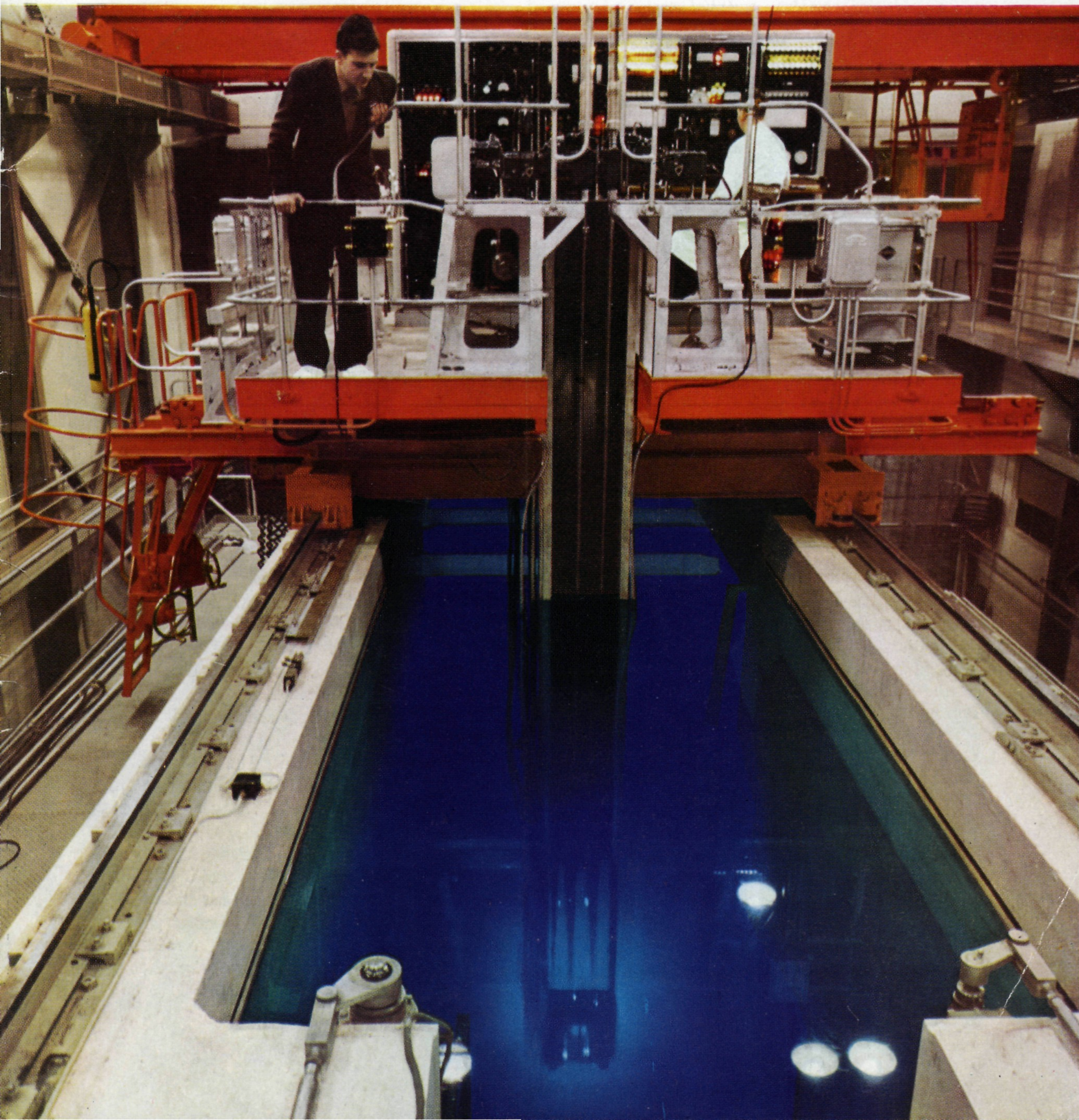
ATOM 1957

An illustrated summary of the
Third Annual Report of the

UNITED KINGDOM ATOMIC ENERGY AUTHORITY

1st April 1956 to 31st March 1957

Price 1*s*. 6*d*. net



An illustrated summary of the third annual report of the United Kingdom Atomic Energy Authority 1st April 1956 to 31st March 1957

During the year 1956–7 there were several major developments in the United Kingdom's nuclear power programme.

The practical achievement of nuclear power was celebrated by the opening of the U.K.A.E.A. station at Calder Hall by Her Majesty the Queen on 17th October 1956.

In December contracts were placed for the erection of the first two commercial nuclear power stations of the Central Electricity Authority. Provisional arrangements were also announced for the construction of a possible third station in England and for a fourth by the South of Scotland Electricity Board.

On 5th March 1957, the Minister of Power announced that the Government's White Paper programme of nuclear power (published in February 1955) was to be expanded. The original aim of 1,500–2,000 megawatts by 1965 was raised to 5,000–6,000 megawatts.

Increased attention was given to the application of nuclear energy to marine propulsion.

On the defence side two weapons trials were held during the period under review and preparations were made for the 1957 tests at Christmas Island.

Important steps were taken towards ensuring the United Kingdom's future uranium supplies both for defence and civil uses.

In March 1957, the constitution of a National Institute for Research in Nuclear Science was announced. The Governing Board of fifteen includes three representatives of the Authority: Sir John Cockcroft, Sir Donald Perrott and Dr. Schonland.

During the year the Nuclear Energy Trade Associations' Conference was formed by the following five trade associations: the British Chemical Plant Manufacturers' Association; the British Engineers' Association; the British Electrical and Allied Manufacturers' Association; the Scientific Instrument Manufacturers' Association; and the Water-Tube Boilermakers' Association.

Cover picture: 'LIDO', the 'swimming-pool' reactor at Harwell which came into operation in September 1956. The reactor is intended primarily for shielding studies and will play a major part in the development of marine propulsion units.

The Making of History

'To-day ... we are present at the making of history ... Atomic scientists, by a series of brilliant discoveries, have brought us to the threshold of a new age ... It may well prove to have been among the greatest of our contributions to human welfare that we led the way in demonstrating the peaceful uses of this new source of power.
I congratulate all those who have shared in this fine project.'

These words were spoken by Her Majesty the Queen when she performed the opening ceremony of the Authority's first nuclear power station at Calder Hall in Cumberland on 17th October 1956.

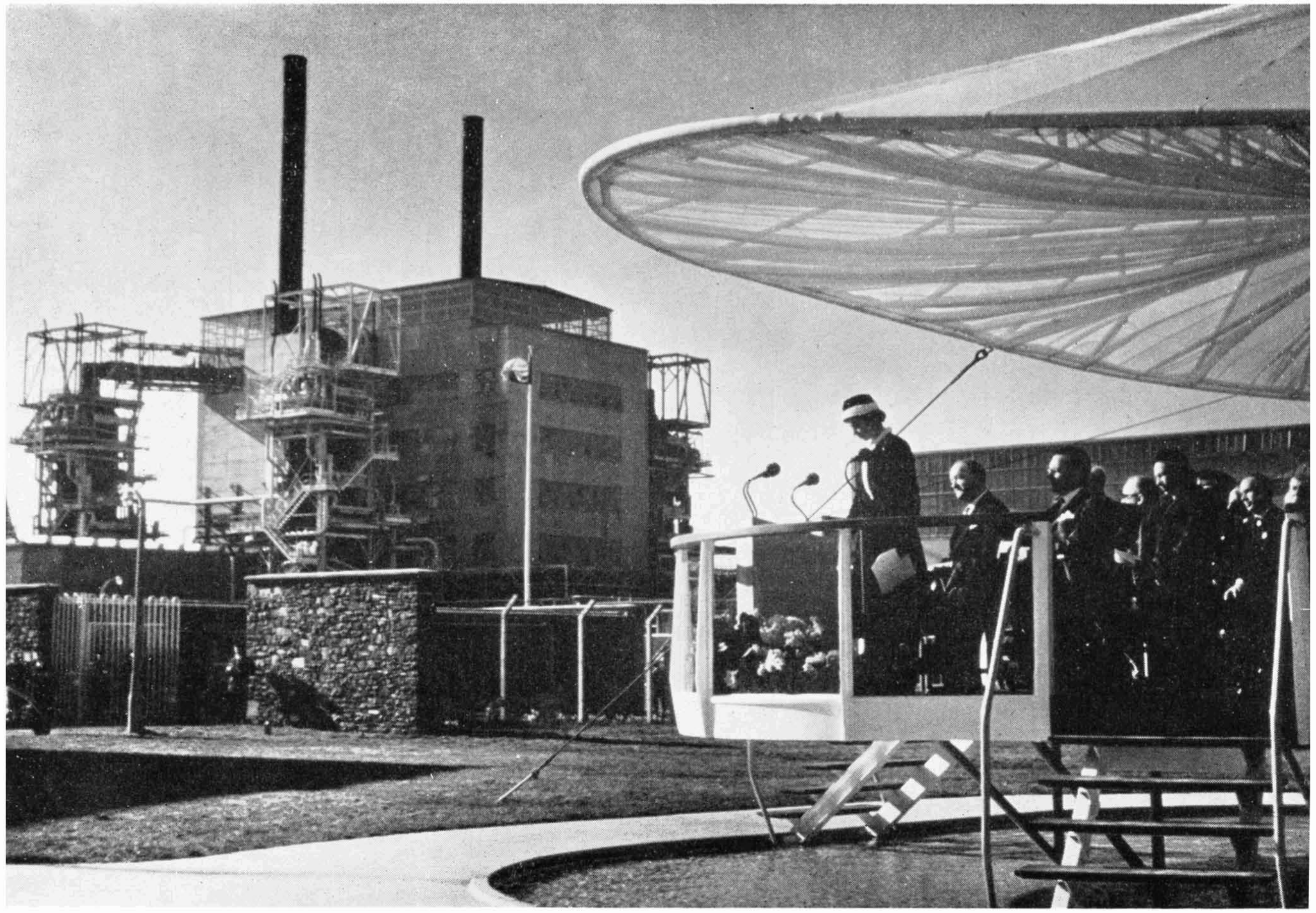
As Her Majesty pulled the switch on the control desk, electricity was diverted from use in the Authority's premises at Calder Hall and Windscale into the Central Electricity Authority's distribution grid.

For the first time, electricity from a full-scale nuclear power station was being delivered to a national distribution system.

Representatives of thirty-nine countries witnessed the ceremony.

The first reactor at Calder Hall was handed over for operation in May 1956. Charging with its uranium fuel began on 17th May and the reactor 'went critical' on 22nd May.

