atom train

guide
to the
travelling exhibition
on
atomic energy

ATOMIC SCIENTISTS' ASSOCIATION

ACKNOWLEDGMENTS

The exhibition has been arranged by members of the Atomic Scientists' Association. This task would, however, have been impossible without the help of many other persons and institutions.

In the first instance, we wish to express our thanks to the Department of Atomic Energy of the Ministry of Supply, and to the Atomic Energy Research Establishment at Harwell, for the loan of the radioactive sources and most of the technical equipment used in the exhibition, and to the Directorate of Information of the Ministry of Supply for help in organizing it.

We are indebted to the Research Department of Metropolitan Vickers Electric Co. for the apparatus to demonstrate the production of artificial radioactivity.

We wish also to acknowledge contributions made by the following:—

Dr. T. E. Allibone.

B.I. Callenders Cables Ltd.

British Museum (Natural History).

British Thomson-Houston Co. Ltd.

Sir James Chadwick.

Department of Scientific & Industrial Research :

(i) Film Office.

(ii) Geological Survey and Museum.

W. Edwards & Co. Ltd.

Gaumont British Equipments Ltd.

Gaumont British Instructional Ltd.

Dr. J. G. Hamilton.

Ministry of Works (Chief Scientific Adviser).

Press Association.

The Science Museum.

U.S. Atomic Energy Commission.

U.S. Navy Department.

To all of them we express our gratitude and thanks.

EXHIBITION COMMITTEE OF THE
ATOMIC SCIENTISTS' ASSOCIATION.

INTRODUCTION

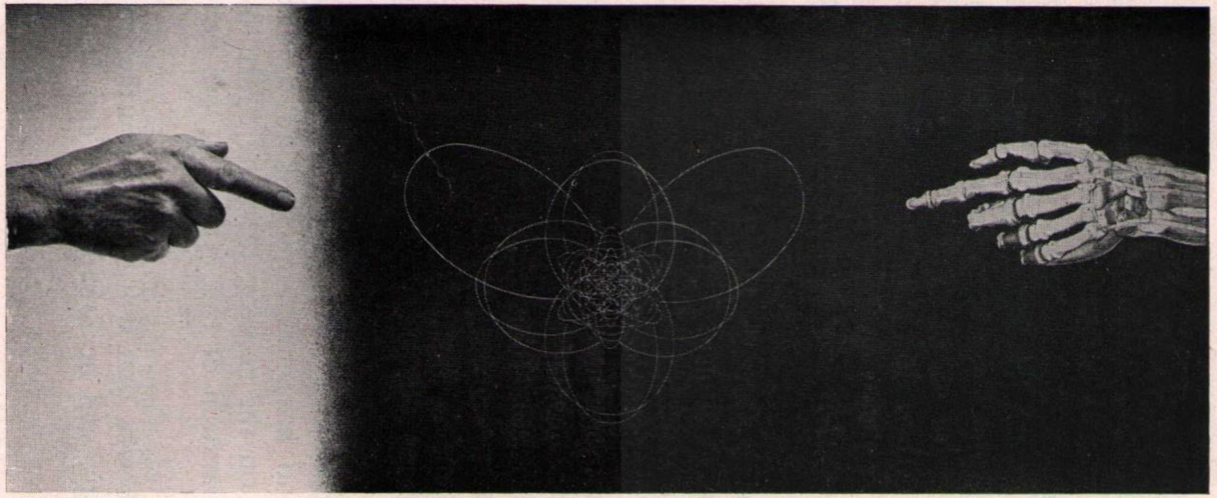
The Atom Train Exhibition has been brought to your town to help you understand the facts about atomic energy. Everyone knows that this new power can be used for destruction ; much less is known as yet of its possibilities for good. Some have exaggerated ideas of what atomic energy can do for us, or think it will give us cheap power to-morrow. Others do not believe it will ever be very useful because nothing very useful has come of it yet. One can get a balanced view only by understanding a little of what is behind it.

After passing through the exhibition you will not be an expert on the subject. You will not understand all the details of the working of an atomic plant. You probably also do not understand all the details of the working of your radio set or watch. Yet you do not regard watches or radio sets as mysteries ; you have got used to them, and you have heard something of the principles that make them work. If we have given you a little of the same feeling for atoms and nuclei, regarding them as things that really exist and whose effects you have seen, we shall be well pleased.

If what you have seen has made you think about these questions, and has made you look for books and other information on the subject, then the effort that has gone into the preparation of this exhibition will have been well worth while.

A list of books that will help you further to understand atomic energy, will be found at the end of this guide.

NOVEMBER, 1947



"Atomic Energy for Good or Evil"

PART ONE
Fundamental Facts

Section 1 - *THE ATOM*

There is no mystery about atoms. They are the smallest bricks of which matter is built and they were familiar to scientists long before there was ever any talk of atomic energy. It is important to keep in mind how extremely small the atom really is and how enormous is the number of atoms that make up even the smallest piece of matter that we can see or handle. The charts try to give you an idea of this number. A million atoms get us nowhere, even a billion (or a million million) atoms is a minute amount and very much smaller than the smallest germ that can be seen under a microscope.

Practically all the weight of the atom sits in its small core or "nucleus" which is very much smaller again than the whole atom. The chart tries to give an impression of the smallness of the nucleus in relation to the whole atom. The nucleus is made of protons and neutrons, which are held tightly together. The protons are electrically charged ; their charge is positive. The neutrons are neutral (hence the name) in other words they carry no electric charge. Besides the nucleus the atom contains electrons. These weigh 2,000 times less than the proton or neutron. They are also electrically charged ; their charge is negative. Unlike charges attract each other and this is what keeps the electrons in the atom.

Picture then the atom as a very small massive core surrounded by empty space in which the electrons revolve like planets round the sun.

Section 2 - *ATOMS ARE KNOWN BY NUMBERS*

The number of protons in the nucleus is called the "atomic number". It is equal to the number of positive charges in the nucleus. The number of electrons in the outer envelope of the atom equals this atomic number because then the whole atom becomes electrically neutral. If an atom were to contain a smaller number of electrons it would have an overall positive charge and would attract more electrons from outside. If it had more electrons it would be negatively charged and would easily lose an electron.

The "mass number" is the number of protons and neutrons in the nucleus. It determines the weight of the nucleus and, therefore, the weight of the atom, since the electrons weigh practically nothing. For instance, the nucleus of the rare gas helium (used sometimes to fill airships) contains two protons and two neutrons. Its atomic number is two, its mass number four. The ordinary helium atom, therefore, contains two electrons revolving round the nucleus.

The nucleus of ordinary oxygen (the gas contained in air on which we depend for breathing) contains eight protons and eight neutrons; therefore, its atomic number is eight, its mass number sixteen.

The atomic number of aluminium is thirteen, its mass number twenty-seven. The aluminium nucleus, therefore, contains thirteen protons and fourteen neutrons (*fig.* 1).

As we shall see, the behaviour of the atom depends mostly on its charge, i.e. on its atomic number. Anything with eight protons in it is oxygen, no matter how many neutrons there are ; anything with thirteen protons in it is aluminium. Each element known in nature has its own characteristic atomic number; the lightest is hydrogen whose nucleus is just one proton and the atomic number one. The heaviest, uranium, has ninety-two protons, atomic number ninety-two. If we write down the numbers from one to ninety-two there is an element in nature belonging to practically every one of them. The chart shows a list of these elements with their names and the symbols used by chemists for them. It contains several elements beyond uranium which have been discovered recently, but which are not found in nature.

ISOTOPES.

