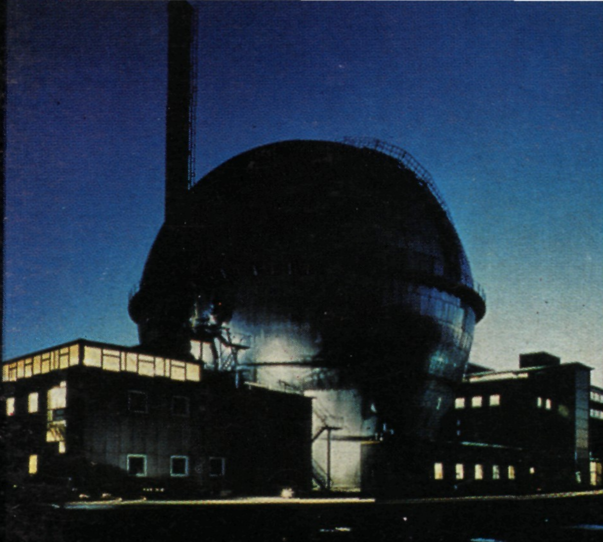
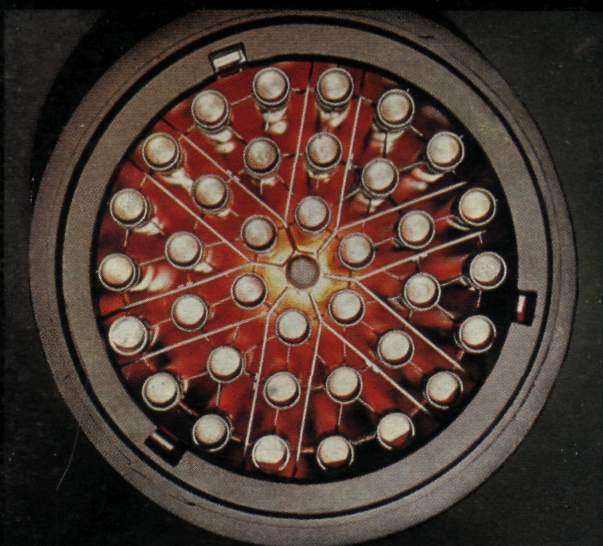
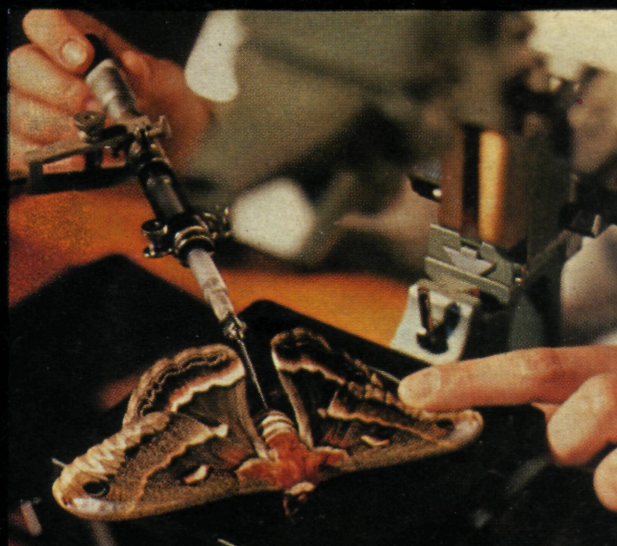
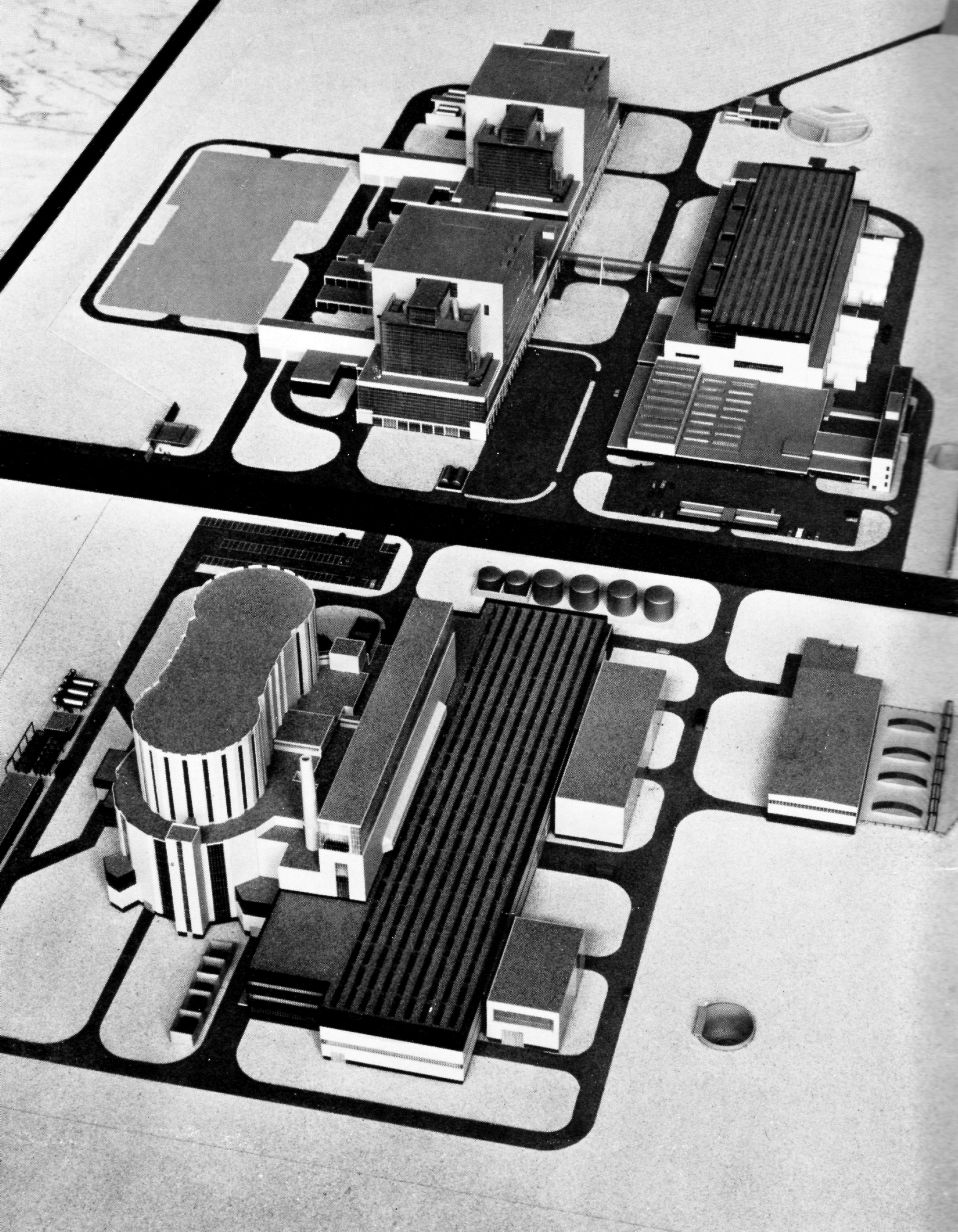


ATOM 1965

United Kingdom Atomic Energy Authority
An illustrated summary of the eleventh annual report
1st April 1964 to 31st March 1965/**price 2s 6d**







The second nuclear power programme

The White Paper – "The Second Nuclear Power Programme" – was issued on 15th April, 1964.

It stated that for planning purposes a programme of 5,000 MW of nuclear generating capacity had been adopted for commissioning in England and Wales during the six years 1970–75. The programme was intended to be flexible and would be subject to review, including the consideration of a further nuclear station in Scotland. The Central Electricity Generating Board would issue an enquiry for tenders for an advanced gas-cooled reactor station.

They would also be ready to consider tenders from British industry for water-moderated reactor systems of proved design. They would ensure that these tenders were judged on a comparable basis. Her Majesty's Government would review, with the supply industry and the Atomic Energy Authority, the results of this enquiry in order to decide the type or types of reactor to be built.

Seven tenders received for the C.E.G.B.'s Dungeness "B" station (three advanced gas-cooled reactors, three pressurised water reactors and one boiling water reactor) were assessed by C.E.G.B., assisted by the Authority.

On 25th May, 1965, the Minister of Power announced in the House of Commons that he had accepted a recommendation from the C.E.G.B. that an advanced gas-cooled reactor system should be adopted at Dungeness "B", this reactor having shown clear economic and technical advantages over the alternative systems and having a good potential for further development.

A statement issued by C.E.G.B. on the same day said that the generating costs from the A.G.R. design submitted by Atomic Power Constructions Ltd would be 10 per cent. less than those from the Boiling Water Reactor (B.W.R.) offered by The Nuclear Power Group in association with the General Electric Company of the U.S.A.

The advantage over the most efficient coal-fired stations scheduled to come into service in 1970 was calculated to be rather greater than 10 per cent.

By 31st March, 1965, nuclear reactors in the United Kingdom (Bradwell, Berkeley, Hinkley Point, Trawsfynydd, Hunterston, Calder, Chapelcross, the Windscale A.G.R. and the Dounreay fast reactor) had fed a total of some 26,000 million units of electricity to the grid, substantially more than the total for the whole free world outside Britain.

A comparison between these two models – made to the same scale – illustrates the compactness of the Advanced Gas-Cooled Reactor design. The station in the background is Dungeness "A" (Magnox) – 550 Megawatts. In the foreground is Dungeness "B" (A.G.R.) with more than twice the output – 1,200 Megawatts.

AGR: the CEGB assessment

A detailed technical and economic study published by the Central Electricity Generating Board on 29th July showed a generating cost of 0·457d. per unit for the A.G.R. as against 0·489d. per unit for the B.W.R. and 0·53d. per unit for the most efficient coal-fired station.

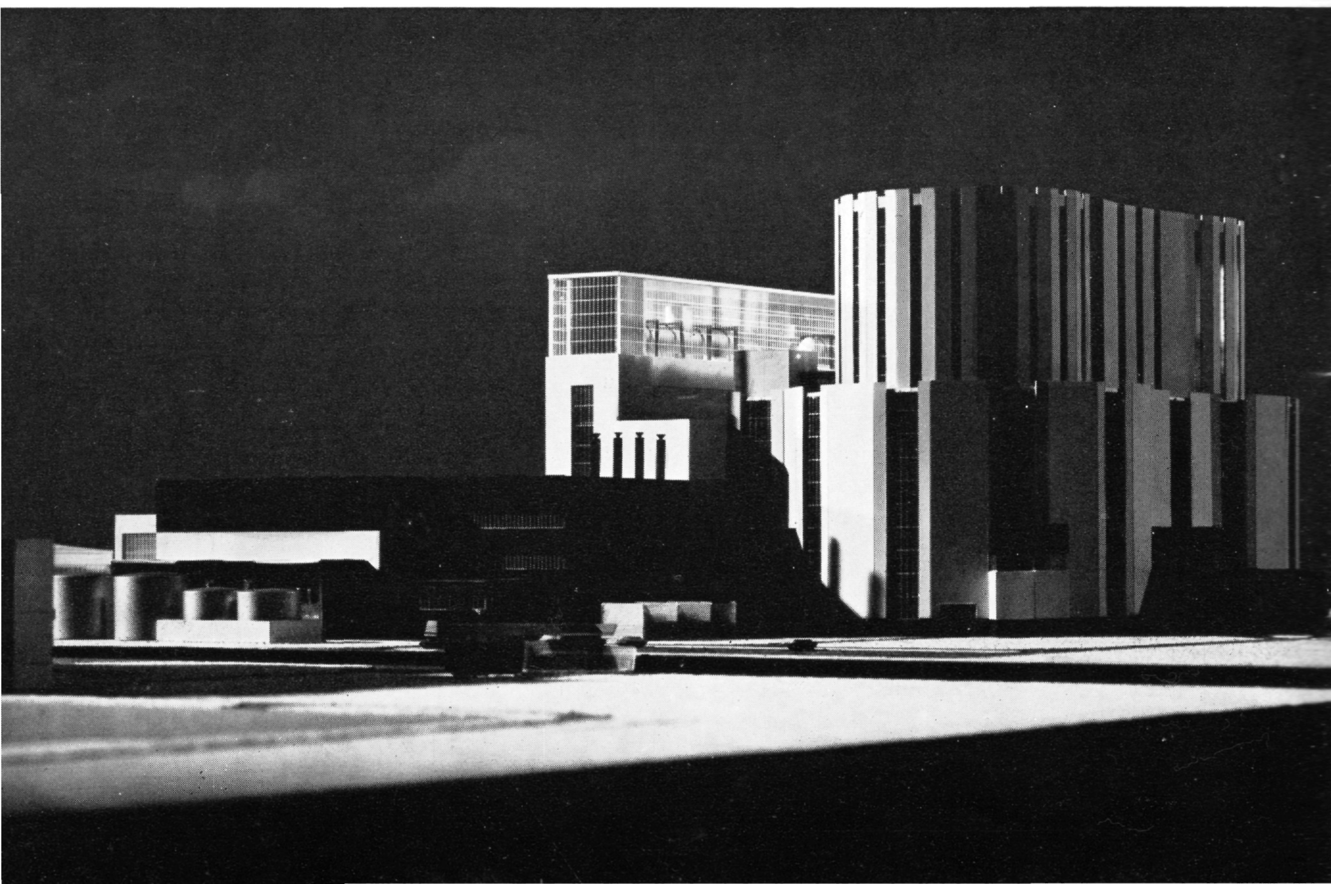
The Board pointed out that a significant factor in the assessment was that the B.W.R. could not be re-fuelled on load and thus had an inherently lower load factor than the A.G.R.

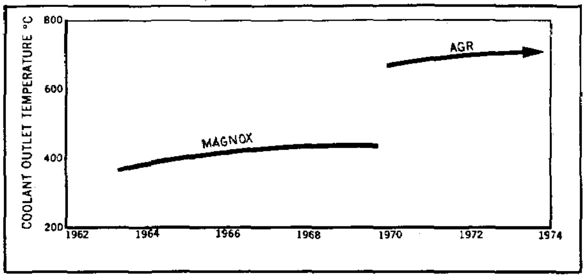
The statement continued: "These estimates of cost include all capital charges as well as the cost of the initial fuel charge of the nuclear reactors, and assume an average load-factor of 75 per cent for the nuclear stations and 38 per cent for the coal-fired stations based on the accountancy life of 20 years for nuclear plants and 30 years for conventional plants.

"If, as may well happen, nuclear stations continue to operate on base load for 30 years and at a load factor of 85 per cent – which are not unreasonable assumptions – the unit cost of Dungeness "B" over its life would be reduced to 0·377d., so increasing considerably the advantage over the best coal-fired stations."

In a document describing details of the A.G.R. design chosen for Dungeness "B" the Board stated: "The A.G.R. has excellent safety characteristics which will enable it to be built closer to centres of population than has been the Generating Board's practice with nuclear power stations in the past."

A model of Dungeness "B" nuclear power station. (Photo by courtesy Howard V. Lobb & Partners (Architects) London.)





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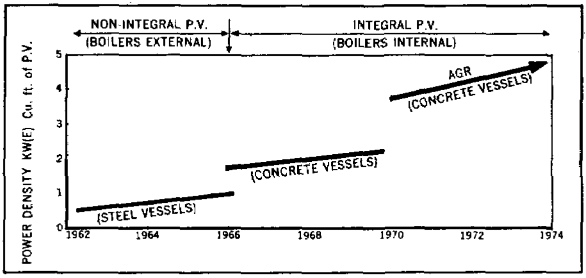

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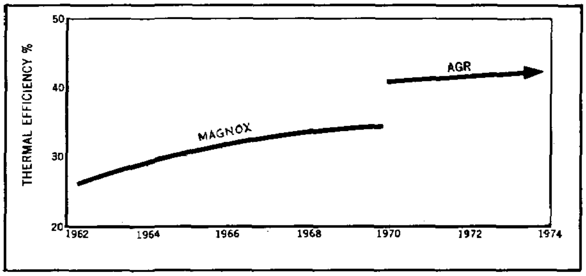

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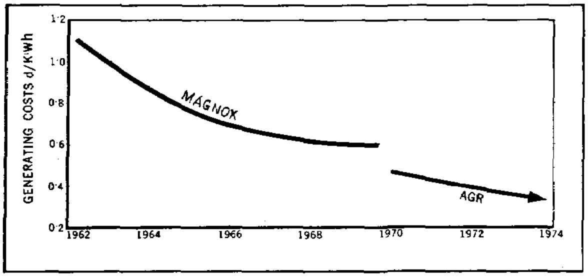
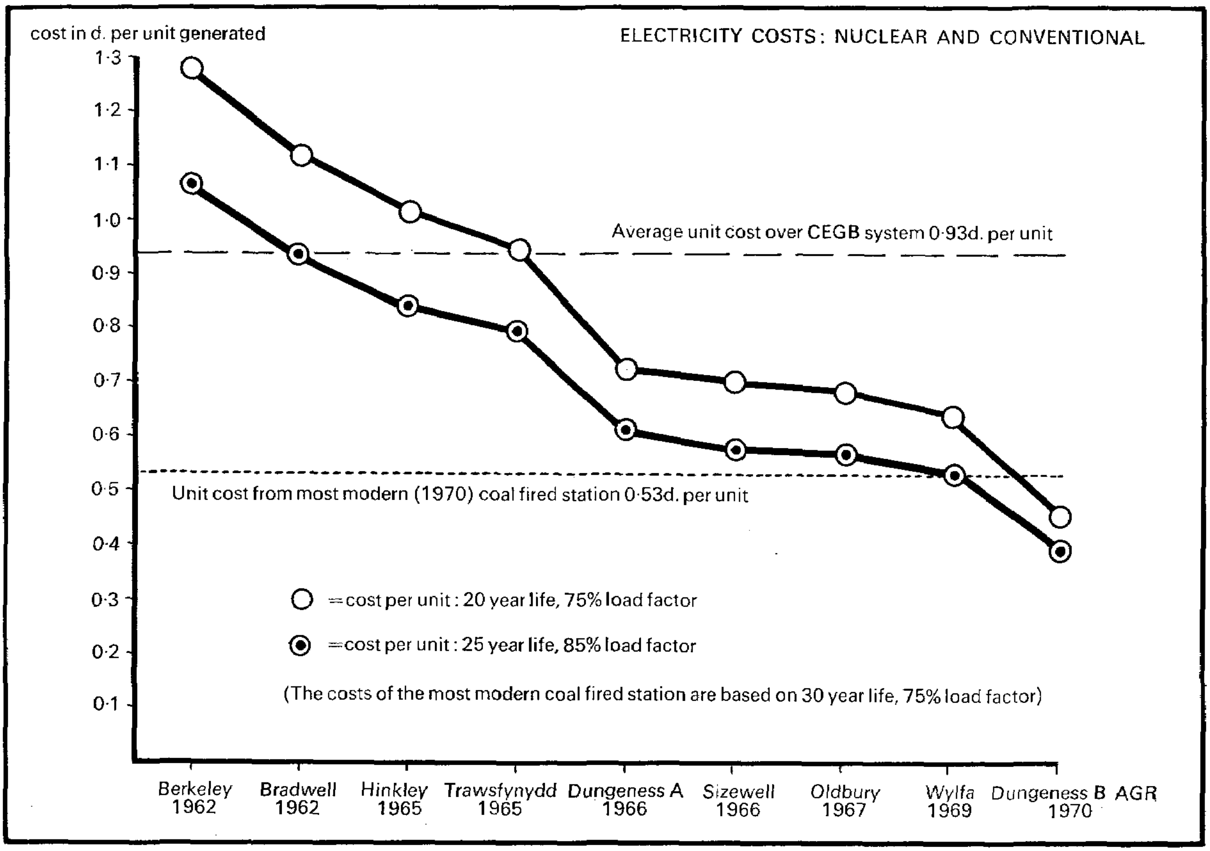


4

The first three graphs above show the progress of technical improvements in the gas-cooled reactor; the fourth illustrates their reflection in improved economics. The success of A.G.R. has been achieved by retaining the many satisfactory design features evolved during the first nuclear power programme but changing the fuel to allow higher operating temperatures and greater output per unit volume of core and pressure-vessel.