The 'critical size' of the reactor – the amount of uranium needed to maintain a chain reaction – was less than had been calculated. This meant that the 'neutron economy' (the excess number of neutrons available after sustaining the chain reaction) was better than had been predicted by theory and experiment.

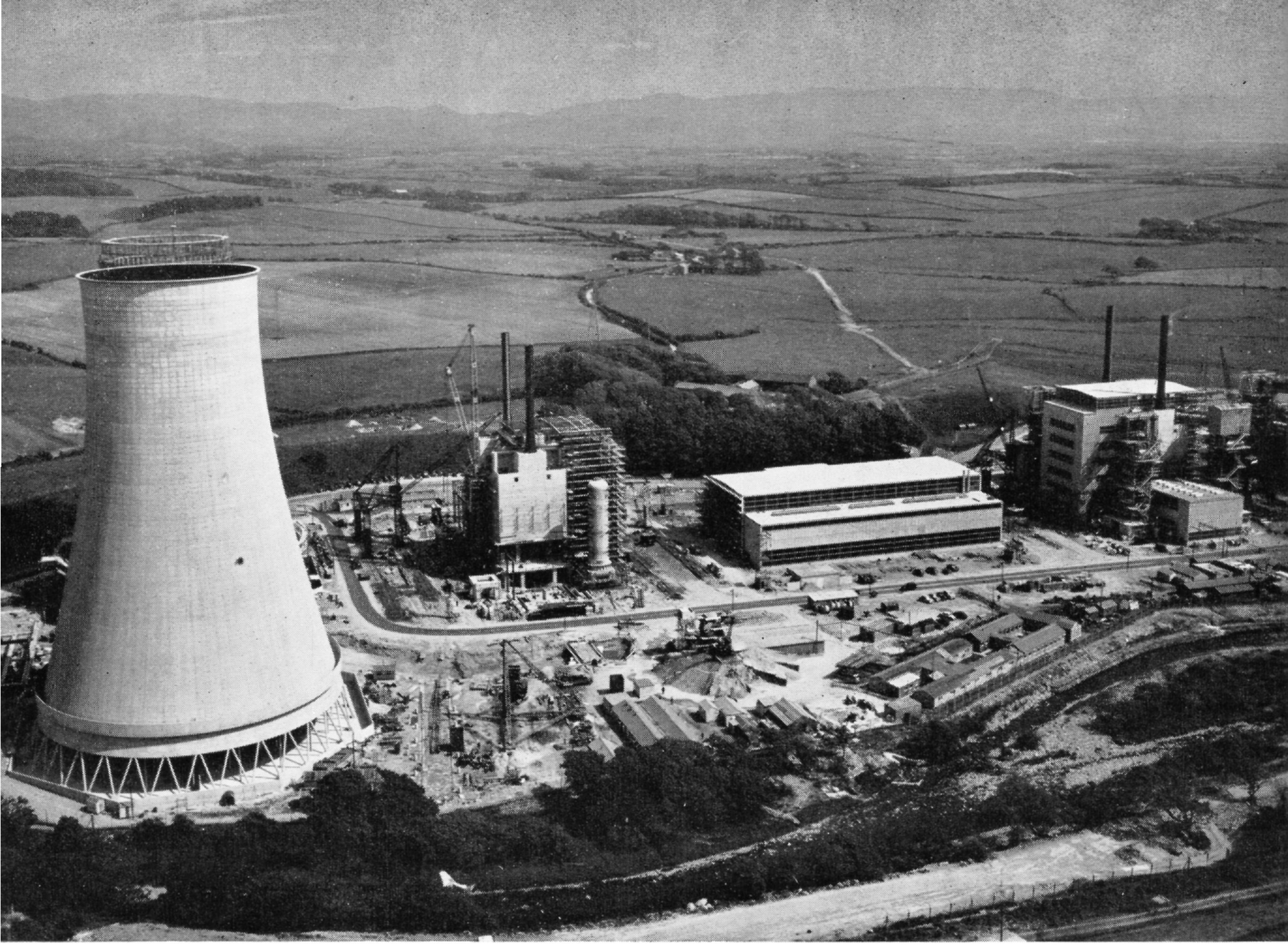


The scene at Calder Hall, Cumberland, when on 17th October 1956, Her Majesty the Queen pulled the switch that sent the first nuclear electricity into the National Grid.

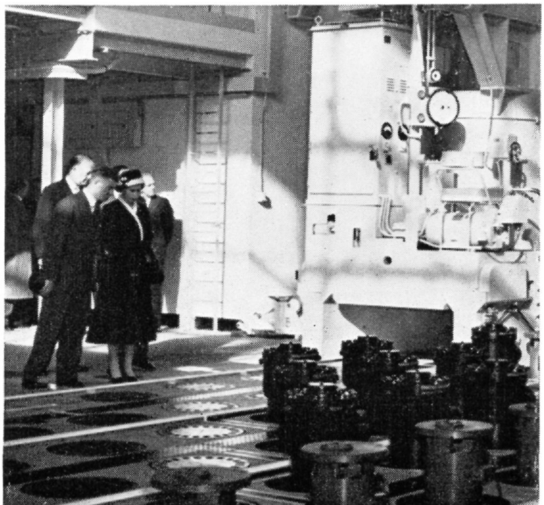
Generally speaking it can be said that operating experience at Calder Hall has been satisfactory. The plant has gone into operation with less trouble than might reasonably have been expected and it has worked reliably at the designed conditions of power level and temperature. These have, indeed, been exceeded with satisfactory results for appreciable periods.

The second reactor of Calder 'A', programmed six months behind the first, passed its testing period satisfactorily. It was handed over for operation at the end of November, 1956.

By 31st March 1957, Calder 'A' had exported 107,825,000 KWH of electricity, almost entirely from the first reactor.



Above: Work in progress on Calder 'B' station, scheduled for completion in 1958. *Right:* Her Majesty the Queen inspects the reactor charge floor of Calder 'A' during her tour of the plant after the opening ceremony. On the right is the fuel discharge machine.



The second reactor of the first Calder Hall station (Calder Hall 'A') was handed over for operation in November 1956. The second two-reactor station at this site (Calder Hall 'B') and the four reactors at Chapelcross, Dumfriesshire, are due to go into operation in 1959.

The total output for Calder Hall 'A' (two reactors) is 92 megawatts (electrical) of which 65 megawatts are supplied to the C.E.A. grid. 'A' and 'B' together will supply 150 megawatts to the grid. The electrical output from Chapelcross will be identical.

The Nuclear Power Programme

Calder Hall and Chapelcross are dual-purpose nuclear-power stations designed for the production of plutonium for the military programme as well as for the generation of electricity. They are owned and operated by the Atomic Energy Authority.

The Government White Paper, *A Programme of Nuclear Power*, published in February 1955, outlined a programme for the building – by the electricity authorities – of nuclear power stations designed first and foremost for the generation of electricity. As a by-product they will produce plutonium, not of 'military quality', but capable of being used as fuel in later, more advanced types of reactor.

The White Paper suggested that, if all went well, nuclear generating capacity owned and operated by the electricity authorities might total 1,500–2,000 megawatts by 1965.

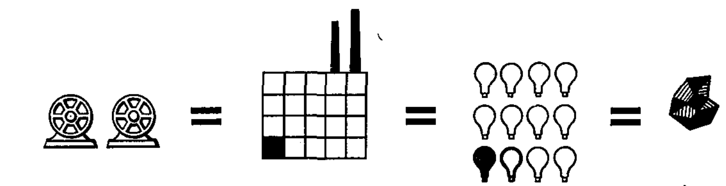
Since the publication of the White Paper technical progress on the basic Calder Hall design has been more rapid than was expected. For example, there has been development in the techniques for welding steel plate. At Calder Hall, the pressure vessel containing the reactor is made of 2-inch steel plate. The first nuclear stations to be built for the electricity authorities will have pressure shells of 3-inch steel plate. This will permit an increase both in the size of the reactor and in operating pressures and temperatures. Numerous other improvements have been made and the cumulative effect of these has been to make possible a much bigger size of station than was foreseen two years ago.

Bearing in mind that the White Paper envisaged that the first commercial stations would be of **100-150 MW** capacities, the rate of progress can be seen from the following figures. The Central Electricity Authority station at Berkeley, Gloucestershire, will have a capacity of **275 MW.** Their station at Bradwell, Essex, will have a capacity of **300 MW.** The South of Scotland Electricity Board are seeking consent for the construction of a **300-320 MW** station at Hunterston, Ayrshire. The Central Electricity Authority have announced that their third station, which is to be built at Hinkley Point, Somerset, will have a capacity of **500 MW.**

Towards the end of 1956 a review of technical developments by the Ministry of Power and other authorities concerned showed that a substantial improvement on the 1955 programme was possible and on 5th March 1957, the Minister of Power, Lord Mills, announced that nuclear power stations with a

Original Target for 1965

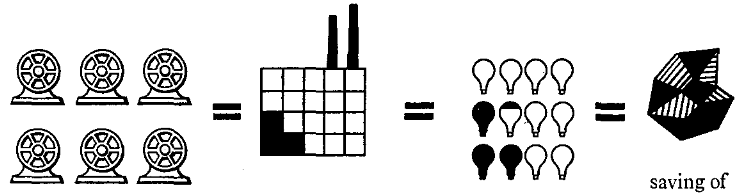
Government White Paper:
A Programme for Nuclear Power
February 1955



1·5 – 2 million kW = 5% total U.K. generating capacity = 9% total U.K. electrical output = saving of 6 million tons of coal

New Target for 1965

announced by Minister of Power, March 1957



5 – 6 million kW = 15% total U.K. generating capacity = 28% total U.K. electrical output = saving of 18 million tons of coal