Many of these elements have several kinds of atoms differing in the number of their neutrons. Atoms with the same atomic number (same number of protons) but different mass number (different number of neutrons) are called "isotopes". Practically the only way of telling two isotopes apart is to weigh them, but in nature they are always found mixed

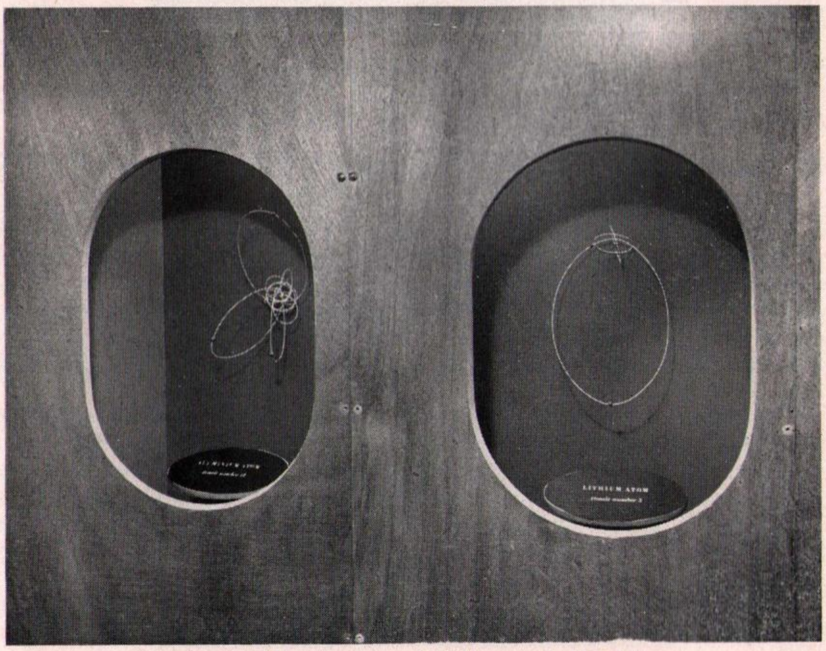


Fig. 1 *Models of atoms of Lithium and Aluminium.*

up with each other and to get out one of the isotopes of a substance is rather like un-scrambling scrambled eggs.

Ordinary hydrogen has in each atom one electron revolving round one proton. The way that electrons revolve in the atoms and the reason why they do not follow their attraction and fall into the nucleus has been studied by scientists for the last 30 years. A lot is known about what they do and how they do it but the details are outside the scope of the exhibition.

There exists another isotope of hydrogen, the so-called "heavy hydrogen" or "deuterium". About one in every 5,000 hydrogen atoms in ordinary water is heavy. Heavy hydrogen has a mass number two. The heavy hydrogen atom behaves exactly like the hydrogen atom, except that its nucleus has an extra neutron attached to the proton and has, therefore, twice the weight.

Uranium (atomic number ninety-two) has three different isotopes with the mass numbers 234, 235, and 238. 238 is by far the most common amongst these ; less than 1% of ordinary uranium is the isotope of mass number 235, and 234 is a hundred times rarer still.

Section 3 - *HOW ATOMS BEHAVE*

All substances are built up from atoms as houses are built up from bricks. The mortar binding them is the chemical attraction between different kinds of atoms, the "chemical force". Atoms like to combine in the right proportions and form groups of atoms (known as "molecules") and a substance made of such molecules is known as a "compound". For instance, ordinary water is made by combining two atoms of hydrogen with one atom of oxygen. Similarly, heavy water is made by combining two atoms of heavy hydrogen with one atom of oxygen. Heavy water looks and behaves just like ordinary water, except that it is slightly heavier, nine pints of heavy water weighing as much as ten pints of ordinary water. This is shown in the demonstration.

Most changes in matter with which we are familiar—burning, explosions, smelting, frying, digesting, bleaching and so on—are chemical processes in which atoms rearrange themselves. In these changes energy may be released. This usually shows up as heat as in the case of burning coal or other fuels.

In the burning of coal, atoms of the carbon which is contained in coal or coke join with oxygen atoms from the air to form carbon dioxide, and the energy that is set free comes out in the form of heat.

In these chemical changes only the electrons of the atoms are involved. In fact, of all the electrons in the envelope of the atom only the few outermost ones take part in the chemical changes.

When we burn fuel we do so in order to set free the energy that results from chemical change. Energy cannot be created or destroyed ; in any quantity of fuel there is only a limited amount of energy that we can get out, regardless of whether we need it to heat our houses, to cook our food, or to drive steam engines or planes. From a ton of fuel we can get roughly 10,000 kilowatt hours (1 kw. hour is the "unit" which appears on your electricity bill).

The store of energy in the nucleus is vastly greater since neutrons and protons attract each other with forces some billion times greater than the strongest chemical force. Actually, weight for weight, the energy contained in the nucleus is several million times greater than what we can get from rearranging the other parts of the atom.

How did one know this even before energy had actually been got out of nuclei ? This knowledge comes from Einstein's discovery that mass (or weight) and energy are the same thing. The weight corresponding to a given amount of energy is extremely small. Roughly 1,000 million kw. hours, which are obtained by burning 100,000 tons of coal, weigh one ounce. It is, therefore, impossible to detect this weight even with the most sensitive balance. Nuclear energies, however, are so much larger (*fig.* 2) that they do change the weight of each atom to a noticeable degree. By weighing atoms and comparing the answer with the weight of the neutrons and protons contained in the atoms, we can learn about their energy content.

The problem was how to set free these vast amounts of energy contained in atomic nuclei.

Section 4 - *RADIOACTIVITY*

The beginning of modern nuclear physics goes back to the discovery of radioactivity in 1896 by the French physicist Becquerel. He found that some materials, like uranium, give out radiations which can, amongst other things, blacken photographic plates, and also give light. The most common radioactive element is uranium, but in 1898 Pierre and Marie Curie extracted from uranium the very much rarer, but much

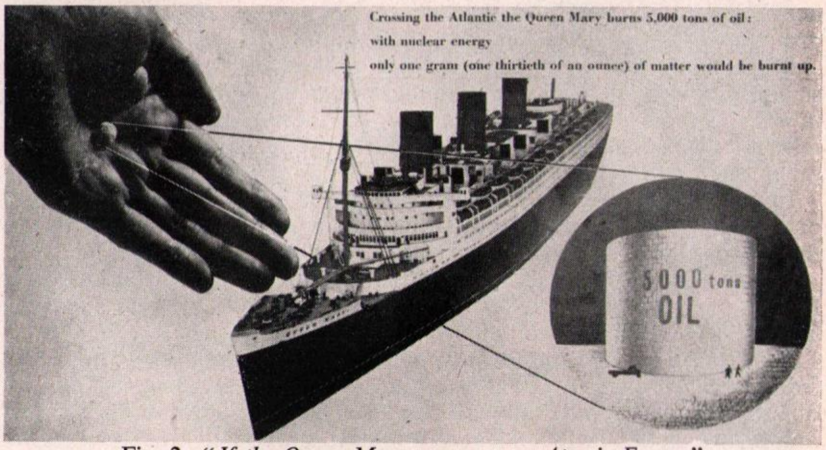


Fig. 2 "*If the Queen Mary were run on Atomic Energy*" more powerful, element radium.

It was found that the radiations from these substances consist largely of rays of fast particles. The most convenient instrument to detect such particles is the Geiger counter which is used in the demonstration of radioactivity (*fig*. 3). Each passage of a fast particle is detected in such a counter and gives a pulse which lights a series of little lamps in succession. Every hundredth particle is indicated on the dial of the register (like a mileage register of a car) and in this way the number of particles that have passed the counter can be seen at a glance. The demonstration shows the radioactivity of a piece of uranium or of pitchblende (the ore from which uranium is obtained). You can also detect the radioactivity of the luminous paint on your watch.

Rutherford showed that the radiations were of three different kinds to which he gave as names the first three letters of the Greek alphabet, alpha, beta and gamma rays.

Alpha rays are fragments of nuclei that have split. They are actually nuclei of helium containing, as we have seen, two protons and two neutrons. Alpha rays are easily stopped by a few inches of air or by a sheet of paper.

Beta rays are fast electrons. They do not really come out of the nucleus but they are produced when the nucleus changes its electric charge and serve to balance the charge, since electric charge cannot be created or destroyed. Beta rays are more penetrating than alpha rays,

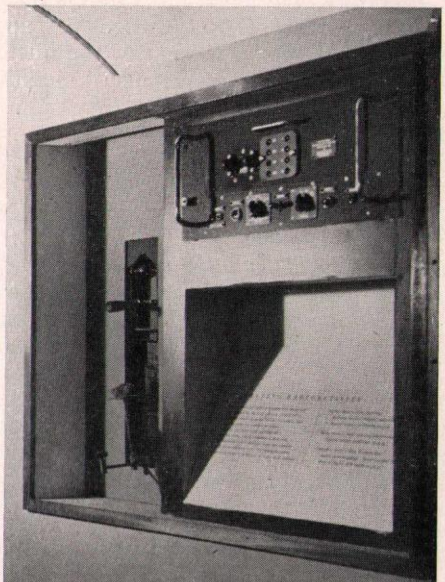


Fig. 3 *Detection of radioactivity by means of the Geiger Counter.*

but they too can be stopped by a thin sheet of metal of the sort of thickness used in a tin can.

