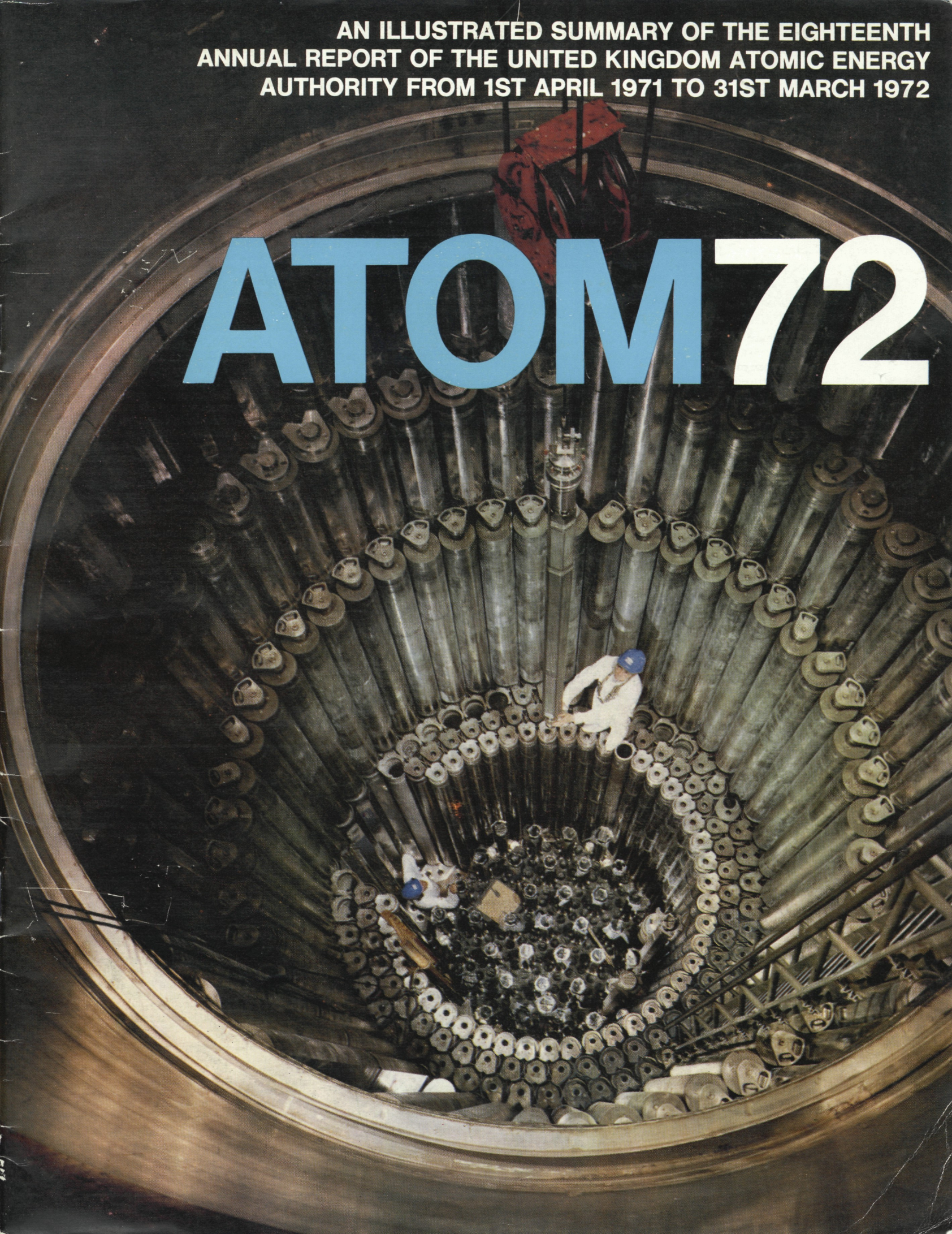
AN ILLUSTRATED SUMMARY OF THE EIGHTEENTH ANNUAL REPORT OF THE UNITED KINGDOM ATOMIC ENERGY AUTHORITY FROM 1ST APRIL 1971 TO 31ST MARCH 1972

ATOM 72



The United Kingdom Atomic Energy

The main tasks of the Authority in 1971-72 were:

to further the progress already made in the development of nuclear fission reactors for the safe and economic generation of electricity;

to continue work towards the eventual generation of electricity by nuclear fusion;

to apply nuclear techniques where they could with benefit be so applied in fields other than the generation of nuclear power;

to carry out the programme of development and manufacture of nuclear weapons in accordance with Government policy*;

to carry out programmes in the non-nuclear field authorised by the Secretary of State for Trade and Industry under the Science and Technology Act, 1965;

to expand the extent and variety of work done on repayment;

to sustain all these activities by programmes of underlying research and exploratory work.

1971-72 was the first year of operation of the two organisations which took over the activities formerly financed out of the Authority Trading Fund, that is to say, British Nuclear Fuels Limited, which has responsibility for the nuclear fuel cycle and for the operation of the reactors at Calder Hall and Chapelcross, and The Radiochemical Centre Limited, which has the responsibility for the manufacture and sale of radioactive isotopes. In both companies the Authority were, for the year under review, sole shareholder. Under the Atomic Energy Authority Act, 1971, not less than 51 per cent of the voting shares of these companies must remain under public ownership.

Nuclear power

In September, 1971 the Fourth United Nations Conference on the Peaceful Uses of Atomic Energy was held at Geneva. At this Conference it was clearly the general view that the issue was no longer whether, but to what extent, nuclear power, already widely adopted, would contribute to the world's growing energy requirements in order to conserve the diminishing (and therefore increasingly expensive) reserves of fossil fuel. Delegates from all the major countries represented at Geneva were unanimous in pointing out that **nuclear power, now broadly competitive with other means of electricity generation, had the additional attractions of security of fuel supplies, comparatively stable fuel prices and demonstrable advantages in the matter of environmental pollution.** The leading industrial nations had therefore recognised nuclear energy as their principal source of electricity for the future, and many of them expected it to form 50 per cent or more of their installed generating capacity by the end of the century.

In the UK the Authority have made good progress in their generic reactor development work (that is to say, work aimed at proving a reactor system to the stage of demonstrating that it can provide a commercially viable method of power generation). The stage has now been reached where it is necessary to make further choices between lines of development which will determine long-term strategy. These choices are important not only for the Authority, but also for the Generating Boards, for industry and, indeed, for the whole country. As recorded in the 1970-71 Annual Report (para. 101), a Working Party, under Department of Trade and Industry chairmanship, has been examining future policy for thermal reactors and this has been complemented by a Working Party considering the fast reactor development programme. While awaiting the outcome of these reviews, the Authority have pressed on with the remaining development tasks concerning the Mk II gas-cooled reactors (the AGRs). They have continued limited development programmes on both the steam generating heavy water reactor and the Mk III gas-cooled reactor (or high temperature gas-cooled reactor). However, the major reactor effort has been on fast reactors; **at the Geneva Conference there was general agreement that in the longer term the fast breeder reactor would be the predominant method of generating electricity.** UK progress with the major prototype at Dounreay, and the associated development programme to enable the early construction and operation of a large commercial fast reactor of over 1,000 MW, were the subject of favourable comment.

Besides their generic work on reactor R and D, the Authority have also carried out important programmes of specific work undertaken for and funded by particular customers, e.g. the Generating Boards and British Nuclear Fuels Ltd. and a number of overseas organisations.

Fusion

The Authority carry out nuclear fusion and plasma physics research with the object of finding out whether or not fusion reactors could be a major new source of power offering new reserves of energy to meet the growing electricity demand expected in future centuries. The Authority's work in this area has been scaled down in recent years, but the experience and capability of the project is highly regarded by other countries in the field, so that it enjoys the advantages of full international collaboration. The programme was under review at the year's end.

It is becoming increasingly clear that the scale of expenditure on further stages of development is likely to be such that few, if any, projects can expect to be able to proceed with a balanced programme of research and development except in collaboration with other countries.

Applied nuclear work

The Authority continued research to promote the use of nuclear techniques and equipment for other purposes than electricity generation. Some of this work was carried out under specific contracts with Government Departments and with industry. Significant advances were made in the application of radioisotope tracing in **hydrology, sedimentation and water pollution studies** and in the accurate measurement of **flow and leak-detection.** Development of miniature isotope-powered **thermoelectric batteries for heart-pacemakers** reached the production prototype stage. Radiation processes and services were extended in the analytical field and irradiations were undertaken for **micro-biological decontamination** purposes and for the development of **wood polymer composites,** etc. New methods with commercial potential were developed for **processing uranium ores.** Techniques originally developed for the nuclear industry were further exploited to assist **raw materials exploration** and the mining and quarrying industry in general.

Non-nuclear work

The object of the Authority's non-nuclear programmes is to put the skills and facilities built-up in connection with their nuclear projects to other useful purposes. Under Section 4 of the Science and Technology Act, 1965, the work is done under the authorisation of the Secretary of State for Trade and

* In August, 1971 the Government announced their decision to transfer the Weapons Group of the Authority to the Procurement Executive of the Ministry of Defence. This transfer will require legislation and it is now expected that the transfer will take place in the spring of 1973.

NUCLEAR REACTOR POLICY

The following statement was made in the House of Commons by the Rt. Hon. John Davies, MBE, MP, Secretary of State for Trade and Industry and President of the Board of Trade, on 8th August, 1972:—

Decisions in the field of nuclear reactor policy have immense importance for the future strength of British industry and for the security and cost of energy supply.

The Government are resolved to build upon the major achievements of the AEA in the past and to ensure the development of a powerful capability for the future in which the AEA will continue to play a vital part.

We have decided therefore to intensify the installation of nuclear plants as far as technological progress, environmental constraints, industrial capability and generating plant requirements permit.

As far as reactor systems are concerned the Government intend:—

To push ahead as rapidly as possible with the development of the sodium-cooled fast reactor, which they see as the main element, in the long-term, of our nuclear generating programme. A small experimental reactor of this type has been running at Dounreay since 1960, and a 250 MW(E) prototype is expected to run next year. In addition, to arrange for a major programme of work to be carried out over the next 5 years at an estimated cost of £15 million, largely directed towards component development. It is expected that this system might be ready for a first full-scale order to be placed in the latter part of the '70s and for it to be assuming the major part of nuclear plant orders from the mid-80s.

Then to commission a complete and specific design and component development programme for the Steam Generating Heavy Water Reactor. A 100 MW prototype of this reactor has been operating satisfactorily for 4 years at Winfrith in Dorset and it is accordingly a strong contender for adoption in the UK grid system. This work is likely to take some 18 months.

To complete urgently, work on the Advanced Gas-Cooled Reactor with a view to optimising the benefit to be achieved from the five generating plants of this type currently under construction: in addition to study whether design improvements can be made with a view to maintaining it as a possibility for future construction.

Two other systems are currently under consideration – the High Temperature Gas-Cooled Reactor and the Light Water Reactor. The HTR's prospects are in the medium term and we shall explore the possibilities of an international collaborative development. For the LWR our objective is to achieve assurance about the questions that have arisen as to its safety.

Within about 18 months all this work should have reached the stage where firm orders can be placed. In appraising the Generating Boards capital investment programmes at that time the Government will seek to

Authority 1971-72

Industry. In 1971-72 the work did not enter into any entirely new fields though four new projects were authorised. In addition 19 projects were renewed or extended and proposals for the extension of eight others were under consideration at the end of the year. This programme fell within six broad technological areas:

(a) **Plant performance and reliability.** Services were provided and research undertaken through the projects in tribology; systems reliability; heat transfer and fluid flow; non-destructive testing.

(b) **Process development.** This area includes high-temperature chemical technology; hydrostatic and helical extrusion projects; a number of desalination techniques, including reverse osmosis which also has application in the treatment of sewage effluents.

(c) **Materials development and quality control.** This work is pursued mainly through the Ceramics Centre, the Carbon Fibre Project, the Analytical Research and Development Unit and the Physico-Chemical Measurements Unit.

(d) **Electrotechnology** and a new project on **laser applications.**

(e) **Computing and Computer Software.** This includes the Linesman Project for air traffic control and optimisation studies on cargo fleet scheduling.

(f) **Environmental research.**

The last mentioned is perhaps a field of particular interest at the present time. From an early stage in its development, the nuclear industry has worked strictly to internationally regulated standards of health and safety both for workers in the industry and for the general public and consequently it has devised and developed many novel techniques for fine measurement. With the increasing public and governmental concern on environmental matters, **the skills and techniques pioneered by nuclear scientists are now being deployed to assess and solve problems outside the original field of operation.**

secure the healthy development of the nuclear industry.

As to the structure of the industry, a much stronger design and construction capacity than is presently available will be necessary to provide nuclear plants on which the Generating Boards will need them in the 80s.

It is also reasonable to envisage that the combination of the extensive R & D effort intended and the level of home orders should lead to valuable export business if we have available a strong design and construction capability.

To this end the Government propose to encourage the consolidation of the present industry into a single strong unit. It should be closely involved with the AEA in reactor R & D and with AEA and British Nuclear Fuels Ltd., in fuel development and fabrication. It should also have powerful technical and commercial backing. Finally it should be capable of playing its part in international and especially European collaboration in the development and exploitation of nuclear reactors, to which the Government attach much importance. I am commencing discussions forthwith with all interested parties with a view to constituting as soon as possible the strong unit I envisage.

In addition, I propose to set up a Nuclear Power Board which will bring together all those having a major part to play in providing me with concerted advice on all aspects of nuclear generation policy and on the Government's role in ensuring the most effective progress in this field. The Board will have a major part to play in the decisions to be made in 18 months' time about the ordering of generating plants.

The plans announced in this statement do not require legislation. I intend to proceed as quickly as possible with any necessary consultations with the interests covered in this country and abroad.

NUCLEAR POWER. Sir John Hill, Chairman of the Authority, presenting a review of "Nuclear Power in the United Kingdom" at the Geneva Conference, 1971.

Scientific and technical support

The Authority possess a powerful range of facilities including research reactors, accelerators, high-activity laboratories, computers and other less specialised equipment, built up over the years and located mainly—though not solely—at Harwell. These are widely used for reactor project work, for services to the nuclear industry, for applied nuclear research and for isotope production.

Additionally, these facilities and the skills of the staff who use them serve to maintain the effectiveness of that important area of activity which (in the Authority) is termed "underlying research". The objectives of this programme are **to increase basic scientific understanding in major fields of importance to the Authority's work and so provide the basis for future advances.** It is so planned as to combine and develop expertise in many disciplines, with an awareness of the practical problems of reactor engineers and others.