5

REVIEW OF THE YEAR

1st April 1964 to 31st March 1965

Shortly before the end of the year under review, the Authority's prototype advanced gas-cooled reactor at Windscale completed two years' operation. During that time it produced over 350 million units of electricity for the national grid and demonstrated a plant availability of 85 per cent., excluding shutdowns for experimental purposes. *Not a single failure was detected in the 30,000 individual fuel elements.*

The Dounreay fast reactor achieved its longest period of high power operation, lasting 77 days, at about 60 MW(H) and 14 MW(E), in the autumn of 1964. The reactor is now being operated primarily as an irradiation test reactor for experimental fuel elements suitable for a prototype fast reactor power station.

During the year, the millionth magnesium alloy-clad, uranium metal (Magnox) fuel element was manufactured at Springfields. The factory also produces other types of fuel for the advanced gas-cooled reactor and for some experimental reactors. *Total production of all types of fuel elements has exceeded $1\frac{3}{4}$ million.*

The Minister of Technology (to whom responsibility for the Atomic Energy Authority was transferred with effect from 1st January, 1965) announced in the House of Commons on 9th February that from the beginning of the financial year 1965/66 the Authority's commercial operations would be separated from the rest of their activities which are financed directly from the Atomic Energy Vote, and organised in a trading fund.

Section 4 of the Science and Technology Act, 1965, empowered the Minister of Technology to require the Authority to undertake research and development in science and technology outside the atomic energy field. **The purpose of the section is to ensure that the considerable resources of skill and experience, and the exceptional facilities, that have been built up in the Authority, can be made available, as opportunity offers, to assist in securing technological advance in industry, particularly in those sections serving export markets.** As the act was passed into law only just before the end of the year under review, it is not yet possible to visualise clearly what will be the scope of Section 4; the first major application will be a programme of development of desalination techniques.

The Minister of Technology, Mr. Frank Cousins, during a visit to the Authority's establishment at Winfrith.

	Expenditure: £ million (approximate)				Qualified Scientists and Engineers	
	1963/64		1964/65		March 31st	March 31st
	Current	Capital	Current	Capital	1964	1965
I Reactor research and development programme						
1 Gas-cooled Systems	10	1.5	9	1	550	500
2 Water-Moderated Systems	5	2	5.5	4	480	480
3 Fast Systems	7	1.5	9	1.5	515	575
4 General Reactor Technology	4	1	4	.5	365	365
II Other research						
1 Basic Research	5	1.5	5	1.5	370	360
2 Health and Safety Basic Research	1	-	1	-	120	120
3 Isotopes Research	.5	-	.5	-	80	80
4 Plasma Physics and Fusion Research	3.5	1.5	3.5	1.5	200	200
	36	9	37.5	10	2680	2680

Although the total number of Authority staff continued to decrease during the year, the rate of decrease, about three per cent., was less than in the previous year. Moreover, not all fields of work were affected and the manpower resources devoted to the Authority's civil research and development programmes were very little changed.

In 1964/65, expenditure from Parliamentary grants on the Authority's programme of civil research and development was £47·5 million of which £37·5 million was current expenditure and £10 million on capital facilities. The number of graduate or professional engineers and scientists employed on the programme at 31st March, 1965, was 2,840 of whom 160 were doing work on repayment for other organisations.

The table above shows the deployment of resources in terms of cash expenditure and qualified staff on the various parts of the programme.

The Authority's net estimates for 1965/66 are £29,140,000 and are £7,642,000 less than the final grant for 1964/65. The reduction was mainly due to the transfer of financial responsibility for the National Institute for Research in Nuclear Science from the Authority to the Science Research Council, but the total is also affected by the setting up of the trading fund.

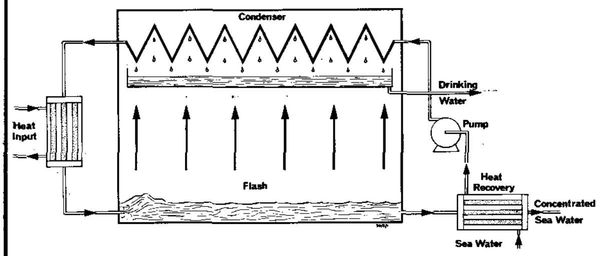
In 1959 the Authority appointed an historian (Mrs. Margaret Gowing) to prepare a history of the U.K. atomic energy project. The first volume, covering the war years, was published in September, 1964, and received warm praise as a work of scholarship. The book also created wide interest in North America and on the Continent; and the Authority were glad to agree to publication of a French version, abridged in collaboration with Mrs. Gowing.

Overseas, the principal event during the year was the Third International Conference on the Peaceful Uses of Atomic Energy, 31st August to 9th September, 1964. Compared with the first two conferences, the accent on this occasion was commercial rather than scientific. The U.K. was strongly represented and, despite the uncertainty concerning the future U.K. nuclear power programme, the British contributions made a good impression.

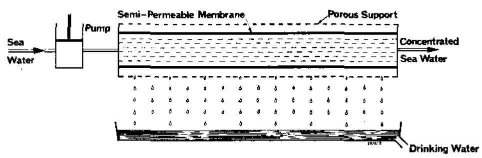
Also in November, two important contracts were signed. One was with the Italian Ente Nazionale per l'Energia Elettrica, for reprocessing the spent fuel elements discharged from E.N.E.L.'s Latina nuclear power station and for the recovery of plutonium. The other was for the sale to the Supply Agency of Euratom, acting for the French Atomic Energy Commission, of 45 kgs. of plutonium oxide worth about £¾ million. This material completes the first fuel charge for the experimental fast reactor Rapsodie, the first half of the charge having been supplied under a contract signed in May, 1963.

In December a joint company was established in Germany by the Authority and the German organisation Nuklear-Chemie und-Metallurgie GmbH. (Nukem). *The main object of the joint company, Nukleardienst GmbH, will be the provision within the European Community and especially in Germany of a complete fuel service for advanced gas-cooled reactors, in particular the manufacture, supply and reprocessing of A.G.R. fuel.*

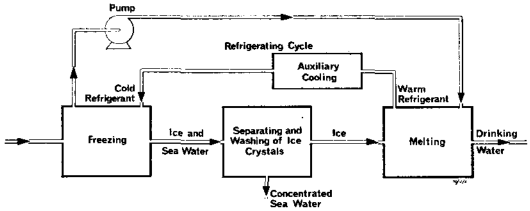
In February, 1965, the Chairman of the Authority and the Chairman of the U.S. Atomic Energy Commission exchanged letters initiating a new ten-year exchange of information in the field of fast reactor technology.



Flash Distillation Process



Reverse Osmosis Process



Freezing Process

The diagrams above show the basic principles of three processes for the de-salting of brine which are being studied by the Authority: flash distillation; reverse osmosis; and freezing.

COLLABORATION WITH INDUSTRY

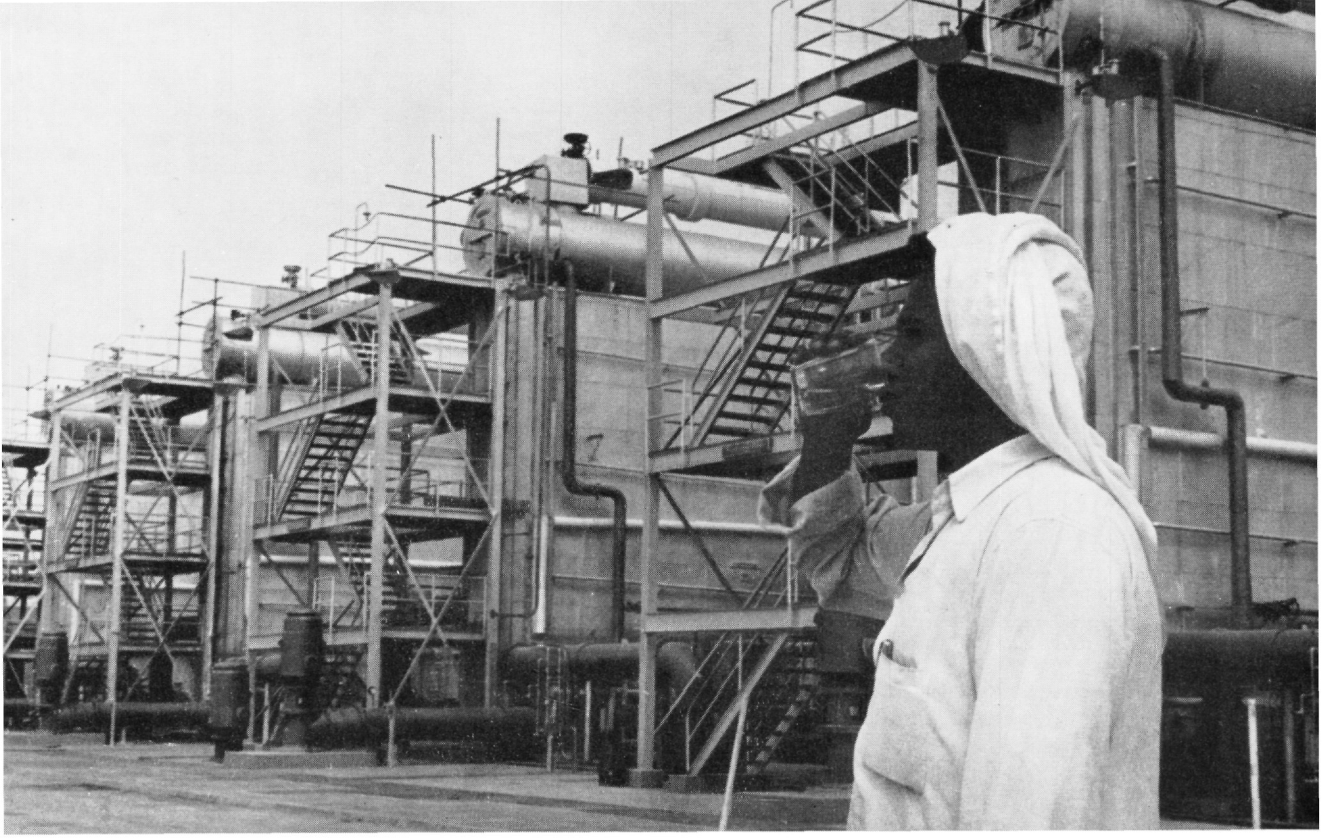
The relationship between the Authority and industry was set out in the answer to a parliamentary question in 1956 as one of close partnership. In order to ensure the maximum practicable use of existing facilities, research and development would be the responsibility of the Authority, who would place contracts with industry in suitable circumstances, while industry would be responsible, with appropriate support from the Authority, for the commercial exploitation of the results of the Authority's nuclear research and development programmes. Assistance given by the Authority to industry in the commercial exploitation of nuclear power was to be governed by two main considerations, namely: –

(i) that industry should, where appropriate, pay for the use of commercially valuable information which had been developed at considerable public expense;

(ii) that individual firms should not be enabled by such assistance to build up monopoly positions.

The Authority have accordingly given industry the maximum help permitted by their technical resources but have acted on the principle that information capable of direct commercial exploitation should be made available to a limited number of interested companies under licensing agreements which protect them from excessive competition in return for a reasonable royalty payment.

So far as the nuclear applications are concerned, the Authority have encouraged the growth of a strong nuclear engineering industry capable of putting the results of the Authority's research and development work to good use. This is accomplished partly by associating industry closely and at an early stage with the construction and development of prototype power reactors and by commis-



A multi-flash desalination plant at Kuwait on the Arabian Gulf built by Weir Westgarth Ltd. of Glasgow. More than two-thirds of the world's de-salted water comes from British-built plants. (Photo courtesy U.S.I.S.)

sioning design studies of equivalent full scale power stations, thus giving industry an early opportunity of applying the developing techniques to the best economic advantage.

The nuclear consortia have as a result successfully collaborated with the electricity generating boards in the United Kingdom and with the Authority in establishing the largest national nuclear power investment in the world. The consortia also secured some of the first export orders for power reactors, and whilst the overseas demand for nuclear power stations has not so far proved as large as had been hoped, it is likely to improve now that nuclear power stations can be offered which will be fully competitive in generating cost with the best new conventional stations.

In addition to the main licences relating to nuclear reactors, nuclear chemical plant and other nuclear applications, the Authority have negotiated with industry in the U.K. and overseas many consultancy, collaboration, access and licensing arrangements designed to promote the use of Authority information, know-how and patents for non-nuclear as well as for nuclear purposes. Over 400 such arrangements are currently in force, mainly in the U.K., and the number is increasing at the rate of about 80 each year.

The broad aim is to agree with licensees terms which will make a reasonable contribution to the cost to public funds of the related research and development, while not inhibiting competitive production or the development of new markets at home or abroad. In a typical licensing agreement, the licensee pays to the Authority a royalty levied as a percentage of the selling price of the product and in return enjoys a non-exclusive licence to make, use and sell. In special circumstances a sole licence is sometimes granted, but is liable to be withdrawn if the licensee does not make reasonable efforts to promote sales of the product.

The Authority's work in nuclear development has also led to the introduction of new and improved equipment in a number of industries, and the adoption on an industrial scale of standards and techniques previously thought possible only in the laboratory. Improved steels for pressure vessels, new techniques of welding and metal forming, high vacuum work, new types of electronic instruments, submersible and other advanced forms of pumps, measuring equipment, high pressure valves, packing materials, specialised electric motors and heaters are a few examples.

Other results of the Authority's research and development work having industrial application are: high speed frame and streak cameras and cameras using a Kerr cell shutter; optical equipment based on glass fibre light-guides; electronic apparatus including transistorised oscilloscopes and amplifiers; seismic instrumentation; telecommunication and telemetry equipment; new developments in chemical technology and engineering, such as foams, adhesives, refractory materials of high strength and low weight, and plant for purifying gases such as argon and nitrogen.

***During the financial year 1964–5 the* Authority placed over 174,800 contracts with industry to a total value of £43,161,000 for plant, equipment, stores, building and civil engineering and maintenance work, and for research and development. Thirty-three of the contracts were each over £100,000 in value and among those were five major contracts totalling over £1,000,000 for plant and civil engineering work in connection with the steam generating heavy-water reactor project.**

The Authority have established extensive and specialised facilities for the nuclear programme, which include sophisticated testing and inspection resources, equipment for isotopic and chemical analysis, computing facilities, etc. So far as is consistent with the Authority's own programme these facilities are made available to industry at a reasonable charge.

In addition to the practical arrangements mentioned above, and the publication of technical information in books, reports, contributions to technical journals, and symposia, the Authority have contributed to the improvement of nuclear technology by receiving representatives of industry as attached staff in their establishments or as students in their schools. The Reactor School, the Reactor Operation School and the Isotope School are internationally known and have met a major need with success. The Instrument Training School at Windscale, which covers a wide range of instruments important in chemical processes, has also been used to some extent by industry.

In October, 1964, the Authority became an Associate Member of the British Nuclear Forum, which was established in 1963 to provide an effective point of contact for all organisations in the U.K. working in the nuclear energy field. As a result of informal discussions between the Authority and the Forum early in 1965 joint working groups are being set up to consider matters of common interest, particularly the promotion of exports.

The Authority make extensive use of the major industrial research institutes and are members of fourteen industry-sponsored research associations. There are nominated officers at the Authority's establishments responsible for liaison with these associations to ensure close collaboration in areas of common interest.

In 1964 Authority professional staff presented to professional bodies, or published in the scientific and technical journals, some 450 papers; in addition 386 reports were made available to the public.

The provision in Section 4 of the Science and Technology Act, 1965, will enable the Authority's considerable technological resources, special techniques and experience to be used in industrial development on a wider front than has been possible hitherto under the Atomic Energy Authority Act, 1954.

A wide variety of suggestions from within the Authority for promising lines of development in the non-nuclear field is under consideration, derived in some cases from earlier work by the Authority which had been discontinued at the point beyond which it could not be justified under the 1954 Act as part of the Authority's nuclear development programme. It is anticipated that this review, which is being undertaken in collaboration with industry, will throw up a number of projects giving promise of significant benefit to the national economy.