Gamma rays are like X-rays, but much more penetrating, and several inches of lead would be needed to reduce their intensity appreciably.

The demonstration shows the effect on a counter of a radioactive source. The counter registers beta and gamma rays, and one can also see that the number of counts goes down a lot when a metal screen is put in, which stops the beta rays.

These radioactive substances are a source of power, but they give out their energy much too slowly to be of practical use. If they gave out their energy much faster they would have disappeared long ago. No outside influence can persuade a radium or uranium atom to give out its energy any faster, except a direct hit on its nucleus.

Another demonstration shows the radium clock in which the action of the radiations is used to charge and discharge a thin rod at regular intervals. Such clocks have been running for long periods of time and serve to demonstrate the power that can be obtained from small amounts of radioactive substances. They are not of any practical value.

Section 5 - *ATOM SMASHING*

To release nuclear energy we must produce changes inside atomic nuclei, and, therefore, the nuclei must be hit, usually by streams of fast particles. Before the discovery of the neutron the only such particles available were electrically charged ones. They are repelled by the positive charge of the nucleus and, therefore, will never hit it unless they travel with very high speed. The repulsion increases the closer they approach, and very fast missiles are needed to get close enough to the nucleus for causing it to change in any way. For instance, a nucleus of medium size will not be reached by a proton unless it travels at about fifty million miles an hour.

The first success in causing atoms to change at our will was achieved by Rutherford in 1919. He let the particles from a radioactive source pass through nitrogen (the gas making up most of ordinary air) and occasionally one of these alpha rays would hit the nucleus of a nitrogen atom, causing it to split. What happened was that the alpha particle knocked a proton off the nitrogen nucleus and attached itself to the remainder, which thereby became oxygen. These protons are not as easily stopped as the alpha particles and will, therefore, come out through a thin layer of paper or other material thick enough to stop the alpha particles from the source.

In those days there were no Geiger counters, and Rutherford had to rely on watching the very faint sparks of light produced by protons or alpha particles when they hit a screen coated with a suitable salt. This meant the observers had to sit for hours in complete darkness watching faint sparks on the screen, and the method was reliable only if very careful precautions were taken. A much better way to show up the smashing of atoms is the cloud chamber invented by C. T. R. Wilson, which makes the tracks of fast particles visible as white lines on a dark background,

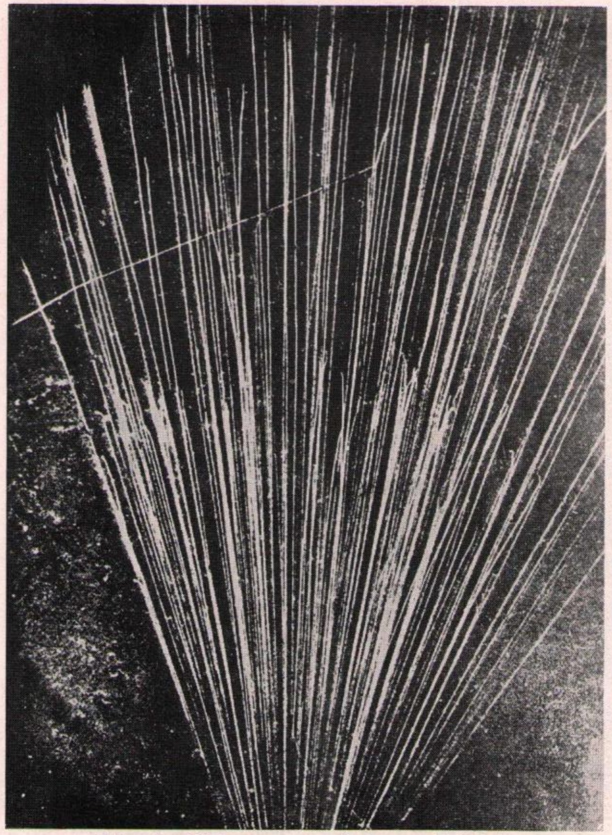


Fig. 4 *Disintegration of nitrogen by alpha particles observed in the Cloud Chamber.*

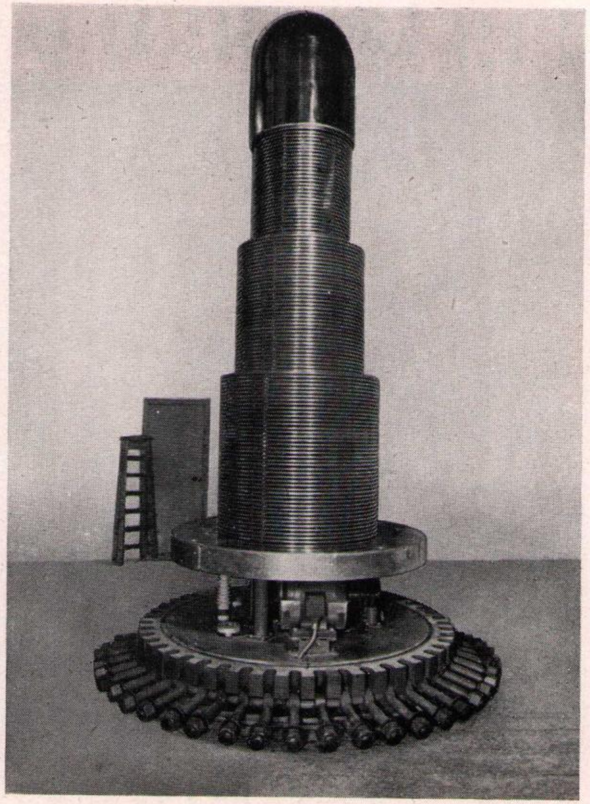


Fig. 5 *Van de Graaff machine to give potentials up to 5,000,000 volts.*

using the same principle that sometimes makes the trails of high flying aircraft visible as white streaks in the sky. The demonstration shows such a cloud chamber in actual operation, making the tracks of fast alpha-particles visible. It does not show an actual atom being split, since one has to look at about a million tracks before this happens once, but photographs of such events are exhibited (*fig*. 4).

The splitting of an atom is very rare, since the atom is a target with an extremely small bull's eye, at which we are firing blind. On the passage through each atom, a particle has a chance of only one in some hundred million of hitting the nucleus. In passing through the outer envelopes of atoms, the power of the particle is spent and it soon slows up so much that it is no longer able to overcome the repulsive force. Altogether it has only a chance of one in a million of splitting an atom. When an atom is split, energy may be released, but to achieve this a million or so particles have to be spent, and, therefore, far more energy has been used up than we gained.

Radioactive sources are not intense enough for a convenient study of atom splitting and the physicist would also like to have at his disposal faster particles than he can get from these sources.

Cockcroft and Walton, working under Rutherford at Cambridge, therefore designed a machine in which protons passed through a tube across which there was an electric potential of 600,000 volts (the potential in ordinary electricity supply is about 230 volts). Pictures are shown of this machine and also of the Van de Graaff machine (*fig*. 5) which can give potentials of five million volts. This is about the limit of electric potentials that one can in practice maintain in any machine.

One can get further with the cyclotron invented by Lawrence at Berkeley in which a much smaller voltage is used to act repeatedly on the same particle, being reversed rapidly so that it always acts to speed up the particle as it passes to and fro. A simple mechanical model is shown to explain the principle. Cyclotrons have now been made to give particles the speed that they would have had in the direct application of a potential of two hundred million volts, and work is going on to exceed this limit by bigger machines of a similar kind.

A valuable addition to our stock of missiles for hitting atoms came when Chadwick in 1932 discovered the neutron. He found that some nuclei, when hit by fast particles, give off a new kind of radiation. He found that this consists of a stream of particles which do not carry any electric charge. He had then discovered the missing brick for building nuclei. Having no electric charge, neutrons do not lose speed in making their way through the outer envelopes of atoms, and they are not repelled by the electric charge on the nucleus. A neutron will, therefore, travel through matter until somewhere or other it hits a nucleus.

