will be clear that once we have given this fast reactor its first supply of plutonium fuel it produces more fuel than it burns. That means that as long as we keep up a supply of uranium 238, which you remember is not fuel, it will keep itself going. So we can see a possible pattern of industrial power stations in Britain for the future. Stations with reactors of the Calder Hall type will produce by-product plutonium which we can use to start up an increasing number of fast reactor stations, which will then keep themselves going indefinitely. But there is another important advantage to be gained from building these reactors—this time an economic one. They enable us to burn up all our uranium, instead of only a small fraction, since the uranium 238—the atoms which will not split—can all eventually be converted to plutonium and used as fuel.

Indeed we can go further. There is another natural element—thorium—which can be converted into nuclear fuel. Its atoms will not split at all, but like atoms of uranium 238, thorium atoms can capture neutrons and change into another isotope of uranium—uranium 233 which is also an artificial nuclear fuel. So we could surround the core with thorium rods in place of the uranium 238 and still breed new fuel. This means that the fast breeder reactor will enable us to add all the earth's store of thorium to the stocks of uranium as a potential source of fuel for atomic power stations.

In saying this I am looking quite a way into the future. It may well be ten years before the fast breeder reactor is developed as a commercial proposition. There are many difficult problems yet to be solved, though the reactor at Dounreay in the north of Scotland—which is really a big experiment—should give us a lot of the answers.

During this period of development, improvements to the Calder Hall type of reactor, which are continually being made, will provide a reliable and efficient source of heat for nuclear power stations, and of course that kind of reactor has the great merit that it runs on natural uranium.

FUSION

The two types of reactor I have described so far are typical of the large range of possible systems, all of which work on the fission principle—the production of heat by splitting atoms. We can, however, as I outlined on page 10, also release heat by the opposite process—building atoms up instead of splitting them down—what we call the fusion process. The simplest of these fusion processes is the joining together of two nuclei of heavy hydrogen to form a nucleus of helium and a spare escaping neutron.

An atom of heavy hydrogen contains one proton and one neutron and when two of these atoms collide at very high speed their nuclei fuse together for a moment and form one atom