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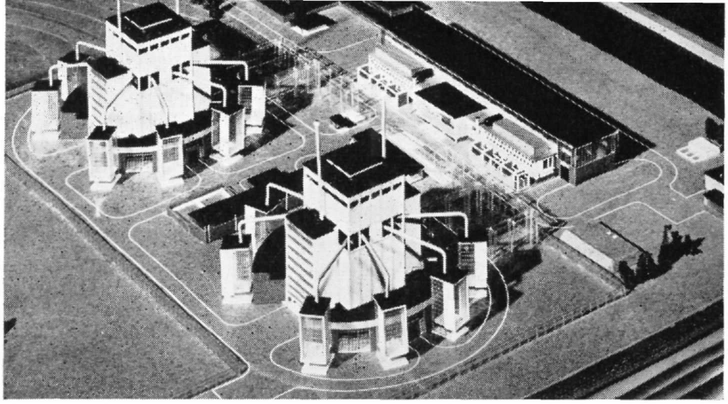
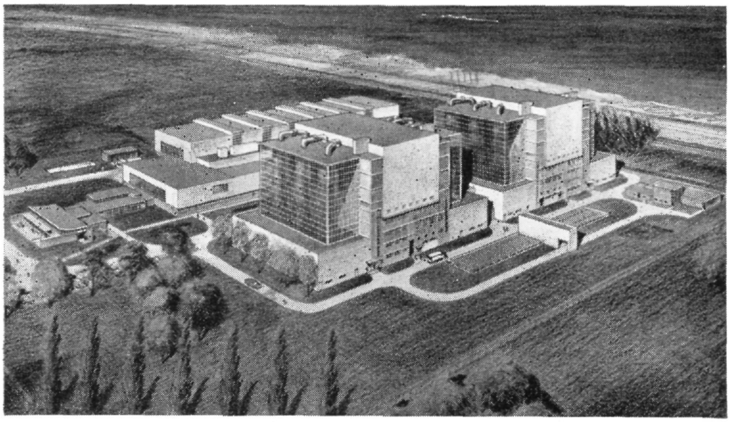
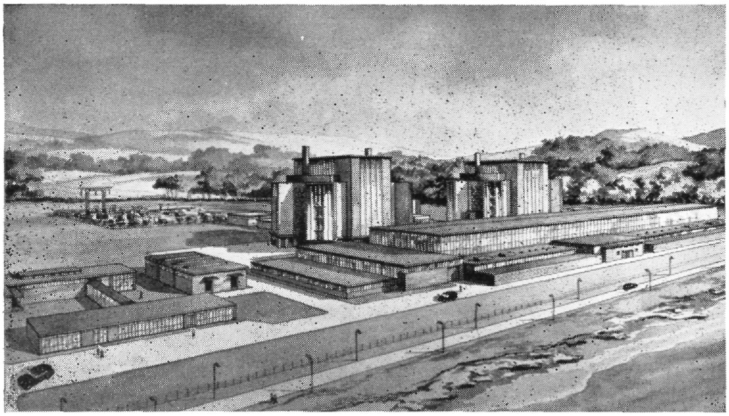


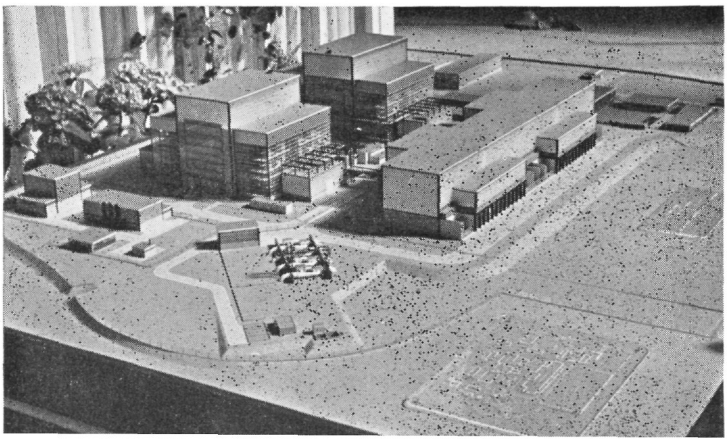
Model of the 275 MW C.E.A. power station now under construction at Berkeley, Gloucestershire, by the A.E.I.–John Thompson Nuclear Energy Company Limited.



Artist's impression of the 300 MW C.E.A. power station now being built at Bradwell, Essex by the Nuclear Power Plant Co. Ltd.



Artist's impression of the projected 300 MW station to be built for the South of Scotland Electricity Board by the G.E.C.–Simon-Carves Industrial Atomic Energy Group.



This is a design by the English Electric–Babcock & Wilcox–Taylor Woodrow Group for a 350 MW commercial nuclear power station. This group are in negotiation with the C.E.A. for a 500 MW station at Hinkley Point, Somerset.

total output capacity of between 5,000 and 6,000 megawatts would be in operation by 1965.

In a full year's operation, 6,000 megawatts of generating capacity, which would amount to some 15 per cent. of total capacity, would – when operating at a high load factor – save about 18,000,000 tons of coal. Thus nuclear power stations would be generating about a quarter of the total United Kingdom output of electricity.

On the same day that the Minister of Power gave details of the revised programme, the Northern Ireland Government announced that the Electricity Board for Northern Ireland would commission a 150 MW nuclear power station in 1963 or 1964.

By embarking on the revised nuclear power programme, the total capital investment of the electricity authorities in the ten years 1965–6 will be about £750 million more than if all the new capacity had been 'conventional' plant (total investment: £3,350 million). Capital costs per kilowatt of nuclear generating capacity, particularly for the early stations, will be high. Fuel costs will, however, be much lower than for conventional stations.

The cost per unit of electricity generated in the first batch of nuclear stations (when used for base load) is expected to be only slightly higher than the cost of electricity generated in the most advanced conventional plant that could have been commissioned at about the same time, assuming present coal and oil prices. The cost from the later batches of nuclear stations will fall and should soon be fully competitive with conventional plant.

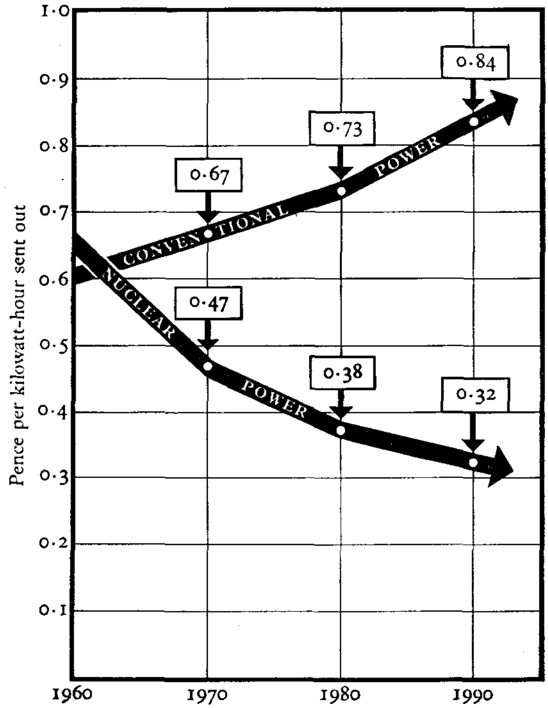
Though the 'power programme' stations will be owned and operated by the electricity authorities, the Atomic Energy Authority have a four-fold interest in their construction:

(i) They are carrying out an extensive programme of research and development. This involves both the development of improved fuel elements for the early stages of the programme and the design of more advanced stations for its later stages.

(ii) They are technical advisers to the electricity authorities for the nuclear side of the new stations.

(iii) It is their duty to procure adequate supplies of special materials such as uranium and graphite for the expanded programme.

(iv) They will fabricate the fuel elements for sale to the electricity authorities and buy them back after use so that they can separate the plutonium which will then be contained in the uranium.

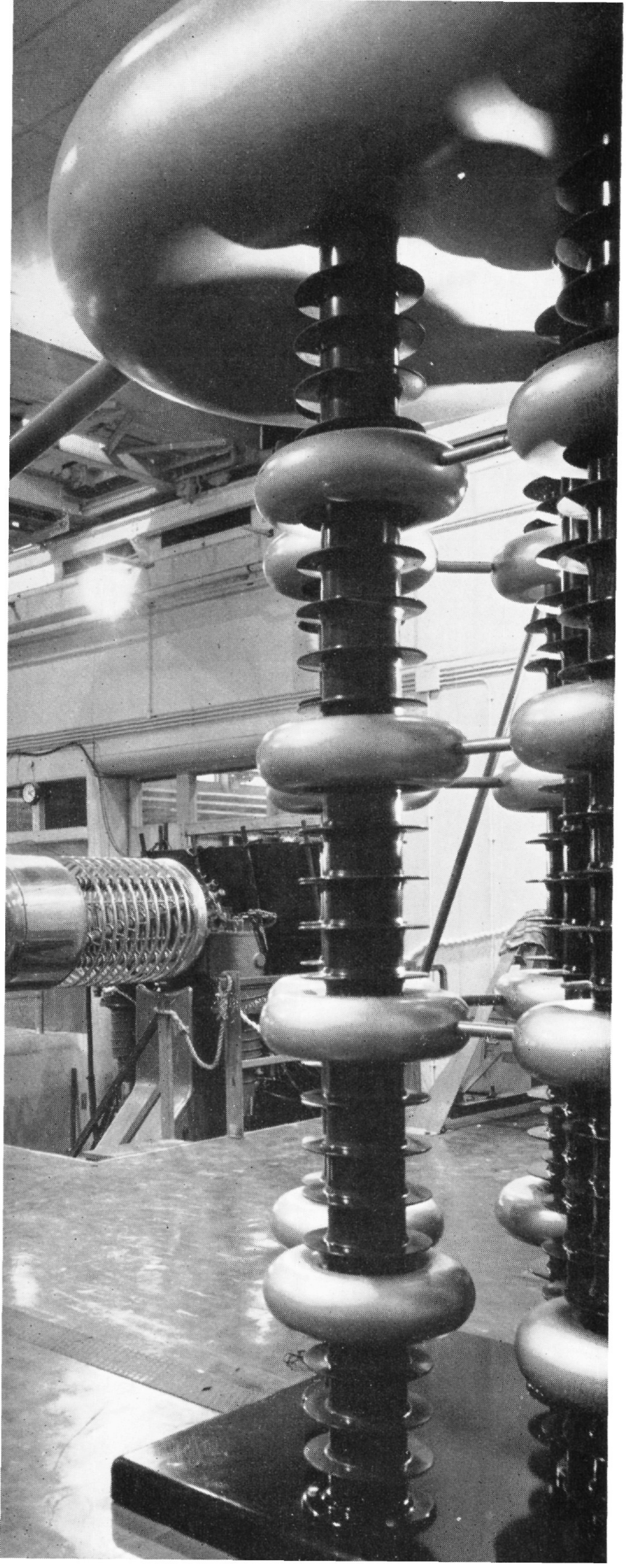


Nuclear Power Costs.

The above graph, comparing probable trends in the cost of power from nuclear stations and from conventional stations, is based on figures given by Sir Christopher Hinton in a lecture in March, 1957. "The figures for 1970, 1980 and 1990", he said, "are not to be regarded as firm estimates. They represent a serious and careful attempt to predict the future."