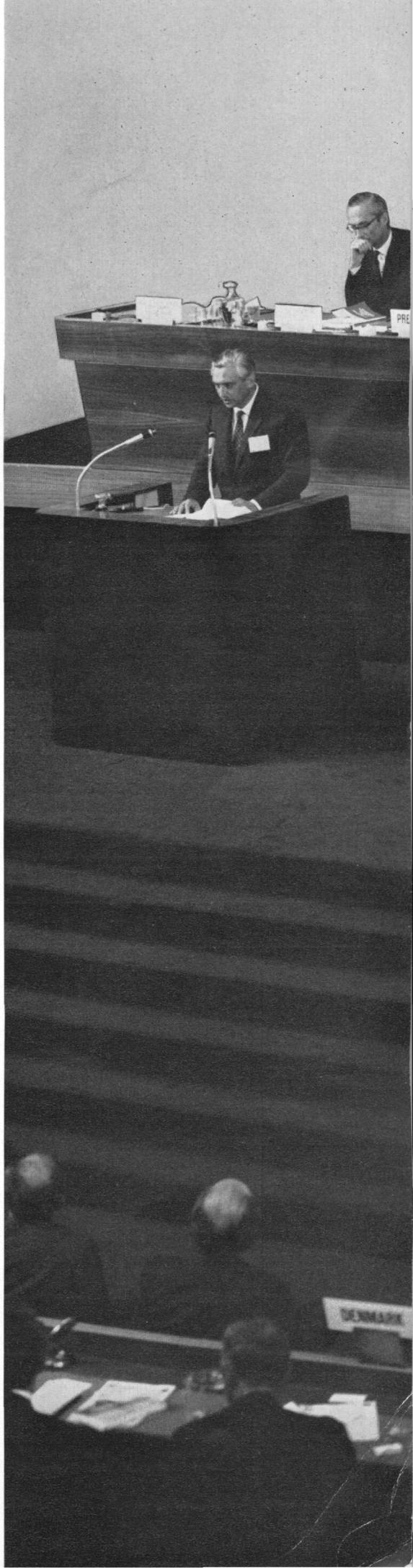
For example, special emphasis is placed on the effects of radiation on reactor materials; on the development and fabrication of new materials and composites; on multiple processor computer systems for automatic control and data handling; and on precision techniques for quality control of reactor components, materials and procedures. Many of the nuclear physics and nuclear beam studies are undertaken in collaboration with Universities and funded by the Science Research Council.

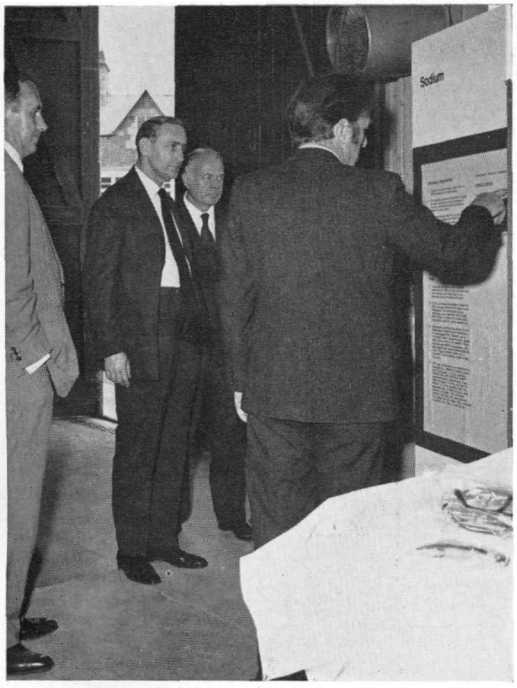
The constituent parts of the underlying research programme cannot, in every instance, be related directly to specific operational objectives, but all of them contribute to the build-up of scientific "capital" relevant to applied programmes as a whole. It is the experience of the Authority that **if the underlying programme has been correctly devised there are numerous occasions when parts of it can be and are used to solve pressing problems of a day-to-day character.**

Sponsored work and work on repayment

In November, 1971, a Green Paper "A Framework for Government Research and Development" was published. This publication included reports by both Lord Rothschild and Sir Frederick Dainton, and in the months which followed publication, there has been much discussion of the importance of ensuring that the potential beneficiaries of each research and development programme are identified, that the programmes themselves are tailored to meet the requirements of the beneficiaries and that—where appropriate—the work is financed by them. The paragraphs which follow attempt to summarise the Authority's approach to these questions.

The Authority have over the years given a great deal of thought to the whole matter of sponsorship. As far as the generic reactor programme work is concerned, the expenditure on bringing a reactor system up to the prototype stage is in the UK and in other countries borne on government funds. But the Authority have long recognised the need for their reactor R and D programme to take account of the views of the customers and users—the design, construction and plant manufacturing companies, the fuel manufacturers and the Electricity Boards. Co-ordinating committees of various kinds have been instituted from the late 1950s, and in 1962 the Reactor Policy Committee was formed with strong representation from the Generating Boards and the design and construction companies, as well as from the Authority. **This committee, with its working parties, enables all those bodies concerned in the development of power reactors to assess and influence the scope and nature of the generic research undertaken by the Authority.**





FAST REACTORS. Mr. Tom Boardman, Minister for Industry (first from left), visited Dounreay in July, 1972.

By means of these and similar arrangements the Authority have sought to develop a consistent and coherent long-term reactor strategy designed to secure the maximum return to the ultimate beneficiaries of nuclear power from the money that is spent. It is perhaps significant in this context that UK Government expenditure on the generic reactor development programme is now well below that being incurred in France and West Germany, as well as the US. In the UK as elsewhere, the Government-financed generic programmes are complemented by reactor development work directly sponsored and paid for by the nuclear and electricity supply industries, and the Authority are providing increasing services in this area on repayment.

The Authority's applied work outside the reactor field is to a large extent directly determined by sponsoring Government Departments and by industrial companies. There are some cases, however, where the Authority have started research programmes with longer term applications, because the prospective benefits (duly discounted) justify the expenditures involved. Where appropriate, the joint DTI/AEA Programmes Analysis Unit is invited to examine and report on the benefits likely to be obtained.

Some non-nuclear work is undertaken on full repayment terms for Government Departments. Other projects having the aim of achieving a general national benefit are—with Departmental approval—financed from the Atomic Energy Vote. In 1971-72 the Authority sought to transfer responsibility for such "national benefit" projects to the sponsoring Departments primarily concerned. A typical example in this category is the work on the development of **reverse osmosis techniques.** These can be applied to many effluent and liquid treatment processes and this work is now to be financed from the funds of the Department of Trade and Industry and the Department of the Environment.

However, **a larger number of non-nuclear projects are primarily organised with industrial rather than Departmental customers in mind.** In some cases these will consist of information and advisory services. In others a contract will be concluded with an industrial customer who defines a research programme for a particular requirement and pays for it in full. Certain programmes of a longer term character are designed to benefit, not an individual customer, but a whole sector of industry; the subject areas for these are selected either by the Department or by the appropriate advisory committee. In yet another category is work of an innovative character which, at an appropriate stage, becomes a joint development project with a commercial company; in cases of this kind the Authority seek a financial return from royalties.

In previous years, the principal trading activities of the Authority were those carried out in the "trading fund" area which is not now part of the Authority's undertaking. However, within their R and D activities the Authority have been building up a growing and substantial volume of R and D work and other services provided on repayment. The Authority's total income from these sources and from sales of uranium ore, heavy water, etc., was £25.9 million compared with £22.9 million in 1970-71.

International relations

When the United Kingdom joins the European Communities under the terms of the Treaty signed on 22nd January, 1972, the provisions of the Euratom Treaty are to be implemented without any transitional period.

This prospective change led the Authority to give increasing attention during the year to the way in which they will be affected by UK membership of the Communities. Informal discussions took place with Commission staff about the present and future programmes of the Community's Joint Research Centre and the way these might relate to Authority programmes. In the negotiation of the Treaty, arrangements were completed for a single wide-ranging exchange of technical knowledge between the UK and Euratom. The Authority are providing the major part of the UK contribution to the exchange.

The informal links between the Authority's Culham Laboratory and the European laboratories already associated by contract with Euratom's five-year fusion research programme were strengthened.

At the same time, the Authority's established bilateral links with atomic energy organisations in other countries have been maintained and in some cases strengthened. In particular, a major agreement has been entered into between the Authority and the Power Reactor and Nuclear Fuel Development Corporation (PNC) of Japan for a joint programme of fast reactor physics experiments to be carried out in the reactors at Winfrith. Negotiations proceeded during the year between the Authority and the German organisations, Gesellschaft für Kernforschung mbH (Gfk Karlsruhe) and Interatom, for R and D agreements in support of the commercial agreements which were under parallel negotiation between the German company Kraftwerk Union and The Nuclear Power Group and British Nuclear Fuels Limited for the development and marketing of fast reactor systems.

CIVIL RESEARCH AND DEVELOPMENT

	EXPENDITURE (£ million)					Staff Deployment[2]	
	1967/68	1968/69	1969/70	1970/71	1971/72	1970/71	1971/72
Reactor Research and Development Programme						Man Years	
(i) Major Development[1]							
(a) Gas-Cooled Systems Mk. II	9·8	7·3	4·7	3·2	5·3	185	175
(b) Gas-Cooled Systems Mk. III	0·7	1·7	3·3	5·2	5·0	310	270
(c) Water-Moderated Systems	11·3	10·2	7·1	5·5	4·1	190	155
(d) Fast Systems	17·8	20·8	26·7	26·3	30·2	690	735
(ii) Other work in support of power reactors and their fuel	2·4	1·3	1·5	1·7	2·0	100	120
	42·0	41·3	43·3	41·9	46·6	1,475	1,455
Other Research							
(a) Applied Nuclear Research	2·0	2·1	1·4	1·6	1·6	100	90
(b) Underlying Research	8·9	7·4	6·7	5·8	5·6	265	265
(c) Radiological Protection Research	0·6	0·7	0·7	0·5	0·5	30	25
(d) Nuclear Fusion and Plasma Physics Research	4·4	4·2	4·0	4·1	4·4	150	140
Non-Nuclear Research under Section 4 Science and Technology Act, 1965	1·5	2·7	3·0	3·6	2·9	235	215
Grants to International Projects	0·8	1·7	0·3	1·0	1·2	—	—
	60·2	60·1	59·4	58·5	62·8	2,255	2,190

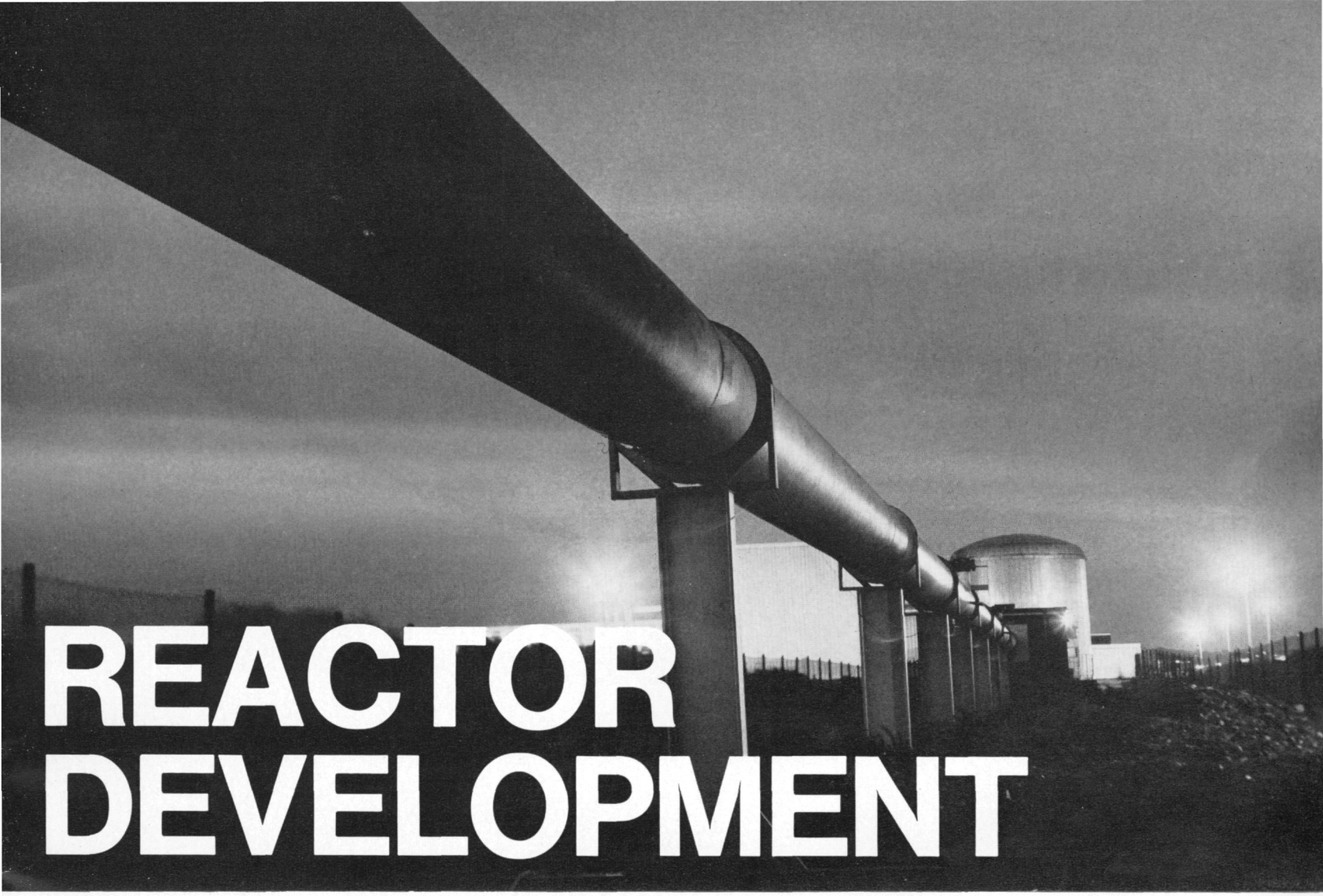
NOTES

1 The cumulative expenditure on the individual Major Development Projects is :— Magnox systems (including £10.9 million related to the development of fuel) £20.6 million ; Gas-cooled systems Mk. II £119.3 million ; Gas-cooled systems Mk. III £15.9 million ; Water-moderated systems £82 million ; and Fast systems £179.6 million.

2 The staff deployment figures relate to qualified scientists and engineers engaged on programmes which are primarily financed by Parliamentary Grant. A proportion of the work, however, attracts substantial cash receipts from other organisations. In addition, 335 qualified staff were employed in 1971-72 (330 in 1970-71) on other civil research and development projects, the full cost of which was met by other organisations.