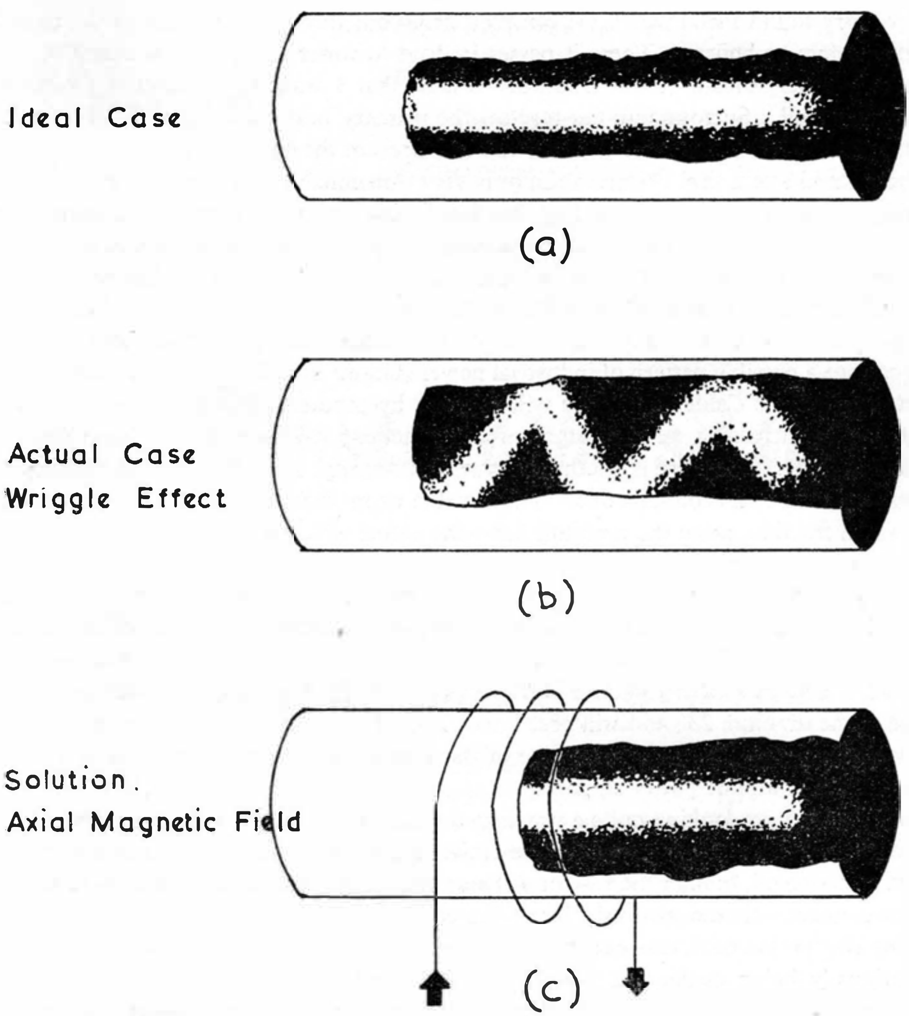


FIGURE 10

of helium. This atom of helium contains the two protons from the heavy hydrogen atoms but only one of the neutrons. The other escapes.

The difficulty with this process is that the atoms have to be travelling at enormous speeds before their nuclei will fuse together. One way of speeding them up is to raise their temperature, but to get them going fast enough to fuse needs a temperature of several million degrees—far hotter than the surface of the sun. Clearly, we cannot reach this sort of temperature, or anything approaching it, by heating the atoms over a fire or in a furnace since all known materials would melt and vapourize at temperatures far lower than this, and so we have to find some other way.

The most promising way, it seems, is to pass a powerful electric current through heavy hydrogen gas in a tube. By this means the gas can be made extremely hot but there is the further task of maintaining this temperature long enough for fusion reactions to take place. Some very successful work has already been done along these lines in both the United States and Britain, and in January 1958, Harwell announced for the first time that they were able to heat up heavy hydrogen gas to a temperature of five million degrees and hold it for a few thousandths of a second.

How was this done? British scientists and engineers at Harwell built a large apparatus called Zeta. It looks like a big transformer the size of a double decker bus. The vital part of Zeta is a large container shaped like the inner tube of a motor car tyre; this tube is about ten feet across and has thick aluminium walls. Heavy hydrogen gas is put into this tube and a jolt of electricity is passed through it from a transformer. The object of this electric current is to heat the gas to a temperature at which the atoms of heavy hydrogen will fuse together.

Fortunately as soon as the electric current begins to flow the gas is automatically squeezed into a narrow column in the middle of the tube away from the walls (*figure 10a*). This happens because all electric currents have magnetic forces acting round them, and in a gas these magnetic forces pinch the gas towards the centre of the tube.