The prices charged for the fuel elements will be calculated on a commercial basis. The price paid for the irradiated fuel elements will be calculated with reference both to the estimated value of plutonium as a fissile material for use in advanced reactors and to the cost of processing the irradiated fuel.

The revised programme does not look beyond 1965. However, it is reasonable to expect that the total nuclear capacity in commission by 1975 should be considerably larger than the 10,000–15,000 megawatts indicated in the 1955 White Paper.



The Way Ahead . . .

The primary objective of the Authority's Reactor Research and Development Programme is the development of reactors offering the prospect of producing the cheapest power possible for this country's nuclear power programme.

The Gas-Cooled Graphite-Moderated Reactor

The gas-cooled graphite-moderated reactor is likely to provide the basis of the United Kingdom nuclear power programme for many years to come. The Authority believe that there are considerable possibilities of further developments of this type of reactor which should lead to substantial lowering of capital costs. One objective is to increase the operating temperature of the fuel from 400° C. to about 600° C. This would increase the thermal efficiency and allow the electrical output of a two-reactor station to be raised to about 800 *megawatts*. This would call for ceramic fuel elements instead of the present metallic elements, and for a canning material capable of withstanding the high temperatures. Uranium oxide ceramic fuel elements and beryllium canning are being developed for these purposes.

It should also be feasible to re-design the reactor to make it suitable for smaller outputs of the order of 30 megawatts of electricity. The reactor size (even using natural uranium) and capital cost would be appreciably less than at Calder Hall.

Left: The Cockcroft-Walton high voltage generator at Harwell, with the injector of the proton-linear accelerator centre-background.

Right: The Dounreay establishment showing the spherical containment vessel of the fast breeder reactor and, to the left, the materials testing reactor.

Research and Development

Sodium-Cooled Graphite-Moderated Reactor

A zero-energy reactor, NERO, has been constructed to study the physics of advanced graphite-moderated reactors. This will provide information on both the sodium-cooled and gas-cooled systems. The use of liquid sodium would allow the amount of heat extracted from each ton of uranium to be increased several times over the early gas-cooled reactors. The advantages over the later types would be less and it is not yet known whether they would justify the building of a prototype.

The Fast-Breeder Reactor

The Dounreay fast-breeder reactor is expected to start operation in 1958. The zero-energy reactor ZEUS at Harwell has been used to study various designs for its core. The Dounreay reactor is essentially a reactor experiment, which could lead to the construction of commercial fast reactors during the 1970's when substantial supplies of plutonium fuel are available from the civil power programme.

The High-Temperature Gas-Cooled Reactor

High priority is being given to the development of a thermal breeder reactor working on the uranium-233/thorium cycle (i.e. uranium-233 producing heat *and* transmuting thorium into a fresh supply of uranium-233 fuel). This would use a ceramic uncanned fuel able to withstand temperatures of the order of 800° C. It should be possible for a reactor experiment on this system (which promises high efficiencies and low fuel costs) to operate by 1960. The results of fuel tests in the BEPO and DIDO reactors at Harwell are encouraging.

The Aqueous Homogeneous Reactor

The uranium-233/thorium fuel cycle could also be used in an aqueous homogeneous (water solution) reactor. The uranium fuel would be dissolved in heavy water. Zero energy studies are proceeding on a facility known as ZETR.

Liquid-Metal Fuelled Reactor Systems

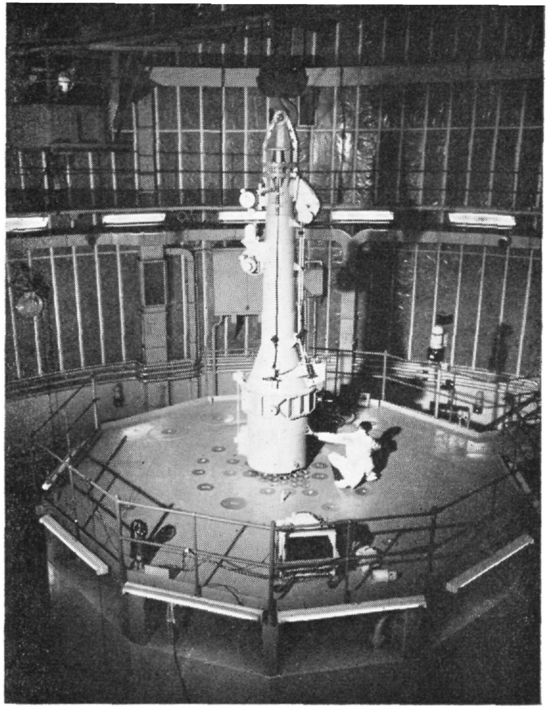
Liquid-metal fuels may be used in thermal breeder systems operating on the uranium-233/thorium fuel cycle or fast fission systems on the plutonium/uranium-238 cycle. One form is a core of uranium-233 fuel dissolved in liquid bismuth; this is surrounded by a thorium slurry.

Ship Propulsion

The development of a pressurised-water reactor for the propulsion of submarines is, by agreement with the Authority, being undertaken by the Admiralty, who have placed development contracts with Vickers Nuclear Engineering Ltd. (Vickers. Ltd., Rolls Royce, Ltd., and Foster Wheeler, Ltd.).

The Authority are collaborating in certain aspects of the work. The LIDO 'swimming pool' reactor at

'Hotspur', the apparatus at A.E.R.E. which removes fission products from irradiated fuel elements by melting.



DIDO, the heavy-water moderated reactor at Harwell, the most powerful of its kind in Western Europe.

Harwell is being used for studies of shielding against radiation. The land-based prototype of the naval reactor will be built at Dounreay. The reactor will use enriched uranium fuel elements in a non-corroding alloy; good progress has been made with their development.

The Authority are represented on an Admiralty Committee for the study of the use of reactors in merchant ships. The large ship, which spends most of its time at sea, such as a tanker, might be powered by a scaled-down version of the Calder Hall type of reactor. For smaller ships it will probably be necessary to develop a new type of reactor. Two systems are being studied. An organic-liquid-moderated reactor might be built in small sizes to give outputs of the order of 20,000 shaft horsepower or less. A heavy-water gas-cooled reactor is the second possibility. The Authority will decide during the present year which should have priority. An investigation into this subject is being carried out at Harwell by the Authority and the British Shipbuilding Research Association.

Nuclear Power Units of Medium Output

It seems probable that a large part of the export demand for nuclear power would be for units of 30 megawatts or less. Power units of the type being considered for ship propulsion may prove to be suitable for this role.

WHAT *IS* A BREEDER REACTOR?

The fuel of a nuclear reactor is called *fissile* material, i.e. its nuclei can be split to produce heat. There are also substances known as *fertile* materials. If a *fertile* material is put into a reactor with a *fissile* material, it can be turned into *new fissile material* as the original fissile material 'burns away'.

In certain types of reactor it is possible to finish up with more new fissile material than you started with. In other words you have been 'breeding' new fuel. So this kind of reactor is called a 'breeder' reactor. It is *not* something for nothing. You will not obtain new fissile material unless you keep the system supplied with fertile material.

Imagine a coal mine with one ton of coal at the surface. By using this ton to drive a steam engine you can haul up new coal from the bottom of the pit. Part of this can be used to work the steam engine again and raise still more coal. Thus you can eventually raise and use *all* the coal.

Fissile materials (pithead): Uranium 235, Uranium 233, Plutonium 239.

Fertile materials (down the mine): Uranium 238, Thorium 232.

Research and Materials Testing Reactors

Three new reactors were commissioned at Harwell during the year:

LIDO. 100 kW swimming-pool reactor; for research into shielding from radiation, particularly the development of light-weight shields; being used in connection with the naval reactor.

DIDO. 10 MW high-flux materials-testing reactor; cooled and moderated by heavy water; will test samples of moderators, coolants and fuels for other reactors.

NERO. Zero-energy graphite-moderated reactor for investigating the physics of the more advanced types of graphite-moderated reactor (gas- or liquid-metal-cooled).

Work proceeded during the year on the two PLUTO materials-testing reactors at Harwell and Dounreay.

Although the greater part of Harwell's research is concerned with the technology of reactors and the processes associated with them, about a fifth of the effort has been devoted to fundamental research – research designed to broaden knowledge about the bases of the sciences from which technology is developed. The aim is to ensure that, when new technical problems arise in project development, the fundamental scientific knowledge on which to base a solution is available.

Controlled Thermonuclear Reaction

Research has continued at Harwell into ways of obtaining power from controlled thermonuclear or fusion reactions (present-day power reactors are *fission* reactors).

The object is to heat isotopes of hydrogen to temperatures in the region of 100,000,000° C. at which the nuclei fuse to form heavier nuclei, releasing energy in the process. Temperatures of several hundred thousand degrees have been recorded. A major piece of experimental apparatus for investigating this problem has been designed and built in collaboration with an industrial firm. With this equipment which is almost complete it is hoped to reach temperatures at which fusion reactions can be detected.

Particle Accelerators

Research in nuclear physics requires machines capable of accelerating charged particles over a very wide range of energies, from a few hundred keV to thousands of MeV. One valuable machine at Harwell is the 4 MeV electrostatic generator.

To extend research on nuclear structure, a new generator is being developed by the Research Group in collaboration with the Weapons Group (who are to have a similar machine) and an industrial firm. It will give particles of energies up to 12 MeV.

A larger machine whose construction is well advanced is the 50 MeV proton linear accelerator. The first stage which will accelerate protons up to 10 MeV is almost complete. The later stages, being manufactured by an industrial firm, should be finished by the end of 1957.

Design is well advanced for a new type of proton synchrotron for an energy of 6,000–7,000 MeV. Protons would be accelerated to 15 MeV in an improved linear accelerator (based on the 50 MeV machine) and injected for the main part of the acceleration into a magnet ring 120 feet in diameter and weighing 6,000 tons. If it is decided to build, this machine will be one of the main tools of the National Institute for Research in Nuclear Science.

Adjusting a fuel element in NERO, the 'infinitely-variable' reactor assembly at Harwell.

The Authority and Industry

The placing of contracts with private industry for the building of the first nuclear power stations for the electricity authorities was the result of two years' close collaboration between the Atomic Energy Authority and four groups of industrial firms.*

During this period of collaboration the design teams of these organisations and staff seconded by the electricity authorities were trained by the Authority in the design of gas-cooled graphite-moderated reactors of the Calder Hall type.

The firms concerned will build their own versions of this type of reactor, designed primarily for power production and incorporating the firms' own technical developments, by arrangement with the Authority, who will grant them a non-exclusive manufacturing licence in return for a royalty on each reactor sold.