3 The presentation of staff figures has been revised since the 17th Annual Report to fall into line with the presentation of expenditure. The staff figures now reflect the effort (in terms of man years) deployed over the year rather than the position at the beginning and end of the year.

4 The staff figures are rounded to the nearest 5 and because of this may differ slightly from figures quoted elsewhere in the Report.



REACTOR DEVELOPMENT

ZEBRA. The zero-power fast reactor, ZEBRA, at Winfrith is used to provide reactor physics design data for commercial fast reactors. Picture shows the exterior, with the 200-metre flight tube for neutron spectrum measurements.

The Authority's programme of development of reactors for electricity generation cover Mk II and Mk III gas-cooled reactors, the steam generating heavy water reactors and the sodium-cooled fast reactor system.

About two-thirds of the expenditure was on fast reactors and one-third on the thermal reactor systems. Expenditure on work for other reactor systems or of general application to all systems (excluding underlying research) amounted to about 4 per cent of the expenditure on the main systems.

It is gratifying to note that the CEGB have stated that the lowest unit generating cost of any power station in 1971-72 was returned by a Mk I gas-cooled reactor; this achievement reflects the high reliability of these gas-cooled reactors.

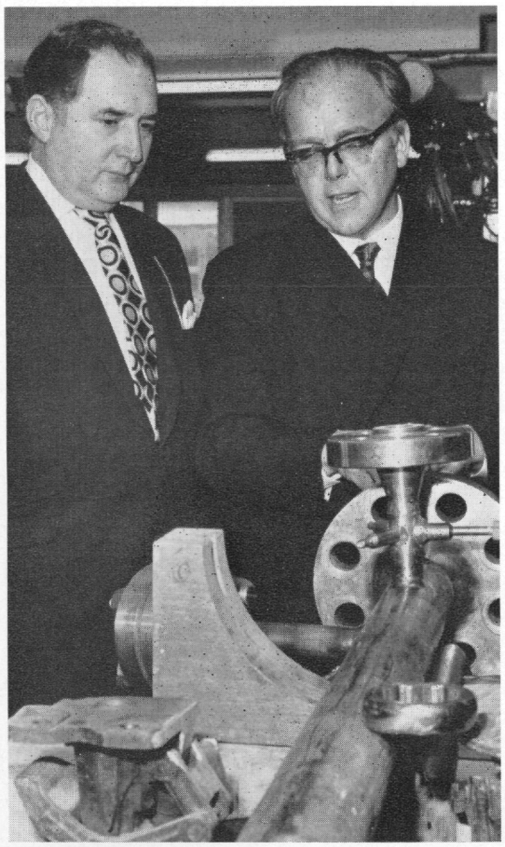
The Authority continued their work in support of the UK Generating Board's installation programme of Mk II gas-cooled reactors (AGR). The majority of the work was to demonstrate the long-term performance of fuel and moderator under power station operating conditions. The Authority have been happy to make arrangements with the CEGB and SSEB for experienced Authority staff to take part in the commissioning of the early stations.

The policy for development and installation of other reactor systems was being reviewed throughout the year by the Department of Trade and Industry in conjunction with the Generating Boards and the Authority. The Working Party examining the future policy for thermal reactors was complemented by a Working Party concerned with fast reactor policy. The Authority were represented on both Working Parties. Pending a decision on future thermal reactor development policy, the Authority maintained development work on both the Steam Generating Heavy Water Moderated Reactor and the Mk III gas-cooled reactor system (HTR).

Information on the substantial progress already achieved was included in the Authority's contribution to the Working Party considering the fast reactor development programme as part of the case for the continued development of this system. Mainly because of late delivery of plant, the original timetable for construction of the 250 MW(E) prototype fast reactor at Dounreay had to be set back, but it is now in its final stages. The completion of construction overlaps with the complex and important phase of testing and start-up. The main objects of this phase are: first, to ensure that PFR itself shall operate steadily and reliably with as few interruptions as possible for repairs and maintenance; and, second, to derive the maximum amount of information for incorporation into the design of fast reactors of the future.

The Authority have maintained their many links in reactor development, both formal and informal, with overseas research organisations. The participation in the OECD Dragon Project and a joint programme on fast reactor physics with PNC of Japan are important examples of international collaborative programmes. The Authority are continuing to seek new formal associations to support the commercial links which are being established between UK and overseas industrial organisations.

SGHWR



WINFRITH. The Winfrith R & D programme was outlined to Mr. Peter Emery, MP, Permanent Under Secretary (Industry) at the DTI (left) during a visit in June, 1972.

Following the licensing agreement with the design and construction companies, signed in the previous year, close liaison has been maintained with the nuclear industry on the results of the Authority's development work on the Steam Generating Heavy Water Reactor and the industry is assisting in formulating the development programme.

Development to support commercial exploitation of the system has continued, centred around the operation of the 100 MW(E) SGHWR at Winfrith. The electrical output of the reactor has been raised and it has operated satisfactorily with power cycles applied daily during part of the year. **During the four-month winter operating period December, 1971 to March, 1972 the "availability" was 97 per cent and the load factor was 92 per cent.** The difference between these two quantities has in part been due to power cycling which has been carried out to prove the long-term integrity of the reactor fuel.

The fuel performance has been particularly encouraging; the most highly-rated pins have achieved nearly half the target burn-up for commercial stations. Approximately 200 daily power cycles to simulate the effects of following the diurnal variations in commercial station load demand have been carried out without adverse effect.

In addition to the work directly associated with the Winfrith SGHWR, experimental work has been undertaken to provide more detailed information on safety aspects of commercial SGHWRs. Fuller and more refined data were obtained on the influence of materials properties on the mode of failure of pressure tubes when tested to destruction, on the behaviour of fuel should the coolant circulation be interrupted and on the performance of the emergency spray cooling system. **The information reinforces the design and safety criteria which have been adopted.**

IRRADIATION SERVICES. A fuel element for the Japanese heavy-water reactor (FUGEN) is inspected prior to irradiation in the Winfrith SGHWR.

Gas cooled reactors

AGR

The major objectives of the development programme for the Mark II gas-cooled reactor (Advanced Gas-Cooled Reactor) are to provide the Generating Boards with information on the operating procedures required for maximum fuel endurance, to establish improved fuel capable of withstanding power cycling and to provide information on coolant behaviour and moderator corrosion inhibition. As in previous years, an important part of the work has been to confirm the behaviour of fuel designs typical of the first commercial stations in the Windscale AGR. **Two new high pressure loops are being installed in the Windscale AGR in which it will be possible to reproduce a range of commercial station operating conditions.**

The Windscale AGR continued satisfactory operation through its ninth year with an overall availability of 85 per cent and an overall load factor of 75 per cent.

Experimental fuel in some channels in the Windscale AGR has now exceeded the target burn-up for commercial stations by as much as 50 per cent and fuel similar to that manufactured for the commercial stations has reached two-thirds of the required burn-up. Over 3800 small power cycles have been applied without discernible effect on fuel endurance.

Information that has recently become available from long-term metallurgical tests started in 1964 has shown that components of 9 per cent chrome steel may experience a higher than desirable rate of corrosion at some temperatures before the end of the 25-year design life of the commercial stations. This could present a problem with a few components in the boilers for the early Mk II stations, as these have already been manufactured. It will be necessary to protect these components from full gas temperatures but on boilers still to be built the problem can be avoided from the outset by suitable choice of materials and operating temperatures. To support the CEGB effort on this topic, the Authority are undertaking a programme of work with the particular object of providing a better understanding of the corrosion mechanism.

HTR

Pending the determination of thermal reactor policy, some sections of the development programme for the Mark III (or High Temperature) Gas-Cooled Reactor have been given less emphasis and capital expenditure has been restricted; effort has been concentrated on continuing the work in key areas, particularly fuel manufacture, irradiation experiments and circuit materials studies.

Good progress was maintained on fuel manufacturing development. Three-and-a-half tonnes of coated particles have been prepared for zero energy experiments by the Reactor Fuel Laboratory, Springfields, some of which were used in the fabrication of 50,000 compacts to the Mk III reference design. Additionally, 10,000 compacts have been made for irradiation and other experiments. Some units of the prototype capacity plant are now automated and on-line quality control has been introduced. The quantities produced have enabled a more accurate estimation of fabrication costs to be made.

Irradiation experiments have been mounted on coated particles, fuel compacts and on fuel pins (compacts contained in graphite tubes) in UK and overseas reactors.

The performance of coated particles in Dragon, materials testing reactors and DFR has continued to support the present target irradiation conditions for Mk III gas-cooled reactors. Currently the emphasis is being placed more on the statistical behaviour of batches of particles, reducing the fabrication cost and improving the performance margins.

In-pile behaviour of the various graphites has been compared to doses well in excess of the target, to aid in choosing the optimum compact material. Other experiments are in progress to obtain the detailed creep, dimensional changes, and physical properties data for design purposes.

Complete fuel pins have been irradiated in both the Dragon and Peach Bottom reactors. Nearly half of the 100 fuel pins irradiated have been discharged for examination; none has failed in irradiations up to about half the peak target burn-up under conditions closely simulating those of the power reactor.

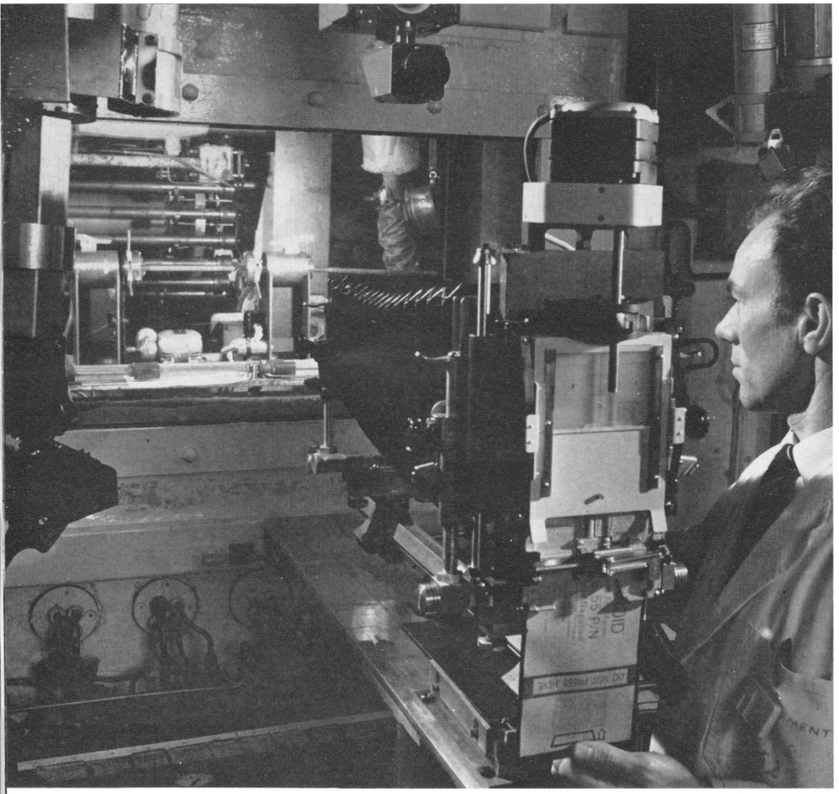
Sufficient data on the corrosion of graphite in helium coolant of a purity appropriate to normal power station operation have been obtained on selected materials for initial design calculations.

The experimental programme on the heated zero energy reactor ZENITH I was completed during the year and provided physics data for the design of commercial Mk III reactors. The ZENITH II reactor was commissioned; this is a low temperature zero energy reactor designed to mock-up the large cores appropriate to commercial reactors. Methods have been developed for calculating fuel management schemes for Mk III reactors based on existing methods used for Mk II reactors.

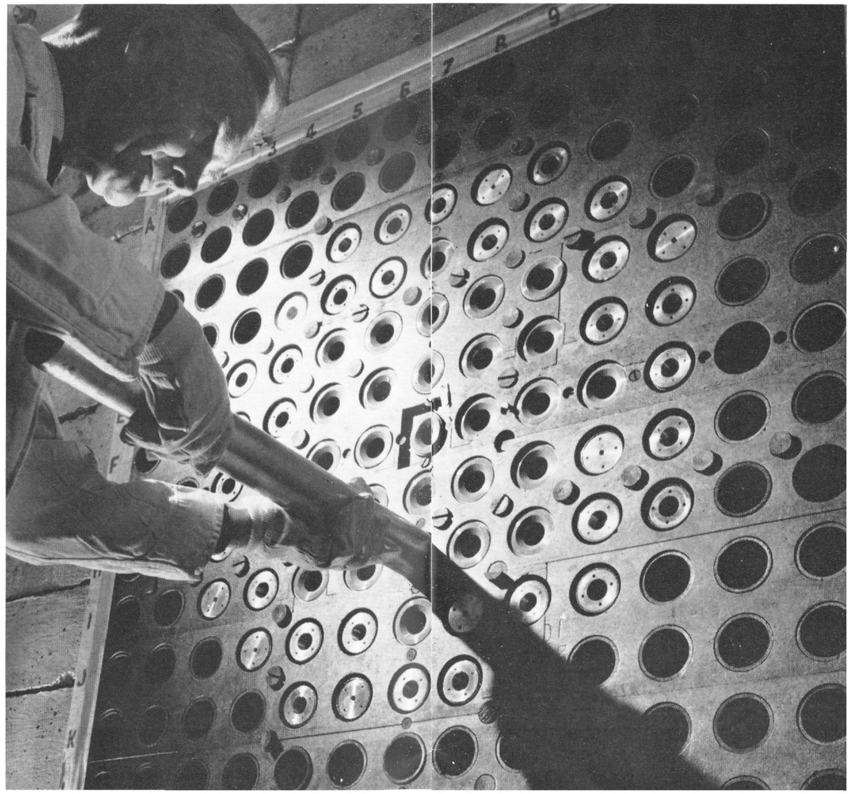
The Authority maintain contact with work in this field overseas through participation in the Dragon Project of the OECD. They have continued technical exchanges with European organisations engaged in development of high temperature reactor technology.

The Dragon reactor experiment continued to be operated by the Authority on behalf of the signatories. Experiments undertaken in the Dragon reactor included several connected with the Authority's own programme on Mk III gas-cooled reactors.