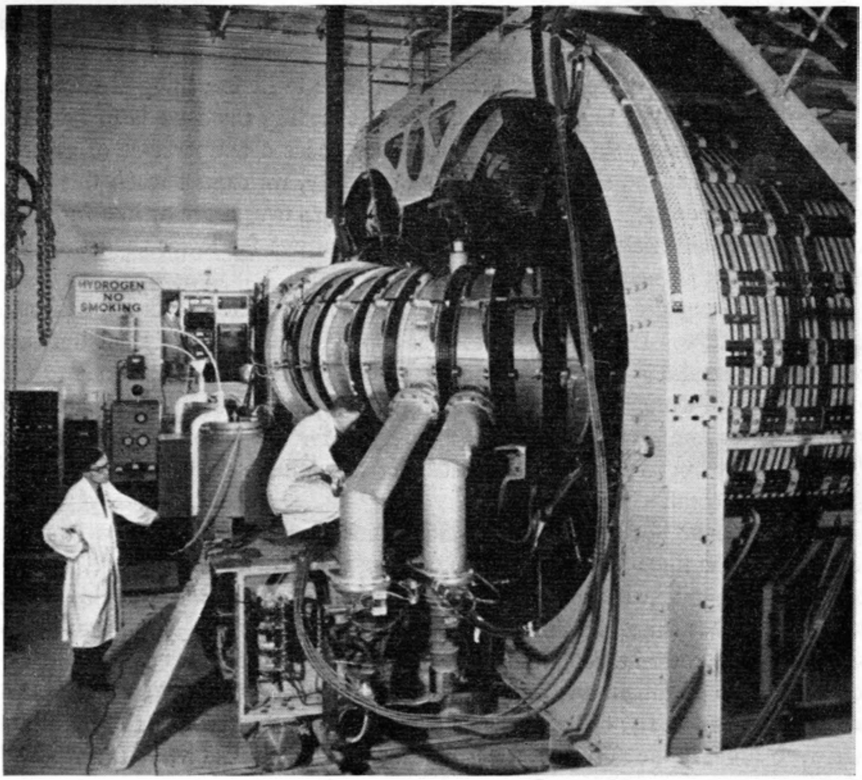
Up to this point nature works in favour of the scientist. But as soon as the gas is squeezed like this, we face a major problem. The gas carrying the electric current immediately begins to wriggle and jump about inside the tube (*figure 10b*). Unless we can do something about this wriggle it will touch the walls and lose its heat and perhaps melt the wall. It is essential to keep the gas in the centre of the tube for as long as the electric current lasts.

In Zeta the gas is kept centrally in the tube and well away from the walls by imposing additional magnetic forces along the path of the current (*figure 10c*). These magnetic forces are generated by winding coils of wire round the outside of the aluminium tube and then passing electricity through the coils. When this is done the wriggle disappears.

The main achievement with Zeta has been to hold the gas in the centre of the tube long enough, and at temperatures high enough, to observe fusion taking place. Now how can we observe fusion?

Well, remember the fusion of two heavy hydrogen atoms gives an atom of helium containing three atomic particles in its nucleus, and in addition a spare neutron. These spare neutrons escape from the tube altogether and it is by detecting them that we know that fusion must be taking place in Zeta.

The next step facing research scientists is to raise the temperature of the gas even higher by putting still more electrical energy into Zeta and its successors. At higher temperatures held for longer times the amount of energy produced from fusion of the gas will increase until



ZETA—Zero Energy Thermo-Nuclear Assembly at Harwell

it exceeds the amount of energy needed to create the tremendous heat. We shall then start showing a profit, and ultimately be able to convert this energy gain into electrical power. But scientists estimate that in order to show the profit we are after we shall need to heat the gas to temperatures exceeding a hundred million degrees.

So the main problems facing scientists are heating the gas to a temperature above a hundred million degrees, holding it at that temperature for much longer times and finding ways of converting the energy gain into electricity. No one can say just how long it is going to take them to crack these enormous nuts—it may well be many years. And even when these major problems have been solved, many engineering difficulties will have to be overcome before we see the fusion equivalent of Calder Hall. (*Figure 11*).

What then is the advantage of the fusion reaction which justifies all this elaborate research? The answer lies in the fuel it burns. We get it from ordinary water. Water is made up of oxygen and hydrogen and I said earlier that most hydrogen atoms have one proton but no neutron, but that one atom in every six thousand is different. It has both a proton and a neutron and is called an atom of heavy hydrogen or deuterium. This in fact is our fuel. It is obtained by a separation process costing only a few shillings a gramme to produce. The energy stored in this thimbleful of deuterium is equivalent to the energy stored in several tons of coal. So the fuel is not only cheap—its supply is inexhaustible.