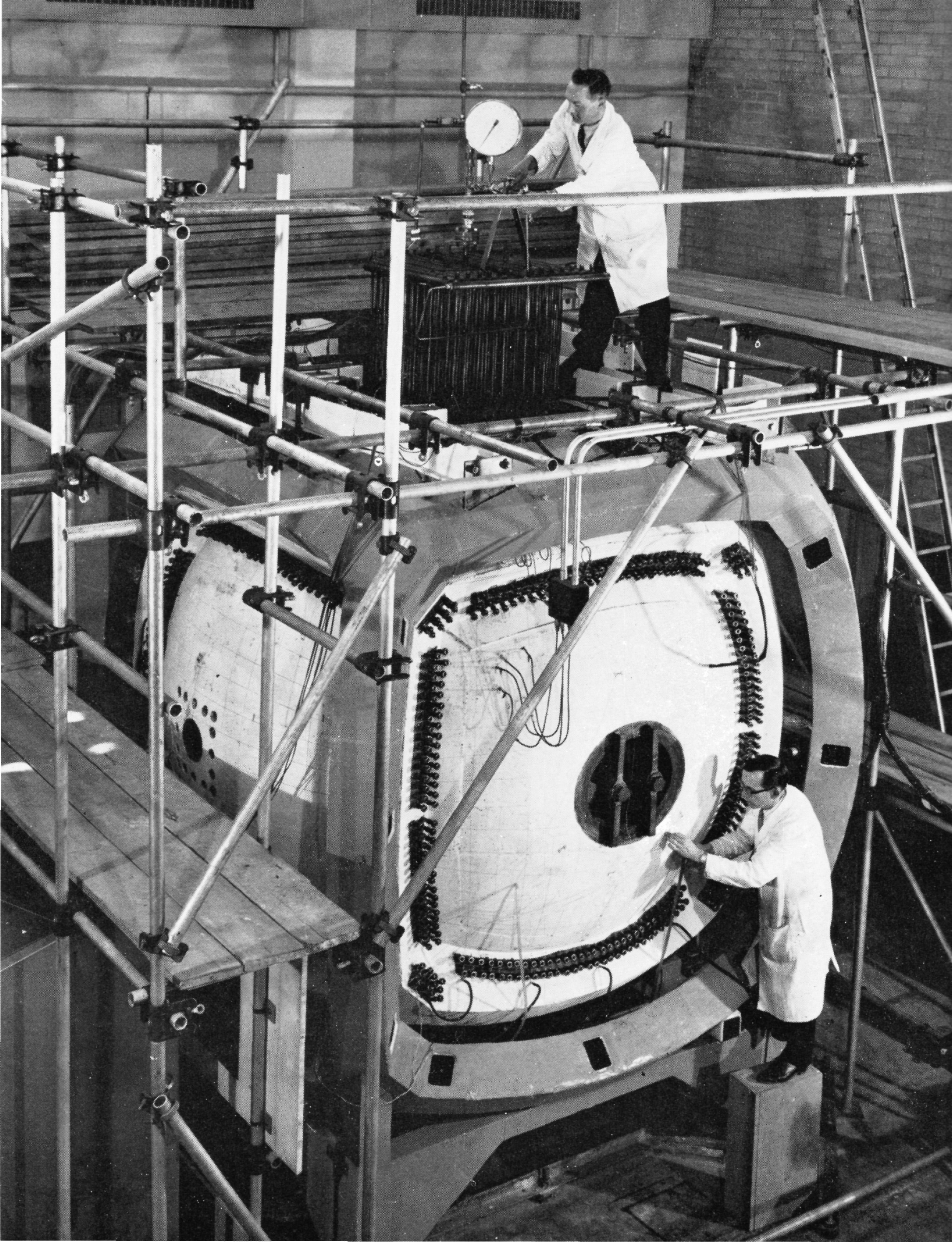
The Authority are also taking steps to promote suggestions from industry for ways in which the Authority can assist in solving the problems of particular industries or companies, under whatever mutually acceptable pattern of collaborative development seems best suited to the individual case. It is not easy for the Authority or for industrialists unless they are acquainted with the Authority's facilities, to know what collaborative projects might best benefit the economy. The Authority would welcome approaches from those responsible for research and development in particular firms who might wish to discuss possibilities of collaboration.

START-UP AT TOKAI. *The British firm of G.E.C. Ltd., were the main contractors for the reactor unit and generating equipment of Japan's first nuclear power station (Calder Hall type) at Tokai, near Tokyo. Authority staff assisted with the commissioning of the station and were present in the main control-room (above) when criticality was achieved in May, 1965.*

One of the most important projects of the Authority's non-nuclear diversification programme will be to investigate economic methods of desalting brine. Close collaboration on this subject has already been established with the Desalination Research Committee* of the Ministry of Technology (D.S.I.R.) and with the Water Resources Board. A joint research and development programme on the flash distillation process is also being negotiated with Weir Westgarth Limited,** a company with great experience in this field. In addition to combined plants for nuclear electricity generation and desalting, other desalting processes, including reverse osmosis and freezing, are also being studied.

* Responsibility for this committee was assumed by the Authority on April 23rd.

** An agreement has since been concluded.



A model pre-stressed concrete pressure vessel under test at Imperial College of Science and Technology, London. The full-scale structure was designed by the Authority and built by Simon-Carves Ltd. (Photo: Imperial College.)

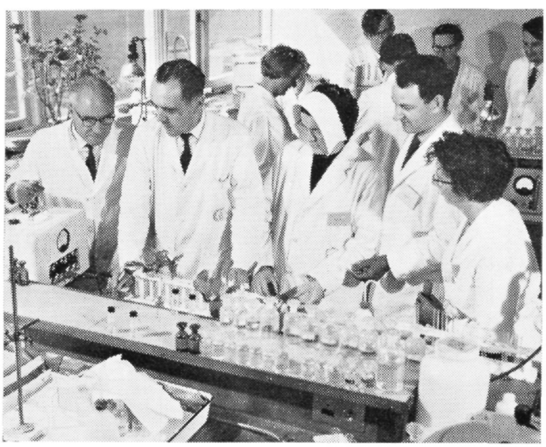
CO-OPERATION WITH THE UNIVERSITIES

The Authority have always recognised the primary responsibility of universities and colleges in the field of basic research and, as provided in the Atomic Energy Authority Act, 1954, have endeavoured to support the work of universities in areas of interest to the Authority's programme.

Extramural research agreements between the Authority and universities and colleges involve some 250 research workers. Some experimental programmes under these agreements have made use of Authority facilities. Authority financial support and the loan of special equipment have led to the establishment of new university groups in such fields as radiation chemistry and plasma physics.

Well-established arrangements made it possible for members of universities to use Authority equipment for carrying out research programmes of their own. Among such equipment are certain research reactors and accelerators at Harwell and Aldermaston. University staff also work in joint teams with Authority staff, e.g., at Culham on plasma physics research. Authority staff and members of universities also take part jointly in seminars and colloquia at various universities and at Authority establishments.

There is frequent interchange of staff between the Authority and universities (both home and overseas) in the course of normal appointments, as well as by exchange and by attachment. Authority establishments offer appointments as consultants to senior staff from universities and accept during vacations members of university staffs, graduate students, and senior undergraduates for research and training. They also offer a few longer-term temporary appointments to senior university members of established reputation, and they award Research Fellowships for about three years on problems of the Fellows' own choice within the Authority's general field of work.



A teachers' training course at the Isotope School, Wantage.

A number of Authority staff are able to make a useful contribution to education in the universities in their own particular fields. For some time regular arrangements have existed with Oxford University, which has close links with Harwell, for Authority staff to undertake university teaching as visiting lecturers.

More recently, arrangements have been made between the Reactor Group and the Manchester College of Science and Technology, for appointments of Authority staff to part-time university posts. Authority staff have also given series of lectures at other universities and colleges, and a number have acted as examiners for higher degrees. Arrangements of this kind are expected to increase with the expansion of higher education and the shortage of qualified teaching staff. The Authority have offered to help and will do all they can to make available suitable scientists and technologists.

Other schemes to increase the interplay between scientists in both spheres include the offer of two-year engagements with the Authority to graduates with some experience intending to take up teaching posts with universities, to enable them to obtain further relevant experience. It is also hoped, in line with the recommendations of the Fielden report, to negotiate arrangements which will give university staff and post-graduate workers the opportunity to work on design projects in the Authority's field.

A measure of the Authority's participation in the academic life of the country is the fact that, during the long vacations in any year, there will be some 400 university students, research workers and staff working in, or in close contact with, Authority establishments.

POWER REACTORS: THE TURNING POINT

The prime purpose of the Authority's reactor development programme is to reduce the cost of nuclear power, and in this respect 1964–65 was a turning point.

The gas-cooled nuclear power stations at present in operation or under construction for the electricity generating boards are based on the Calder Hall design, and the later stations could well achieve parity in generating costs with many of the coal-fired stations coming into operation at the same time.

The Authority, however, have been developing the advanced gas-cooled reactor system in the expectation that a series of power stations based upon it would produce base-load power significantly cheaper than that from conventional stations or alternative reactor systems.

The A.G.R. owes much of its technology – and the confidence in it – to the well-proved Calder Hall design, since both are cooled with carbon dioxide and moderated with graphite. The essential difference is that the Magnox fuel element (uranium metal clad in magnesium alloy) of the earlier reactors is replaced in the A.G.R. by a ceramic fuel (uranium dioxide pellets) clad in stainless steel. Gas-cooled reactors fuelled with ceramics can operate at higher temperatures than those with metal fuel. This permits higher rates of heat extraction; higher thermal efficiencies; smaller cores and boilers for the same power output and the use of standard modern turbo-alternators.

Progress in 1964/65 has confirmed the economies that arise from these technical improvements. Detailed design studies and experimental work carried out during the year have shown that there is no technical barrier to constructing a series of commercial power stations of the A.G.R. type, and economic studies have confirmed earlier predictions about generating costs. Safety studies of A.G.R. power stations have also shown that the combination of the uranium dioxide/stainless steel fuel and the integral design possible with concrete pressure vessels, may allow a relaxation of siting restrictions as compared with earlier gas-cooled stations.

The A.G.R. is likely to remain highly competitive with all other forms of power generation for many years to come with improvements to present technology which can now be envisaged. These improvements, together with increases in the size of reactors, are expected to reduce power costs by about 20 per cent. over a programme of installation.

The prototype A.G.R. at Windscale has operated with channel gas outlet temperatures of up to 600°C. To achieve further economies, the trend of future gas-cooled reactor technology, in the longer term, will probably be towards still higher temperatures and it may be advantageous to dispense with the stainless steel fuel can and find improved high temperature resistant materials for some of the components in the coolant circuit. This line of development may well derive benefit from the high temperature reactor technology as exemplified by the experimental Dragon reactor of the Organisation for Economic Co-operation and Development. A continuous line of development in gas-cooled reactors can be foreseen where each successive improvement can be made with confidence based on years of safe and reliable reactor operation, and engineering economies based on proved technology.

While the immediate aim of the reactor development programme must be to continue the reduction in the cost of generating electricity in the United Kingdom consideration must also be given to the development of:

(i) systems which utilise fuel more efficiently, so as to minimise our imports and the effects of possible rises in the cost of uranium;

(ii) systems which are particularly suitable for overseas requirements, which may lead to exports;

(iii) small economic reactors for special applications such as ship propulsion and electricity generation in areas where local demand requires a small power output.

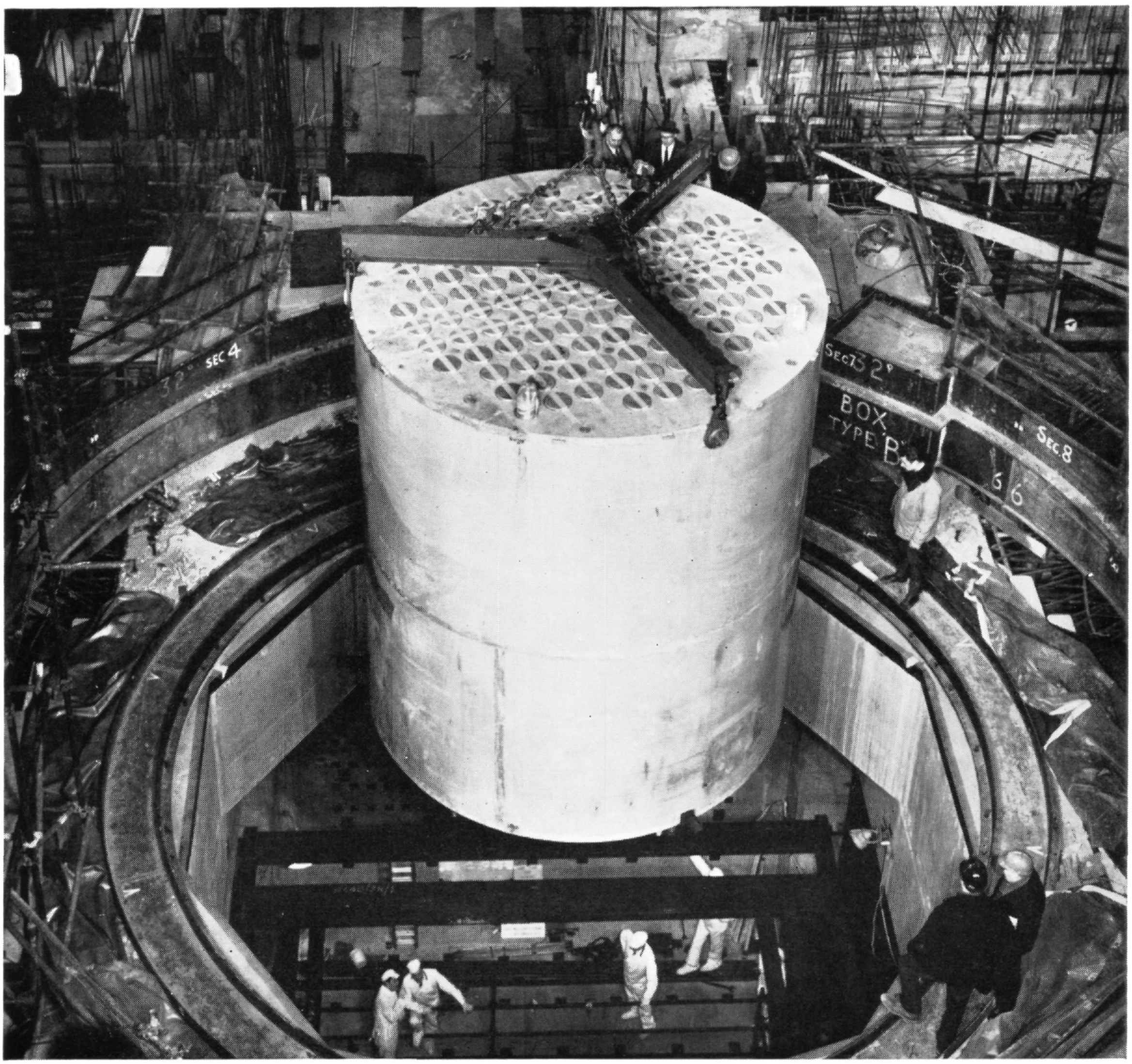
The sodium-cooled fast reactor is being developed to meet the first requirement, and the Authority are devoting at present greater effort in terms of qualified scientists and engineers to fast reactors than to any

The calandria being winched down into position inside the S.G.H.W. prototype reactor at Winfrith.

other system. The prime advantage of fast reactors is that they are particularly suitable for using as fuel the considerable quantities of plutonium which will have been produced as a by-product in the thermal stations by the mid-1970's. Fast reactors have another advantage in that, by converting non-fissile material placed around the core, they can produce more fissile material than they consume, thereby extracting a far higher proportion of the energy from a given quantity of nuclear fuel.

The experimental fast reactor at Dounreay has continued to work well at full power, having reached a peak of 62·5 MW(H). It has successfully demonstrated that a liquid-metal-cooled fast reactor core can be safely operated and controlled at the required heat ratings. It is now being used primarily as a test-bed for fast reactor fuels, materials and techniques. Proposals for constructing a prototype fast reactor power station will be submitted to Her Majesty's Government later this year.

To meet the second requirement for smaller-size reactors the Authority have concentrated mainly on the steam generating heavy-water-moderated reactor and are building a 100 MW(E) prototype at Winfrith. This reactor shows promise for use in power stations of small or medium output, and in addition is an efficient plutonium producer. To meet the third requirement the Authority are also studying other designs of water reactors for smaller power, primarily for ship propulsion including the Vulcain system, which is the subject of joint development work with a consortium of Belgian firms.



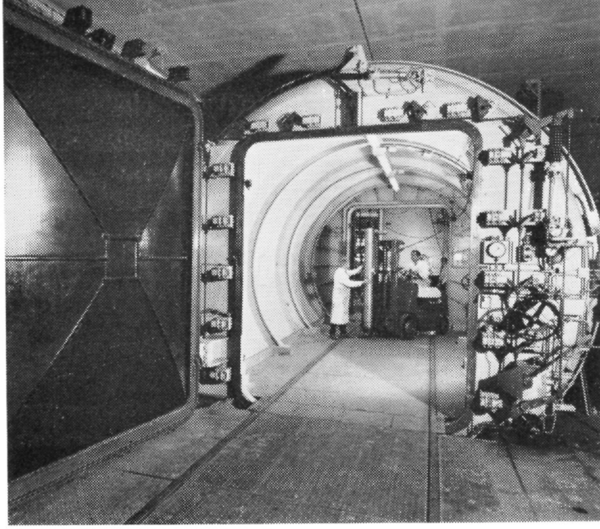
ADVANCED GAS-COOLED REACTOR

The Windscale A.G.R. has continued to operate reliably and well and is now in its third year on power. The average full power output of the reactor during the year to 31st March, 1965 was 108 MW(H) and the turbine was re-bladed to allow an increase in net electrical capacity to about 36 MW(E). Plant availability continues to be high. It has averaged 85 per cent. since the reactor first went on power, excluding shut-downs for experimental purposes.