As part of these licence arrangements the Authority will continue to keep the firms informed of the results of further research and development work undertaken by the Authority on this type of reactor. Collaboration will continue between the Authority, the electricity authorities and the manufacturers with the object of further improving the basic design.

To keep industry broadly informed of work in progress which might lead eventually to industrial application, the Authority hold conferences from time to time to which representatives of industry are invited.

Access Agreements

Access agreements may be granted to firms seeking information with a view to its commercial exploitation. Although there has been a steady flow of enquiries from industry, only a few have as yet resulted in the negotiation of such agreements. One reason is that many firms were unaware of the large amount of published information already available.

Exports

Although the export of reactors is the responsibility of industry, the Authority are closely concerned for three reasons. First, the Calder Hall type of reactor is the only type of reactor of British design at present available for export from the United Kingdom. As its designers and operators, the Authority are well qualified to describe its features and advantages to potential customers. Secondly, it will be the responsibility of the Authority to supply fuel elements for reactors of British origin exported by industry. Thirdly, the Authority have a part to play in the inter-governmental negotiations which are necessary before reactors or fuel elements may be supplied to other countries.

Patents

It is the Authority's policy to make their inventions available for use by British industry. Apart from inventions of major importance to the nuclear power programme, the Authority now have some 230 inventions which are protected by patents or patent applications and cover a wide range in the engineering, chemical, metallurgical, electronic and instrument fields. Thirty-nine patent licences have been granted to British firms and six to firms in other countries.

In addition, the rights in a considerable number of United Kingdom patents and patent applications, covering atomic energy inventions that originated in the U.S.A. and Canada, have been acquired by the Authority under an interchange agreement entered into on 24th September 1956, between the United Kingdom, U.S.A. and Canadian Governments.

Information

For well-known historical reasons, a large proportion of the technical information on atomic energy has become concentrated in the hands of the Authority and continuing research places more there. The Authority have a duty to disseminate this information, especially within industry, as widely as is compatible with the national interest.

In 1946 nearly all atomic energy information was subject to security restrictions. These have been

* The four original groups of industrial firms (sometimes referred to as 'consortia') are: The G.E.C. – Simon Carves Industrial Atomic Energy Group; Nuclear Power Plant Co., Ltd.; The English Electric Co., Ltd. – Babcock and Wilcox, Ltd. – Taylor Woodrow, Ltd.; A.E.I. – John Thompson Nuclear Energy Co., Ltd. A fifth group has been formed by the association of Atomic Power Constructions, Ltd., and Nuclear Civil Contractors.

progressively relaxed by periodic conferences between the United Kingdom, the U.S.A. and Canada. The only information now classified is that relating directly to plants producing fissile materials for military purposes, to military propulsion and package reactors, and, of course, to nuclear weapons.

Among the subjects now 'declassified' is a very wide range of information on the design, construction and operation of power reactors of all kinds, together with details of the metallurgy of fuel materials, the fabrication of fuel elements, and the effects upon them of radiation – all crucial matters for power development.

To make these changes effective the Authority are reviewing the thousands of classified reports to see which can be made available to the public; in doing so they have to take account not only of the agreed security rules, but also of the commercial protection required.

The more useful documents will be reprinted and distributed, as are new reports, to the 'depository libraries'* in the United Kingdom and to official atomic energy projects abroad. Others, considered obsolescent, will not be reprinted; but lists of them will be issued and it will be possible to borrow them from Authority libraries.

In addition to documents of this type, the Authority publish many unclassified reports and a large number of papers by Authority staff appear in scientific and technical journals. During 1956–7 there were about 350 reports and 450 published papers. A monthly list of these may be obtained from the Librarian, Atomic Energy Research Establishment, Harwell. Copies of unclassified reports are placed in the depository libraries. Some reports are sold through Her Majesty's Stationery Office. Bibliographies and lists of articles in the world's technical press are issued free of charge by the Librarians of both the Research and the Industrial Groups.

Training

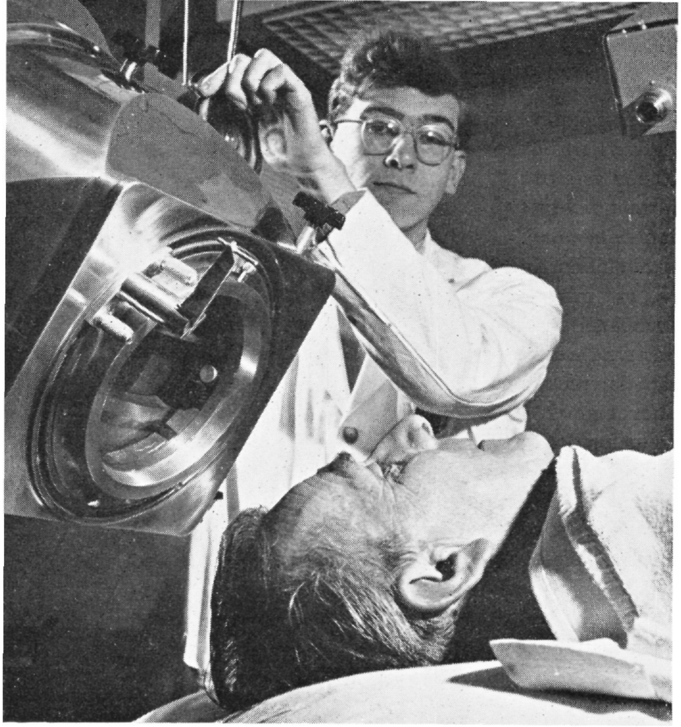
The Reactor School at Harwell has continued to give training to suitably qualified students from industry on the science and engineering of nuclear power stations and their ancillary processes. Up to and including the first course in 1957, a total of 471 students had passed through the school. In addition two short courses have been given to industrial executives with a technical background.

*See page 22.

Students from British industry, attending the Harwell Reactor School, at work in the control room of the reactor GLEEP.

A Reactor Operations School has been set up at Calder Hall, where students receive theoretical and practical instruction in the operation of the reactors. Students for the six weeks' course will be expected to have attended the Harwell Reactor School or to have reached a comparable standard of knowledge.

Over 900 students have passed through the Isotope School at Harwell, since it opened in 1951. During the current year specialised courses have been held in radiological protection, autoradiography and the uses of radioisotopes in medicine. There are plans to increase the size and scope of the school.



The Caesium 137 unit, installed at the Royal Marsden Hospital, Sutton, for the treatment of cancer.

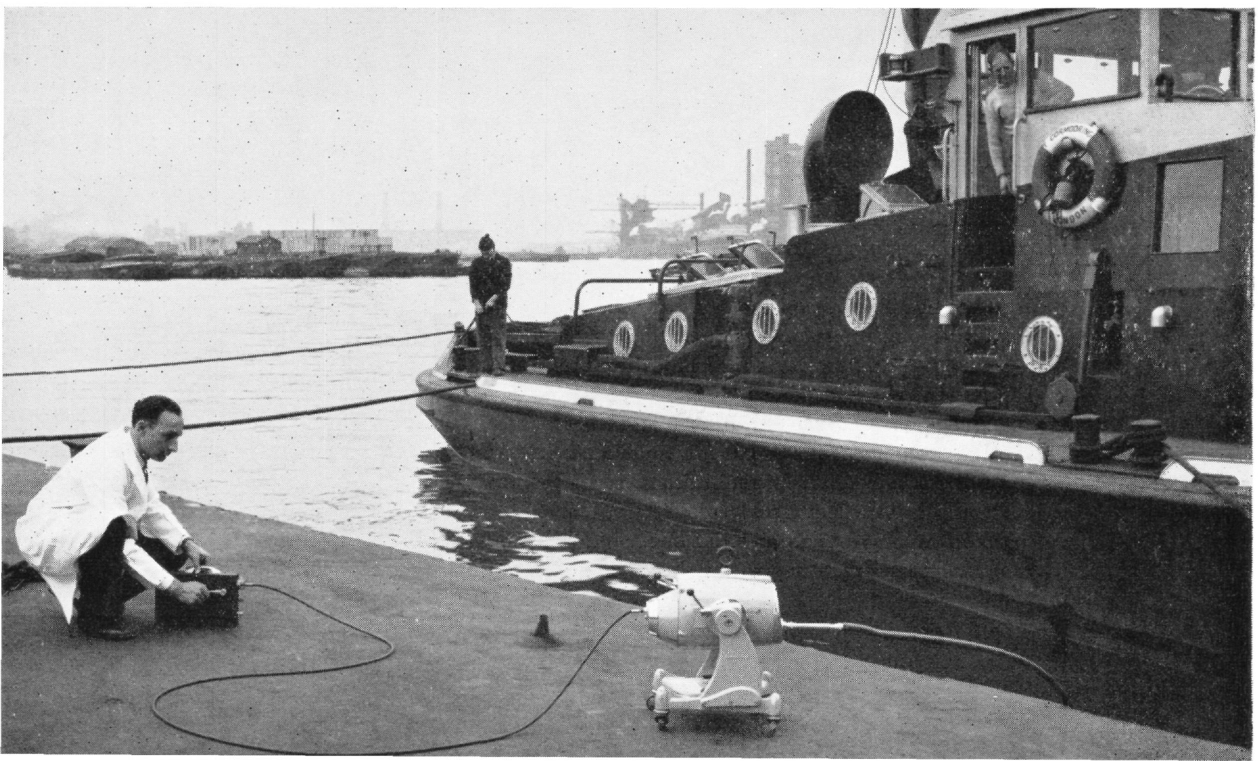
Mobile gamma radiographic equipment in use at Greenwich; an underwater radiograph of a tug's side-plate is being made to investigate a suspected fracture.

Isotopes and Irradiation

Sales of radioisotopes continued to increase during the year. The total value of sales was about £541,000 of which £154,000 was from the Isotope Division at Harwell and £387,000 from the Radiochemical Centre at Amersham. This total represents an increase of 12 per cent. over the previous year.

Half of these sales were overseas. Exports went to 52 countries, among the principal buyers being Canada, France, Germany, Japan, the U.S.A. and Sweden.

There will be a substantial increase in the quantity of radioisotopes produced by irradiation in nuclear reactors when the new high-flux reactors DIDO and PLUTO are brought into use for isotope production. In addition the production of cobalt-60 in the Calder Hall reactors is being considered. Fission product caesium-137 is being separated in an experimental plant at Windscale and several large sources have been made. A certain amount of strontium-90 has also been produced. The demand for these sources



far outruns present production capacity and the Authority is considering the construction of a plant to produce very much larger quantities of caesium-137 and strontium-90.