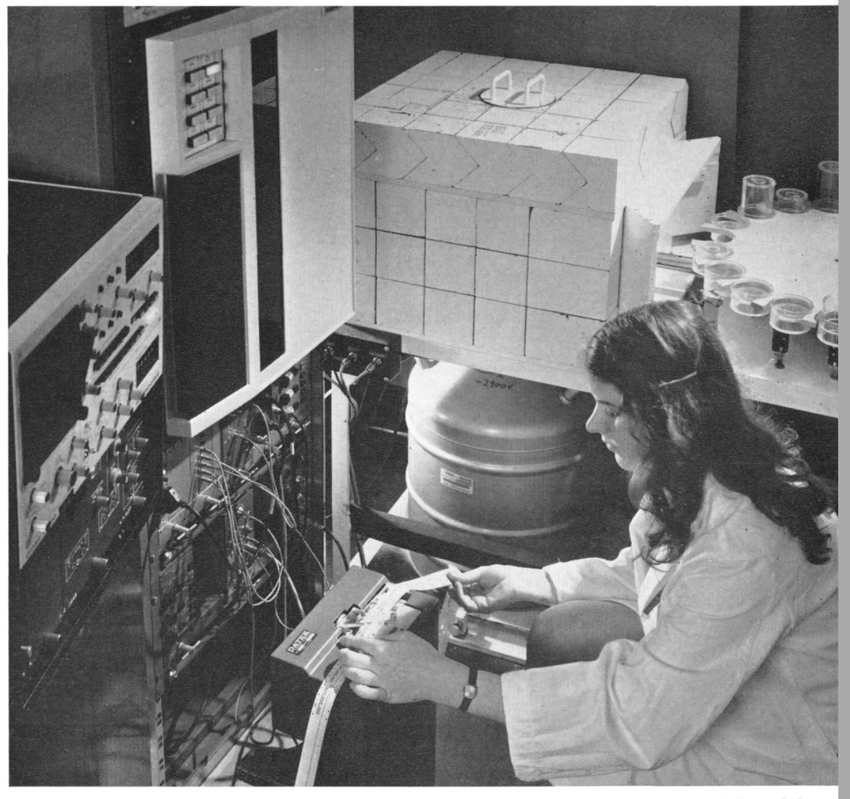
ZENITH II. Winfrith's new reactor, is used for Phase 3 of the experimental reactor physics programme on HTR.



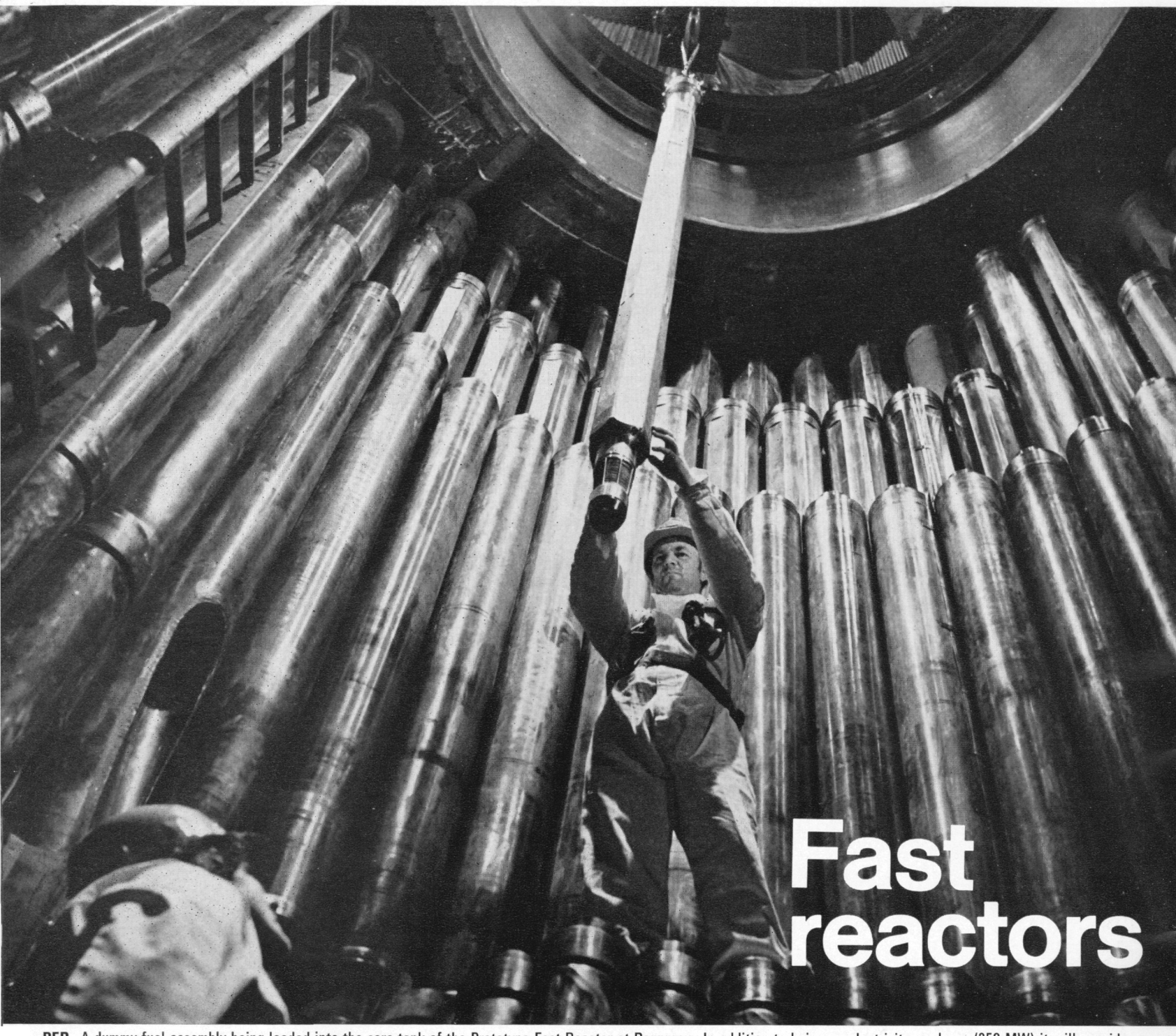
AGR. Periphery photography – at the Reactor Development Laboratories, Windscale – of fuel pins irradiated in the Windscale AGR. The photograph is taken through the zinc bromide windows of the fuel examination "cave".



NESTOR. The 10 kW NESTOR reactor at Winfrith provides an intense source of neutrons for reactor physics experiments. Photograph shows loading of compacted fuel into a Mark III (HTR) gas-cooled reactor lattice.



HTR FUEL. Micro post-irradiation examination of HTR fuel at Harwell. A complete radiochemical analysis is carried out of fission products, actinide elements and burn-up.



Fast reactors

PFR. A dummy fuel assembly being loaded into the core tank of the Prototype Fast Reactor at Dounreay. In addition to being an electricity producer (250 MW) it will provide an invaluable irradiation test facility for further development.

An assessment of the technical and economic features of fast reactors has confirmed the advantages which would follow from the UK's long-standing strategy of installing fast reactors to complement, and later supplant, thermal reactors.

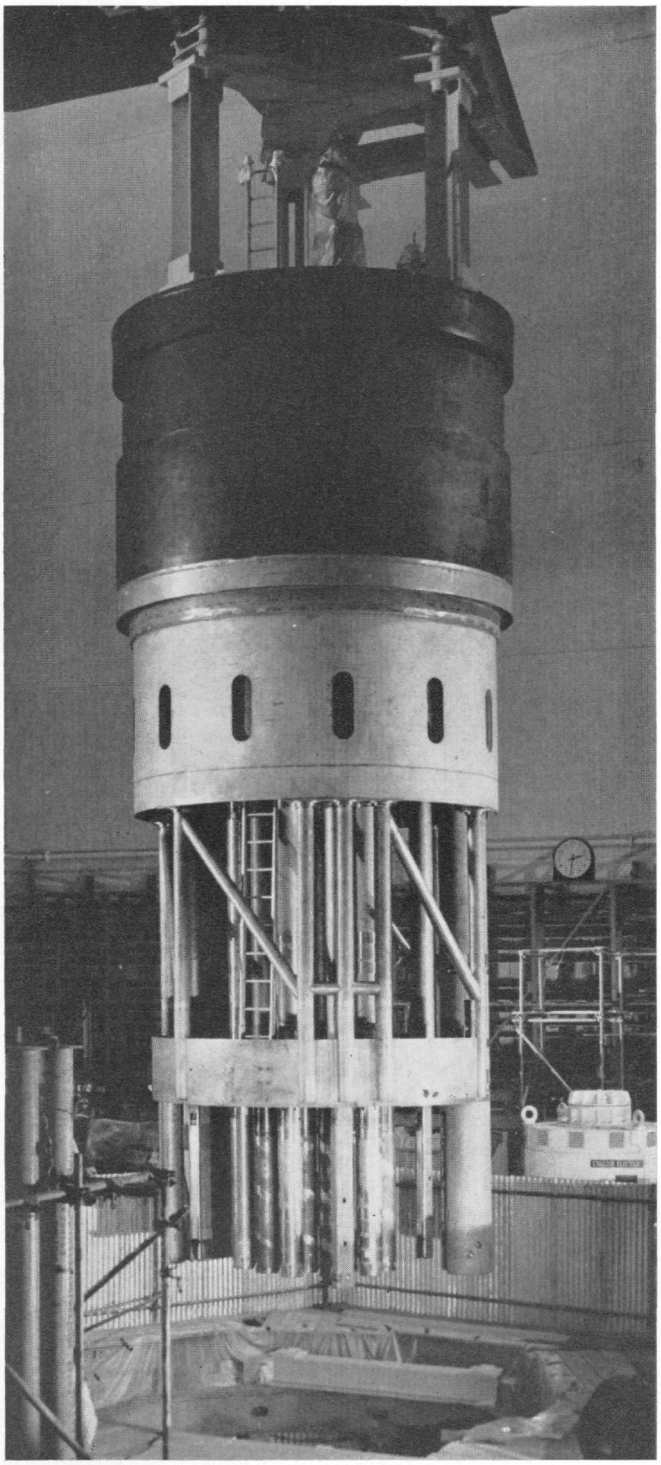
A strategic plan, drawn up in 1970, envisaged the possibility that construction of the first commercial station might start in 1974, but it is now the firm intention that the first station shall be developed to a stage at which it will be suitable for replication. This is likely to lead to a somewhat longer timetable, the actual dates of which will be dictated by the performance of the prototype fast reactor during its first year of operation.

The Authority have continued to place contracts with the design and construction companies to establish the design features of a commercial fast reactor around which the development programme should be planned. The contract with TNPG is for a design study which should lead directly to the design of the first commercial station incorporating the design concepts of the PFR; arrangements were made to ensure that the work would be integrated with a design contract to be placed later by CEGB; BNDC are studying alternative core designs involving, for example, carbide fuels to guide the more advanced fuel development programme.

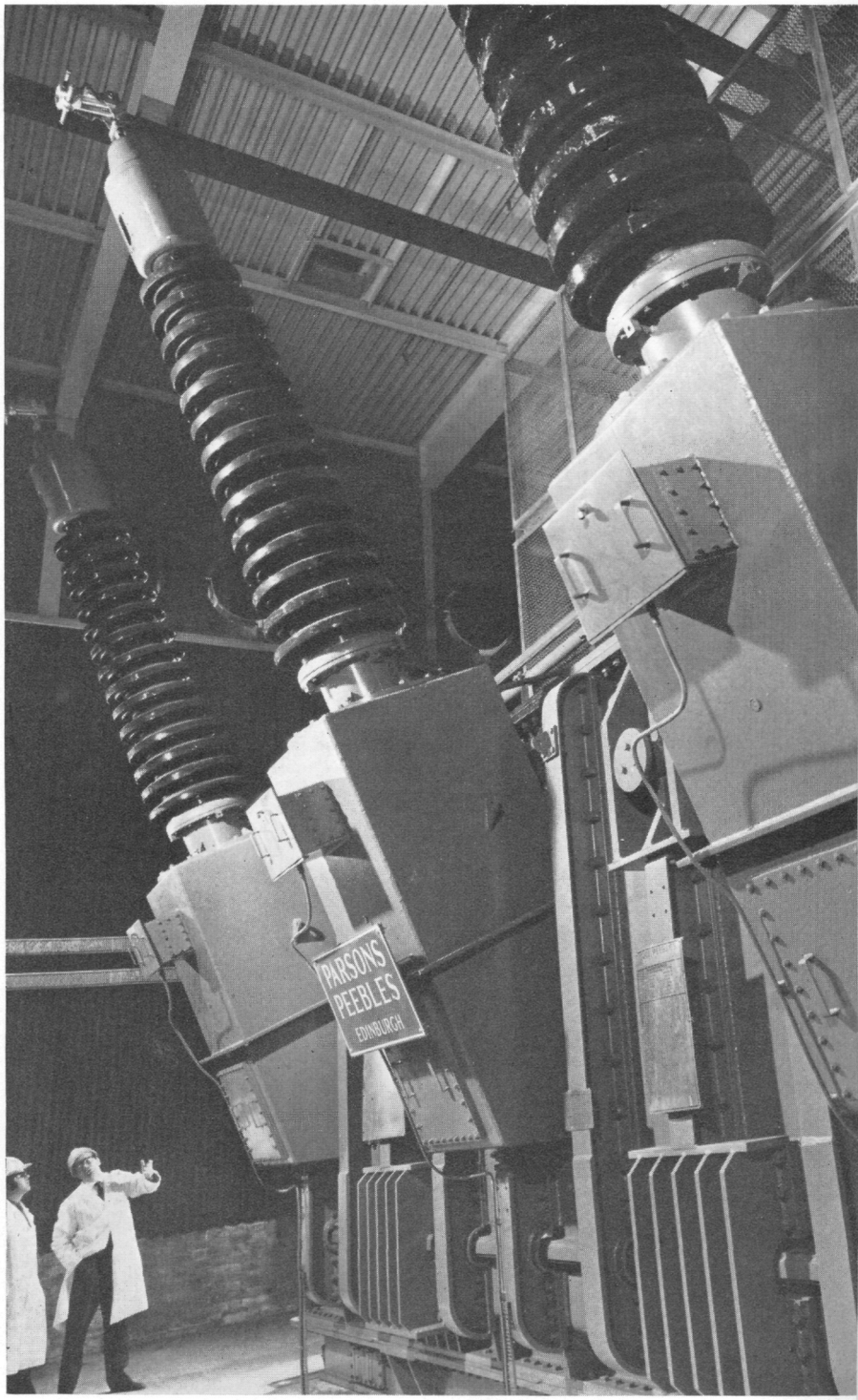
Discussions with the CEGB, the design and construction companies and the manufacturers of components have identified the need for more extensive engineering development to support the design of some components for the first commercial fast reactor (CFR I), such as pumps and steam generators. The object of the work is to establish aspects of the detail design of CFR I and the reliability of the plant not adequately covered by the experience of PFR, mainly because of the larger size of CFR I. The development needs to be initiated before the construction contract for CFR I is placed; discussion of the programme in which the manufacturing industry will be closely involved, is proceeding.*

The construction work for the 250 MW(E) PFR has generally proceeded satisfactorily at Dounreay. The tank which contains the core and primary circuit is now located in the vault and the tank roof is in position. Most of the major components, including the pumps and the intermediate heat exchangers, have been delivered to site. The turbine hall is complete and the turbine ready for commissioning. The construction programme has, however, been affected by manufacturing and erection problems encountered with several specialised components not specific to fast reactors. The Authority are determined to commission the reactor with maximum care and consequently the filling with

* In his statement in the House of Commons on 8th August, the Secretary of State for Trade and Industry indicated that a five-year programme would be undertaken at an estimated cost of £15 million.