The fuel elements in the Windscale A.G.R. have continued to behave faultlessly. At the end of the year, the average burn-up of the original charge exceeded 5,400 MWd(H)/t with a peak burn-up of 11,000 MWd(H)/t. Further experiments in the reactor on fuel elements with deliberately punctured cans have confirmed that there would be ample time to deal with this type of defect in practice and that only a simple burst can detection system is needed in an A.G.R. By the end of the year one fuel element with a slit in the can had been left in the reactor for eight months without any sign of trouble.

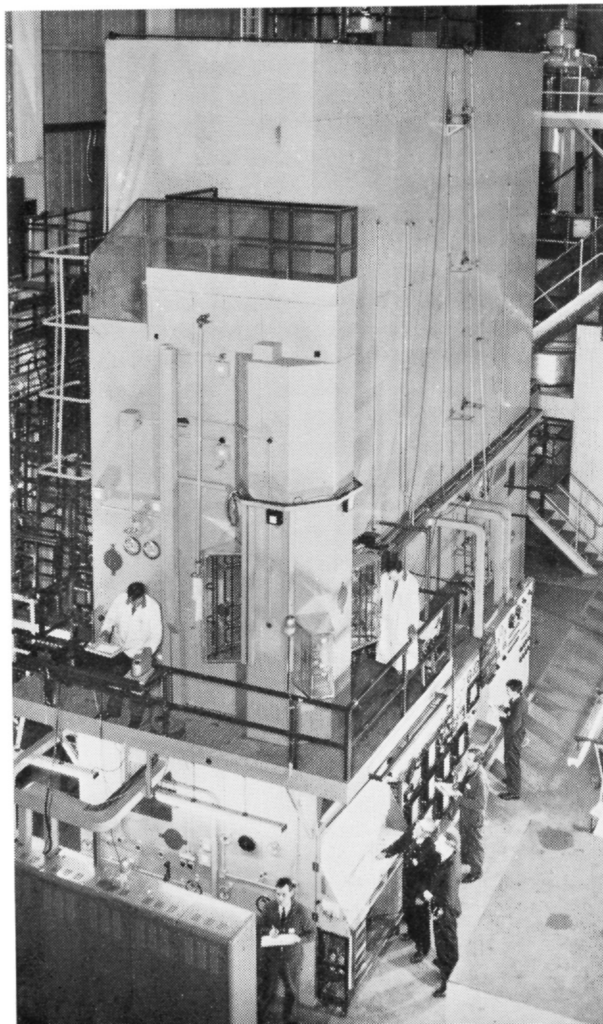
Numerous fuel channels containing experimental fuel elements have been operated at temperatures appropriate to commercial designs of the A.G.R. system. The maximum temperatures of fuel cans in these channels have ranged between 700°C and 780°C., and of the gas outlet temperatures between 560°C. and 630°C. Comparable figures for reactors fuelled with uranium metal in Magnox cans are 450°C. and 400°C. respectively. More than a quarter of the channels in the reactor contain experimental fuel stringers, and all are behaving well under irradiation. The highest irradiation reached in any experimental element during the year was 13,000 MWd(H)/t and in elements running near the conditions proposed for the first commercial A.G.R., 5,500 MWd(H)/t.

Longer term development has continued for ceramic fuel elements dispensing with a metal can. Specimens of two types of fuel have been prepared: uranium dioxide dispersed in beryllia, and a dispersion in silicon carbide or uranium carbide coated with pyrolytic carbon or silicon carbide. Both types have an outer fuel-free sheath of matrix material to replace the metal can. Development has now been concentrated on the carbide type because it holds the greater promise of reductions in overall capital and generating costs.



A canned fuel-element being loaded on a fork-lift truck inside the vehicle airlock of the "Dragon" reactor.

This rig at the Reactor Engineering Laboratory, Risley, is an adjunct to the Fast Reactor fuel-element test facility.



The two major problems related to the moderator have been: (*a*) changes in graphite dimensions under irradiation; and (*b*) corrosion of graphite by the carbon dioxide coolant under irradiation.

During the past few years accelerated tests of the irradiation behaviour of graphite have been carried out in DIDO and PLUTO and in the BR-2 reactor at Mol, Belgium. Recent experiments have shown that the neutron intensity in the Dounreay fast reactor is high enough to test graphite in the course of a few months to the irradiation dose expected in the full life of a large commercial A.G.R. By 31st March the dimensional stability and creep ductility of graphite under irradiation had been tested to well over half of the lifetime dose in an A.G.R.

The creep tests showed that there is a mechanism for relieving stress in the graphite blocks of an A.G.R., and experiments are being continued to test the graphite to the lifetime dose expected in more highly developed A.G.R.s. with higher ratings.

Satisfactory control of the radiation-induced corrosion of graphite has now been demonstrated in the Windscale A.G.R. which has been operating with the coolant containing a small addition of methane since February, 1964. Reaction between the graphite moderator and the coolant has been monitored by a sensitive technique based on the use of a graphite specimen containing the radioactive isotope carbon-14, and it has been demonstrated that the rate of reaction has been reduced to a level well below that considered tolerable over the full life of a large commercial A.G.R.

HIGH TEMPERATURE GAS-COOLED REACTOR

The Authority continue to support the Organisation for Economic Co-operation and Development Dragon reactor project sited at the Atomic Energy Establishment, Winfrith.

The Dragon reactor achieved criticality on 23rd August, 1964. The reactor is operated on behalf of the Dragon project by a team of Authority staff. Supporting services include the breakdown and examination of active fuel elements in the Winfrith active handling building, which was brought into use during the year.

Testing of coated particle fuels for high temperature reactors has continued in collaboration with the Dragon project. Techniques have been developed for preparing fuel elements in which the particles are dispersed in a carbonaceous matrix covered with a fuel-free layer of matrix material. The work has been extended to include particles of thorium and plutonium carbides. Experiments in a loop in PLUTO have demonstrated that, under operating conditions, simultaneous failure of all particle coating should not occur, and that the rate of release of fission products from fuel in which the particles are coated with silicon carbide is extremely low. Fuel elements for the Dragon reactor were designed on the assumption that the helium gas flowing directly over them would need to be separated from the main gas stream and cleansed of fission products. Such "purged" elements are enclosed in porous graphite containers, and a special low permeability graphite has been developed for the purpose. However, the experiments with coated particles mentioned above have shown that it should be possible to design fuel elements which do not need to be purged, and further studies are proceeding on this concept.

STEAM-GENERATING HEAVY-WATER REACTOR

Construction of the prototype steam-generating heavy-water reactor at Winfrith, which began in May, 1963, is proceeding according to programme, and the building which will contain both the reactor and the turbine is virtually complete.

The building forms the secondary containment, and low leakage is ensured by a system of double cladding. The cladding has been erected and the required standard of leak-tightness achieved. The design has made it possible to complete all the reactor concrete work before beginning erection of the core, and this is now under way in good working conditions. The first neutron shield tank was delivered to site in January and the calandria at the beginning of February. These and all other reactor components are shop-fabricated and, in the case of the shield tanks, pre-assembled at works.

The limit of the power output of a fuel channel in an S.G.H.W. reactor is set by the phenomenon known as "burn-out": the generation of steam becomes so rapid as to force the cooling water out of effective contact with the fuel elements. This is influenced by several factors, including the rate of coolant flow up the channel, which depends in turn on the resistance to flow resulting from the generation of steam. Methods have been devised for predicting the steam flow in individual channels to determine the safe maximum power of each channel. To test these predictions of coolant conditions and thermal performance, a high pressure boiling rig containing a full size simulated reactor channel has been constructed at Winfrith.

It is the largest rig of its type in the world and contains a cluster of 36 electrically heated rods representing fuel pencils. A maximum power of 6 MW can be applied to the test section and it has already yielded valuable results.

A 6 ft. long fuel element irradiated to about 5,000 MWd(H)/t in the X-6 loop in the NRX reactor at Chalk River, Canada, was found on examination to be in excellent condition, and irradiation of fuel assemblies has started in the Halden reactor in Norway.

The S.G.H.W. reactor is designed for fuelling with slightly enriched uranium dioxide, but the alternative of using natural uranium – metal or oxide – is being studied.

The Authority have sponsored a collaborative design study by the consortia of a commercial nuclear power station of 100/200 MW(E) based on the Winfrith design. This is being extended to designs of larger output.

PLUTONIUM IN THERMAL REACTORS

Investigations have continued on the use of plutonium as an alternative to uranium-235 for enriching the fuel used in thermal reactors. Many of the reactor physics uncertainties about using plutonium in the A.G.R. system have been resolved by the experimental programme with plutonium oxide-uranium oxide fuel in the SCORPIO sub-critical assemblies and in the zero energy reactors HECTOR and HERO. Using fuel of three different plutonium enrichments, these experiments have checked methods of calculating reactivity, temperature coefficients and power distribution.

It has become clear that the physics of using plutonium in the A.G.R. presents no major difficulty and it seems likely that an A.G.R. can be designed to use either uranium or plutonium at will.

Physics experiments on plutonium enrichment of the S.G.H.W. reactor system are to be carried out in the JUNO zero energy reactor. An economic comparison will be made between using plutonium in thermal reactors and using it in fast reactors, when the necessary fast reactor information is more fully established as although there may be benefits from being able to use plutonium in thermal reactors, the most efficient user is likely to be fast reactors.

DOUNREAY FAST REACTOR

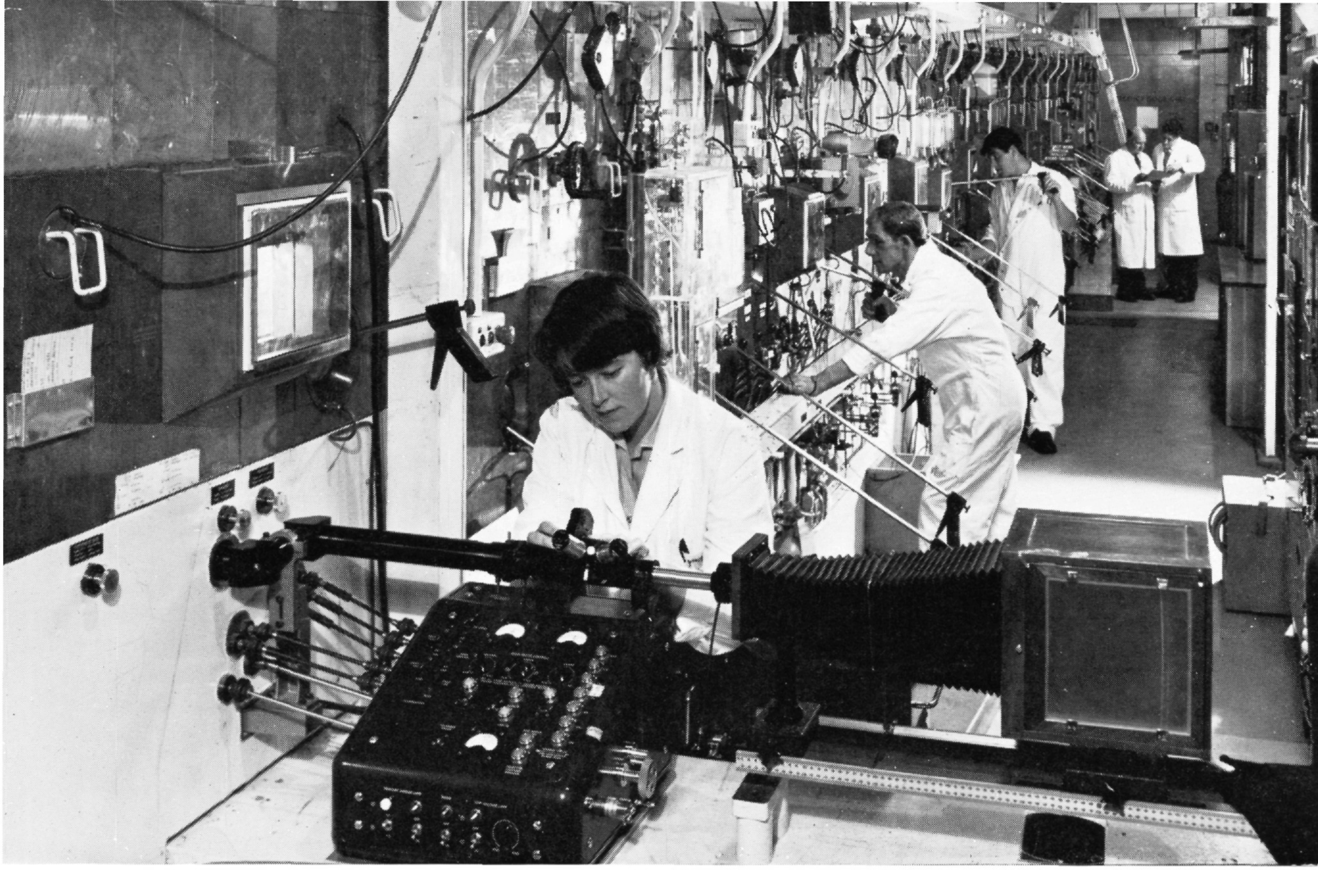
The Dounreay fast reactor has continued to perform well at full power. By the end of the year the total heat output since the reactor started power generation was about 21,000 MWd and the total electricity generated about 100 million kWh, of which nearly 70 million kWh had been supplied to the North of Scotland Hydro-Electric Board. These figures are greatly in excess of those for any other fast reactor, and confirm that the D.F.R. has successfully pioneered the application of sodium-cooled fast reactors to power production. The reactor is now being operated as an irradiation test facility, primarily to obtain information on advanced fast reactor fuels at high burn-up, but also to obtain information for the development of other reactor systems.

Utilisation of the reactor has progressively improved over the year. Two runs were completed of 64 days and 77 days respectively, and on 31st March, 1965, a third had reached 72 days and was still in progress at the end of the year under review. (The run terminated on 9th April after 81 days.) There are over 80 experimental rigs in the reactor, and a standard pattern of loading has been evolved to reduce shutdown time. The operating costs of the reactor are being lowered by more efficient utilisation of fissile material, improvements in methods of fabricating fuel elements and improvements in equipment and operating procedures.

The design, specification and estimates of capital cost of a 600 MW(H) (250 MW(E)) prototype sodium-cooled fast reactor were completed during the year, and effort was concentrated on the detailed design and the preparation of enquiry specifications and bills of quantities for the major plant and civil engineering contracts.

A design study of a 2 × 1,000 MW(E) fast reactor station was also completed. This was a combined exercise by the Authority, the C.E.G.B. and the consortia, and included estimates of generating costs. The exercise showed the suitability of the P.F.R. design for adoption as the basis for large commercial reactors. The larger design is subject to change, but the major engineering principles involved in fast reactor power stations will be demonstrated in the P.F.R.

A study has been made of the siting and safety of a series of large fast reactors, and gives confidence that they should not be at a disadvantage in comparison with other reactor types.



The remote-handling line at Windscale for the examination of A.G.R. fuel to ascertain the effect of irradiation.

FUEL/the next phase

In the field of reactor-fuel production 1964/5 was primarily a year of preparation for the next phase of the nuclear power programme.

A vital component and major contributor to the cost of fuel elements for the next generation of reactors will be slightly enriched uranium oxide. Plans have been prepared to modify the Capenhurst diffusion plant to supply the low enriched material required. Development work on new units for the plant has progressed well and it is now clear that very much improved efficiencies can be achieved. These improvements can be incorporated into a part of the present plant and the factory re-organised to meet the requirements of the new nuclear power programme. Further additions can be made later which will enable Capenhurst to meet the requirements of an expanding programme throughout the 1970's. A government decision as to whether to implement these plans is expected to complement the decision on the nuclear power programme itself.

Pending these decisions, the Capenhurst plant is being operated at a minimum level of production of 2 per cent. enriched uranium-235 in order to maintain diffusion technology and a trained labour force in readiness to meet possible future demands.

Enriched uranium oxide fuel has for some time been produced at Springfields on a moderate scale. However, for the next phase of reactors, larger scale commercial production will be required, and to provide this a major development programme is nearing completion. Thus a fluidised bed process for uranium hexafluoride production has been developed to the pilot plant stage and a large production plant designed on this experience will supply feed material to the Capenhurst diffusion plant at less than half the present processing cost. Plant has also been developed for conversion of enriched uranium hexafluoride to uranium dioxide pellets on a continuous and largely automatic basis.

A major programme of oxide fuel manufacture involves the loading of millions of uranium dioxide pellets into many thousands of stainless steel or zirconium tubes which have then to be assembled into fuel element clusters. Appropriate production line methods have been evolved for these canning and assembly stages, and plans have been made to install the new units to match reactor construction programmes.

In December 1964, Springfields manufactured the millionth Magnox fuel element and during the year some 185,000 elements were produced. Initial charges were completed for the first reactor of the C.E.G.B. station at Sizewell and for the Tokai Mura reactor in Japan. Replacement fuel was made for the C.E.G.B. reactors at Bradwell, Berkeley, Hinkley Point, Trawsfynydd and Dungeness, for the S.S.E.B. reactor at Hunterston and for the Authority's own reactors at Calder Hall and Chapelcross.

The Tokai Mura fuel was the first to be manufactured at Springfields with hollow uranium rods in place of the usual solid rods. Over 17,000 of these more complex elements were manufactured and shipped to programme.