We shall later stress the importance of the difference between fast, medium and slow neutrons. Fast neutrons move at many thousand miles a second, slow neutrons at a few miles a second. Because there is

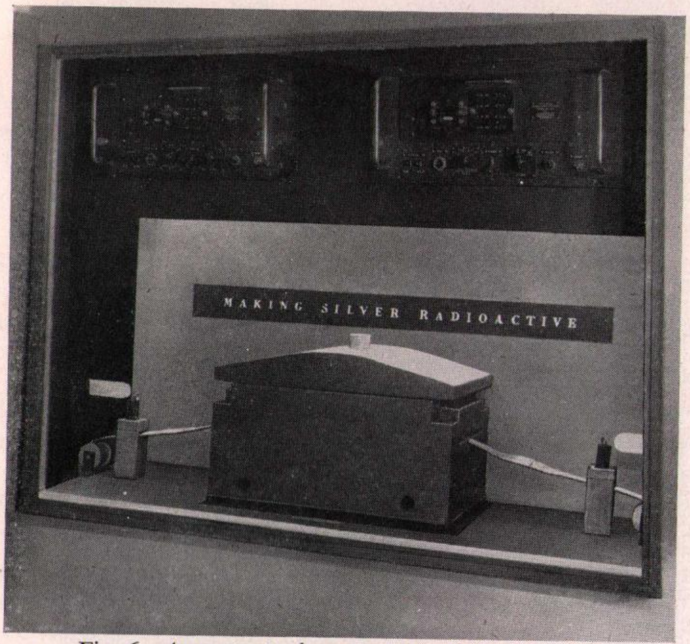


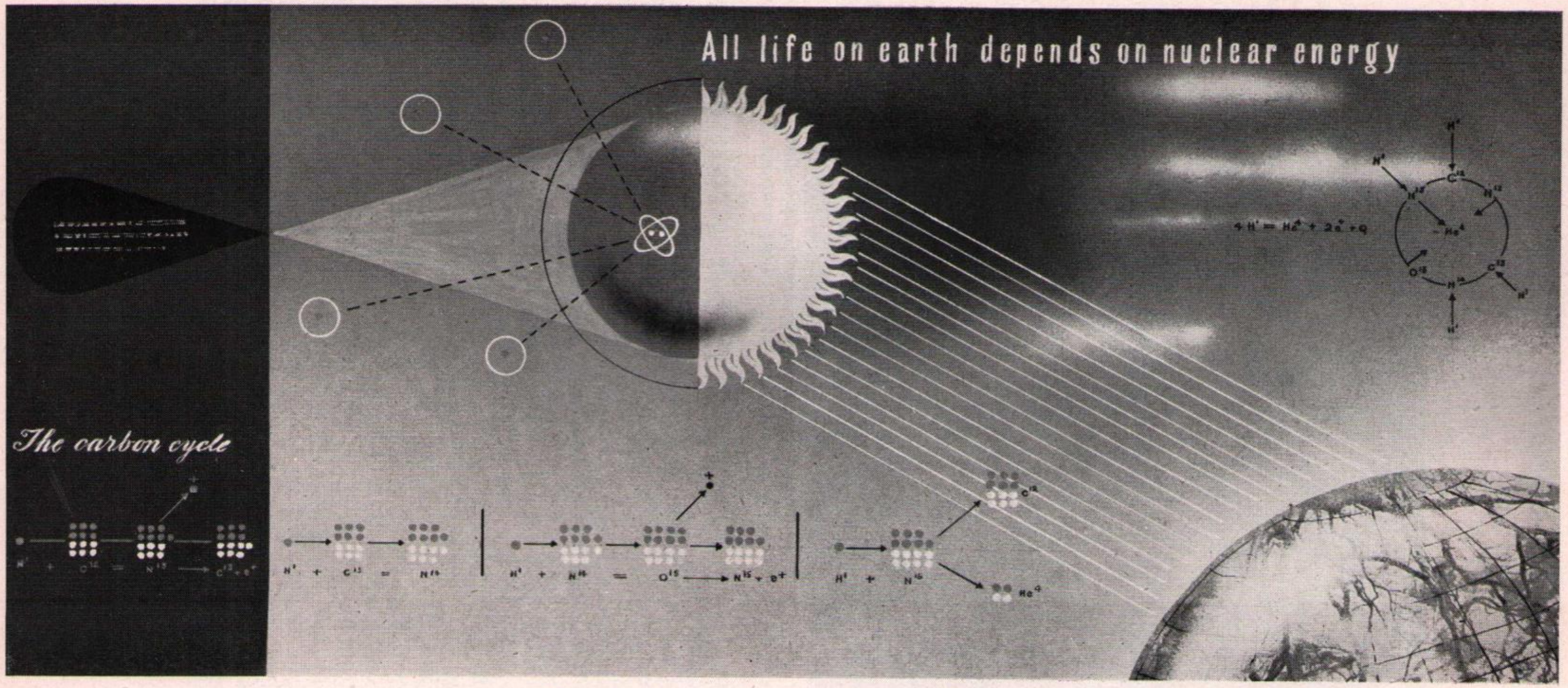
Fig. 6 *Apparatus to demonstrate production of radioactivity in silver by bombardment with neutrons.*

no repulsion, even slow neutrons can hit nuclei and they usually do so more effectively.

A simple model is shown demonstrating the different behaviour when a proton or a neutron tries to approach a nucleus.

Section 6 - *ARTIFICIAL RADIOACTIVITY*

In 1934 Joliot and his wife Irene Curie found that, if aluminium is exposed to alpha rays, a nucleus which has been hit continues to give off rays after the bombardment has ceased. The rays were found to be similar to beta-rays, and it followed that the aluminium nucleus had been changed into a nucleus that behaved like one of the radioactive elements. Later Fermi showed that the same effect could be produced by bombardment with neutrons which in turn had been obtained from the bombardment of a light atom by alpha rays. A demonstration shows how the bombardment of a piece of silver can turn some of it into radioactive silver, whose radiation can be recorded on a Geiger counter (*fig.* 6). The neutrons used are slow ones, as they are more effective. The fast neutrons emitted from the source—which is inside the lead castle—are slowed down in paraffin wax.



“The Sun is running on Atomic Energy”

SUMMING UP

At this point we have reached the limits of our knowledge of atoms and nuclei as it was available in 1938. By then the atomic nucleus and its properties were becoming familiar to scientists. They had learnt how to bombard the nucleus with various particles, how to knock pieces off it and to add pieces to it. But all these experiments concerned only tiny amounts of material, enough to be detected with the ingenious tools of the physicist of which you have seen some in the exhibition. The amounts of material involved in all these reactions were far too small to be of any practical interest.

Physicists knew already then that nature was carrying on the production of atomic energy on a gigantic scale, since all heat and light that we receive from the sun is maintained by the release of atomic energy, which takes place in the interior of the sun. We all realise that the sun provides us directly with heat and light, but most other sources of power available to us are also indirectly derived from the sun. For instance, plants use sunlight to extract carbon from the air and thus to provide us with timber and coal. Water power represents the effect of water being evaporated from the ocean by the sun's rays and deposited as rain on higher ground. If the sun is running on atomic energy then all our normal activities are really derived from atomic power.

We now know that the source of energy in the sun is the building up of bigger nuclei from smaller ones. One important way in which this happens is the so-called "carbon cycle", in which a carbon atom undergoes a series of nuclear re-arrangements, during which it picks up four protons in succession. Two of these protons change into neutrons (by emitting two positive electrons) and finally the two protons and the two neutrons are ejected together to form a helium nucleus, leaving the original carbon as it was in the beginning. The net result, therefore, is the manufacture of helium from hydrogen, and since the helium atom weighs less than two protons and two neutrons, the remaining weight is emitted in the form of energy. This is the main source of energy from the sun. The carbon merely makes the process easier, but is not used up. Even with quite a small stock of carbon, the sun can carry on until it has used up most of its hydrogen which, fortunately for us, will take a few more million years.