Two sources of 1,200 curies of caesium-137 have been made for teletherapy work. One of these is already in use at the Royal Marsden Hospital, Sutton. Cobalt-60 for industrial and medical uses has been sent in quantities of 100–150 curies to fourteen countries including Japan and Australia. A number of hospitals and universities have been equipped with cobalt-60 sources.

The Grove airfield site, now known as the Wantage Radiation Laboratory, has facilities for two 10,000-curies sources of cobalt-60; eight sources of 2,000 curies each; and four sources of about 200 curies each. A 4 MeV linear accelerator has also been installed.

Novel products can be prepared by irradiation. For example, rubbers and plastics can be treated by radiation to withstand higher temperatures than untreated products. The Technological Irradiation Group maintains close collaboration with industry and eight firms have seconded staff to work at the laboratory.

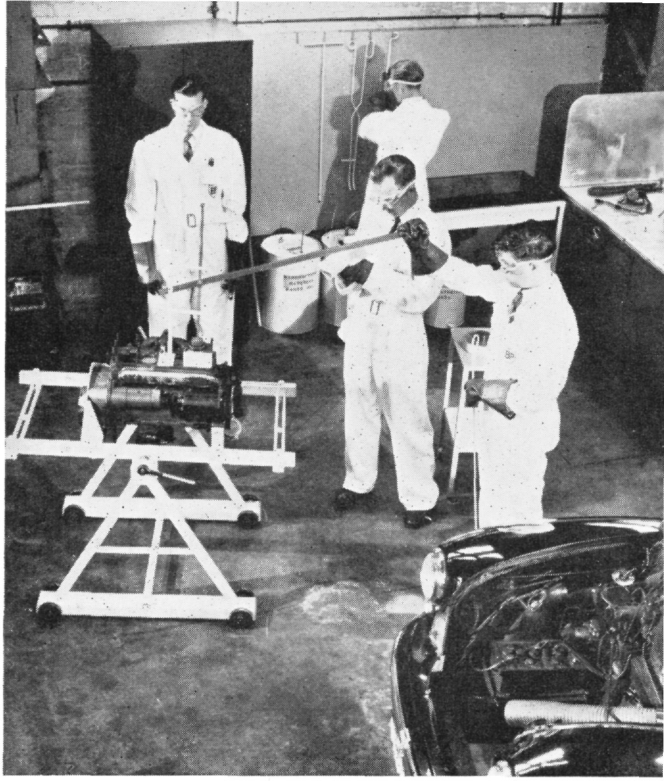
Radiation can also be used to sterilise heat-sensitive materials including drugs; bones and arteries used for surgical transplants; and a range of food products. There is also research on radiation effects on plant genetics and the control of insect pests.

New Uses for Radioisotopes

The movement of pebbles on beaches has been followed by 'labelling' them with radioisotopes and tracing them with portable detectors after they have been put into the sea. Ten times more effective than the use of painted pebbles, this method opens up new possibilities for studying coastal erosion and build-up.

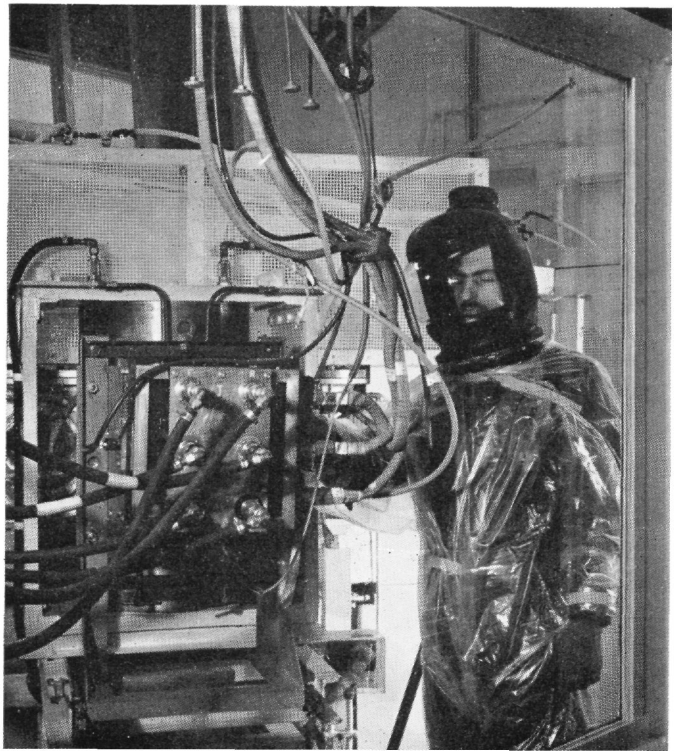
A cheap method has been developed for continuously determining sulphur and lead contaminants in liquid hydrocarbons in oil-processing.

Radioisotopes have been used as tracers to measure the material throughput rates, hold-up and re-circulation in cement and fertiliser plants. Other industrial applications have included a self-adjusting gauge to indicate continuously the liquid level in enclosed pipes and a compact gauge to be used in a borehole for underground measurement of soil density.



Above: fitting a radioactive piston ring into a car cylinder block as a preliminary to a study of engine wear.

Below: 'Hermes' – the Heavy Element Radioactive Material Electro-magnetic Separator at A.E.R.E.



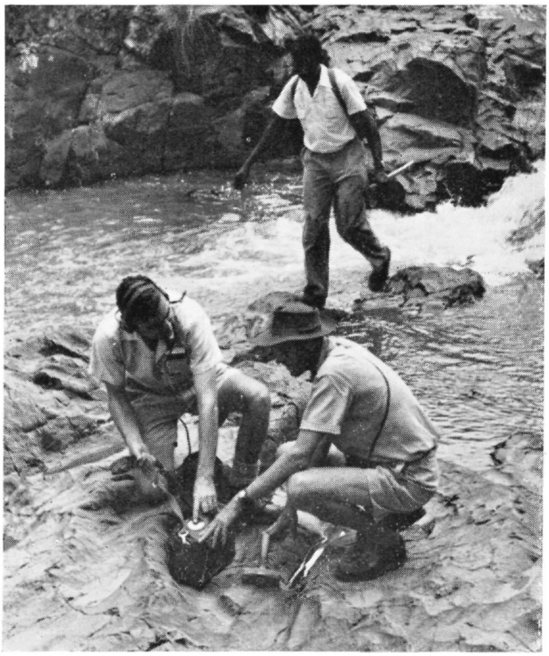
New Fuel for New Power

The Atomic Energy Authority is responsible for obtaining uranium for the nuclear power programme.

The requirements of such a programme – together with Britain's military requirements and what is known of the civil demands of other countries – would, a few years ago, have seemed impossible to satisfy.

This is no longer so. Production of uranium oxide in the free world has increased many times in the past ten years and is expected to be about 40,000 tons a year by 1959.

The Authority's requirements are assured for some years ahead. Nevertheless more uranium from more mines will be required to feed the programme in the later 1960's. Indeed it is clear that demand for uranium will increase throughout the 1960's.



Geologists in Southern Rhodesia check an outcrop of rock for radioactive ore content with a Geiger counter.

In the 1970's it should be possible to expand the programme without a *proportional* increase in the need for uranium. This is for two reasons. First, more advanced reactors should have a better 'burn up' of uranium. Secondly, reactor systems should be in operation that can use thorium; thorium is not naturally a nuclear fuel but in certain types of reactor it can be turned into a fuel.

It is none the less essential that vigorous prospecting should continue. Consequently the Authority decided that they should play a greater part in stimulating prospecting in suitable areas.

The Authority have indicated their willingness to buy chemical concentrates (containing 500 short tons per annum of uranium oxide) in the *Federation of Rhodesia and Nyasaland* and expect shortly to publish terms on which they will buy uranium ores up to an annual total of 100 tons of contained uranium oxide. This offer framed to meet the needs of small producers will remain open for seven years. The Authority have also offered the Federation free geological assistance in the search for uranium.

As the year ended arrangements were in hand for a similar type of guarantee to buy concentrates from existing or future mines in certain of the *Colonial and Dependent Territories.*

The Authority's office at Salisbury, *Southern Rhodesia*, continued to give advice and assistance to prospectors throughout the Federation. Arrangements were made to open a similar office at Dodoma in Tanganyika to serve *Kenya*, *Uganda* and *Tanganyika.* Reconnaissance surveys were undertaken during the year of the promising Buller Gorge area in *New Zealand* and of parts of *Swaziland.* Towards the end of the period, reconnaissance work was undertaken in *West Africa* and *British Guiana* on the Authority's behalf.

Where the volume of prospecting for radioactive minerals is inadequate the Authority intend, from time to time, to undertake prospecting work. They will not, however, enter into mining operations on their own account.

Two experimental airborne surveys were undertaken during 1956: one in *Northern Rhodesia* and one

A helicopter in use at Buller Gorge, New Zealand, where extensive uranium-prospecting surveys are in progress.

in *Southern Rhodesia*. These surveys provided encouraging evidence of the efficacy of the latest types of electro-magnetic apparatus and Harwell scintillation counters.

During the year manufacturers of electronic equipment produced an improved form of ratemeter which will assist the prospector on foot. Weighing only about three pounds, these instruments work on torch batteries which have a long life in the field.

The Authority are providing to the Colonial geological Surveys, on extended free loan, one of these instruments for every geologist in the field. Two specially adapted instruments were provided for the *British Antarctic Expedition*.

No uranium from new sources was received during the year. The material arriving at the uranium factory at Springfields, Lancashire, still consists of concentrates from the *Belgian Congo, South Africa,* Rum Jungle and Radium Hill (*Australia*).

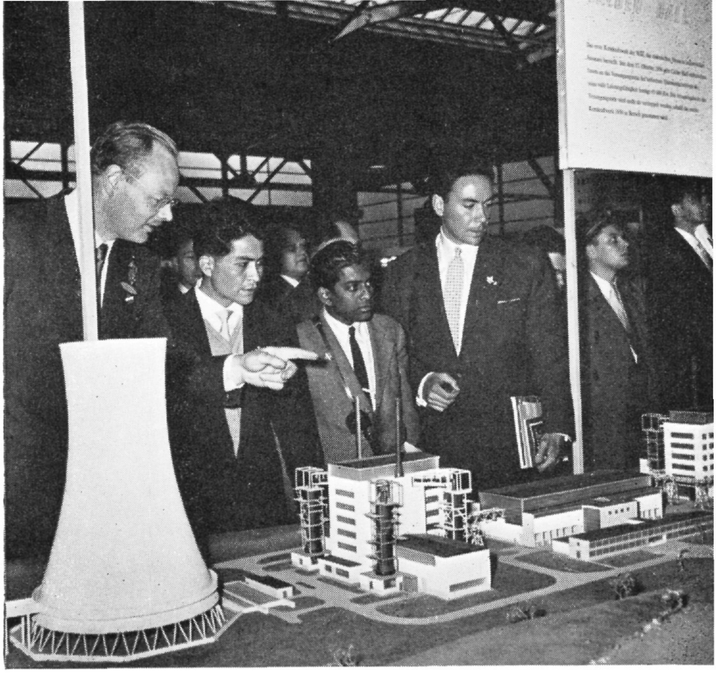
The Authority will purchase, during the next five years, uranium to the value of about $115,000,000 from the Canadian Government Agency. Supplies from *Canada* to meet the Authority's needs after 1962 were under negotiation at the end of the period.