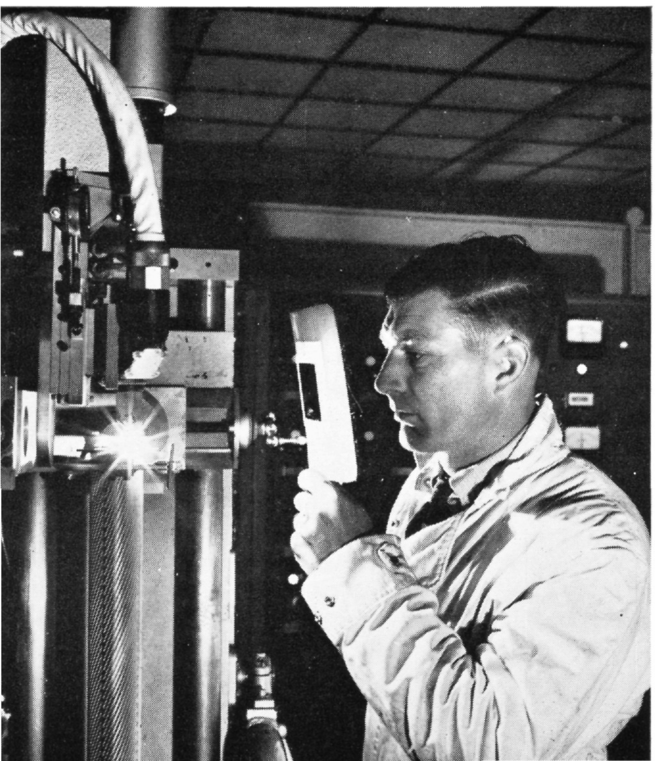
Prototypes of fuel elements for the C.E.G.B. stations, irradiated in the Calder Hall and Chapelcross reactors, have now achieved a heat output exceeding 4,000 Megawatt-days per tonne compared with the 3,000 MWd/t design target. Advantage can be taken of this in the present stations either by prolonging the life of the fuel or by operating the reactors under more onerous conditions to give higher outputs. The Authority announced at the Geneva Conference in September, 1964, that they were sufficiently confident of the satisfactory performance of Magnox fuel to guarantee fuel elements for future large reactors to a burn-up of 4,000 MWd/t.

A new chemical reprocessing plant was commissioned at Windscale in June 1964. It replaced the original separation plant which was built fourteen years ago. Although the throughput is larger, the new plant employs fewer operators because of extensive use of purpose-designed instruments and automatic control. Commissioning of the plant was accomplished remarkably quickly, and during even the first campaign processing rates were achieved which were well in excess of the design capacity.

Plans have been completed for the conversion of part of the now disused first separation plant to provide a pretreatment unit for oxide fuels in a variety of claddings so that these also can be reprocessed in the new plant. Development of the additional equipment and processes is well advanced. With the addition of this plant the reprocessing complex which will be available at Windscale will cater for all the fuels from the present Magnox reactors and from the advanced reactors of the second nuclear power programme and could also undertake a wide range of overseas business.

Plutonium is an alternative to uranium-235 for enriching future fuels. In a small-scale plutonium fuel manufacturing plant at Windscale, experimental fuel has been made for the Windscale A.G.R., the Ågesta reactor in Sweden, and the BR.3 reactor in Belgium. The skills and experience being built up will be used in the design and operation of a larger plant which will initially manufacture fuel for the prototype fast reactor, but will later also be available for the manufacture of plutonium fuels for thermal reactors and export.

A total of 7,300 materials testing reactor (M.T.R.)-type fuel plates were fabricated in the year for supply to the Authority research reactors and to other reactors in the U.K. and abroad. Over 600 M.T.R. fuel elements were reprocessed including 125 from Denmark. Nearly 1,000 fuel elements from Doun-



Automatic welding at the Fuel Element Development Laboratories, Springfields.

In November 1964 the Authority obtained a contract for the re-processing of fuel from the Latina station in Italy. The contract was signed by Sir Alan Hitchman, Deputy Chairman, U.K.A.E.A. (left) and Professor A. N. Angelini, Director-General, E.N.E.L.

reay fast reactor were also reprocessed; this work involved dealing with materials of higher specific activity than any other reprocessing plant has ever handled.

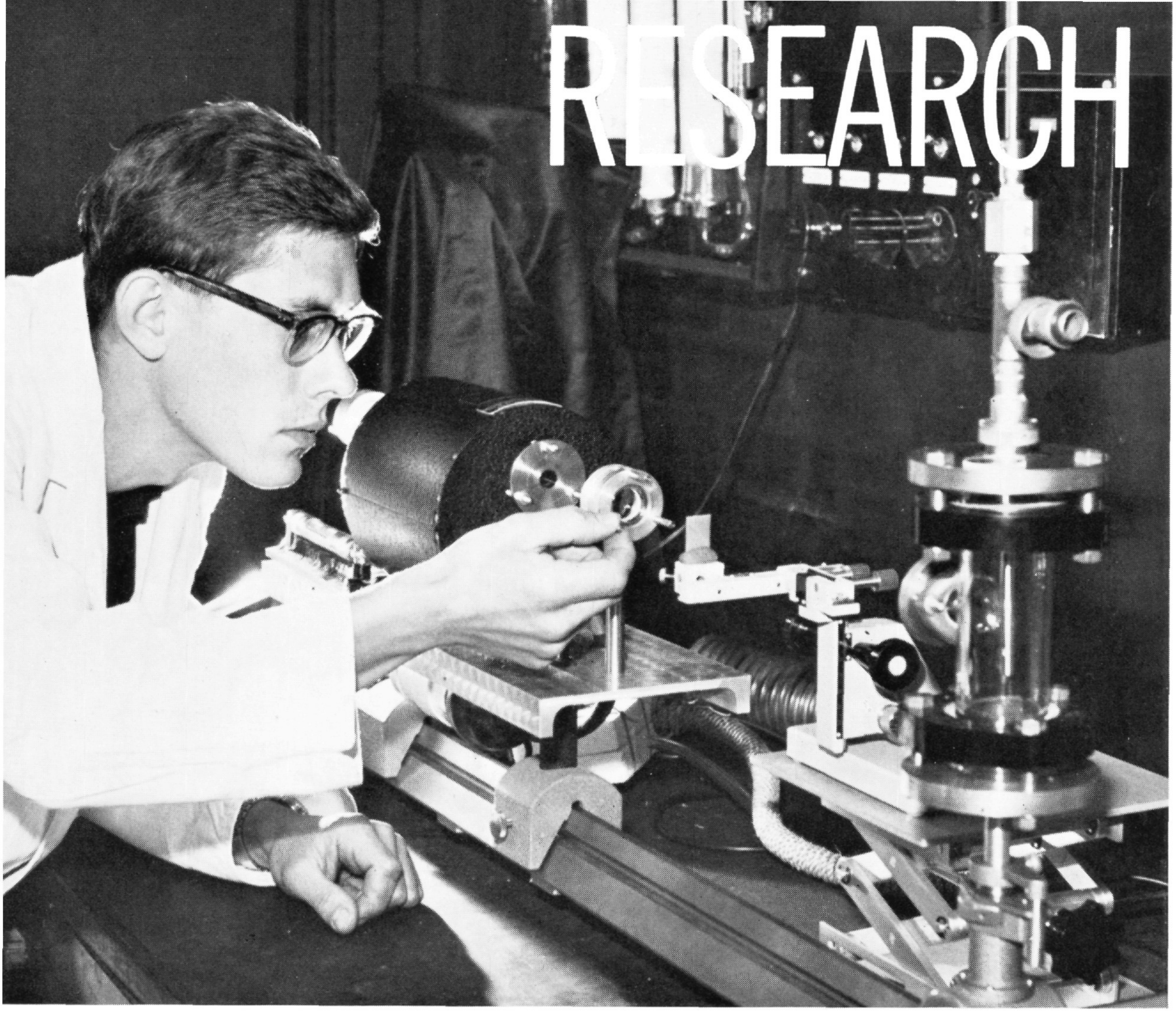
The total value of reactor fuel and other sales in 1964/65 was over £30,000,000–£24,500,000 at home and £5,600,000 overseas. Sales of Magnox fuel elements to the United Kingdom electricity generating boards will continue at a high level for the next few years, but there will be year-to-year fluctuations depending on requirements for initial charges.

Although the majority of commercial sales are in the domestic market, the scale of effort overseas was considerably increased during the year. Because of the good economics of the large fuel production and reprocessing plants at Springfields and Windscale, the Authority are able to quote competitive prices for fuel cycle services throughout the world.

The most valuable new overseas contract secured in 1964/65 was with the Italian Ente Nazionale per l'Energia Elettrica for the reprocessing of irradiated fuel from the Latina nuclear power station. The contract lasts until 1970 and is extendable to 1974. It includes the transport of the radioactive fuel from an Italian port to Windscale and in this connection the Authority have broken new ground by chartering a ship specially for carrying the fuel and appropriate insurance cover has been obtained.

As more countries develop their own substantial nuclear power programmes, it becomes necessary to take special steps to ensure continuing outlets for the Authority's products. One way of achieving this is by co-operation with local industry on a basis which enables at least part of the fuel manufacturing processes to be carried out in the countries concerned. In December, for example, the formation was announced of a joint company called Nukleardienst (Nuclear Services) for the supply and reprocessing of A.G.R. type fuel in Germany and in other Common Market countries; the partners in this company are the German organisation Nukem and the Authority.

A further quantity of replacement fuel for the Latina reactor will be required in 1965/66 before there is any possibility of its manufacture in Italy, and during 1964/65 the Authority made an offer for the supply of this fuel. (This offer was subsequently accepted and a contract was signed in June, 1965.)



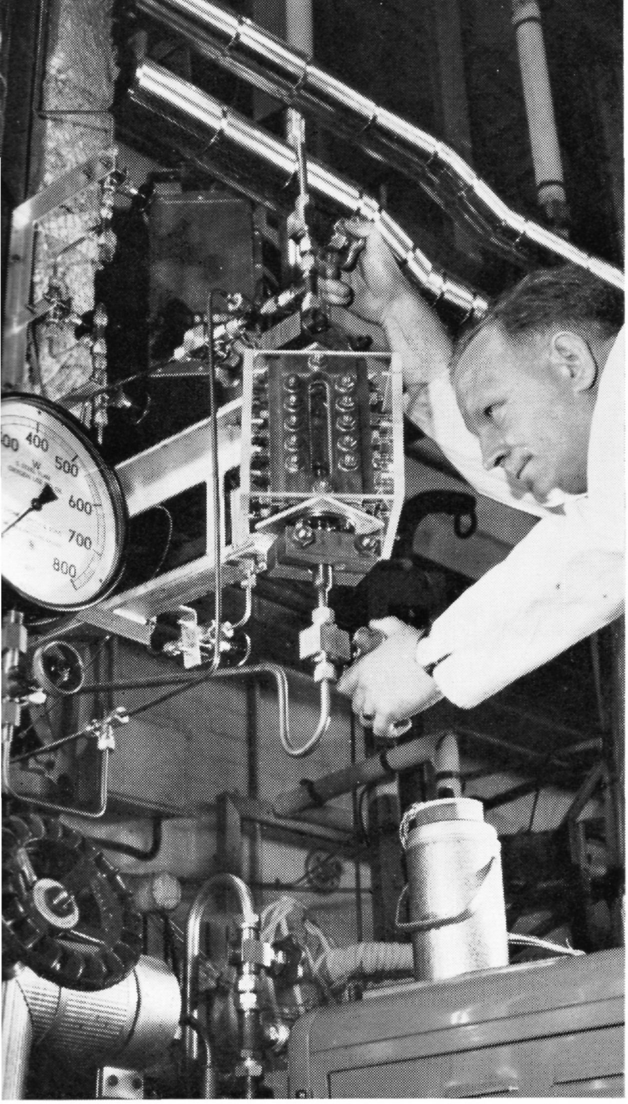
Adjusting high-energy laser equipment at Harwell prior to a can-puncture experiment. Fuel cans are punctured inside a vacuum apparatus so that the fission gas can be analysed.

Research within the Atomic Energy Authority falls into a number of separate categories. For example, in addition to the work for specific power reactors there are many programmes of research which are applicable to more than one type of reactor. A large part of the Research Group's work comes into this category as do many important researches in the Reactor and Weapons Groups. These programmes include measurements of nuclear properties; studies of reactor physics and of new reactor systems; properties of fuels and other materials; safety matters.

In addition there are long-term researches of a general nature which are undertaken to provide the scientific information upon which to base the Authority's technological work. These include work on materials and their properties and the effect upon them of radiation; on metallurgical and chemical processes; nuclear and theoretical physics; instruments and techniques; the direct conversion of heat to electricity.

Yet another important field of work is that concerning plasma physics and fusion research.

In many of the programmes – especially those that can be classified as basic research – there is close collaboration with university departments. In other fields there is co-operation with industry and overseas agencies.



Adjusting the controls of a high-pressure heat-transfer rig at Harwell. It is designed to yield information applicable to reactors such as S.G.H.W.

Some of the researches carried out by the Authority are of possible relevance to industries other than the nuclear energy industry.

URANIUM FROM SEA WATER

Uranium is present in sea water in a low but constant concentration of 3·34 micrograms per litre; nevertheless the total quantity of the element in the oceans is over 4,000 million tons.

Experiments were begun a few years ago on possible methods of extraction. Various organic and inorganic materials were tested in a small laboratory at Portland Harbour; hydrated titanium hydroxide gel was the one found to be most suitable for further development. An engineering design study of a plant using tidal lagoons in a similar manner to a tidal power plant showed that contacting very large volumes of sea water with the absorbing material need not be excessively expensive. The work was stopped and the Portland Laboratory closed some time ago; a great deal more development would be necessary before a plant could be designed with confidence but the results so far obtained give grounds for hope that medium-cost uranium might ultimately be obtained from the sea.

PLANETARY SWAGING

Swaging is a process by which the diameter or the wall thickness of a metal tube can be reduced; it is especially useful for preparing tubes to fine tolerances.

A new technique of planetary swaging, developed at Harwell, is being used in the production of tubes, mainly as a finishing or sizing operation on seamless tube stock; it gives closer control of dimensions and better surface finish than ordinary methods.

The scope of the method has been extended as a result of investigations on heat treated butt-welded seamed tubes made from stainless-steel or zircaloy strip. This work has shown that the weld and heat-affected zones can be eliminated by planetary swaging and heat treatment. The resultant tubing is as good metallurgically as the more expensive seamless tubing and has better surface finish and closer dimensional tolerances. The method is being developed for refractory metals.

By a combination of special heat treatment and a planetary swaging operation, stainless steel tubes for A.G.R. fuel elements have been made which have greater ductility at high temperature than tubes produced by other combinations of working and heat treatment. Improved ductilities have also been observed with zircaloy fuel cans and tubes.

HYDROSTATIC EXTRUSION

A prototype machine for hydrostatic extrusion (the forming of metal under high fluid pressure) has been in operation at Springfields for a year. It has been used for general metal forming, co-extrusion of fuel elements, and extrusion of super-conducting materials. As far as is known it is the first machine designed specifically for the industrial application of the hydrostatic extrusion process and it has aroused interest for ordinary industrial purposes as well as for nuclear purposes. Development work on the method has included extrusion from pressures as high as 450,000 lb./sq. in. into back-pressures of 100,000 lb./sq. in. and a general investigation into the extrusion of complex cross-sections.

NEW REACTOR SYSTEMS

Among the novel reactor types and applications being investigated by a small group at Winfrith are the fused salt reactors. These show long term promise and are also under study in the U.S.A. Investigation of the fused fluoride system operating on the uranium-233/thorium fuel cycle has shown that the good neutron economy obtained by continuously processing the fluid fuel, together with the excellent characteristics of uranium-233 as fissile material, should make it possible to run a reactor as a self-sustaining thermal breeder.

DIRECT CONVERSION

The exploratory programme at Harwell on methods for directly converting heat to electrical energy has continued with further studies of the feasibility of the M.H.D. (magnetohydrodynamic) method using non-equilibrium ionisation of the hot gas. These studies have been made with voltages applied from an external source. The possibility of similar effects when the voltage is generated by the M.H.D. interaction in the flowing gas, are being investigated in the rig described in the 10th Annual Report.

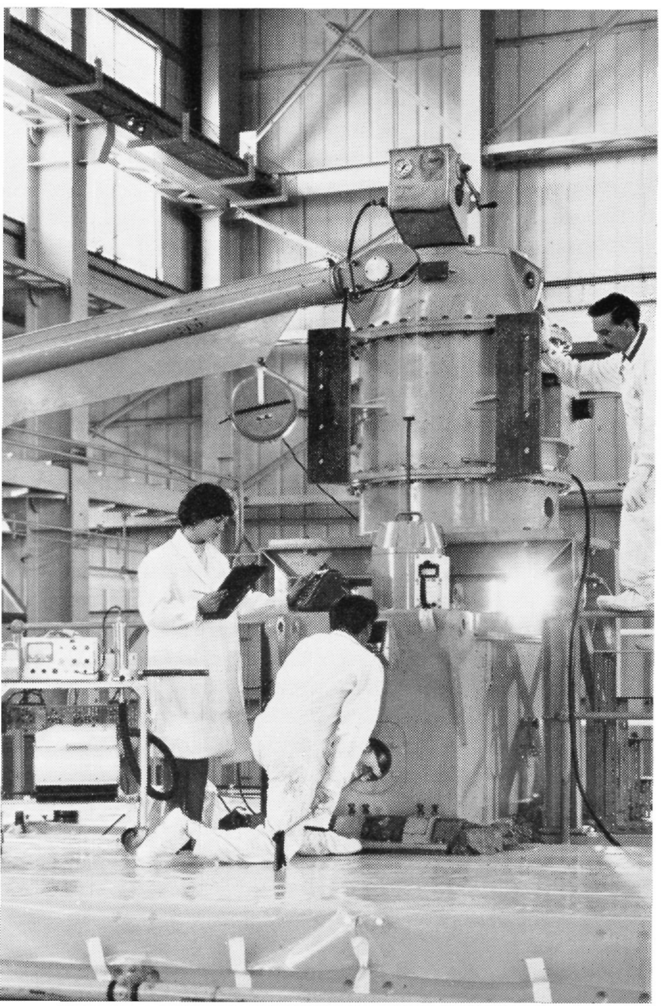
Three more thermionic diode converters, with caesium neutralisation of space charge, have been operated in the PLUTO reactor to determine their efficiency. The emitters were fissile carbide, either unclad or clad in refractory metal. These devices delivered about 40W of electricity from 10 sq. cm. of emitter surface.

In work on thermoelectric generators with radioactive isotopes as heat sources, design studies have been made for generators of several sizes and types. A demonstration generator known as RIPPLE (Radioisotope Powered Pulsed Light Experiment) has been built and operated successfully, to show the possibilities of the system for flashing-light buoys and similar applications. The isotope source was strontium-90 (as the titanate); the thermoelectric elements were of bismuth telluride. Power output was 50 mW. The isotope plutonium-238 is also suitable for use as a heat source in thermoelectric generators; about 1 gm. has been separated at Harwell by an ion-exchange process from neptunium-237 irradiated in the Dounreay Materials Testing Reactor.