PFR. The rotating shield for the Prototype Fast Reactor being lowered into position in the reactor roof above the core.



250 MW. From 1973 onwards PFR will feed electricity into the North of Scotland grid. Picture shows a transformer on the generator.

sodium is now programmed to take place during the first half of 1973.

The plutonium fuel is being manufactured by BNFL at Windscale and sufficient oxide fuel has now been completed to provide about one-half of a PFR core charge. Carbide breeder fuel will also be produced by BNFL at Springfields.

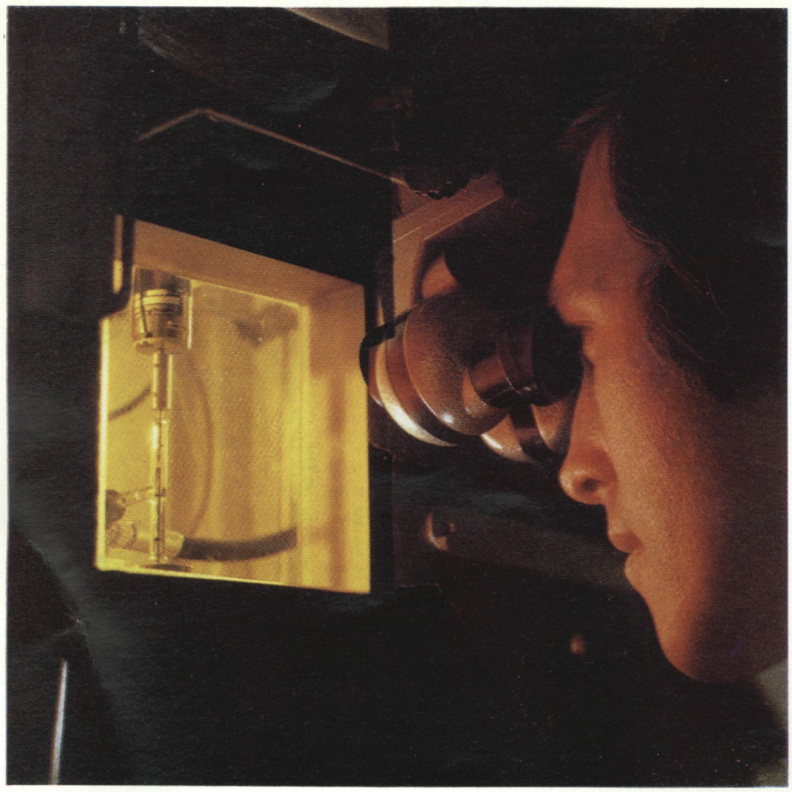
The study of converting the reprocessing plant at Dounreay to reprocess irradiated fuel as it arises from PFR has confirmed the technical feasibility and economic basis of the scheme; design work and procurement of new items required for the conversion has started. The operation of the modified Dounreay plant will provide valuable information and experience for the design of large-scale fast reactor fuel reprocessing plants.

The programme of plant improvements to the Dounreay fast reactor is virtually completed. **The past year has seen the longest uninterrupted high power run in the history of the DFR and the power generation increased by about 23 per cent over that of the previous year.** The decision to continue to operate the reactor while it contains failed experimental fuel pins is providing valuable experience to the reactor operators and also useful information on the likely endurance limits and failure characteristics of prototype and commercial fast reactor fuels.

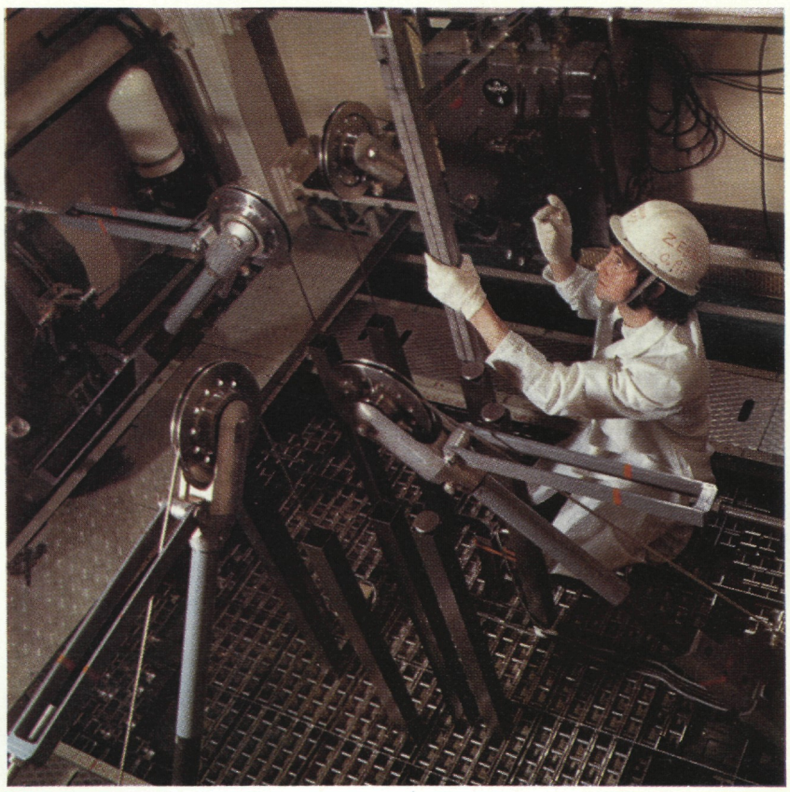
Considerable progress has been made in the fuel testing programme in the DFR. Of particular significance is the performance of three sub-assemblies each comprising 77 fuel pins related to the PFR reference oxide design which have attained peak burn-ups exceeding the target of seven and a half per cent of heavy atoms. One of these sub-assemblies has been seen by detailed examination to be in good condition; the other two have shown no indication of abnormal behaviour during operation. **Following an assessment of all the data, the fuel burn-up target for commercial fast reactors has been raised from seven and a half per cent to 10 per cent peak burn-up.**

Experiments covering several fuel element concepts incorporating carbide fuel continue to give promising results. The irradiation experiments in the DFR are being used to sort the most promising concepts for irradiation in PFR. The programme of fuel element and materials experiments which will be mounted in the PFR at start-up is now in an advanced stage of planning and manufacture has started.

Several exchange agreements with overseas organisations have now led to joint experiments. These include fast reactor safety studies with the French, using loops in their reactors, and with the Germans, using Authority facilities. A further arrangement with the Germans covers the use of one of their sodium rigs for out-of-pile testing of a fuel sub-assembly. The joint programme with PNC of Japan using the Authority's ZEBRA zero energy reactor is proceeding well.

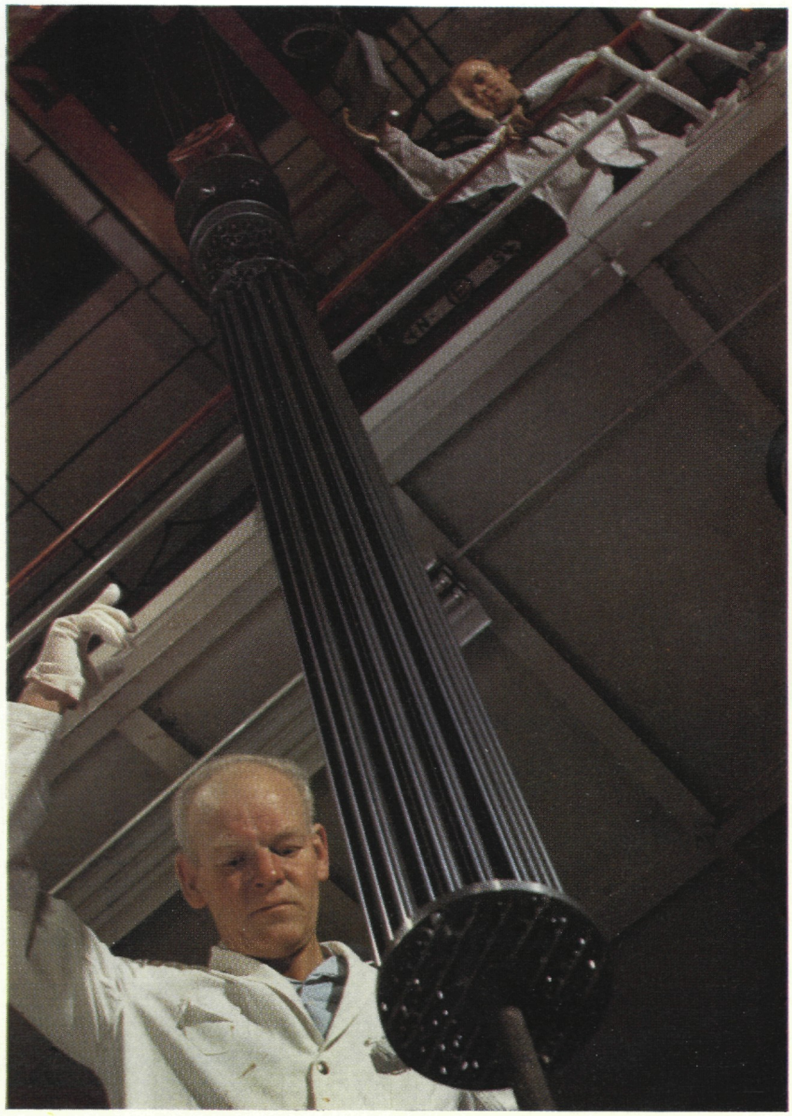


HARWELL. A scientist measuring the gas pressure inside an irradiated coated-particle of the type used as fuel for the High Temperature (Mark III) Gas-Cooled Reactor.

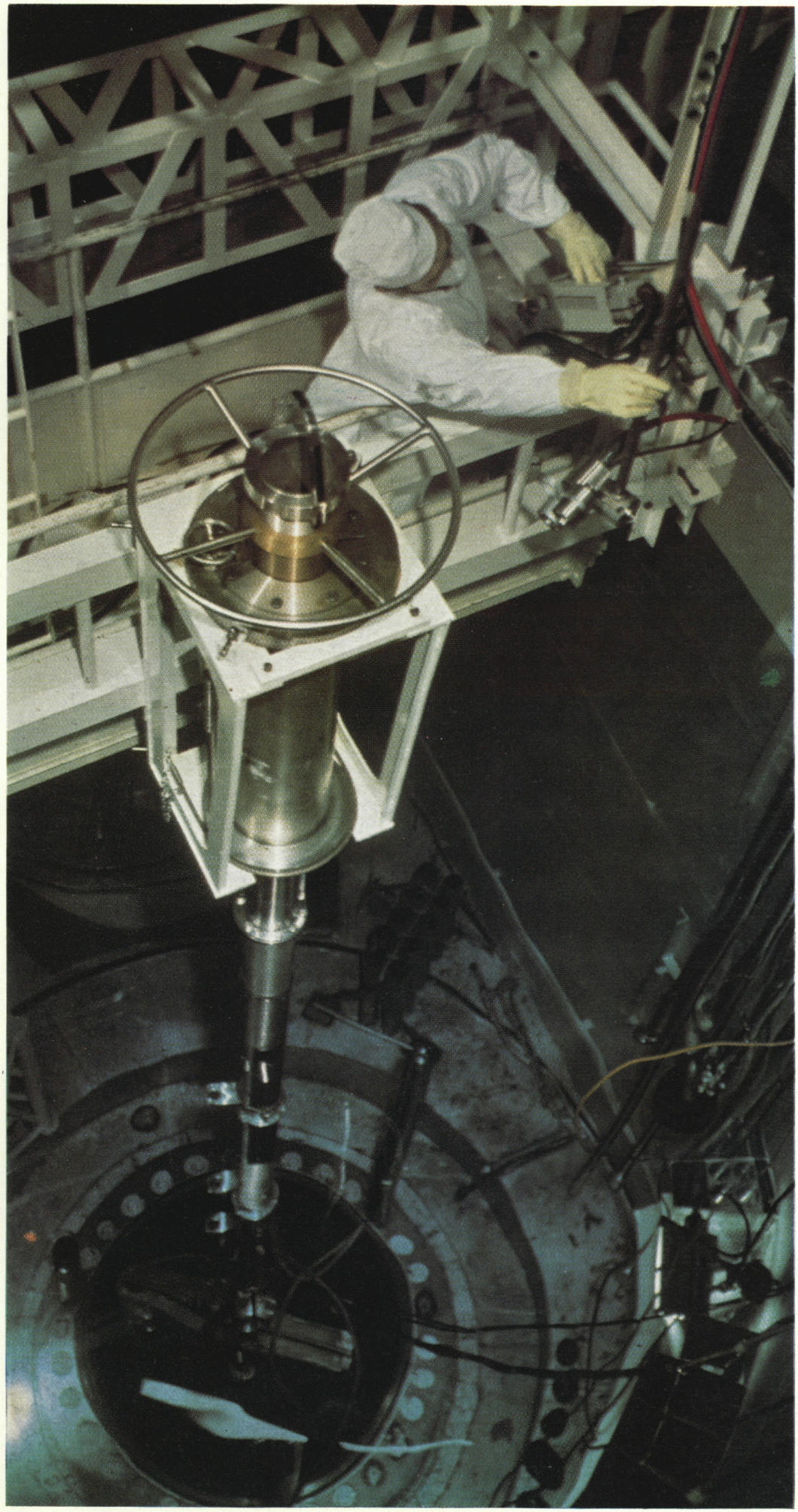


WINFRITH. Changing a fuel element in the zero-power fast reactor, ZEBRA. It is used to provide design data for commercial fast reactors.

DOUNREAY. A primary pump being lowered into the Prototype Fast Reactor. Fast reactors are expected to be major power producers from the late 1970's onwards.



BNFL. SGHWR tubes being removed after treatment in an autoclave at the Water Reactor Fuel Plant of British Nuclear Fuels Ltd, at Springfields.