Progress in bringing the Mary Kathleen Mine (*Australia*) to production has continued. Production of uranium began at the Nkana Mine in the *Central African Federation*. This small plant will be used in connection with the Authority's offer to buy small parcels of ore from small producers in the Federation.

The Authority's office at Salisbury in *Southern Rhodesia* has helped to evaluate a deposit of monazite (a thorium-bearing mineral) at Monkey Bay on Lake Nyasa.

Purchases of beryl have been increased because of the likelihood of the use of beryllium as a 'canning' material for the fuel rods of natural uranium in a graphite-moderated reactor.

Relations with other Countries



A representative of the Nuclear Energy Trade Associations' Conference explains a site model of Calder Hall to visitors from Peru, India and Portugal at the 1957 Hanover Trade Fair.

Representatives of thirty-nine countries attended the inauguration of the Calder Hall nuclear power station by Her Majesty the Queen and even larger numbers of scientists and engineers from overseas attended the Calder Hall Symposium held by the British Nuclear Energy Conference in November 1956, when representatives of the Authority and industry described the technical problems encountered and overcome.

The successful commissioning and operation of Calder Hall created great interest in the natural-uranium gas-cooled type of reactor in many countries. For countries with increasing energy demands and shortages of fossil fuels, the type of nuclear power station now being constructed for the United Kingdom electricity authorities offers an attractive prospect of obtaining power in a relatively short time and at reasonable cost, from a reactor type which is inherently safe and of proved reliability. The Authority, in close co-operation with the United Kingdom firms principally concerned, have taken great pains to ensure that all overseas enquirers are given the information they need to evaluate the suitability of this reactor type for their own purposes and in their own particular circumstances. In addition the Authority have declared their readiness to supply fuel elements, under long-term contracts, for nuclear reactors exported from the United Kingdom.

Active co-operation with many countries and international organisations continues to grow and in a number of cases formal agreements are in course of negotiation. These are necessary where reactors or significant quantities of nuclear fuel are to be supplied from the United Kingdom. Relations with the following countries call for special comment:

Canada: A steady two-way flow of visitors and information continues. Closer collaboration on certain reactor systems is under consideration.

Australia: The DIDO research reactor at Lucas Heights (Sydney), nears completion. Australian A.E.C. staff who have been working at Harwell returned during the year to take up work at the Commission's own research establishment.

South Africa: Sir Edwin Plowden, Chairman of the Authority, visited South Africa to establish closer contact on uranium production and other aspects of atomic energy development.

India: Mr. Nehru acknowledged the Authority's advice and help in providing fuel for the Indian swimming-pool reactor. The Authority have helped India to obtain materials for her research programme and seconded a Harwell scientist to assist in the establishment of radiochemical laboratories.

Pakistan: During the year an Atomic Energy Commission was established in Pakistan. The Authority are advising on organisation and training scientists from Pakistan in their establishments.

U.S.A.: Close contact with the U.S.A.E.C. was maintained in accordance with the co-operation agreement of June, 1955, amended in June, 1956, to extend the field of co-operation. Visits have been exchanged by teams working on the fast breeder projects in the two countries and parties from U.S.A.E.C. have visited the Authority to discuss Calder Hall. There have been joint discussions on controlled thermonuclear reactions.

Belgium: Two Belgian scientists have been in residence at Calder Hall and Belgian experts have discussed with the Authority and industry the suitability of the gas-cooled power reactor to Belgian conditions.

German Federal Republic: An agreement for co-operation in research on the peaceful uses of atomic energy was signed on 31st July 1956. German authorities are to buy two research reactors and a small power reactor from British firms. Interest is being shown in large nuclear power stations of the type being built for the United Kingdom electricity authorities.

Japan: Japan's problem of maintaining sufficiently rapid expansion of power supplies is like that of the United Kingdom and a visit to Japan by Sir Christopher Hinton aroused great interest in the Calder Hall type of reactor. A favourable report on its merits and suitability was made by a Japanese mission which visited this country.

Italy: Several Italian electricity undertakings have been evaluating various types of nuclear power station. Italian engineers have had discussions with the Authority and Authority staff have visited Italy.

The Authority have continued collaboration in the research and development field with a number of other countries including France, Sweden, Norway, Denmark, the Netherlands, Portugal, Spain and Yugoslavia and have had visits from and discussions with atomic scientists from many more.

International Organisations

A Preparatory Commission is drafting plans for the organisation of the International Atomic Energy Agency, the Statute of which was agreed in October 1956. The Authority give technical advice of United Kingdom representatives taking part in the discussions and will be the principal medium through which the United Kingdom will assist in the operations of the Agency when it has been set up.

The Authority have contributed similarly to the work of the other United Nations agencies, such as the U.N. Economic and Social Council and the U.N. Scientific Committee on Radiation Hazards.

Representatives of the Authority have played an important part in three working parties set up by the

Dr. B. F. Schonland, deputy director of A.E.R.E., in conversation with King Feisal of Iraq during His Majesty's visit to Harwell in August, 1956.

Sir Christopher Hinton, Managing Director, U.K.A.E.A. Industrial Group, talks to Japanese pressmen during his visit to Tokio in 1956.

Nuclear Energy Steering Committee of the Organisation for European Economic Co-operation. These working parties were concerned with training; joint experimental reactor projects; and a joint chemical processing plant. Authority staff contributed lectures to a Nuclear Energy Course for Management under the auspices of the European Productivity Agency in April 1957.

It would be difficult, having regard to the size and comprehensive nature of the United Kingdom's existing atomic energy programme, to notify direct participation by the Authority in many joint O.E.E.C. projects. But the United Kingdom has intimated its readiness to consider taking part in a joint project to develop a reactor system and to consider siting such a project alongside one of the Authority's development establishments should the other co-operating countries so desire.

In February 1957, the Authority had discussions in the United Kingdom with representatives of the European Atomic Energy Community composed of Belgium, France, Western Germany, Italy, Luxembourg and the Netherlands (Euratom). The Authority agreed to facilitate contacts between firms in the United Kingdom and in the Euratom countries interested in building nuclear power stations and to help with the training of scientists and engineers. (Euratom envisage a programme of 15,000 megawatts of nuclear power installed by 1967.)

To help the establishment of a nuclear training centre in Baghdad (for use by member countries of the Baghdad Pact) the Authority have trained two instructors each from Iraq, Iran, Pakistan and Turkey. Mr. W. J. Whitehouse, of Harwell, is first Director of the Centre. He and four other members of the Authority's staff went to Baghdad early in 1957 to instal equipment provided by the United Kingdom and to organise the first courses. The Centre will, for the time being, specialise in radioisotope techniques with special reference to Middle East requirements.

The Authority have continued to play an active part in the work of the World Health Organisation, the International Commission for Radiological Protection, the European Council for Nuclear Research, the European Atomic Energy Society and a number of other bodies. A number of places at the Reactor and Isotope Schools are taken by overseas students.

The Euratom Committee which visited the United Kingdom in April 1957 with Sir Edwin Plowden, Chairman, U.K.A.E.A. *Left to right:* M. Louis Armand (France), Sir E. Plowden, Herr Franz Etzel (Germany) and Prof. Francisco Giordani (Italy).

Health and Safety

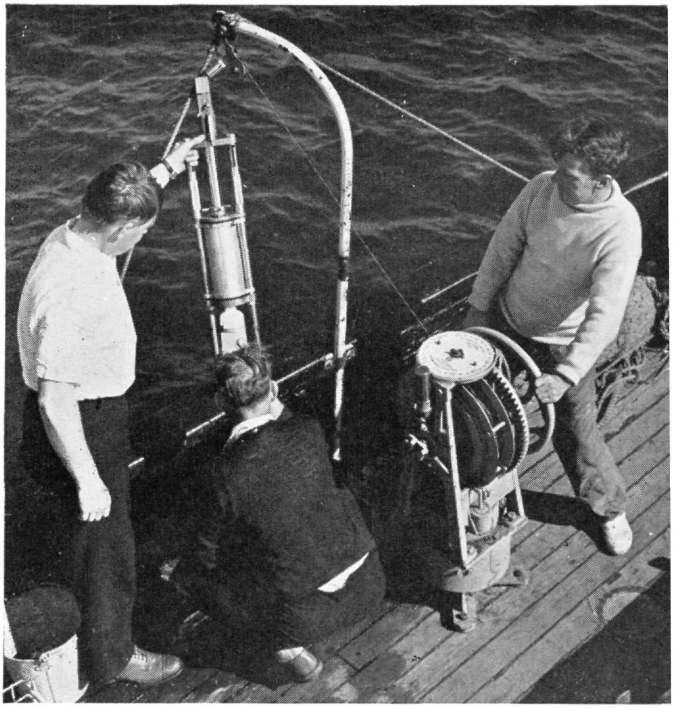
The Atomic Energy Authority Act 1954 placed on the Authority the duty of securing that no ionising radiation from any of their premises or from any waste discharged from their premises should cause any hurt to any person or damage to any property whether on such premises or elsewhere.

The Authority continue to hold a good record in the field of normal industrial safety. The lost time frequency rates for the year were 1·19 per 100,000 man-hours for the Industrial Group, 0·68 for the Weapons Group and 0·70 for the Research Group.

There has been no case of injury arising from radiation or from the handling of radioactive substances; there has been one fatal accident from electrocution.

The report of the Medical Research Council on *The Hazards to Man of Nuclear and Allied Radiations* was issued during the year and was accepted by the Authority as their standard for future control of radiation exposure. The report confirms the recommendation of the International Commission on Radiological Protection of a permissible weekly dose of 0·3 rad (a rad is a unit of absorbed dose from any form of radiation). This has been the basis for the control measures which were adopted on the design and operation of the plant now in use.