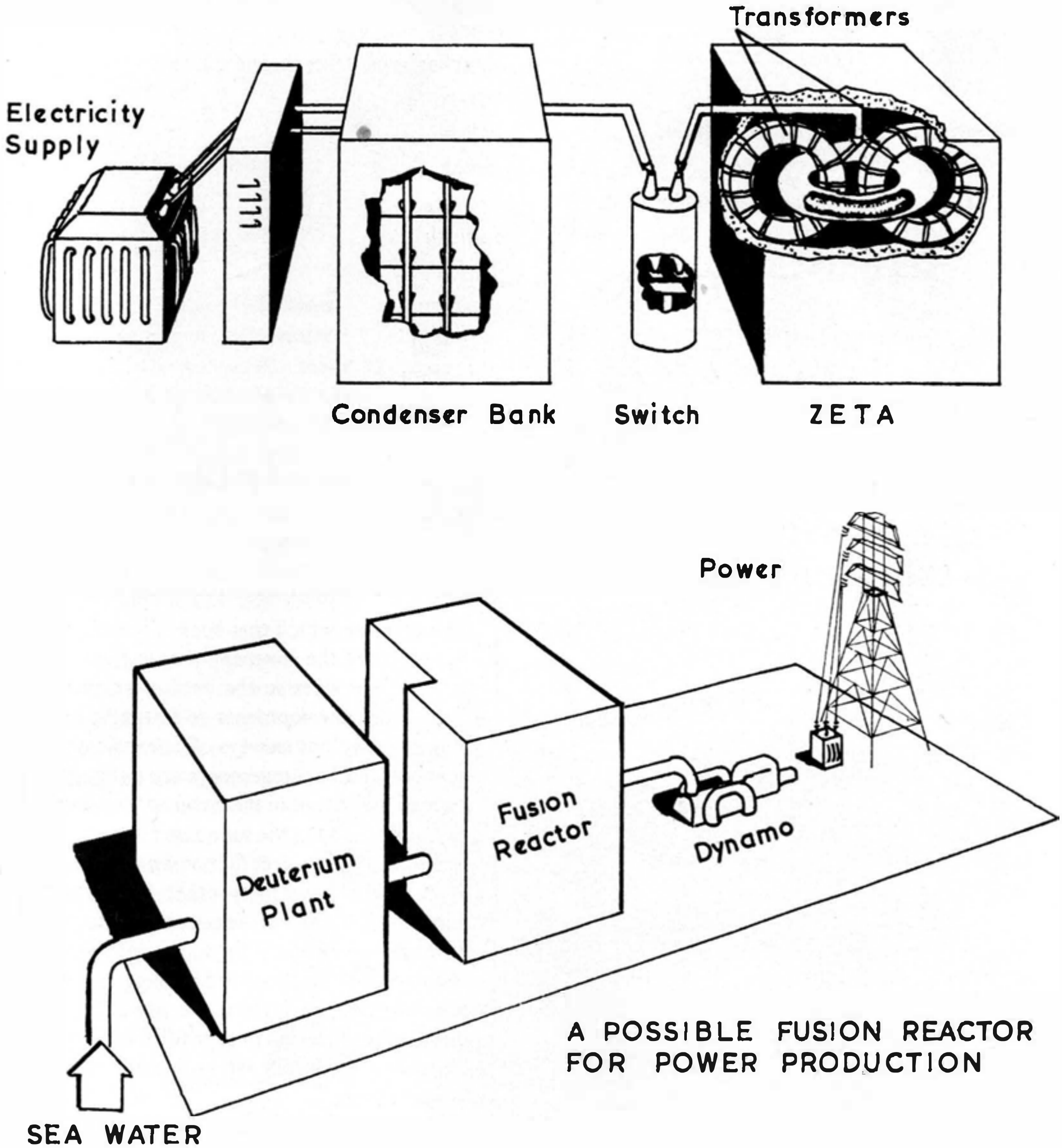

Transformers
Electricity Supply
Condenser Bank
Switch
ZETA
Power
Fusion Reactor
Dynamo
Deuterium Plant
A POSSIBLE FUSION REACTOR FOR POWER PRODUCTION
SEA WATER