REACTOR INSPECTION. The Reactor Plant Inspection Service, Risley, has been set up primarily to inspect the pressure vessels of water reactors. Photograph shows inspection by Reactor Group staff of the BR.3 reactor in Mol, Belgium, in December, 1971.

Services to the nuclear power industry

Over the past 25 years various establishments of the Authority have been engaged in the development of nuclear power, with activities ranging from scientific studies of nuclear processes to the construction and operation of prototype power-producing reactors. **This work provided the foundation for the establishment of a nuclear power industry in the UK. The Authority has a unique range of major nuclear facilities, including research and prototype reactors, particle accelerators and post-irradiation handling and examination equipment.**

The full range of the Authority's experienced R and D and project teams is made available on fully commercial terms to the UK nuclear industry in support of commercial reactor systems; this work is additional to the continuing work on future reactor systems financed from Exchequer funds. The Authority also sell their services to nuclear organisations overseas.

The rapid growth of these commercial activities has been maintained. **More than 250 contracts, of total value about £9 million were signed during the year.**

Research and Development Organisations

Overseas national R and D organisations supplement their own facilities by contracting to have experiments, particularly irradiation experiments, carried out in Authority facilities. They also make use of the Authority's specialised fuel fabrication and reprocessing plants.

The demand for irradiation tests in the Authority's reactors, particularly the Dounreay Fast Reactor, was maintained at a high level. Irradiations using the materials testing reactors, the variable energy cyclotron and the high voltage microscope at Harwell were undertaken and the first contracts for irradiations in the SGHW reactor at Winfrith were received. The services provided often included the design and manufacture of test rigs for the irradiation experiments and detailed examination of the test specimens after irradiation.

Enriched uranium fuel elements were manufactured for overseas materials testing reactors and irradiated fuel was reprocessed in the fuel plants at Dounreay.

The Authority operate the Dragon reactor at Winfrith on behalf of the OECD Dragon

Project. Other services to the project include the detailed metallurgical and radiochemical examination of irradiated fuel elements to obtain data on fuel endurance and fission product behaviour.

Many of the irradiation experiments carried out for the nuclear power industry in the materials testing reactors at Harwell, Aldermaston and in the Dounreay Fast Reactor and the Windscale AGR involved the design and construction of novel irradiation rigs. Noteworthy examples are two circulating gas loops which were designed and successfully operated in PLUTO.

The Authority have provided services to BNFL and to TNPG and BNDC and their associated companies in support of their work for Mk I and Mk II gas-cooled reactors. Plutonium bearing fuels for physics experiments were manufactured at Winfrith, under contract to BNFL.

The Harwell particle accelerators are used extensively for rapid simulation studies of the effects of reactor irradiation on materials.

Harwell gave support to BNFL on future centrifuge designs for uranium enrichment.

This included work on constuction materials and studies of flow and pressure conditions in centrifuge machines.

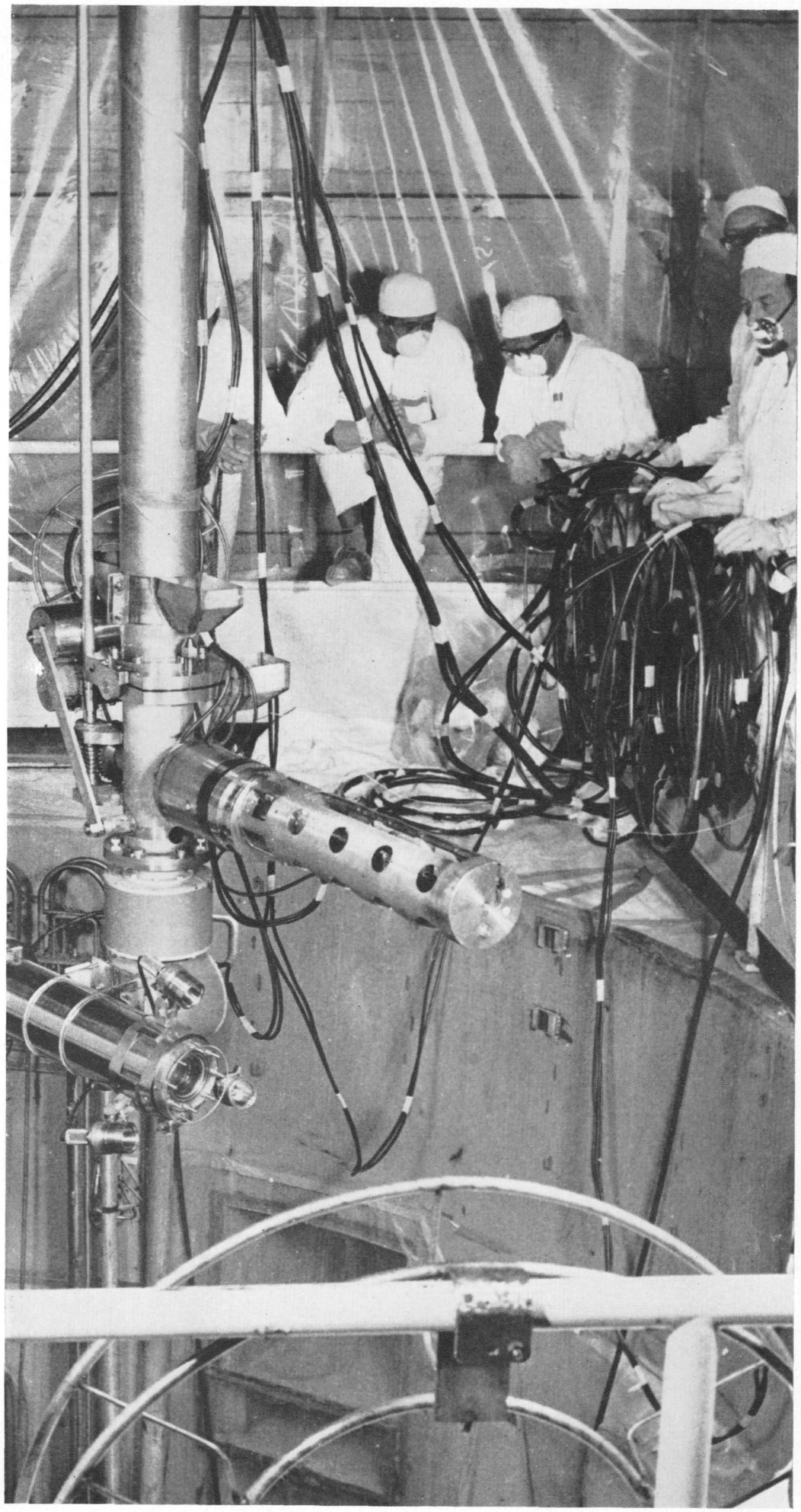
Hochtemperatur Reaktorbau are constructing a thorium high temperature reactor at Schmehausen in Germany, the fuel of which is in the form of spheres of graphite containing highly enriched uranium fuel. The company awarded the Authority a contract to supply a solid moderated reactor (SMR) to be located on the reactor site. On discharge from the reactor the fuel spheres are passed through the SMR to determine their burn-up. The SMR is to be designed, built and calibrated at Winfrith.

Stone & Webster Engineering Corporation, one of the leading US Engineer-Constructors in the nuclear field, placed a major contract with the Authority for an advisory service on inspection and quality assurance at the Corporation's construction sites in the US. The contract is initially for a two-year period.

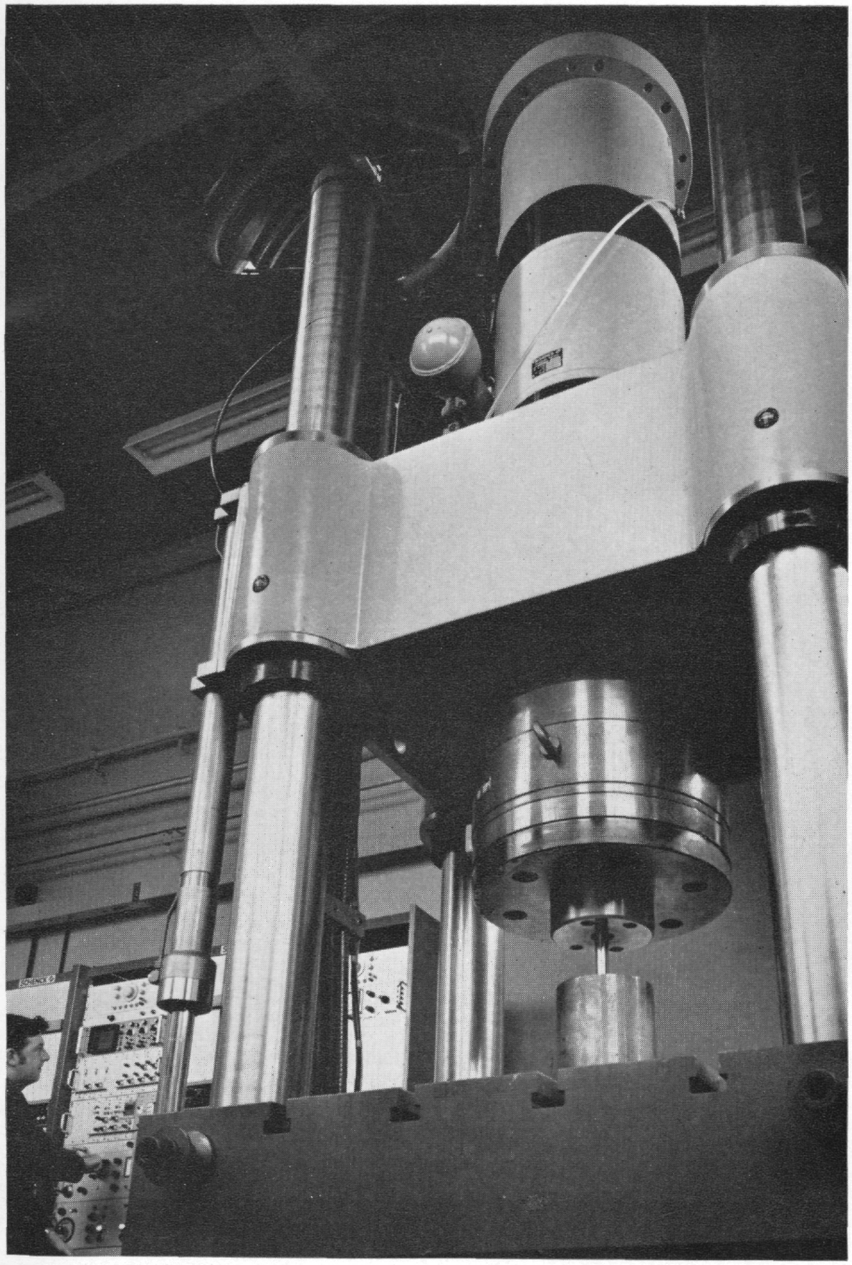
Reactor Inspection

The Reactor Plant Inspection Service set up last year (17th A.R., para. 140), primarily to inspect the pressure vessels of water reactors on completion of construction and periodically during their service lives, made substantial progress. The BR3 reactor at Mol, Belgium, was inspected in December, 1971. With the consent of the owners, Centre d'Etude Nucléaire, the inspection techniques and procedures in use on the BR3 reactor were demonstrated to an invited audience of potential users of the inspection service. **Two contracts for inspection were later awarded and negotiations for further inspections were proceeding at the end of the period.** The first contract provides for a final pre-service inspection, followed by periodic in-service inspections during maintenance shutdowns over the first 10 years of operation of the two reactors at the Doel power station in Belgium. The second contract provides for the inspection of the pressure vessel of the Borssele reactor in Holland.

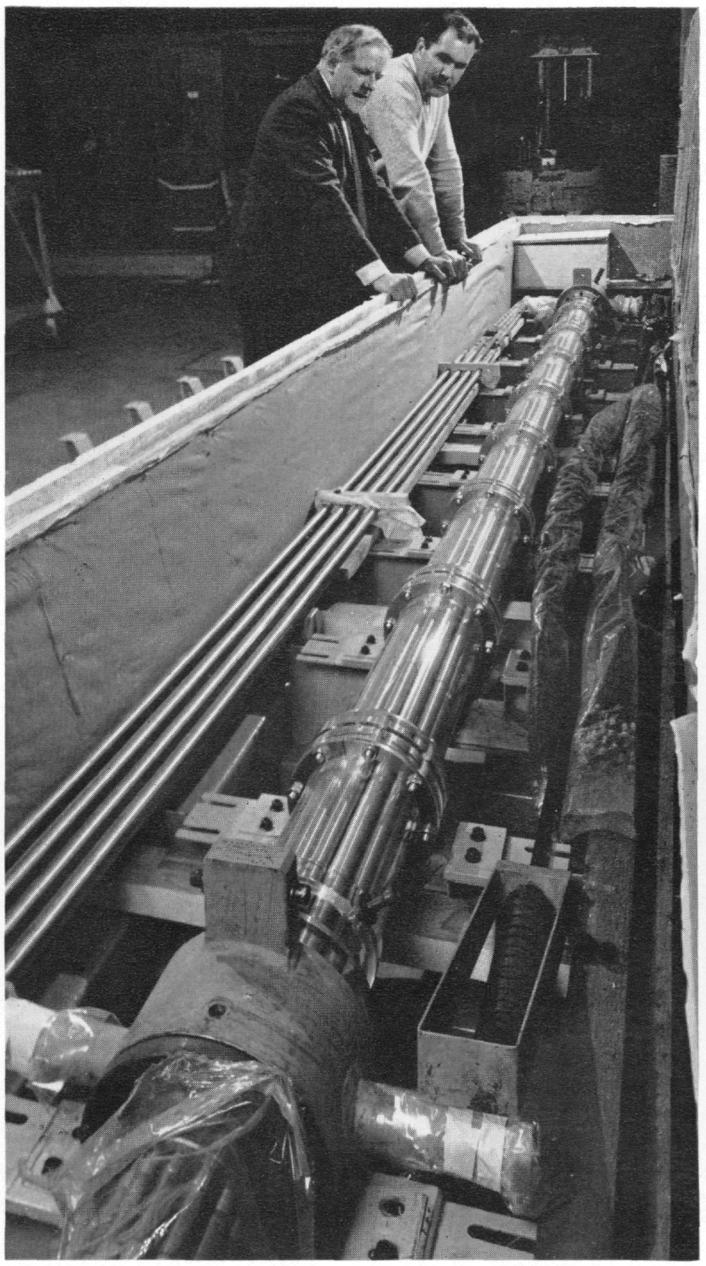
The Authority are exceptionally well-equipped to provide a Reactor Plant Inspection Service, having developed a wide range of necessary techniques for non-destructive testing.