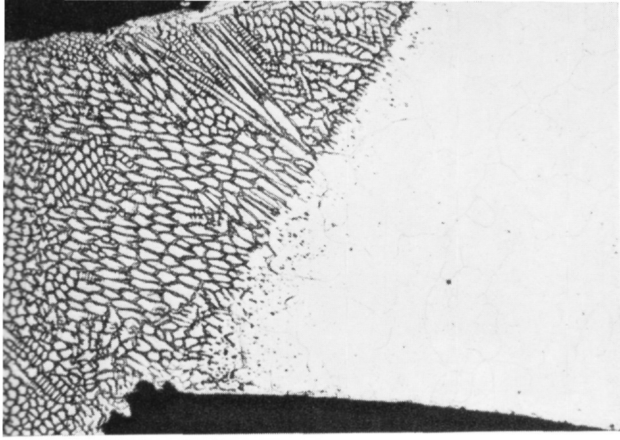
ELECTRONICS

The programme of research at Harwell on solid-state particle detectors has continued. Silicon of high purity has been used in a range of devices developed for precise measurements of particle energies, for high-speed counting, and for a variety of applications to radiation survey and monitoring. The small size of these devices is an advantage in medical applications. Many of the silicon semiconductor devices are now in routine commercial production.

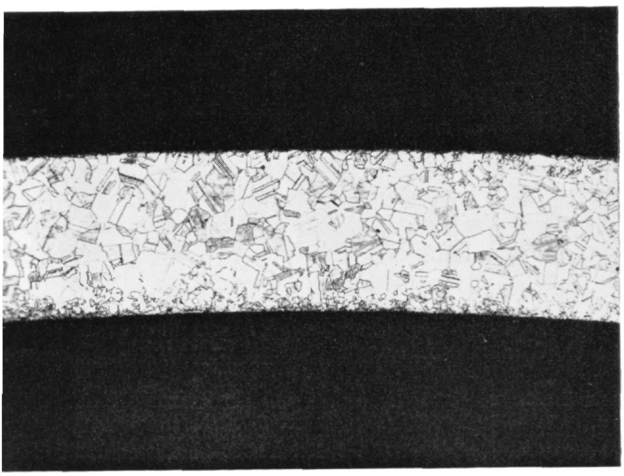
However, detectors based on silicon are of limited use for measuring gamma radiation, for which germanium detectors offer advantages though they have to be operated at liquid-nitrogen temperature. Using these detectors it has been possible to assay mixtures of radio-elements in which gamma energies differ by



Irradiated fuel from the Windscale A.G.R. being loaded into the HECTOR reactor at Winfrith to determine the changes in reactivity which have taken place.



PLANETARY SWAGING *followed by recrystallisation heat treatment can rectify the inferior metallurgical structures and mechanical properties in the weld zone of butt welded seamed tubes made from metal strip. The "before" and "after" pictures above and below show that, by this method, tubing is produced with uniform metallurgical quality that compares very favourably with the expensive seamless variety made by conventional extrusion and cold drawing processes; in addition such tubing also remains free from certain serious defects often inherent in solid drawn tube*



only 10 keV, without any chemical separation of the component parts of the mixture.

NUCLEAR PHYSICS

The Authority's programme of research in experimental nuclear physics is directed to the elucidation of nuclear structure and of the basic nuclear interaction forces. At Harwell, studies of nuclear structure are done with the tandem generator, the 5 MV electrostatic generator, and the 3 MeV pulsed electrostatic generator IBIS and by the photo-effect group working with the linear accelerator. The synchrocylotron is used for work on both nuclear structure and nuclear forces. Current interest centres on recently-initiated studies of isotopic spin analogue states, many of which become accessible with reactions induced by particles such as deuterons, tritons, helium-3 and helium-4 ions.

At Aldermaston the new neutron time-of-flight spectrometer and pulsed injector have been used with the tandem generator to measure the scattering of 10 MeV neutrons from lithium-6 and lithium-7. A large amount of accelerator time has been devoted to the production of tritium beams with energies up to 13 MeV. These have been used for the study of nuclear structure and the mechanism of fission.

FUSION

The aim of fusion research is the controlled release of useful energy from the fusion of light nuclei. Temperatures of the order of 100M°C. are needed and they must be maintained long enough for the energy released by fusion collisions to exceed that fed into the system. The greater the number of nuclei per unit volume the shorter the time required.

At such temperatures collisions have detached all electrons from the atoms, and the resulting assembly of free nuclei and electrons is called a plasma. Plasma is thus both electrically neutral and highly conducting. The latter attribute is particularly significant, since it means that plasma does not readily cross magnetic field lines. Indeed magnetic fields appear to be the only practical means of enclosing hot plasma and isolating it from the walls of the containing vessel.

Unfortunately in many magnetic enclosures plasma is in a state of uneasy equilibrium. It rapidly follows any disturbance of its boundaries which opens the way to the weaker parts of a magnetic field. The magnetic field lines displaced during this motion effectively slip into the space formerly occupied by the plasma – hence the term interchange instability.

Instabilities apart, plasma will always travel along magnetic field lines. Magnetic enclosures can be divided into two broad classes by the way in which they tackle this potential means of escape. With closed magnetic traps the magnetic field lines remain within the system so that motion along the field does not give rise to any loss. On the other hand, the magnetic field lines forming an open-ended magnetic trap are bunched together as they approach and leave the trap. In this way plasma moving along the field lines encounters regions of increased magnetic field strength which limit the rate of escape, although some losses are inevitable.

In both classes of magnetic trap, containment has hitherto been prevented by interchange instabilities, but recent developments suggest that such troubles can be eliminated in open-ended traps. Theoretically when plasma lies in a magnetic field whose strength increases in every direction an interchange instability cannot arise. So far all experiments using "magnetic wells" of this kind have confirmed that interchange instabilities have been held in check. The theoretical and experimental development of magnetic wells has been one of the main features of the Culham Laboratory's work during the past year.

SEISMIC RESEARCH

The analysis of seismic records has continued at Aldermaston. The majority of the explosion records obtained at distances between 2,000 and 6,000 miles from the firing sites show a characteristic and simple waveform. This supports the view that the range 2,000–6000 miles represents a seismic "window" through which signals travel with very little distortion. Thus records from natural or man-made events obtained at such distances are characteristic of the source and its immediate geological environment in the earth's crust and can be used as a basis for the study of source mechanisms.

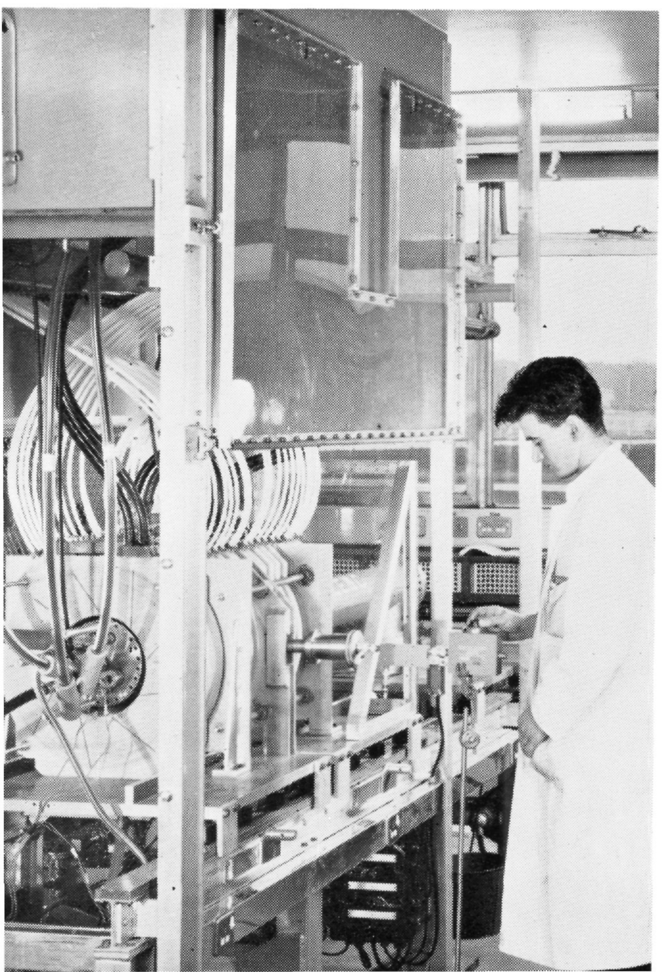
Theoretical work based on simple models of explosions and the crust in which they occur has given good quantitative agreement with observation in most, but not all, cases. This theoretical work is now being extended to try and explain the wide variety of earthquake records by including in the analysis both the source asymmetry associated with earthquakes and the complexity of the earth's crust. Although some success has been achieved in specific cases, no generally applicable results have been obtained.

In addition to improving their arrays the Authority are continually examining the accumulating data and seeking new techniques for identifying the source of seismic signals. A large number of earthquake records has been examined and, although the majority have distinctive characteristics, there still remain some 10 per cent. from events which are not separable from explosion records.

Apart from the application of this work to the detection of nuclear explosions, the techniques which have been developed have interest for seismologists because of the information they can give about the mechanism of earthquakes and the earth's structure. This is instanced by the wide interest shown in the Royal Society symposium on seismic recording and analysis which was held in January, 1965, and which was attended by scientists from many countries.

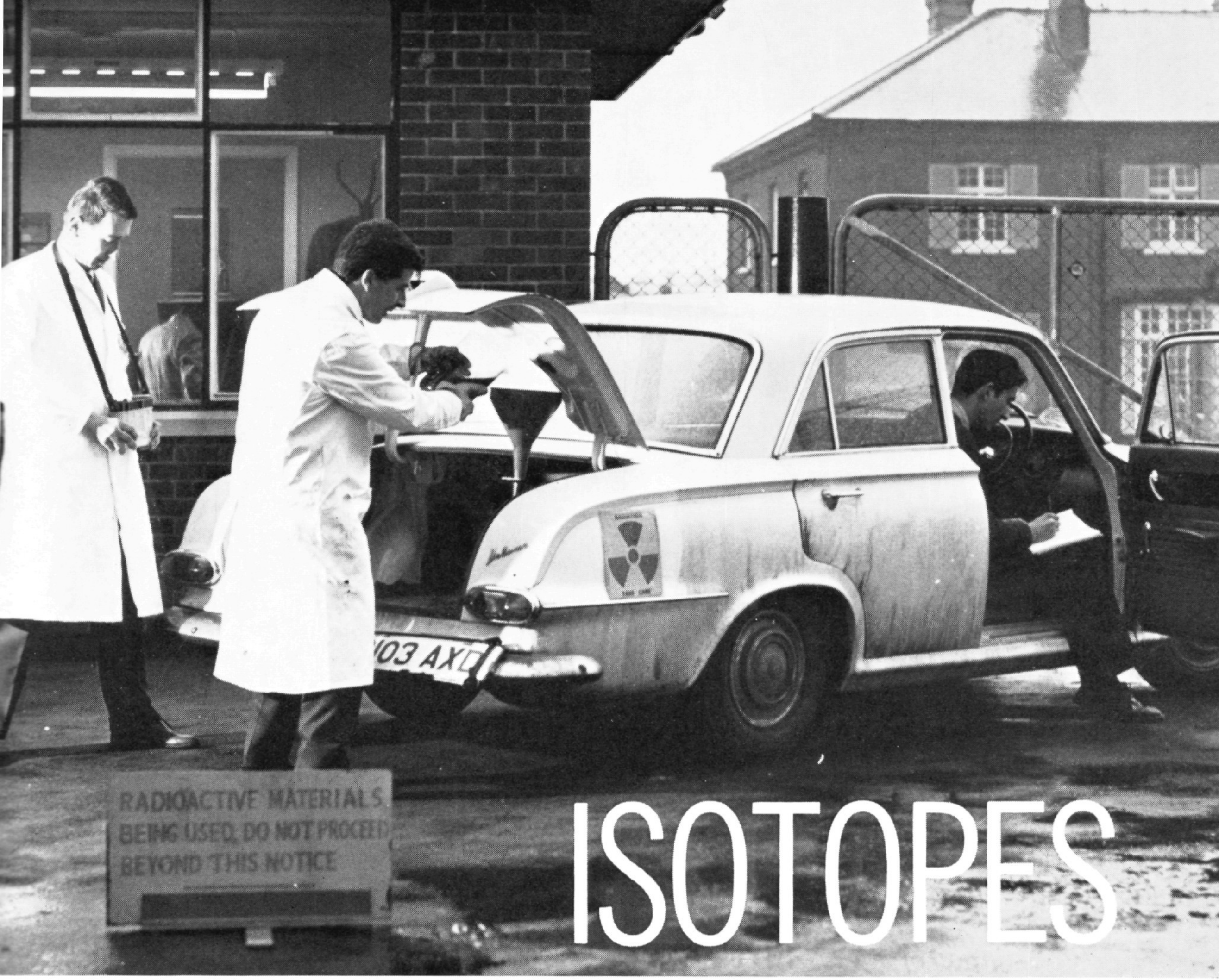
CENTRIFUGES

Development is continuing on the use of centrifuges for isotope separation. The possibility of some of the non-secret aspects of this work being applied to development of very high speed centrifuges for liquid separation for use in medical research is being explored in conjunction with the Medical Research Council. Such machines could be of benefit in the study of viruses and biological minutiae.



Resistivity measurements on a potassium plasma at Culham.

ISOTOPES



Radioactive materials are used for testing wear in the components of cars. The components are irradiated in Harwell's BEPO reactor; after use-tests the radioactivity of the lubricating oil enables component wear to be calculated. (Photo: Vauxhall Motors Ltd.)

The Authority's work with radioactive isotopes falls broadly into two parts. The Radiochemical Centre at Amersham manufactures and markets internationally a wide range of radioactive products for use in industry, medicine and research. The Wantage Research Laboratory, which is a part of the Research Group, studies the basic properties of radioisotopes and develops new techniques for using them as tracers and sources of radiation.

The Radiochemical Centre supplies virtually the whole of the requirements for radioisotopes in the United Kingdom, and also sells its products abroad in competition with foreign suppliers – of whom, according to the International Atomic Energy Agency International Directory of Radioisotopes, there are now seventy. Accordingly the sales figures are an indication of the growth of isotope usage in the U.K. and also a measure of the success of the British products overseas. The trends may be judged from the figures for the last five years and for the year under review.

In the five years from 31st March, 1960, to 31st March, 1965, total annual sales rose from £1,100,000 to £1,900,000, by an average increment of 11 per cent. Exports amounted to 53 per cent. of total sales. In aggregate over this period, total sales were £7,700,000 and exports £4,100,000.

Results for the year 1964/65 have been distinctly better than average. Sales increased by 19·2 per cent. to £1,900,000, and exports exceeded £1 million for the first time, amounting to 58 per cent. of the total. The number of consignments despatched was 56,000.

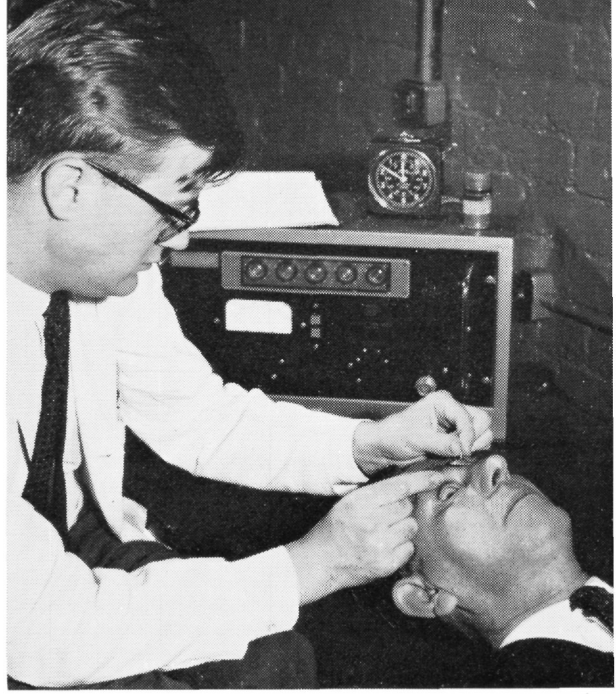
As reported a year ago the Authority are providing at Amersham a cyclotron which has been specially designed for isotope production. Construction of the machine and the building have run somewhat ahead of programme, and at the year's end the installation at Amersham was almost complete. Production of some of the more important cyclotron isotopes will be started in 1965, but several years of technical development will be necessary before the full potential of the machine can be exploited. Meanwhile the demand for cyclotron isotopes continues to grow rapidly and confirms the decision taken to instal this machine.

Provision of cobalt-60 for industrial irradiation plants has continued on a substantial scale. Contracts for supplying cobalt-60 for the first two commercial gamma radiation sterilising plants being built on the continent of Europe have been obtained this year. Throughout the world there are five installations of this kind already in operation using cobalt-60 supplied by the Authority, having a total installed activity exceeding one million curies.

The range of carbon-14 and tritium compounds for use in biological and other researches has been extended by thirty-five new items this year, and six hundred compounds of these two isotopes are now available. Additions have been made particularly to the lists of nucleic acids and their derivatives, which are much in demand for studying molecular biology, and of steroids and carbohydrates. In some cases, several forms of the same compounds can now be supplied. For example, the nucleoside thymidine which is used extensively by biologists for labelling D.N.A., is now available in four forms, of which two are labelled with tritium and two with carbon-14.

Labelled compounds of many isotopes continue to find increasing use in diagnostic medicine, particularly in connection with the radioisotope scanning technique.

Neohydrin labelled with mercury-203 or mercury-197, which was reported as being under development last year, has now become the preferred agent for location of brain tumours and is in routine use. The isotope technetium-99m, which has characteristics that are particularly favourable for isotope scanning with minimum radiological dose to the patient, is being used increasingly for similar purposes. As the half-life is only six hours, the Centre supplies the parent isotope molybdenum-99 in a form from which the technetium can be obtained quite simply as required.