PART TWO
Practical Applications

Section 7 - *THE FIRST PRACTICAL RELEASE OF ATOMIC ENERGY*

In 1939 the German physicists Hahn and Strassman showed that if you bombard uranium with neutrons you can cause a very much greater change in the nucleus than had hitherto been found. Lise Meitner and Frisch explained their results by the fact that the uranium has been split in two, the two fragments being roughly equal in mass and charge. The fragments are very intensely radioactive; they travel at very high speed and, therefore, carry about one hundred times as much energy as do the alpha rays from radium. This process is called **fission.** It was later found that in this process neutrons are also given out, and they probably come from the two fragments after the split. There is, on the average, more than one such neutron for each fission, but less than three. The actual average is still regarded as a military secret.

A demonstration shows the detection of fission (*fig.* 7). The fragments produce electric impulses which can be observed on the screen of a cathode ray oscillograph or heard by means of a loudspeaker.

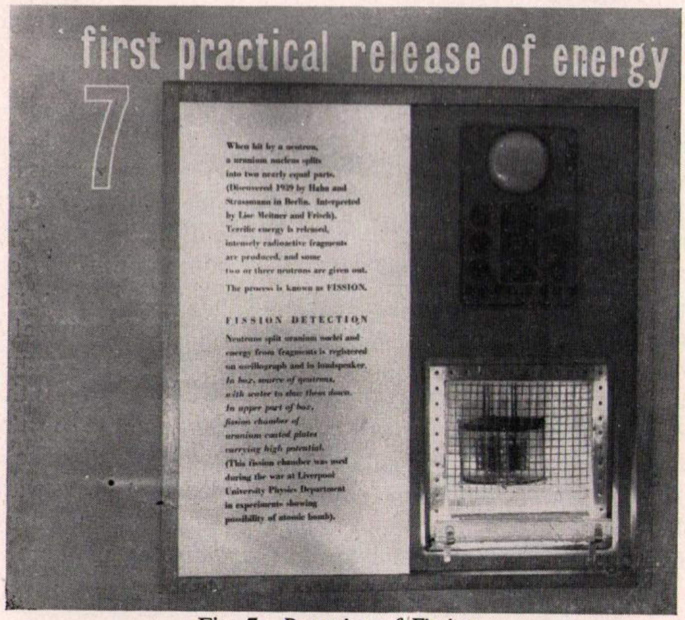


Fig. 7 *Detection of Fission.*

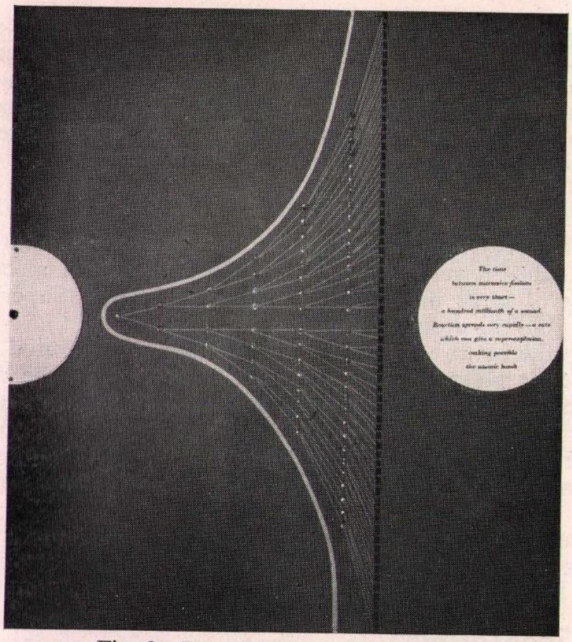


Fig. 8 *Principle of the Chain Reaction.*

In this fission process the rare isotope uranium 235 is of outstanding importance, and in normal circumstances the small amount of U235 contained in common uranium is responsible for almost all the fission, since it can be split by any neutron regardless of speed.

The common isotope U238 suffers fission only under the bombardment with fast neutrons. When hit by a slow neutron it becomes radioactive, leading (through the intermediate element neptunium which is also radioactive) to the new element plutonium.

Plutonium, a new element of atomic number ninety-four, is like uranium 235 in that its fission is caused by both fast and slow neutrons, and the results of the fission are very similar to the case of uranium.

The fact that in fission more than one neutron is released makes a "chain reaction" possible. Supposing there were just two neutrons released in each fission, then each of them might cause fission in its turn, producing four neutrons in all. Their "offspring" will then number eight, the next generation sixteen and so on (*fig.* 8), and these numbers mount up so quickly that after eighty generations a weighable amount, say a pound, of uranium will have suffered fission.

This is possible only if not too many neutrons are lost through other causes than hitting a nucleus of U235, and also if the amount of uranium is sufficient, since otherwise too many neutrons will escape from the surface before they have done their job. If through escape or other causes so many neutrons are lost in each generation that, on the average, there is less than one neutron left over from each fission process, then this chain reaction cannot develop. Therefore, we have a well-defined "critical size." In an amount slightly greater than the critical size a chain reaction can develop, in an amount slightly less than the critical size it cannot. The film illustrates the development of a chain reaction.

Section 8 - *THE ATOMIC BOMB*

When a chain reaction is produced with fast neutrons, the time between successive fissions is very short—a hundred millionth of a second. This rapid release of large amounts of energy can give a super explosion, making possible the atomic bomb.

How does the bomb work ? It must contain concentrated atomic fuel (either U235 or plutonium) in an amount more than the critical size. Until the bomb is intended to go off, this is separated into smaller pieces, each of which is less than the critical size. As soon as they are brought together the explosion will start. The only point of difficulty is to bring the pieces together quickly enough to avoid the explosion starting piecemeal.

To get the concentrated fuel is, however, an enormous job. Several ways were open and they were all used. One is to get U235 by isotope separation. Three methods of isotope separation are demonstrated.

Isotope Separation

GAS DIFFUSION

If a mixture of gases passes through a membrane with fine pores, the lighter atoms move faster, and more of them pass through the pores. The mixture therefore, contains more of the light gas when it has gone through the membrane; the part that stays behind contains more of the heavier gas.

This is demonstrated with a mixture of hydrogen and carbon dioxide, the hydrogen being lighter. The colour of an electric discharge shows up the composition of the mixture. From this apparatus the mixture comes out only slightly richer in the light gas and to get it completely pure one has to repeat the process many times over. The real plant of which a picture is shown, is, of course, enormously more complicated than the model because the weights of U235 and U238 differ only by a small fraction, because there is very little 235 in ordinary uranium, and because the only gaseous form in which one can obtain uranium is highly corrosive. The model shown is in the same relation to the real plant as your bicycle dynamo to Battersea Power Station, only much more so.

THERMAL DIFFUSION

Another method of isotope separation is that using thermal diffusion. In idea it consists of a vertical column of which one side is kept hot and the other cold. Then the lighter gas will rise to the top and the heavier will collect at the bottom. This is demonstrated by such columns working on a mixture of helium and bromine, the latter being a very heavy gas and dark in colour shows up the effect better so that the separation is visible. The use of this method with uranium turns out to be very costly in fuel and the method was employed only for a short period to improve the output from the other methods.

ELECTROMAGNETIC METHOD

The third way of separating the isotopes is the electromagnetic method. This relies on the curious fact that in the field of a magnet, electrically charged particles tend to run in a circle. This is shown with electrons running inside a vacuum tube. One can notice, in particular, the narrowing of the beam at the opposite end from the starting point. This is known as focussing and means that a fairly wide beam can be collected by a small receiver in a suitable place. The size of the circle depends on the mass of the particle and will be slightly different for U235 and U238. Hence two receivers can collect the two isotopes separately, as shown on the model, but for this purpose all the uranium we want to handle has to pass through the apparatus in the form of a fine beam of electrified atoms and this again involves an enormous installation.

Carbon Piles

Instead of separating the isotopes we can produce plutonium. For that we must run an atomic chain reaction as in the bomb, but in a controlled instead of in an explosive manner. This is done with ordinary (not separated) uranium, which can sustain a chain reaction only if means are provided to slow down the neutrons as soon as they are produced. The material in which neutrons are slowed down is called "moderator". The whole reactor, of which a rough model is shown, is called a pile (*fig*. 9).