MOL. A further stage in Risley's RPIS inspection of the Mol reactor in Belgium. The Service now has major long-term contracts to inspect other commercial reactors in Europe.

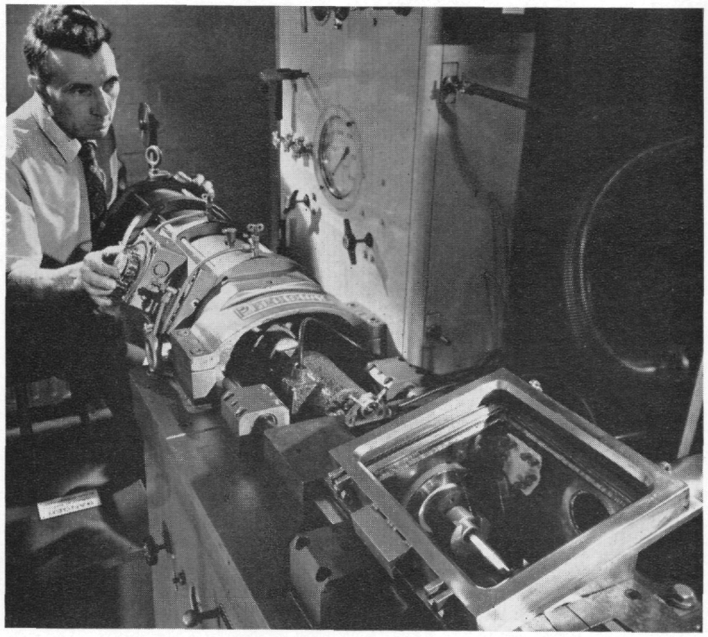


CLADDING. The Materials Sciences Group of the Reactor Fuel Laboratories, Springfields, tests nuclear fuel element cladding materials. Picture shows a test piece in a 40-ton machine which applies a programmed test cycle.



WATER REACTORS. A "simulated" water reactor fuel bundle being tested in the Heat Transfer Laboratory at Winfrith. (Photo: Courtesy CISE, Milan, Italy).

PIE. The post-irradiation examination facilities at Harwell can be applied to the fuel elements of any type of reactor.



GLEEBLE. This machine at RFL, Springfields, can apply a predetermined thermal cycle to a tube or bar and, at any point, apply a tensile stress.

The longer term: fusion research

The Authority carries out research into controlled nuclear fusion reactions, which take place when light elements, such as the isotopes of hydrogen, are heated to very high temperatures, with the aim of finding out whether or not fusion reactors could be a major new source of power.

The prime motivation for research towards a fusion reactor using light element fuels, as an alternative or addition to the fission reactors using uranium fuel as in present-day nuclear power stations, is the ever-increasing world demand for electrical power. The advent of fusion reactors would substantially increase energy stocks by bringing new cheap fuels into use. Initially lithium and deuterium (hydrogen-2) would be used together as the fuel, but eventually reactors burning deuterium alone, a fuel of virtually limitless availability may be possible. Fusion promises a power source for which the problems of nuclear safety have simpler solutions than in the case of fission and for which there is no significant problem of radioactive waste disposal.

At the very high temperatures required for fusion all matter is in the form of a fully ionised gaseous plasma—consisting of an electrically neutral mixture of atomic nuclei and electrons. To study the properties of this state of matter a new branch of physics—high temperature plasma physics—has been developed over the last two decades, with particular emphasis on the use of magnetic fields to control and confine the plasma.

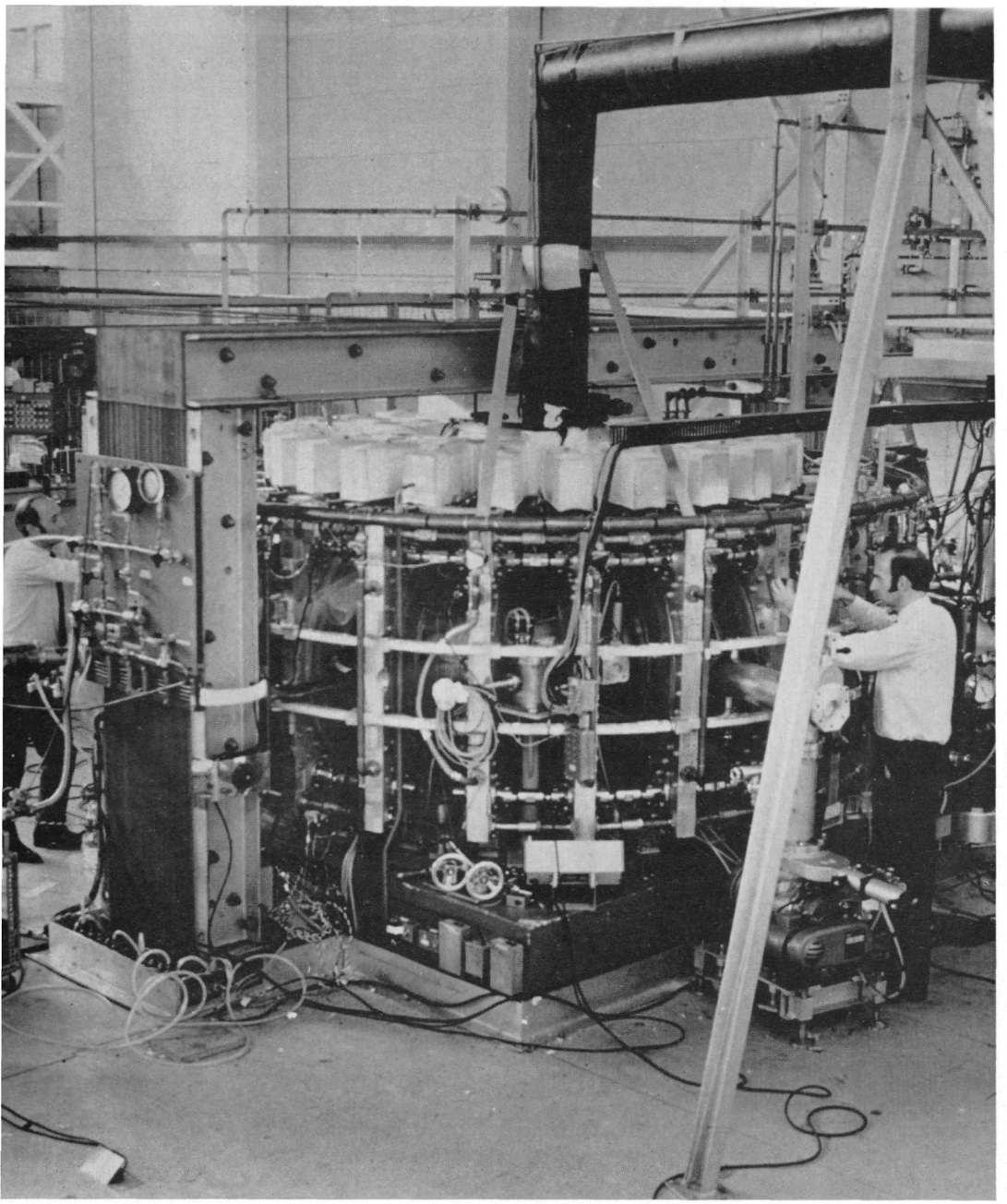
The Authority's effort on controlled nuclear fusion and high temperature plasma physics research, carried out at Culham Laboratory, is now largely on plasma confinement experiments using magnetic fields and on methods of producing and heating plasma, together with a modest programme on basic plasma physics and on theoretical and computer simulation studies.

Advanced technology and engineering which has been developed in support of the physical research includes **high voltage pulsed capacitors, vacuum systems, superconductivity and data processing.** Some effort has recently been devoted to defining and exploring the technological problems of possible fusion reactor systems.

The basic requirement for useful exploitation of controlled fusion is that a dense plasma should be confined at a temperature of the order of 100 million degrees for a long enough time to provide for a net release in energy from thermonuclear reactions (the important parameters are temperature and the product of number density and confinement time). To seek to achieve the required conditions of temperature density and confinement time simultaneously would require a large and costly magnetic field system, so that at present plasma confinement is studied in smaller systems in which, for example, the density is of the right order but the confinement time is short and the temperature is lower.

Progress during the year both in the confinement of high temperature plasma and in an understanding of plasma behaviour, at Culham Laboratory and other world fusion laboratories, increases confidence that the conditions needed for controlled fusion reactions can be attained. At the same time, technological and economic studies of possible fusion reactor systems indicate the advantages which such systems may offer.

In the SUPERCONDUCTING LEVITRON, construction of which is proceeding, the confinement of plasma is to be studied in a strong axisymmetric toroidal confining field. Long confinement times are expected.



CLEO. Commissioning of the CLEO Tokamac plasma confinement experiment at Culham Laboratory. The neutral particle injector can be seen on the right hand side.

Fusion Reactors

THE HIGH BETA TOROIDAL EXPERIMENT (HBTX), which is based on a combination

of successful aspects of plasma confinement in the old ZETA and THETA-PINCH devices, has been operational since October, 1970.

The Tokamak system, developed in Russia, is also a form of toroidal pinch. Following the successful collaboration with the Kurchatov Institute in Moscow in 1969, when Culham scientists measured the plasma conditions in the Russian Tokamak confinement device and confirmed that they were the most advanced, a rapid growth in the world Tokamak research has followed and there are now at least a dozen major devices of this type working or under construction outside Russia; experiments at Princeton USA have now also confirmed the Russian results and show that **its potential for scaling up towards a reactor is very promising.**

It is planned to operate the new toroidal experimental assembly CLEO as a Tokamak during 1972.

Evaluation of the technical, safety, and economic aspects of fusion reactors has continued on a modest scale. Although the technological studies are still to a large extent system-independent, more detailed consideration of some engineering aspects of a Tokamak reactor has been started. This includes discussion of the construction of the reactor vessel, alternative heat removal methods, and means of access for repair and structural replacement. A preliminary assessment has been made of the safety problems of a deuterium-tritium fuelled reactor.

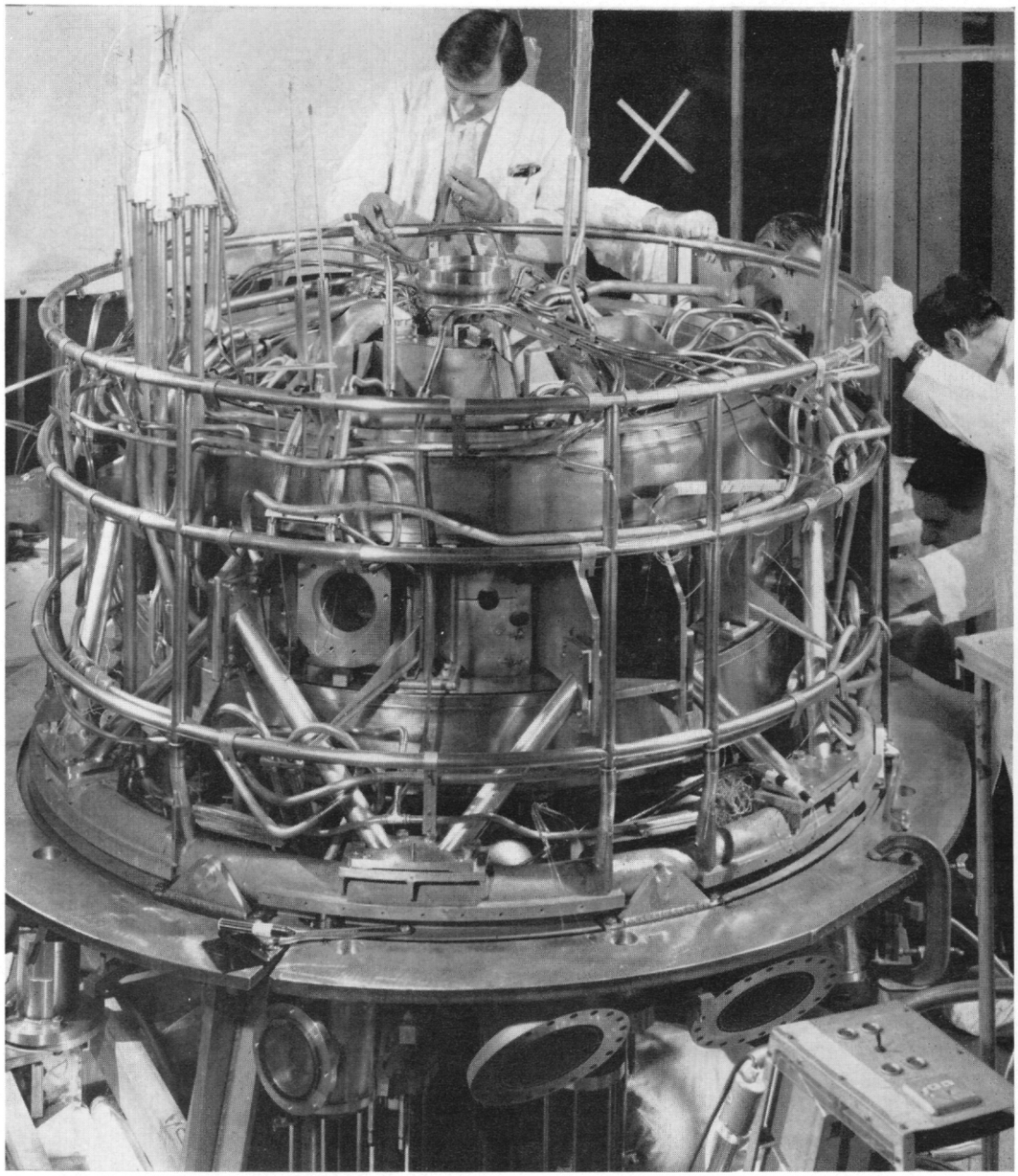
Because the superconducting magnet is the largest item of capital cost in several types of reactor, studies have been started of the maximum allowable magnetic field, current density, and mechanical stresses in a magnet in order to specify its design in more detail. A study by the International Research and Development Co was commissioned to estimate the future costs of high field superconductors, and showed that substantial price reductions should eventually be possible. The effects of pulsed magnetic fields imposed on a superconducting magnet are being studied experimentally, since they will be important in the next generation of plasma physics experiments as well as in a reactor.