A radio-strontium applicator being used for the treatment of an inflammatory eye condition. (Photo: St. Paul's Eye Hospital, Liverpool).

There has been a progressive improvement in the efficiency and safety of radiation sources intended for medical therapy. Strontium-90 has been used to provide powerful sources of beta radiation for teletherapy, and for irradiating the blood stream externally to the patient. The service of supplying gold-198 grains for interstitial therapy has been improved so that the accuracy is now the same as for radon seeds, which it is expected will ultimately be replaced by the gold grains.

The Wantage Research Laboratory is concerned with the development of techniques using radioisotopes as tracers or as sources of radiation. Close contacts are maintained with industry to ensure that the research programme is appropriate to industrial needs and that manufacturers are kept aware of developments which might improve the quality or lower the cost of their products.

As an example there is at present a considerable demand for a simple continuous system to measure coal ash to control cleaning and blending processes at the pit head and to control combustion efficiency in the electricity generating, steel and chemical industries.

A prototype instrument (using a $^{3}H/Zr$ source) which is insensitive to ash composition and uses dried coal crushed to minus 72 British Standard

Sieve (less than fourteen thousandths of an inch maximum particle size) has been developed at Wantage.

This instrument has been tested by the National Coal Board and found to be very satisfactory. As a result two additional units are now being constructed by the Central Engineering Establishment of the N.C.B. and will shortly be installed in a coal washery for control purposes. Large quantities of small coals (less than half-inch) are handled by the board and significant gains in time and money would result if this coal could be measured without further crushing or drying. Initial work towards this goal is very encouraging; satisfactory results have been obtained for coal with less than $\frac{3}{8}$-inch particle size with 10 per cent. moisture content.

The international Hydrological Decade began in 1965 and marks an increase in the already considerable interest in the U.K. in problems of water supply from surface and underground sources. Measurements of naturally occurring tritium in water provide an additional tool for hydrologists and engineers and a unit is operating at Wantage to carry out tritium measurements at these low levels.

Tritium is formed in the atmosphere by cosmic radiation and nuclear weapons testing. This tritium appears in rain and ultimately in surface and ground waters. The amount present in ground water decreases due to the tritium decay (half life 12·26 years). Measurements of the activity of ground water therefore give some indication of its age.

During the last year the revival of interest in the use of radiation to modify plastics and to initiate chemical reactions has continued. The possibility of using gamma radiation to produce a new detergent has aroused interest in the U.K. and the Wantage Research Laboratory is studying the formation of detergent by this method. The important new feature is that the detergent is decomposed by bacteria and its use would reduce toxic pollution and foaming on rivers and at effluent plants.

There has been a steady increase in the use of gamma radiation for medical sterilisation, and the package irradiation plant at the Wantage Research Laboratory has processed a record quantity of medical equipment. The laboratory has launched an irradiation service for sterilising items from British hospitals; the scheme is specially intended for items which cannot be sterilised by heat. One purpose of the service is to help in estimating the possible usefulness of a gamma irradiation unit within the precincts of a hospital.

The recent report of the Ministry of Health Working Party on Food Irradiation has clarified the U.K. position regarding the distribution of irradiated food. It recommends that individual food applications must be submitted for approval by an appropriate committee and must be supported by experimental evidence of the non-toxicity of the irradiated product.

Feeding studies using experimental animals are therefore continuing at Wantage. Following work on wheat and egg, irradiated cod is now being tested, and this project is partly supported financially by the White Fish Authority. The project was initiated in support of work at the Low Temperature Research Station, Cambridge, and the Torry Research Station, Aberdeen, which demonstrated the usefulness of gamma radiation in extending the "on ice" storage life of fish.

Microbiological studies on the use of radiation for the elimination of salmonellae from various foods have continued. Following the publication of the above-mentioned report negotiations have been reopened with the Port of London Health Authorities regarding the installation of a cobalt-60 plant at the Port of London to be used initially for the irradiation of imported pet-meat suspected of contamination.

Samples being prepared at Amersham for analysis in a scintillation counter.

INTERNATIONAL RELATIONS

The opening session of the Third International Conference on the Peaceful Uses of Atomic Energy at Geneva on 31st August, 1964.

Sir William Penney, Chairman of the Authority, led the United Kingdom delegation to the Third Geneva Conference on the Peaceful Uses of Atomic Energy. The delegation also included Mr. J. C. C. Stewart (Member for Reactors) and representatives of the Ministry of Power, the Central Electricity Generating Board and the industrial consortia.

Britain contributed 75 to the total of 739 scientific papers from 71 countries.

In co-operation with the International Atomic Energy Agency, staff of the Authority have acted as consultants and as members of panels and study groups on: the use of plutonium for power production; the industrial applications of radioisotopes; research reactor experimental techniques; nuclear data; and the design and equipment of hot laboratories. Authority representatives participated in eight scientific meetings arranged by the Agency.

The Authority also provided the technical adviser to the U.K. representative on the Agency's Working Group which elaborated a safeguards system for precluding the military use of nuclear materials and nuclear equipment made subject to the system.

The Authority continued their arrangements under which overseas scientists holding I.A.E.A. fellowships are given training in their schools and at their establishments.

E.N.E.A.

The "Dragon" High Temperature Gas-Cooled Reactor at Winfrith – operated by the European Nuclear Energy Agency (O.E.C.D.), in which the United Kingdom is a partner – achieved criticality in August, 1964.

The Halden reactor programme of E.N.E.A., in which the Authority are participating, has made satisfactory progress. Two Authority engineers have been working on attachment to the project and 18 other members of the Authority staff went to Norway.

Mr. D. W. Colvin, of Harwell, was seconded to act as first director of the Nuclear Data Compilation Centre set up by the O.E.C.D. at Saclay, France, in June. Another O.E.C.D. venture, a Computer Programme Library, was opened at Ispra, Italy, in April. The Authority and 17 other U.K. establishments, including universities and industrial organisations, are co-operating with the library.

EURATOM

The fifth meeting of the U.K./Euratom Continuing Committee, set up under the Agreement for Co-operation signed in February, 1959, was held in London on 22nd June, 1964. The committee reviewed existing collaboration and discussed other fields in which this might be extended. The Authority have given the Euratom Supply Agency assistance with the procurement of special materials for research and development programmes in Community countries.

C.E.R.N. AND C.E.N.T.O.

The Authority have taken a considerable interest in the activities of the European Organisation for Nuclear Research (C.E.R.N.) and the Central Treaty Organisation (C.E.N.T.O.).

INDIVIDUAL COUNTRIES

A significant development in the Authority's relations with the U.S. Atomic Energy Commission during the year under review was the renewal and extension of the exchange of information on fast reactor development. Active collaboration between the Authority and the Commission continued in many fields of nuclear research through exchanges of reports and through discussions during individual visits or at conferences and other more formal meetings.

A visit by Professor Baxter, Chairman of the Australian Atomic Energy Commission, to the U.K. in September, 1964, was the occasion for discussions on general co-operation between the Authority and the Commission and future arrangements for the supply of fuel elements for the Australian HIFAR reactor.

Collaboration between the Authority and Atomic Energy of Canada, Ltd., on the development of heavy-water-moderated reactors continued satisfactorily. Mr. J. Lorne Gray, President, headed an A.E.C.L. team at a meeting with the Authority in November.

Indian visitors to the Authority during the year included Dr. Bhabha, Chairman of the Indian Atomic Energy Commission and Head of the Department of Atomic Energy.

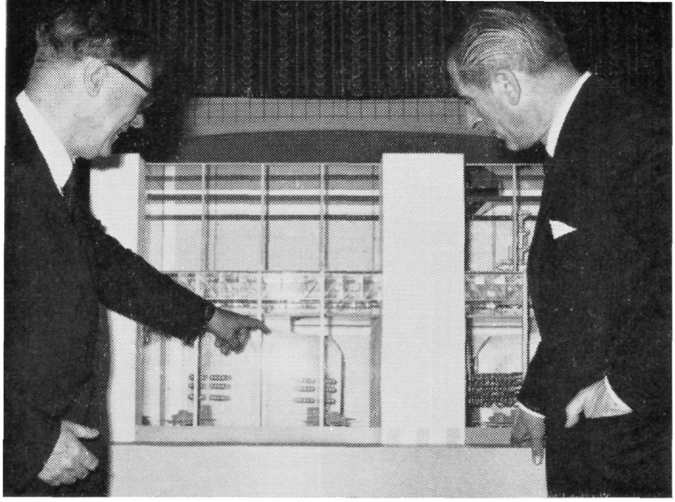
An Authority team visited Pakistan in January, 1965, to discuss water supply problems and the possible application to them of desalination associated with nuclear reactors.

The Authority, in pursuance of their agreement with the Belgian company Belgo Nucléaire on spectral shift marine propulsion reactors (the Vulcain system), collaborated in the design and construction of a new zero energy test reactor Venus, which came into operation in May, 1964. It is being used to test the core for the Vulcain power reactor experiment. The Authority also continued to use the BR.2 reactor of the Belgian Centre d'Etude de l'Energie Nucléaire for irradiation experiments.

Sir William Penney, Chairman of the Authority, shows Professor I. I. Rabi, of the U.S. delegation, a display of models illustrating the scale of the British nuclear power programme (Geneva, 1964).

Professor A. M. Petrosyants and other representatives of the U.S.S.R. State Committee for the Utilisation of Atomic Energy, at the Authority's Winfrith establishment.

A party of Indian Members of Parliament are shown a model of the BEPO reactor during a visit to Harwell.



The Chairman of the Authority shows President Eduardo Frei, of Chile, a model of a possible design for a 2,400 MW A.G.R. power station.

Delegates from Denmark, France, Mexico, Spain, Switzerland, Euratom and the U.S.A. who were among those attending a reactor safety course organised by the Authority.

Visiting scientists from the French Atomic Energy Commission at the Dounreay Experimental Reactor Establishment in December, 1964.

A review meeting between representatives of the Authority and of the French Commissariat à l'Energie Atomique (C.E.A.), now established as an annual event, was held in London in June, 1964.

In addition to visits and exchanges between commercial services of the Authority and the Italian organisations concerned with nuclear power, further talks aimed at increasing collaboration between the Authority and the Comitato Nazionale per Energia Nucleare (C.N.E.N.) were held in October, when two senior C.N.E.N. officials visited London.

An experienced reactor operator was attached to the Japan Atomic Power Company to assist with the commissioning of their first nuclear power station at Tokai Mura, which is British designed. The Authority also continued to support the efforts of their U.K. licensees, who had already carried out the preliminary design study, to secure the main contract for the design of the plant for reprocessing irradiated fuel planned by the Japan Atomic Fuel Corporation.

The contacts established between the Authority and the Mexican Comision Nacional de Energia Nuclear over possible assistance with the latter's plans for their first nuclear research centre have led to wider co-operation through a number of high level visits.

An Agreement for Co-operation on the Peaceful Uses of Atomic Energy was concluded between Her Majesty's Government and the Swiss Government on 11th August, 1964, and will come into force when ratified by Switzerland. This agreement makes provision for the U.K. to supply Switzerland with research or power reactors or components and associated fuel.

The second series of visits agreed between the Authority and the Soviet State Committee for the Utilisation of Atomic Energy was completed during the year, a visit on radiation chemistry being made in each direction. A third series of visits will run into the spring of 1966. This third series started with a visit in November/December to the U.S.S.R. by a U.K. team concerned with isotope research.

Two Soviet scientists arrived in the U.K. in March to work for six months at the Culham Laboratories and at the Rutherford Laboratories of the National Institute for Research in Nuclear Science respectively. In parallel with these attachments, two U.K. scientists from those establishments have gone to the U.S.S.R. to work for the same period in similar fields.

Health & safety

The protection of employees and the general public, and the safety of reactors and plant, are important features of the Authority's work. Although radiation is recognised as a potential hazard, experience shows that, properly controlled, it carries less risk than many other features of daily work.

Some 19,800 employees are now issued with film badges, a slight increase over last year. The average dose to these workers has remained constant at 0·4 rems per year in the last three years. The control level for whole body dose from gamma radiation (3 rems in thirteen weeks) was exceeded on ten occasions. In all cases arrangements were made to reduce subsequent exposure to ensure that the long term dose limits were not exceeded.

The new multi-filter film badge (developed by the Atomic Energy Research Establishment, Harwell, and the Radiological Protection Service) is now in general use. This dosimeter has six filtered areas to provide information about radiation of different kinds and energies; each area on the exposed film has to be separately measured and the doses calculated from these measurements. To enable this to be done without a prohibitive increase in work a fully automatic densitometer has been developed, which identifies the serial numbers of the films, reads the densities, and feeds the results on punched cards into a digital computer.

For work involving radiation doses to the fingers only, special measuring techniques may be necessary, and Winfrith and Aldermaston have now introduced lithium fluoride luminsecent fingertip-dosimeters for this purpose.

The lost time accident frequency rate for industrial staff in 1964 was 1·05 per 100,000 man-hours worked. This is not significantly different from the rate for previous years and compares favourably with the overall average for the country. Efforts to promote safety consciousness have been maintained. Particular attention has been paid to eye injuries. For example, at Dounreay (where the number of eye injuries was already low) the increased use of safety spectacles was followed by a 45 per cent. reduction in eye injuries due to foreign bodies.

Much effort has been devoted to helping with the revision of the International Atomic Energy Agency transport regulations *(published in 1965, I.A.E.A. Safety Series No. 6)*. Authority staff have continued to assist in the drafting of U.K. regulations on transport of radioactive material.

The Authority have also provided advice to a number of Departments, in particular the Ministries of Transport and Labour and the Navy Board.

Specific assistance to the Ministry of Power in assessing nuclear power stations was almost completed, but technical liaison with the Ministry's Inspectorate of Nuclear Installations is continuing.

Studies of civil A.G.R. designs have confirmed the excellent safety characteristics of a reactor employing oxide fuel clad in stainless steel, enclosed, together with heat exchangers, in a pre-stressed concrete pressure vessel. Since no fuel failure has occurred in the Windscale A.G.R., artificially defected elements have been introduced to investigate the emission and movement of fission products in a working reactor circuit. The results indicate that the emission is small; the oxide fuel is undamaged; and fission product deposition, especially on cool surfaces, serves effectively to reduce contamination of the coolant.

Continuing studies have led to an increased understanding of the safety problems of a prototype fast reactor; the early detection of conditions likely to cause fuel over-heating and the course of events following fuel failure are topics of special interest. Model work at Foulness has yielded valuable information on containment design.

INTERNATIONAL CO-OPERATION

International relations in health and safety involve discussions both with countries having large nuclear programmes and with those who are less advanced. Co-operation with the International Atomic Energy Agency is the main vehicle in both cases.

The Authority provide the U.K. representative on the Health and Safety Sub-Committee of the European Nuclear Energy Agency, which serves as a forum for the exchange of information on current problems and for joint action in appropriate cases. An Authority representative took the chair at an E.N.E.A. meeting in March to consider possibilities of European co-operation in reactor safety research.

The alternate U.K. delegate for the United Nations Scientific Committee on the Effects of Atomic Radiation, which met twice in 1964, was again provided by the Authority, and Authority staff took part in the work of the International Commission on Radiological Protection through its committees and task groups.

AUTHORITY ESTABLISHMENTS

Aldermaston: The Atomic Weapons Research Establishment
Headquarters of the Weapons Group. Development of nuclear warheads, together with supporting research. Nuclear research and certain development work in aid of the Authority's civil nuclear energy programme.

Amersham: Radiochemical Centre
Production and marketing of radioisotopes.

Blacknest: near Aldermaston
Centre for seismological research.

Bracknell Factory, Berkshire
Provides additional workshop capacity for the Atomic Energy Research Establishment, Harwell, especially for the machining of graphite and the small scale production of electronic equipment.

Capenhurst Works, Cheshire
Development work on uranium enrichment processes and operation of the gaseous diffusion plant for the supply of enriched uranium.

Chapelcross Works, Dumfriesshire
Operation of production reactors, including the supply of electricity to the national grid and plutonium production; experimental fuel irradiation and radiological research.

Chatham
Part of the Analytical Chemistry Branch of the Chemistry Division, Atomic Energy Research Establishment, Harwell.

Culcheth, Warrington: Reactor Materials Laboratory
Investigation of physical and chemical properties of reactor and fuel element materials.

Culham Laboratory, Abingdon, Berkshire
The Authority's centre for plasma physics and nuclear fusion research.

Dounreay Experimental Reactor Establishment, Caithness
Site of the Dounreay fast reactor. Fast reactor development including the fabrication, irradiation and reprocessing of fast reactor fuel. Provides a comprehensive irradiation service using the Dounreay materials testing reactor, and reprocesses M.T.R. fuels for United Kingdom and overseas operators. Also provides site services for the Navy Board submarine reactor project.

Foulness, Essex
Laboratory experiments and field trials in aid of weapons development. Studies of materials and structures under stress loading for civil defence, military and reactor safety purposes.

Harwell: Atomic Energy Research Establishment
Largest establishment of the Research Group. Research mainly on materials, their properties (including nuclear properties) and the effects upon them of radiation. The work includes many branches of physics, chemistry and metallurgy, and also electronics, health physics engineering and chemical engineering. Has three materials testing reactors, three low energy reactors, several particle accelerators, and specialised laboratories for experiments with radioactive materials at all levels of activity up to kilocuries.

London Office
Headquarters of the Authority. Co-ordination with the groups of policy decisions and of the Authority's relations with government departments and other organisations in the U.K. and overseas. In addition, certain of the Authority's financial, commercial and administrative services are centred on the London Office.

Orfordness, Suffolk
Development and application of environmental testing in the weapons field.

Risley, Warrington, Lancs.
Headquarters of the Engineering, Production and Reactor Groups, providing the following main services.

REACTOR GROUP
Reactor design; technical and economic assessment studies; commercial operations and relations with industry; consultancy. The Reactor Engineering Laboratory is engaged on the engineering development of reactor components and irradiation test equipment.

PRODUCTION GROUP
Co-ordination of the production activities of the Authority's works, and commercial operations.