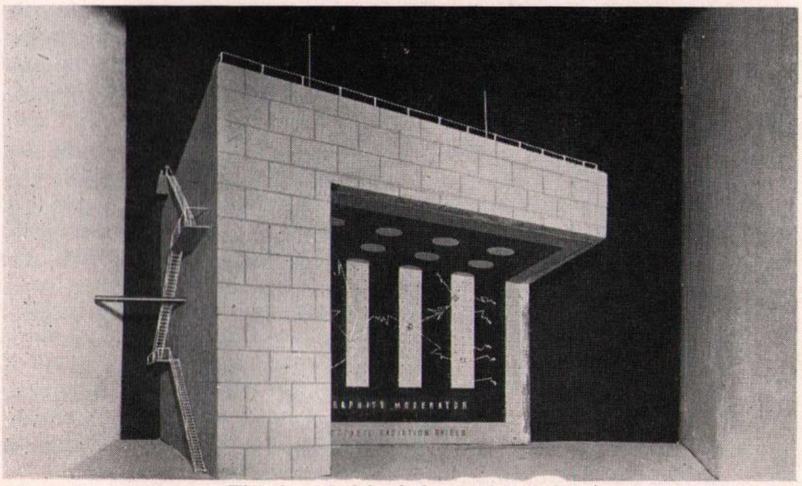


Fig. 9 *Model of the Carbon Pile.*

MODERATOR

The main structure of the pile is the moderator, usually graphite (a special form of carbon used commercially in carbon arcs and in pencil leads). Heavy water is even more suitable as a moderator, but it is much more expensive. Besides the moderator the pile must contain :—

URANIUM RODS

In these, the fission takes place. Neutrons from the fission will in general leave the uranium rod, be slowed down in the moderator and, after wandering around, find their way into another (or the same) uranium rod. Some of them will hit atoms of U235 and cause fission. This gives out more neutrons, which set out on a similar journey and so keep the process going. Other neutrons will hit U238 atoms and will convert them eventually into plutonium.

CADMIUM RODS

Cadmium is a metal which takes up neutrons very readily. If more cadmium is present in the pile, a greater fraction of the neutrons will be lost, and by putting in enough cadmium one can prevent the chain reaction altogether. Rods of cadmium are pushed in and pulled out by the operator in charge of the plant, so as to keep the chain reaction going just at the rate that is wanted and to prevent it getting out of hand. For safety there are automatic devices to push some of these rods into the pile in an emergency so as to shut down the plant.

A COOLING SYSTEM

Fission releases energy in the uranium, which means that the uranium rods tend to get very hot. To prevent their overheating some kind of cooling fluid, either a liquid or a gas, has to flow through the plant to cool the rods and carry the heat away. It can then be wasted, or it might be used to generate steam to drive steam engines or it might be put to other useful purposes. The plants existing in America were built for the purpose of making plutonium ; to get a large output of plutonium one must make the process run at a fast rate and that means carrying much heat away.

PROTECTIVE WALLS

While a pile is running, and even for some time after it has been shut down, very dangerous radiations come out from it. These include stray neutrons which get out, and also gamma rays given off by the fission products, i.e. the fragments into which the uranium atoms are split, since these fission products are intensely radioactive. To protect the personnel and other people in the neighbourhood, thick walls of concrete are erected round the plant. These have to be several feet thick to give sufficient protection.

Belonging to the pile there must be a chemical plant, since one wants to extract the plutonium that has collected in the uranium rods. For this purpose the rods are taken out of the pile from time to time and passed into the chemical plant for treatment. Since these rods are highly radioactive, this plant must also work behind concrete walls, and all operations must be carried out by automatic devices or by remote control.

The same dangerous radiations which the pile produces are also

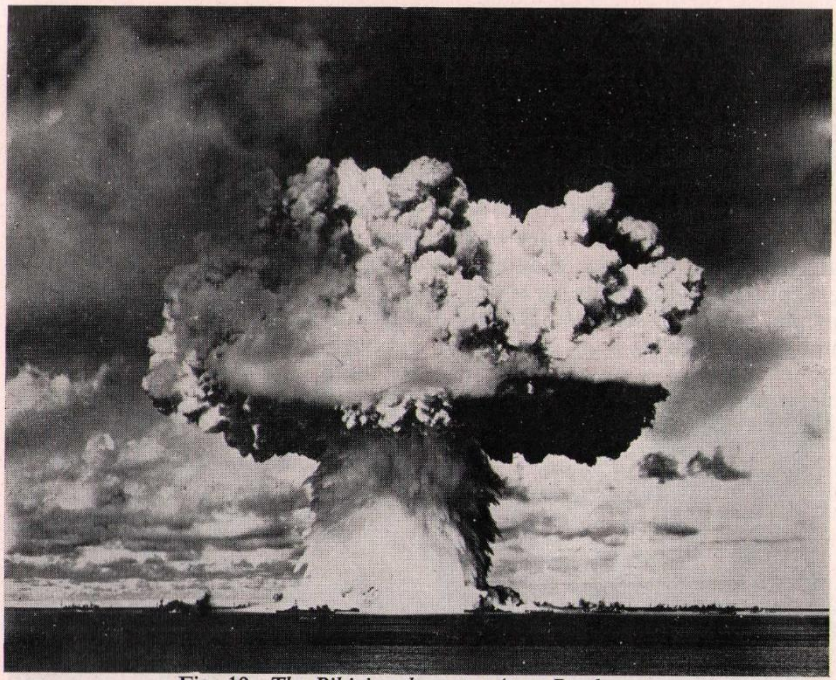


Fig. 10 *The Bikini underwater Atom Bomb test.*

produced by an atomic bomb. Part of it comes out at the instant of the explosion and causes radiation injuries. The radioactivity of the fission products remains after the explosion is over. If the bomb explodes in the air, as it did at Hiroshima and Nagasaki, this activity is carried up into the clouds by the rising column of hot air, no dangerous activity remaining on the ground. If the bomb is exploded near the ground, as in the New Mexico test, some activity may remain on the ground and make the area uninhabitable for some time. If the bomb explodes in the sea, as in the Bikini test (*fig.* 10) much of the activity stays in the water and leaves it dangerous to life for a considerable time.

A demonstration shows the radioactivity of a sample of sand taken from the place where the first trial bomb exploded in the desert of New Mexico. The heat of the explosion has fused the sand into a kind of glass.

Hiroshima, the first target for atomic bombing, is shown in pictures. The exact number of people killed by the bomb is not known since too many records were lost with them, but it is estimated at 80,000. We do not know much about Japanese cities and it is hard to picture what life in this place was like before the bomb fell. We have, therefore, tried to show what one would expect to happen in London (*fig.* 11), or in your local town, if an atomic bomb were to explode there. Within half a mile of the centre most people would be killed by blast, burns or radiation, and many would receive severe burns at a distance of three quarters of a mile. Up to two miles distance there would be casualties from radiation sickness, though many of these would recover. Houses are likely to be damaged beyond repair up to a distance of one mile and some damage would be caused as far as two and a half miles away. In London, this would render 400,000 people homeless. All this damage would be done by a bomb carried by a single raiding plane. The explosive power of this bomb equals that of 20,000 tons of T.N.T. Several thousand planes would be needed to carry such a load of ordinary bombs.

This, in brief, is the story of the atom bomb. It is not easy to make atom bombs, but once they are used, there is no defence against them, except to stop the plane, or rocket or ship that is bringing it. In the words of the American scientist, Robert J. Oppenheimer, "the only defence is not to be there".

Fig. 11 (*A*) *Nearly everyone killed within half a mile.*
(*B*) *Severe burns over three quarters of a mile away.*
(*C*) *Damage to property and radiation sickness up to two miles.*

Section 9 - *THE BRIGHTER SIDE*

If atomic fuels are not going to be wasted for war and destruction, atomic energy can bring great benefits. It can make a substantial addition to our resources of fuel for power production, it can give research tools of enormous importance to medicine, biology, chemistry, and many other branches of science. In some cases, it has already proved useful for treatment of diseases and it is likely that more cases will be found in which it will effect a cure.

Atomic Power

We have already seen that an atomic pile produces large amounts of heat. This could be used to raise steam, which will drive steam engines or turbines to make electric power. At present no such power station is in existence since the first piles were not built to withstand high enough temperatures. The cooling water of the big piles at Hanford, U.S.A., (in which the plutonium was made) is below boiling point ; hence it produces no steam. It will not be long, however, before the engineers will have designed a plant for the production of useful power. The sketch (*fig*. 12) shows the probable design of such a plant. The fuel consumption of such a plant will be extremely small, because one pound of uranium can give as much energy as 1,500 tons of coal.