FIGURE 11

THE BBC OVERSEAS SERVICES

broadcast 348¼ programme hours per week

General Overseas Service	149
Pacific—Australia, New Zealand, and South Pacific	5¼
South African—South Africa, Rhodesia, and Nyasaland (English)	¾
North American (including French for Canada)	29¾
African, Caribbean, and Colonial Services—	
West Africa and West Indies (English)	8¼
East Africa (English)	¾
Falkland Islands (English)	½
Maltese	1
Hausa for West Africa	½
Somali for East Africa	½
Swahili for East Africa	½
'London Calling Asia' in English	5¼
Eastern—Hindi	4¼
Tamil	½
Marathi	½
Bengali	1
Sinhalese	½
Urdu	4¾
Arabic	66½
Hebrew	3½
Persian	7
Far Eastern—English	3½
Cantonese	1¾
Kuoyu	3½
Burmese	1¾
Malay	1¾
Thai	3½
Japanese	5¼
Indonesian	3½
Vietnamese	3½
Latin American—Spanish	21
Portuguese	8¾

THE BBC EUROPEAN SERVICES

broadcast 213½ programme hours per week

English and 'English by Radio'	36½
French	12¼
Czechoslovak (Czech and Slovak)	12¼
Hungarian	14
Polish	15¾
Greek	7
Italian	10½
Spanish	8
Turkish	7
German	28¾
Albanian	3½
Bulgarian	10½
Rumanian	12¼
Russian	15¾
Yugoslav (Serbo-Croat and Slovene)	11¾
Finnish	7¾

The talks on which this book is based are examples of the coverage that is given in all BBC services in the field of science. The latest developments in scientific research as well as surveys of scientific and technological achievements are a regular part of the output in the External Services of the BBC and in the sound and television broadcasting services for home audiences.

In English and forty other languages the BBC's External Services are heard throughout the world for some eighty-one hours a day. Thirty-nine BBC high-power shortwave transmitters are used, while radio organizations in over fifty countries regularly rebroadcast selected BBC programmes.