A new recommendation in the M.R.C. report aims at limiting total exposures received *over periods of many years* to a level corresponding to about 50 rads per decade (0·3 rad per week, if maintained continuously for ten years would equal 150 rads). Whilst this demands an exposure rate which is lower than that for which some of the Authority's plant was designed, it was found that out of over 8,000 employees exposed to radiation only 290 (less than 1 in 25) did in fact exceed 5 rads in the year. In other words more than 96 per cent. of the employees concerned were below the new level before the M.R.C. published their report. The other instances do not conflict with the M.R.C. recommendation since their average over a ten-year period can still be brought down to the new level. The Authority's aim to keep all radiation exposure to a minimum will be continued during the current year by adjusting operations in such a way that a smaller percentage of employees will receive doses exceeding 5 rads.



The Oceanographic Deep-Sea Sampler in use for the 'Mermaid' tests on effluent dispersal during investigations into the suitability of a proposed research station site at Winfrith, Dorset.

The record of the Authority was noted by the M.R.C. in these words: 'With regard to occupational exposure we consider that the record of the Atomic Energy Authority shows the high standard that is attainable and the practicability of being satisfied with nothing less'.

Waste Disposal

All establishments have been visited by representatives of the authorising Ministries who have expressed approval of the records relevant to the discharge of gaseous, liquid and solid wastes, and who have certified that the authorisations issued by the Ministries have been observed. Continuous surveys are made on all the Authority's sites and information on the effect of discharge to sea is collected from the Cumberland coast.

U.K.A.E.A. Establishments

UNITED KINGDOM ATOMIC ENERGY AUTHORITY,
St. Giles Court, 1/13 St. Giles High Street, London W.C. 2.
Telephone: Museum 6838

U.K.A.E.A. RESEARCH GROUP,
Atomic Energy Research Establishment,
Harwell, Didcot, Berks.
Telephone: Abingdon 1220

U.K.A.E.A. INDUSTRIAL GROUP,
Industrial Group Headquarters,
Risley, Warrington, Lancs.
Telephone: Warrington 31244

U.K.A.E.A. WEAPONS GROUP,
Atomic Weapons Research Establishment,
Aldermaston, Berks.
Telephone: Reading 0060

THE RADIOCHEMICAL CENTRE,
White Lion Road, Amersham, Bucks.
Telephone: Little Chalfont 2278

ATOMIC ENERGY AUTHORITY FACTORY,
Western Road, Binfield,
Bracknell, Berks.
Telephone: Bracknell 1078

U.K.A.E.A. RESEARCH GROUP (WANTAGE),
Wantage Radiation Laboratory,
Grove, Wantage, Berks.
Telephone: Wantage 458

U.K.A.E.A. RESEARCH GROUP (WOOLWICH),
Woolwich Outstation,
Building C.37, Royal Arsenal,
Woolwich, London, S.E.18.
Telephone: Woolwich 2044

U.K.A.E.A. RESEARCH GROUP (CHATHAM),
Chatham Outstation,
H.M. Gun Wharf, Chatham, Kent.
Telephone: Chatham 4201

Some Publications on the Work of the U.K.A.E.A.

Harwell, The British Atomic Energy Research Establishment, 1946–51. Prepared by Ministry of Supply (K. E. B. Jay) and the Central Office of Information. London, H.M. Stationery Office, 1952. 6s.

Atomic Energy Research at Harwell by K. E. B. Jay. London, Butterworth's Scientific Publications, 1955. 5s.

Britain's Atomic Factories. The story of atomic energy production in Britain by K. E. B. Jay. London, H.M. Stationery Office, 1954. 5s.

Calder Hall. The story of Britain's first atomic power station by K. E. B. Jay. London, Methuen & Co. Ltd., 1956. 5s.

First Annual Report of the United Kingdom Atomic Energy Authority (for the period 19th July 1954 to 31st March 1955). London, H.M. Stationery Office, 1955. 2s.

Second Annual Report of the United Kingdom Atomic Energy Authority (for the period 1st April 1955 to 31st March 1956). London, H.M. Stationery Office, 1956. 2s. 6d.

Third Annual Report of the United Kingdom Atomic Energy Authority (for the period 1st April 1956 to 31st March 1957). London, H.M. Stationery Office, 1957. 3s.

Atom (Monthly information bulletin and news journal of the U.K.A.E.A.). London, U.K.A.E.A., Public Relations Branch, St. Giles Court.

Depository Libraries

The following libraries are depositories for U.K.A.E.A. documents:

Science Museum Library, South Kensington, London S.W.7
Central Library, Surrey Street, Sheffield 1
Central Library, Ratcliffe Place, Birmingham 1
The Mitchell Library, North Street, Glasgow 3
Central Library, William Brown Street, Liverpool 3
Central Library, St. Peter's Square, Manchester 2
Central Library, New Bridge Street, Newcastle-upon-Tyne 1
Central Library, High Street, Acton, London W.3
Central Library, Albion Street, Kingston-upon-Hull

A Short List of Films on Atomic Energy

Atomic Achievement (First decade of British Atomic Energy work). Eastman colour Commentary 16/35mm. 20 minutes (1956) C.O.I.*

Calder Hall (Construction of the power station). Eastman colour Commentary 16/35 mm. 30 minutes (1955) C.O.I.*

Great Day (Construction and Royal Opening of Calder Hall). Eastman colour Commentary 16/35 mm. 20 minutes (1956) C.O.I.* (Free).

New Tool for Industry (Typical radioisotope uses in industry). Black and white Commentary 16 mm. 20 minutes (1955) C.O.I.*

Atoms at Work (Radioisotopes, production and uses). Black and white Commentary 16/35 mm. 11 minutes (1952) C.O.I.*

Atoms in Industry (Development of peaceful uses of atomic energy). Black and white Commentary 16/35 mm. 14 minutes (1955) C.O.I.*

A full list of 145 films on atomic energy and related matters has been prepared by the Scientific Film Association. This list is given in the Scientific Film Review, Vol. 2, No. 4 (October 1956) which may be obtained from the Editorial Office, 164 Shaftesbury Avenue, London W.C.2, at 3s. 6d.

* The Central Office of Information Film Library (Government Buildings, Bromyard Avenue, Acton, London W.3) supplies those films marked C.O.I. on hire at a modest rental.

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The Authority's Reactors, 31st March 1957

(*a*) EXPERIMENTAL REACTORS AT HARWELL

Name	*Date of start-up*	*Peak neutron flux*	*Maximum heat output*	*Moderator*	*Coolant*	*Fuel*	*Purposes*
1. GLEEP	1947	$3 \cdot 7 \times 10^{10}$ thermal n/cm^2/sec	100 kW	Graphite	Air	Natural uranium metal and oxide	Initially isotope production and general neutron physics. Now routine graphite, uranium quality testing; research with oscillator; biological irraditions.
2. BEPO	1948	2×10^{12}	6 MW	Graphite	Air	Natural uranium	Isotope production and general radiation source.
3. ZEPHYR	1954	8×10^{8} (fast)	a few watts	None	None	Plutonium	Fast reactor studies.
4. DIMPLE	1954	about 10^{8}	100 Watts	Heavy water	None	Varies	Thermal reactor studies.
5. ZEUS	1955	5×10^{9} (fast)	100 Watts	None	None	Uranium 235	To study a particular core design for Dounreay fast reactor.
6. ZETR	1955	4×10^{5}	negligible	Heavy or Light water	None	Uranium 233, 235 or plutonium	To study physics of homogeneous aqueous systems.
7. LIDO	1956	10^{12}	100 kW	Natural water	Natural water	Uranium 235	Thermal reactor studies, including shielding.
8. DIDO	1956	10^{14}	10 MW	Heavy water	Heavy water	Uranium 235	Isotope production, neutron physics, radiation chemistry, nuclear reactor material studies.
9. NERO	1957	about 10^{8}	Less than 100 watts	Graphite	None	Slightly enriched Uranium	Investigations for advanced graphite moderated reactors.

Name	*Location*	*Date of start-up*	*Peak neutron flux*	*Maximum heat output*	*Moderator*	*Coolant*	*Fuel*	*Purpose*
(*b*) **EXPERIMENTAL REACTORS UNDER CONSTRUCTION**								
10. Fast Reactor, Dounreay	Dounreay, Caithness	1958	—	60 MW	None	Liquid metal	Enriched Uranium or plutonium	Fast reactor breeding studies.
11. PLUTO	Harwell	1957	10^{14}	10 MW	Heavy water	Heavy water	Highly enriched uranium	Studies on nuclear reactor materials.
12. DMTR (Pluto type)	Dounreay, Caithness	1957	10^{14}	10 MW	Heavy water	Heavy water	Highly enriched uranium	Studies on nuclear reactor materials.
(*c*) **PLUTONIUM PRODUCING REACTORS IN PRODUCTION**								
13/14. Windscale (2 reactors)	Cumberland	1950	—	n.a.	Graphite	Air	Natural uranium	Plutonium production.
(*d*) **POWER/PLUTONIUM PRODUCING REACTORS IN PRODUCTION** [1]								
15/16. Calder A (2 reactors)	Cumberland	1956	—	180 MW[2] per reactor	Graphite	Carbon Dioxide	Natural uranium	Power and plutonium production.
(*e*) **POWER/PLUTONIUM PRODUCING REACTORS UNDER CONSTRUCTION** [1]								
17/18. Calder B (2 reactors)	Cumberland	1958 (1st reactor)	—	180 MW(2) per reactor	Graphite	Carbon Dioxide	Natural uranium	Power and plutonium production.
19/22. Chapelcross (2 stations, A and B, 4 reactors)	Annan, Dumfries-shire	1959 (3 reactors)	—	180 MW per reactor	Graphite	Carbon Dioxide	Natural uranium	Power and plutonium production

1 All power stations operated, or under construction for future operation by the Authority, are "two reactor" stations. These are Calder Hall A, Calder Hall B, Chapelcross A and Chapelcross B.

2 Total output for Calder A (2 reactors) is 92MW (electrical) of which 65 MW is supplied to the C.E.A. grid. When both Calder stations A and B (2 reactors each) are in operation, the total output will be 184MW (electrical) and the feed-back percentage from each reactor will be slightly reduced, so that the combined output to the C.E.A. grid from both Calder stations (4 reactors) will be 150MW. The electrical output from Chapelcross A and B stations will be identical in all respects with Calder A and B.

Back cover: the six million volt Van der Graaf electrostatic generator at the Atomic Weapons Research Establishment, Aldermaston. The machine is used to accelerate beams of atomic particles to high energies, initiating nuclear reactions in target materials.

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