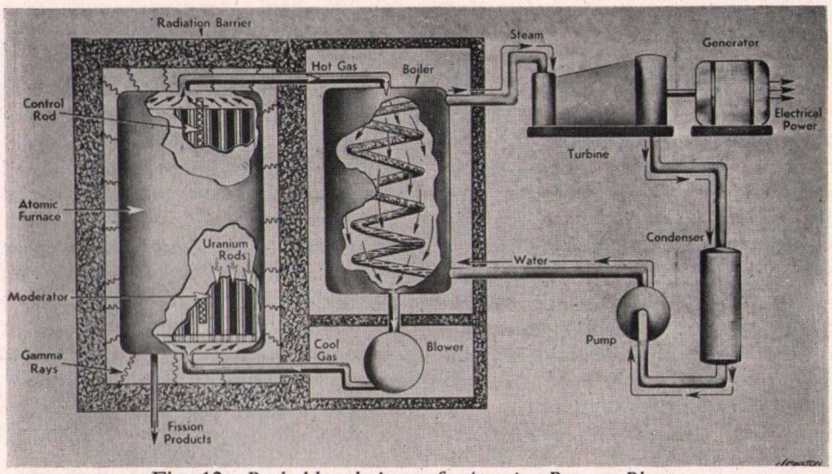


Fig. 12 *Probable design of Atomic Power Plant.*

There is therefore no transport problem in keeping an atomic power station supplied with fuel, and it can be built wherever it is most convenient for the consumer of electricity. At present power stations depend vitally on railways or canals to bring their coal.

Atomic power could serve for most of the jobs for which coal is used now, allowing us to reserve this valuable material for the purposes for which it is really essential, such as use in small engines (railways and small ships) and as a chemical (smelting of metal ore, plastics industry). Time is, of course, needed before the first atomic power stations will operate ; more time will elapse before so many of them have been built that they play any noticeable part in the economy of any nation (or even of the world). By then more will be known about the amount of uranium ore that can be mined, and how much of it can actually be utilized in the piles.

If there is a sufficient supply of uranium, atomic power need not be more expensive than that from coal.

Mobile Atomic Power

From the description that has been given of a pile, it is clear that atomic piles are too big to be carried in motor cars or trains. They might be carried in ships, particularly if it is possible to use piles burning enriched fuel (i.e. either uranium 235 from a separation plant or plutonium from a big pile) which makes the pile somewhat smaller. Such an enriched pile would, however, burn more expensive fuel than an ordinary one.

Atomic propulsion for ships therefore looks quite feasible. One may even think of atomic aeroplanes, though they would have to be enormous in size to be worth while. Atomic ships could travel many times round the world without refuelling.

Radio-Isotopes

Besides power, the greatest importance of atomic energy lies in the production of radioactive substances. We have seen before that most elements possess isotopes, i.e. atoms whose nuclei contain the same number of protons, and hence have the same chemical behaviour, but different numbers of neutrons and, therefore, different weight. Such isotopes can be stable. If, however, the number of neutrons in them is too high or too low, the nucleus becomes radioactive. Every element has such radioactive isotopes. These can be made either by a neutron hitting a nucleus and getting stuck there, or by a fast neutron knocking another neutron or proton out of a nucleus.

Radioactive isotopes are also produced as a result of the fission of uranium. The fragments resulting from this process usually contain too many neutrons. In this way one obtains a host of new radio-isotopes which cannot in practice be made in any other way. Hundreds of new types have been listed.

These radio-isotopes can be used in two ways. They provide sources of radiation similar to radium, and they can be used for all purposes for which radium is now used, but they are much cheaper and there is much greater variety. One can get, to order, radiations which are strongly penetrating or radiations which are stopped in quite thin layers of materials. At the same time one can choose radiations which are carried by substances of different chemical properties and which will, therefore, settle in certain parts of the human body, or of a plant, in which we want to provide strong radiation effects. One can also choose radio-isotopes of a suitable life-time so that the radiation will stop itself when required.

Tracers

Another, and in the long run more important, way of using radio-isotopes is as tracers. This relies on the fact that for every chemical element we can find a radio-isotope which has the same chemical behaviour and which, therefore, in the human body or in a plant or in any other chemical process, will suffer precisely the same fate as that element, but which can be traced easily because of the rays it emits. They make it possible, therefore, to trace the movement of some particular kind of atom throughout the process.

ATOMIC ENERGY AND MEDICINE

Use for Radiation Treatment

Radium is already in wide use for treatment of many diseases, in particular of cancer. Radiation can destroy tissues in the body which are not accessible to the surgeon, and in some cases cancerous tissues are more sensitive to the radiation than healthy ones. Radio-isotopes will be more cheaply available than radium and they will make it possible to inject the correct dose if a radio-isotope of the right life-time is chosen. In some cases they will migrate to the right part of the body on which to act. For instance, practically all iodine in the body is taken by the thyroid gland, and if a patient is given radio-iodine it will go to the thyroid and produce a strong dose of radiation there. This treatment has already proved effective in some special thyroid conditions for which previously no treatment was available. Similarly, phosphorus is used by the body in the bones, and radio-phosphorus will settle in the bones and give irradiation to the bone marrow, which is responsible for manufacturing red blood cells. Radio-phosphorus can, therefore, be used for the treatment of certain diseases of the blood.

Use of Tracers

Tracers are proving a tool of enormous value to medicine since they allow us to trace the course of any element through the human body. For instance, radio-calcium behaves in the same way as ordinary calcium, which is used in building up bone and teeth. While many kinds of food contain calcium, not all of it is easily taken up by the body to get into the bones and teeth. Medical science can, with the aid of radio-calcium, detect whether the calcium from some particular kind of food or drug is useful, by adding some radio-calcium to the food or drug and seeing whether any radiation can be found in the bones. In this, as in all other tracer work, the amount of radiation must, of course, be so small that it has no direct effect on the body. Fortunately, the Geiger counters, which were shown in the earlier demonstrations, are so sensitive that they can detect radiation in amounts far less than would cause any harmful effects.

Radio-calcium is also a useful tool in studying the healing of fractures where new bone material has to be built.

Radio-iron can be used to study the functions of the blood, since blood is particularly rich in iron. Apart from the scientific study of the formation of new blood cells, it can be used for a rapid check of blood circulation. In gangrene a part of the body is not reached by a fresh blood supply. By injecting radio-iron it may become possible to tell rapidly the extent of the region in which circulation has stopped and, therefore, help the surgeon.

The film illustrates the use of radio-sodium to study the circulation of blood in the human body.

Other tracer elements can be built into special hormones such as the ones which control growth of the sex functions of the body; this will help to increase our knowledge of these hormones and their activities.

These samples are only a small selection from the applications that are already being tried. As medical science progresses, new and almost unlimited fields will be opened up for the use of these new tools.

Up to the present almost all the work with radio-isotopes has been limited to the United States, since only there have the supplies been available in large quantities. Recently, however, arrangements have been made for supplying other countries with these materials. At the same time a small pile has been constructed at the Atomic Energy Research Establishment at Harwell in Berkshire, which can provide small amounts of radio-isotopes for research in this country.

ATOMIC ENERGY IN AGRICULTURE

In agriculture, as in medicine, the use of tracer elements can help to add to our knowledge. Applying tracers to fertilizers, it is possible to tell at once how much of a certain food the plant actually derives from the fertilizer and how much from other materials in the soil ; this will also help us to improve the performance of fertilizers. Applied to insecticides, one can tell how much of the poison enters the body of the insects and in what form. The position is the same with the study of chemicals used for the control of weeds.

In the study of plant diseases, tracers can be used in the same way as in medicine and they will play an important part in understanding the normal processes of life in the plant.

Important advances are just now being made in the study of the effect of sunlight on green plants. The green substance in the plant (chlorophyl) uses the energy from sunlight to take carbon from the carbon dioxide in the air and to build it into the body of the plant.

One particular way of using tracers is to show in what part of the plant certain elements are used. It is necessary only to place the plant, after feeding it with substances containing tracers, on a photographic plate which will show up the location of the radio-isotopes. Pictures are exhibited of tomato plants fed on phosphates containing radio-phosphorus, showing the places where the plant uses the fresh phosphate. Similarly, a picture is shown of slices of tomato fruit fed on radio-zinc ; one can see at a glance where the zinc has gone.