ENGINEERING GROUP
Chemical plant and fuel element production plant

design and building and civil engineering design and construction work on major capital schemes for all Authority groups. The group also includes specialist sections such as electrical engineering, plant instrumentation, estimating, engineering standards and progress and inspection of plant and equipment supplied by manufacturers.

Springfields Works and Laboratory: Salwick, Preston

Uranium ore treatment and fuel element design and fabrication. The Reactor Fuel Element Laboratory works on the development of fuels and duel elements for thermal reactors.

Thurso, Caithness: Superannuation Office

This office is responsible for the day to day administration of the Authority's superannuation schemes.

Wantage Research Laboratory, Berkshire

A laboratory housing the Isotope Research Division of the Atomic Energy Research Establishment, Harwell. The task of the Division is to further the application of radioisotopes, particularly in industry, by advice and by devising and developing new methods employing radioactive materials. The laboratory houses the package irradiation plant for experimental and pilot scale irradiation of material with gamma rays.

Windscale and Calder Works and Laboratory: Sellafield, Cumberland

Operation of production reactors, including the supply of electricity to the national grid, plutonium production, and a training service for reactor operators. Also the operation of chemical plants for the separation of plutonium, uranium, and fission products from irradiated fuels. The Reactor Development Laboratory is engaged on the development programme for the advanced gas-cooled reactor and on A.G.R. physics, using HERO. Other work done by the laboratory covers irradiation testing, including A.G.R. fuel elements, post-irradiation examination and heat transfer studies.

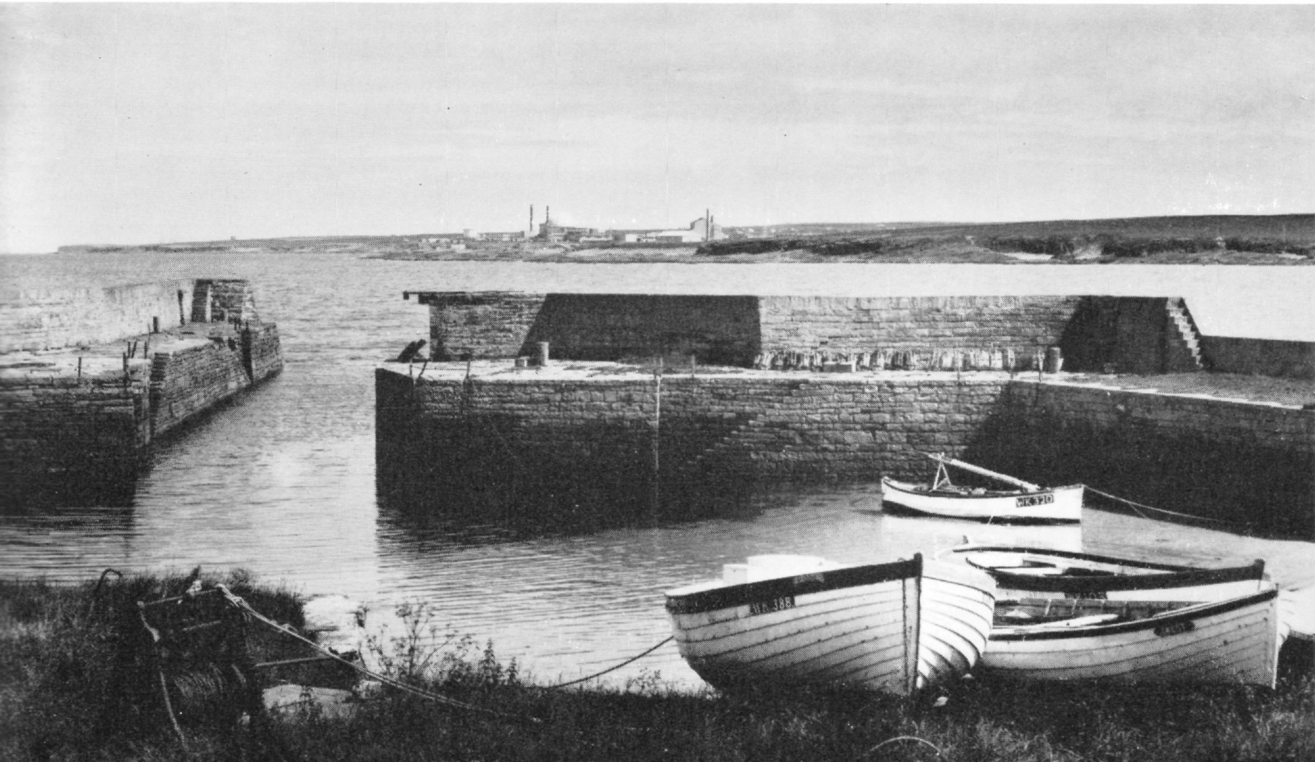
Winfrith, Dorset: Atomic Energy Establishment

Work is done in the following fields: theoretical and experimental aspects of neutron physics, reactor physics and kinetics for a range of reactor types; heat transfer and transport in reactor coolants, reactor instrumentation and control; gas bearings; reactor assessments; and supporting design and manufacturing services. The establishment also provides site services to the Organisation for Economic Co-operation and Development Dragon Project.

Woolwich (Royal Arsenal)

Part of the Analytical Chemistry Branch of the Chemistry Division, Atomic Energy Research Establishment, Harwell.

The Dounreay establishment seen from Sandside Harbour, Reay.



THE AUTHORITY'S REACTORS as at 31st March, 1965

	NAME	LOCATION	DATE OF START-UP	PEAK NEUTRON FLUX THERMAL n/cm² sec.	MAXIMUM HEAT OUTPUT	MODERATOR	COOLANT	FUEL	PURPOSE
RESEARCH AND EXPERIMENTAL REACTORS									
1	GLEEP	Harwell	1947	10^9	3 kW	Graphite	Air	Natural uranium	Routine testing of the quality of graphite and uranium; research with oscillator; biological irradiations.
2	BEPO	Harwell	1948	about 2×10^{12}	6 MW	Graphite	Air	Natural uranium	Studies of nuclear reactor materials; isotope production; neutron physics; radiation chemistry.
3	LIDO	Harwell	1956	about 1.4×10^{12}	100 kW	Light water	Light Water	Enriched uranium-aluminium alloy	Thermal reactor studies including shielding and neutron spectra measurements.
4	DIDO	Harwell	1956	about 2×10^{14}	15 MW	Heavy water	Heavy water	Highly enriched uranium-aluminium alloy	Studies of nuclear reactor materials; isotope production; neutron and solid state physics; radiation chemistry.
5	PLUTO	Harwell	1957	about 2×10^{14}	15 MW	Heavy water	Heavy water	Highly enriched uranium-aluminium alloy	Studies of nuclear reactor materials; isotope production; neutron and solid state physics; radiation chemistry.
6	D.M.T.R.	Dounreay	1958	$1.6\text{-}1.7 \times 10^{14}$	12-15 MW	Heavy water	Heavy water	Highly enriched uranium-aluminium alloy	Studies on nuclear reactor materials.
7	HORACE	Aldermaston	1958	about 10^8	10 W	Light water	Light water	Uranium-235	To obtain basic nuclear information for HERALD.
8	FAST REACTOR (D.F.R.)	Dounreay	1959	2.55×10^{15} (Fast)	61 MW, 14 MW(E)	None	Sodium-potassium alloy	Enriched uranium	Fast neutron irradiation testing of advanced fuels, structural materials, etc.; development of fast reactor technology.
9	ZENITH	Winfrith	1959	2×10^8	100 W	Graphite	Nitrogen used as heating gas	Enriched uranium; plutonium	Reactor physics investigations for advanced graphite-moderated reactors.
10	HERALD	Aldermaston	1960	5×10^{13}	5 MW	Light water	Light water	Highly enriched uranium-aluminium alloy	Studies in neutron physics, radio-chemistry and nuclear reactor materials, including work with universities.
11	VERA	Aldermaston	1961	—	100 W	None	None	Highly enriched uranium or plutonium	Experimental studies of fast reactor systems.
12	NESTOR	Winfrith	1961	10^{11}	10 kW	Light water and graphite	Light water	Highly enriched uranium-aluminium alloy	Source of neutrons for sub-critical assemblies giving thermal fluxes of 10^8 in the assemblies.
13	DIMPLE	Winfrith	1962	3×10^8	Less than 100 W	Light water, heavy water, organic liquid or mixtures	None	Uranium or plutonium	Testing a wide range of lattices at uniform temperatures up to about 80°C.
14	HERO	Windscale	1962	3×10^9	A few 100 W	Graphite	Carbon dioxide used as heating gas	Enriched uranium oxide	Reactor physics studies for the advanced gas-cooled reactor system.
15	DAPHNE	Harwell	1962	about 10^9	100 W	Heavy water	Heavy water	Highly enriched uranium-aluminium alloy	To simulate DIDO or PLUTO; to provide basic physics information in support of these reactors.
16	A.G.R.	Windscale	1962	1.6×10^{13}	116 MW, 32 MW(E) net	Graphite	Carbon dioxide	Enriched uranium oxide	To study the advanced gas-cooled power reactor system and to test fuel elements for the system.
17	ZEBRA	Winfrith	1962	—	100 W	None	None	Uranium-235; plutonium	A flexible system intended primarily to investigate the physics of large, fast reactors.
18	HECTOR	Winfrith	1963	3×10^8	100 W	Graphite	Carbon dioxide used as heating gas	Permanent fuel: highly enriched uranium-aluminium alloy Central core variable	Oscillator reactor: reactivity measurements on materials and fuel elements.
19	JUNO (formerly NERO)	Winfrith	1964	3×10^8	Less than 100 W	Heavy water, light water or mixtures	None	Uranium or plutonium	Reactor physics investigations of marine systems or of the steam-generating heavy-water reactor.
20	S.G.H.W.	Winfrith	1967	—	280 MW excluding super heat, 100 MW(E)	Heavy water	Light water	Enriched uranium oxide	To study the reliability, safe operation and economics of this type of reactor.
POWER/PLUTONIUM PRODUCING REACTORS (IN PRODUCTION)									
21–24	Calder (2 stations "A" and "B") (4 reactors)	Calderbridge	Station "A" 1956 Station "B" 1958	—	235 MW per reactor, 45 MW(E) including steam	Graphite	Carbon dioxide	Natural uranium	Power and plutonium production; experimental work in aid of the U.K. nuclear power programme. Output quoted includes 9 MW(E) equivalent of steam supplied to the Windscale site services.
25–28	Chapelcross (4 reactors)	Annan	1958 (1st reactor) 1959 (reactors 2, 3 and 4)	—	One reactor at 235 MW, three reactors at 240 MW, 45 MW(E)	Graphite	Carbon dioxide	Natural uranium	Power and plutonium production; experimental work in aid of the U.K. nuclear power programme.

NOTE: *ZEUS was dismantled in* 1957, *ZEPHYR and HAZEL in* 1958, *and NEPTUNE in* 1959. *NERO and DIMPLE were dismantled at Harwell and re-erected at Winfrith in* 1960 *and* 1961 *respectively. NERO was dismantled in* 1963, *and rebuilt as JUNO.*

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Deputy Chairman

Sir Alan Hitchman, K.C.B.

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Lord Geddes of Epsom, C.B.E.
Mr. R. M. Geddes, O.B.E.
Mr. C. F. Kearton, O.B.E., F.R.S.
Mr. S. J. Pears, F.C.A.

Secretary

Mr. D. E. H. Peirson, C.B.E.

Sir William Cook left the Authority on 1st August, 1964, on appointment as Deputy Chief Scientific Adviser to the Minister of Defence. He was succeeded as Member for Reactors by Mr. J. C. C. Stewart. Dr. J. M. Hill was appointed to succeed Mr. Stewart as Member for Production for a term of five years.

Sir Claude Pelly retired from the Authority on 31st December, 1964, and was succeeded as Member for Weapons Research and Development by Dr. Nyman Levin.

The Authority deeply regret that Dr. Levin died suddenly on 25th January, 1965, after a heart attack. Air Chief Marshal Sir Denis Barnett was appointed Member for Weapons Research and Development for a period of five years from 1st May, 1965.

Sir Leonard Owen's term of office as Part-time Member expired on 30th June, 1964. Mr. R. M. Geddes was re-appointed as a Part-time Member for one year from 20th November, 1964. The Minister of Technology appointed Mr. J. C. Duckworth, Managing Director of the National Research Development Corporation, to be a Part-time Member for three years from 15th February, 1965.

Professor A. H. Cottrell, F.R.S., resigned his Part-time Membership on 1st July, 1965.

INFORMATION SERVICES

Technical Reports and Libraries

The libraries of the Atomic Energy Research Establishment Harwell, Didcot, Berkshire, and of the Reactor Group Headquarters, Risley, Warrington, Lancashire, provide a scientific and technical information service for industry, including the supply of unpublished reports and information of commercial value to organisations having appropriate agreements with the Authority.

All available reports are listed in the Authority's monthly List of Publications available to the Public, which is obtainable free from the Librarian at Harwell, who will also supply details of a Subscription Service for unclassified and declassified reports.

Copies of unclassified reports, bibliographies and translations published by the Authority are supplied to and available on loan from:

Science Museum Library, London.
The Mitchell Library, Glasgow.
National Lending Library for Science and Technology, Boston Spa.
Stafford County Library, Stafford.

and the Central Public Libraries in Acton, Belfast, Birmingham, Bristol, Cardiff, Edinburgh, Kingston-upon-Hull, Leeds, Leicester, Liverpool, Manchester, Newcastle-upon-Tyne, Nottingham, Sheffield.

Similar collections are deposited with the official and other atomic energy organisations of most foreign countries.

Most of these publications can be purchased from H.M. Stationery Office bookshops or agents.

Weekly information bulletins of atomic energy literature references (from British and foreign sources) and library book lists are obtainable on request from the Harwell and Risley Librarians.

Information Centre and Photographic Library

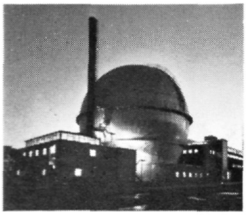
An information centre at which members of the public may see Authority scientific and technical reports and other publications of a more general character is located on the ground floor of 11, Charles II Street, London, S.W.1. It also comprises an Isotope Information Bureau and a photographic library for the use of the press and members of the public.

General Publications and Films

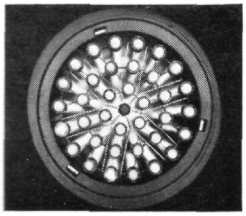
The monthly bulletin "Atom", which contains press releases, Parliamentary Reports and a selection of recent speeches and lectures by Authority staff is available from the Public Relations Branch at the above address, together with a selection of booklets, leaflets and reference material and a film catalogue giving details of 47 films on different aspects of the work of the Authority.

Key to the cover illustrations:

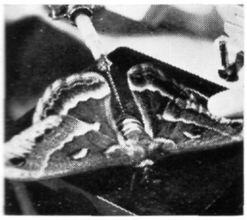
Front cover



Windscale Advanced Gas-Cooled Reactor. The commercial A.G.R. chosen by the C.E.G.B. for Dungeness "B" will be the most powerful nuclear power station in the world.



End-view of 36 pin Advanced Gas-Cooled Reactor fuel-assembly. The Authority's Production Group will manufacture the fuel-elements for Dungeness "B".



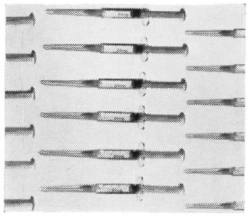
For the study of insect metabolism, the wild silk moth in the illustration is being injected with a Carbon-14 labelled organic compound, one of the products of the Radiochemical Centre, Amersham. (A Shell photograph.)

A self-luminous powder containing tritium produced at the Radiochemical Centre, Amersham for the luminising industry.

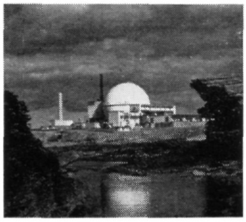
One of the most important projects in the Authority's non-nuclear "diversification" programme is to investigate methods of de-salting brine. Harwell has conducted research into the extraction of uranium from sea-water.

Designed by Ronald Terry.
Published by Public Relations Branch, United Kingdom Atomic Energy Authority,
11 Charles II Street, London, S.W.1.
October, 1965.
Printed by Alabaster Passmore & Sons Ltd., London and Maidstone.

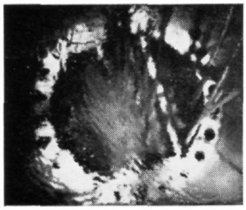
Back cover



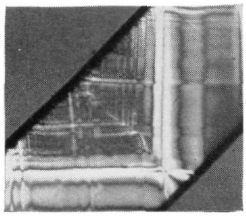
Disposable plastic syringes. There has been a steady increase in the use of gamma radiation for medical sterilisation. The package irradiation plant at the Wantage Research Laboratory processed a record quantity of medical equipment in 1964/5.



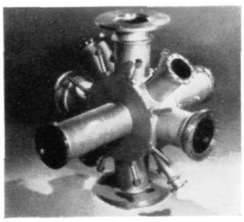
The Fast Reactor, Dounreay, has successfully pioneered the application of sodium-cooled fast reactors to power production. The design, specification and estimates for a 250 MW(E) prototype and a design study for a 2 × 1,000 MW(E) commercial station have been completed.



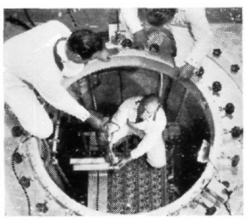
Looking down into the core of the light water-moderated and cooled HERALD reactor at Aldermaston. It is used for the study of neutron physics, radio-chemistry and nuclear reactor materials. The programme includes work with universities.



An mportant area of Authority research is that concerned with the investigation of materials and their properties. This photomicrograph produced by Harwell's Basic Ceramics Group shows strain in a deformed magnesium oxide crystal revealed by polarized light.



The centre chamber of a fusion experiment at Culham.



Winfrith's water-moderated experimental reactor JUNO has been used to provide the physics information needed for the design of small reactor cores. It can operate with either ordinary or heavy water.