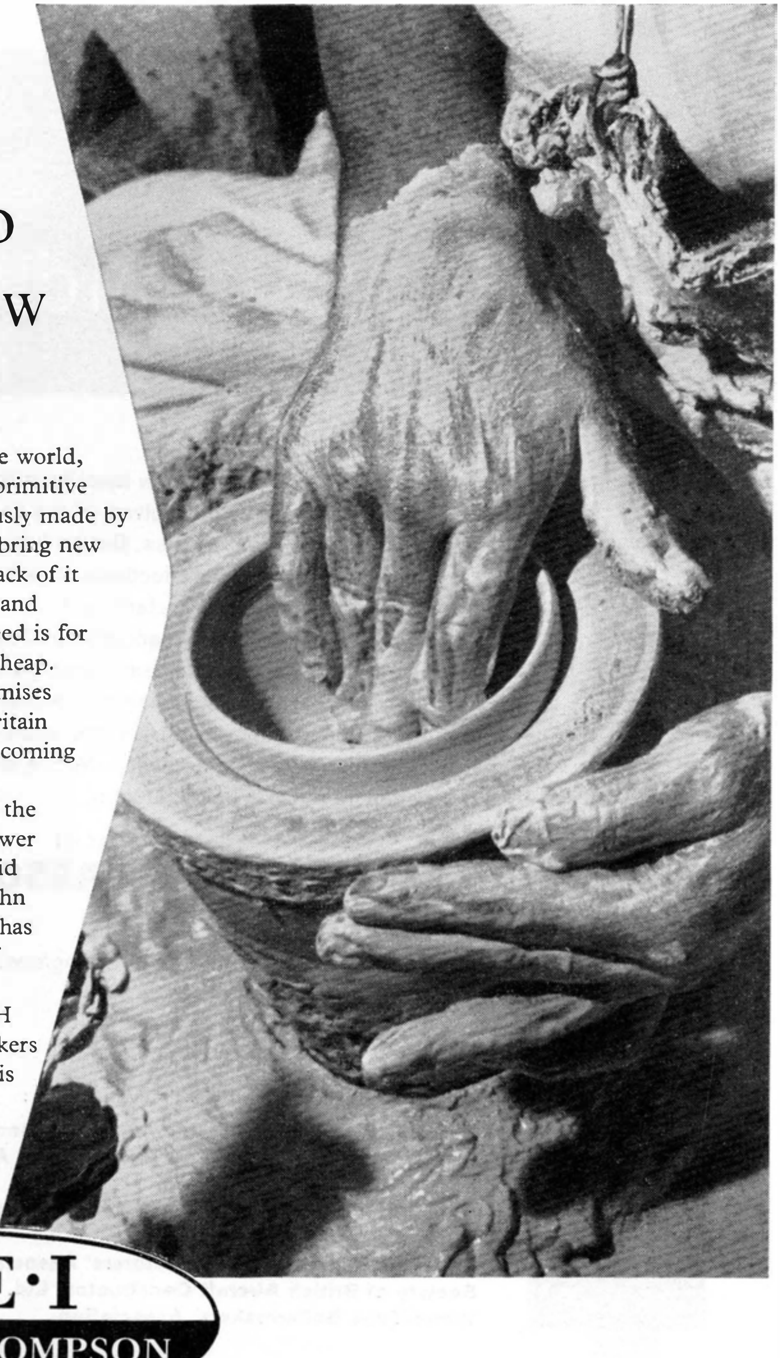
Some one thousand news bulletins a week are broadcast in thirty-five languages and these bulletins are governed by the same aims of objectivity and impartiality as all other BBC news output.

Power to foster new industry

In many corners of the world, the bare essentials of primitive living are still laboriously made by hand. Industry could bring new hope to such places; lack of it brings only bitterness and distrust. Their first need is for power, plentiful and cheap.

Nuclear energy promises such power, and in Britain that promise is fast becoming a fact.

At Berkeley, one of the first of our nuclear power stations is making rapid progress. The AEI-John Thompson Company has harnessed the skills of such mighty firms as John Thompson, BTH and Metropolitan-Vickers to the task. Today, this consortium of talents is at the service of the world.



A·E·I

JOHN THOMPSON

Britain leads in this Atomic Age

Over 1,000 British firms are now manufacturing nuclear equipment, or are directly involved in the development of nuclear engineering techniques. British Industry can, therefore, claim to be effectively organised to give complete service in this important field.

The Nuclear Energy Trade Associations' Conference (N.E.T.A.C.) welcomes the opportunity to assist enquirers and intending purchasers with advice and information about appropriate British manufacturers and sources of supply of any nuclear equipment — from a single instrument to a complete nuclear power station.

Enquiries should be addressed to:

THE NUCLEAR ENERGY TRADE ASSOCIATIONS' CONFERENCE

32, Victoria Street, London, S.W.1., England.
(Telephone: Abbey 2141.)

The members of the
Nuclear Energy Trade Associations' Conference are:

British Chemical Plant Manufacturers' Association
British Electrical and Allied Manufacturers' Association
British Engineers' Association
British Industrial Measuring and Control Apparatus Manufacturers' Association
Scientific Instrument Manufacturers' Association
Society of British Aircraft Constructors Ltd.
Water-Tube Boilermakers' Association

NETAC

Published by The British Broadcasting Corporation, 35 Marylebone High Street, London, W.1
Printed by Novello and Company Limited, London, W.1 *No. 3806*