ATOMIC ENERGY IN INDUSTRY

We have already mentioned the possibility of power from atomic energy. This may help to overcome shortages of fuel and may provide a power supply in areas to which fuel cannot be carried. Where there are deposits of ore in remote areas it will be cheaper to build an atomic power station close to the mine and do the processing on the spot, rather than carry the raw ore to a place where supplies of fuel makes a processing plant possible.

Tracers can help the study of materials vital to industry. For instance, alloys are mixtures of different metals, in which the motion of one particular compound (such as zinc in brass) can be studied by tracer methods. This is more important in the study of more modern kinds of alloys in which some metals are contained in very small amounts.

For the chemical industry tracers can also be used to follow the course of a chemical reaction and to check its efficiency. In studying corrosion, the use of tracers can show the beginning of a chemical attack on some particular part of a surface long before the action has gone far enough to make the corrosion visible or detectable by chemical analysis. In large-scale chemical plants, such as distillation columns or oil processing plants, tracers can show up what happens to any component.

In surveying oil fields they can also help to identify batches of oil and follow their movement underground so as to show, for example, whether oil coming to the surface in one place is part of an underground flow found somewhere else.

In engineering, tracers can be used to detect wear on surfaces, for instance in a bearing. If a radio-isotope is included in the bearing metal, wear on its surface will bring radioactivity into the lubricating oil : this may be detected without dismantling the machine and it does not matter if at the same time the machine contains other bearings in which wear takes place.

Small intense sources of radiation made of radio-isotopes may be used for radiographs of metal parts where space does not allow the use of X-ray tubes.

Again one could go on adding to this list of uses and many new ideas will emerge of which no one has thought as yet.

CONCLUSION

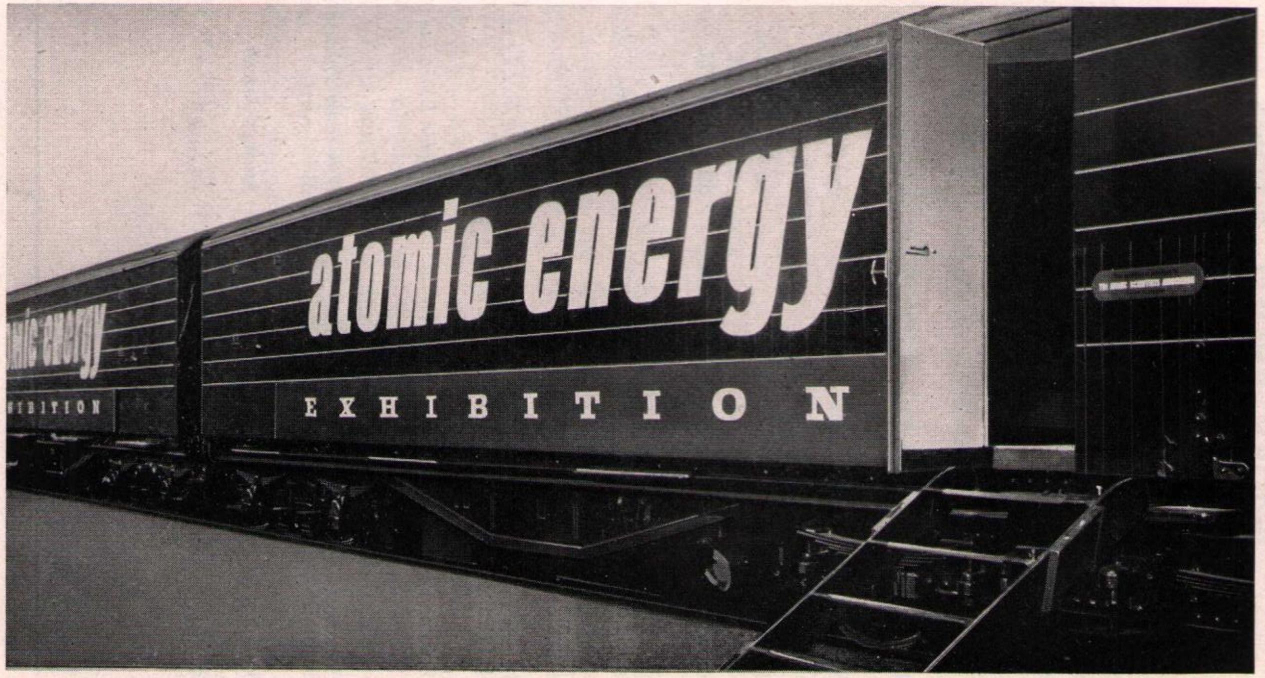
The exhibition you have seen has shown you the vast possibilities of atomic energy for good and evil.

DESTRUCTION

The atom bomb provides tremendous power for destruction. There is no defence against it. There is no secret about it, except some technical details which are discovered easily enough. Any industrial nation can discover these secrets and start producing atom bombs if it wishes. All industrial nations will want to set up plants for atomic power. These same plants produce materials from which to make atom bombs, if it is desired to misuse them for destruction.

CONSTRUCTION

If atomic energy is not so misused, it holds promises of great advances in medicine, in industry, in the supply of power, and as a result in our standard of living. *Which is it to be* ?


atomic energy
EXHIBITION

BOOKS ABOUT ATOMS AND ATOMIC ENERGY

Authors.	*Titles.*	*Publishers.*	*Price.*
E. N. da C. Andrade	"THE ATOM AND ITS ENERGY"	*Bell*	10/-.
Atomic Scientists' Association	"ATOMIC SURVEY"	*A.S.A.*	9d.
O. R. Frisch	"MEET THE ATOMS"	*Sigma Books Ltd.,*	10/6
G. Gamow	"ATOMIC ENERGY IN COSMIC AND HUMAN LIFE"	*Cambridge University Press.*	7/6.
K. Mendelssohn	"WHAT IS ATOMIC ENERGY"	*Sigma Books Ltd.,*	6/-.
R. R. Nimmo	"ATOMIC ENERGY"	*Pilot Press Ltd.,*	9/6.
R. E. Peierls and J. Enogat (Editors)	SCIENCE NEWS. No. 2 (Atomic Energy Number)	*Penguin Books Ltd.,*	1/-.
A. K. Solomon	"WHY SMASH ATOMS ?"	*Penguin Books Ltd.,*	1/-.
J. D. Cockcroft and others	"ATOMIC CHALLENGE"	*Winchester Publications Ltd.,*	8/6.
C. E. Vulliamy	"MAN AND THE ATOM"	*Michael Joseph*	8/6.
H. E. Wimperis	"WORLD POWER AND ATOMIC ENERGY"	*Constable*	6/-.

THE ATOMIC SCIENTISTS' ASSOCIATION

(Limited by Guarantee)

The Atomic Scientists' Association was formed early in 1946 by scientists of whom most had taken part during the war in the Atomic Energy project in Britain, Canada and the United States. Full membership is limited to graduate scientists with specialised knowledge of Atomic Energy ; the Association can thus speak as a body of experts.

The aims of the Association are as follows :

1. To bring before the public of this country the true facts about Atomic Energy and its implications.
2. To investigate and make proposals for the international control of Atomic Energy in order to help in the solution of this most pressing problem.
3. To help to shape the policy of this country in all matters relating to Atomic Energy.

The Association has held many discussions on the political problems of atomic energy, both domestic and international. In particular, it has issued memoranda on the vital subject of the international control of atomic energy, copies of which were sent to the delegates at the United Nations meetings. The Association has provided speakers for more than a hundred meetings during the last year and has co-operated with other organizations, especially the United Nations Association.

Associate membership is open to all interested members of the public at an annual subscription of one guinea. Associate members receive all publications of the A.S.A. including the monthly printed bulletin "Atomic Scientists' News". This bulletin can also be subscribed by non-members at the rate of 10/6 per annum.

Any inquiry about the Association or about membership should be sent to :—

THE GENERAL SECRETARY,
Atomic Scientists' Association
Clarendon Laboratory,
Parks Road, Oxford.

Published by the

ATOMIC SCIENTISTS' ASSOCIATION

(Limited by Guarantee)

Registered Office:

15 Bloomsbury Square, London, W.C.1

Printed by

EATON PRESS, OVERTON STREET, LIVERPOOL 7