International Co-operation

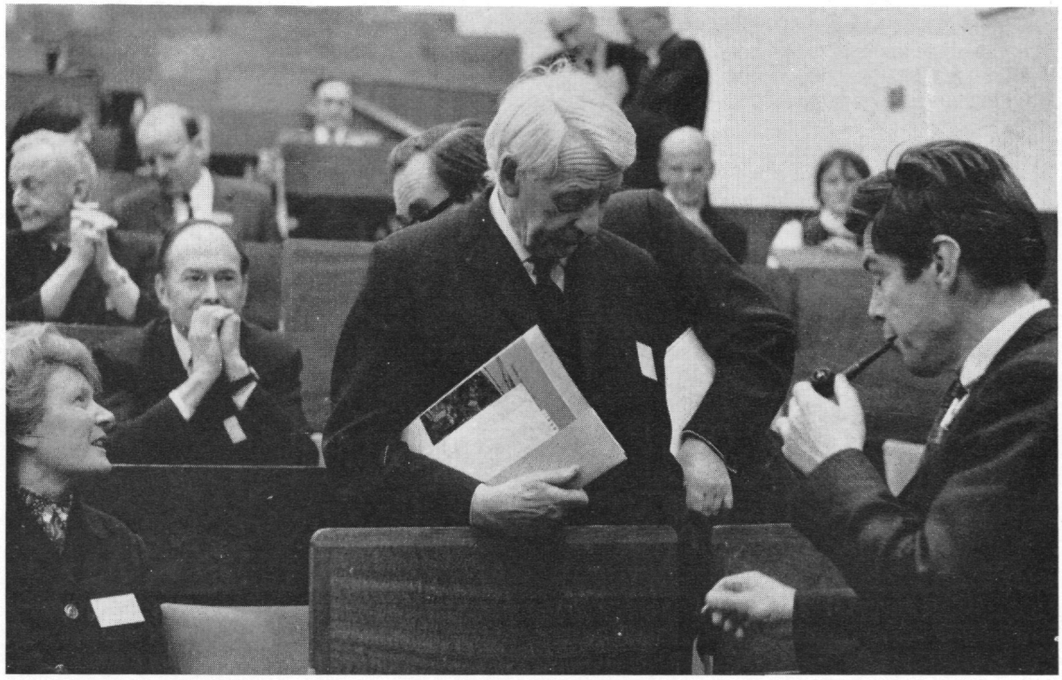
The Authority's fusion research programme has always been carried on with a large measure of international co-operation. World confidence is now high in eventual ability to build a fusion reactor but before this can be done several further stages of development will be needed. **These will become increasingly difficult to accommodate within the resources of any one national fusion project, and so the trend in co-operation is towards closer co-ordination of national programmes.**

In June, 1971, Euratom agreed to contribute 46.5 million dollars towards a five-year 180 million dollar fusion programme embracing the work of all the national fusion laboratories within the EEC. The arrangements set up during the previous year between the Authority and Euratom for informal collaboration on fusion research have worked well with the result that the Culham research programme is already partly co-ordinated with that of Europe. Preliminary discussions have taken place about a possible Contract of Association between the Authority and Euratom. Such collaboration would provide a firm frame-work in which to establish a European development project capable of leading to fusion power for Western Europe in the 21st century.

In February, 1972, the Authority set up a panel to review the future of the UK fusion research programme. **The outcome of this review, and of the EEC negotiations, will set the scale and pattern of the UK fusion project and the extent to which it can be internationally co-ordinated.**



LEVITRON. A stage in the construction of Culham's SUPERCONDUCTING LEVITRON. The main coil system and cooling pipes are shown complete and the outer copper radiation shield is being fitted. The whole assembly is eventually closed in a large stainless steel vacuum tank.

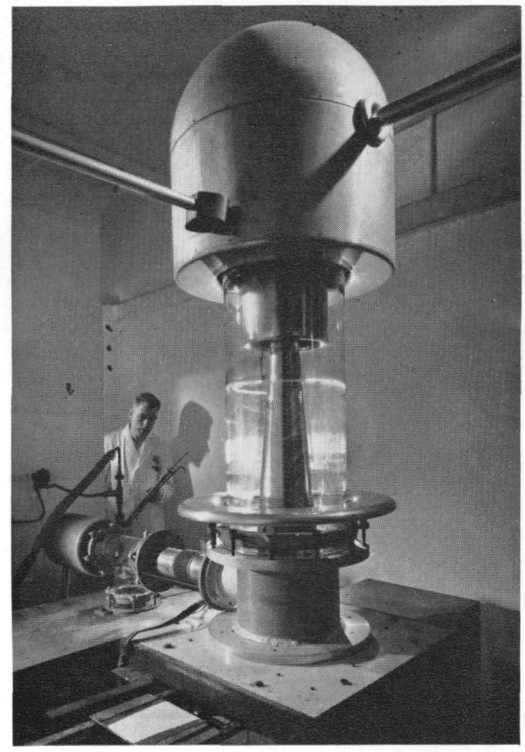


SIR GEORGE THOMSON who started experimental work on fusion at Imperial College in 1947 discusses "the state of the game" with Dr. R. S. Pease, Director of Culham. The occasion was a visit to the laboratory as part of the Royal Society's celebration of the centenary of the birth of Lord Rutherford.

NUCLEAR TECHNIQUES IN INDUSTRY

The Authority's Applied Nuclear R and D programme is carried out almost entirely in the Research Group and is designed to promote the use of nuclear processes and equipment for the national benefit. In cases where successful exploitation requires development additional to that for the Authority's own purposes, the benefits are assessed by the joint DTI/Authority Programmes Analysis Unit or by the Economics and Programming Branch before further work is authorised. Cash returns are secured from R and D contracts, consultancy, services to customers, royalties following licensing or profit-sharing and from the manufacture of prototype or pilot equipment and plant.

Four new projects were authorised during the year: Applied Radiation Chemistry and a Nuclear Analytical R and D Unit at Harwell; Nuclear Electrotechnology and a project (fully rechargeable to Computer Technology Ltd.) on software for Satellite II at Culham.



PAINT CURING. Harwell's 200 keV electron beam accelerator used for paint curing and irradiation of polymeric films.

Isotope Techniques

The application of radioactive tracing in hydrology, sedimentology and water pollution studies expanded rapidly during the year. Measurements of low-level tritium in groundwater samples continued for the Water Resources Board and the Natural Environment Research Council as part of a detailed study of **groundwater movement through chalk strata.** Tritium dating techniques were further developed in order to study the flow pattern in other geological strata and to determine **the susceptibility of ground water to pollution from chemical wastes.** Carbon-14 dating was used to study long-term water movement in the London Basin (in collaboration with the Water Resources Board) and for dating archaeological specimens.

Large scale investigations of **pollution in rivers** included three in the Severn estuary undertaken in collaboration with the Usk River Authority; discharged effluents were labelled with radioactive bromide (bromine-82) and thus could be traced over a complete tidal cycle. Design studies were initiated to investigate **sand-wave movement** in the shipping approach routes to the Thames estuary. A self-contained scintillation detector was developed in collaboration with Underwater & Marine Equipment Ltd. for **deep sea mineral surveying** (at depths down to 3,000 m), the data being transmitted via an acoustic link to a precision depth recorder on the survey ship.

Radioactive tracer techniques are readily applied to accurate **measurement of flow.** Industry made increasing use of the Harwell Flow Measurement Service for flow meter calibration (both at Harwell and on industrial sites); calibration certificates were introduced and the facilities were extended to include low pressure measurement of gas flow. Another important application is leak detection and a non-radioactive tracer method for testing subsystems in the Cos B series of satellites is being developed under an agreement with the **British Aircraft Corporation.** Assistance was given to the **British Petroleum Company** to establish their own radiotracer applications unit.

Sponsored development of radioisotope instruments included equipment to measure low flow rates of hydrocarbon vapours, the moisture content of low density materials, the thickness of coatings such as gum on envelopes and continuous methods for measuring the densities of flowing liquids in biochemical processes.

Development of miniature isotope-powered thermoelectric batteries for heart pacemakers reached the production prototype stage and effort was concentrated on the specification of a reproducible manufacturing process to hand over to the licensees, **Mining and Chemical Products Ltd.** in the UK and **Gulf General Atomics** in the USA. Collaboration proceeded with several heart pacemaker manufacturers to integrate battery design with the pacemaker and prototype batteries were supplied. A Safety Code for the design and use of heart pacemakers powered by miniature nuclear batteries has been drafted by ENEA. Battery design was improved to provide much greater resistance to mechanical shock, which had been identified as the cause of some earlier failures.

Radiation Processes

The small Radiation Sterilisation and Microbiology Project at Harwell provided advice and practical help on the microbiological decontamination of materials. Irradiations were undertaken under contract for industrial companies in the pharmaceutical and allied medical fields, such as **Johnson and Johnson, Gillette** and **The Radiochemical Centre Ltd.**

The Applied Radiation Chemistry Project is developing wood polymer composite materials for applications where such properties as hardness and dimensional stability are important. Impregnations and irradiations were carried out for several companies including 17 tons of treated wood for **BP Chemicals** to construct **corrosion-resistant walkways** for their chlorine plant at Baglan Bay. A prototype wood composite parquet floor was laid for trial at the **Tropical Stored Products Centre,** Slough (in co-operation with the Department of the Environment).

Trial electron beam irradiations and contract work were undertaken for firms interested in the curing of surface films, including paints, and the modification of surface properties.

Research and development of ion implantation techniques and their application in industry were further advanced by the installation and commissioning of the variable geometry electro-magnetic separator at Harwell; the machine also provided a routine implantation service to industry for pilot scale manufacture of semi-conductor devices. A machine and target chamber was sold by the Authority's licensee **(Lintott Engineering Ltd.)** to a Japanese semi-conductor manufacturer. Systematic studies were started of the anomalous penetration of some ions in silicon crystals, in collaboration with the **Mullard Company.**

The High Voltage Electron Microscope

The objectives of the high voltage electron microscope project were successfully completed, i.e. to continue development in collaboration with **AEI Scientific Apparatus Ltd.,** of the AEI EM7 1 MV electron microscope (the first was installed at Harwell in 1970) in order to improve its marketability. Modifications and simplifications of certain parts were introduced and will be adopted by AEI in future instruments. A wide range of devices and accessories were designed and constructed to extend the fields of application and many were sold to existing EM7 users.

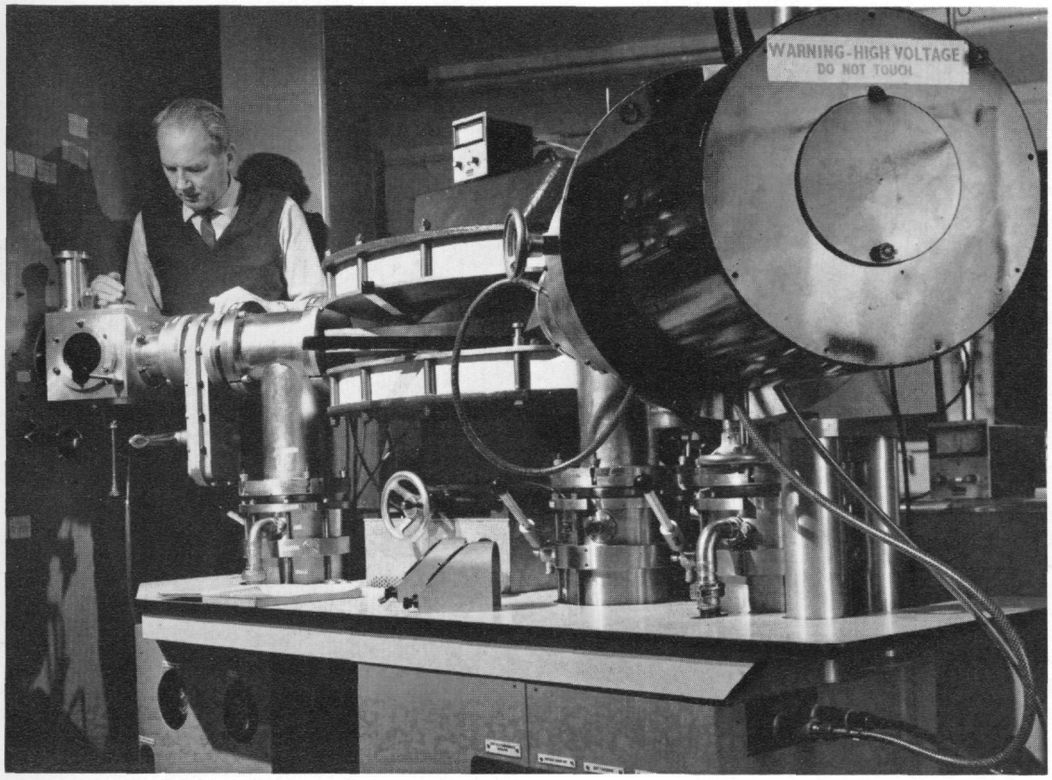
The machine is especially valuable for studying many kinds of materials problems because of the ability to produce high rates of radiation damage and to observe this damage as it occurs.

The Activation Analysis Unit was combined with the Analytical R and D Unit in October, 1971, thus providing an integrated range of techniques for industrial analytical problems. Samples were analysed for over 80 customers from industry, universities, hospitals and government laboratories; ranging from sodium and vanadium in oils, to mercury in water and foodstuffs.

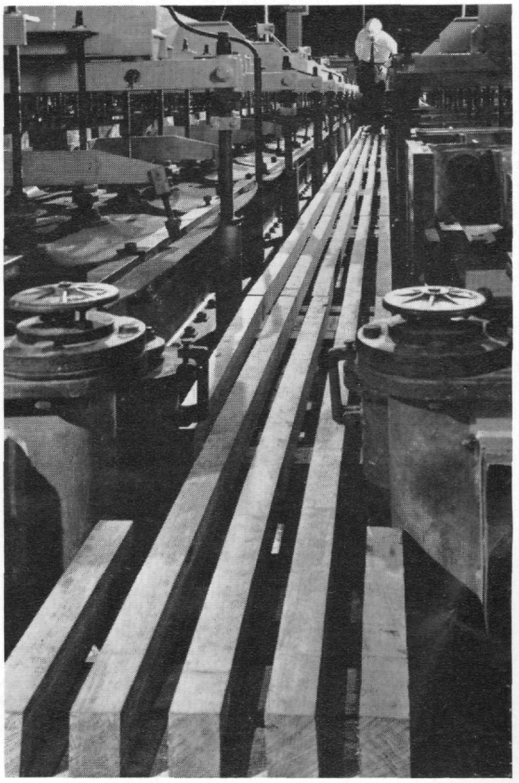
Sponsored research was undertaken in neutron activation techniques and neutron instrument systems were developed to simplify process control, e.g. one such instrument reduced the time for determining boron in metal alloys from about eight hours to a few minutes. A general agreement was signed with **Marconi Elliott Avionic Systems Ltd.** to promote widespread exploitation of these high speed neutron systems for laboratory and on-line process control.

Prospecting and Mining

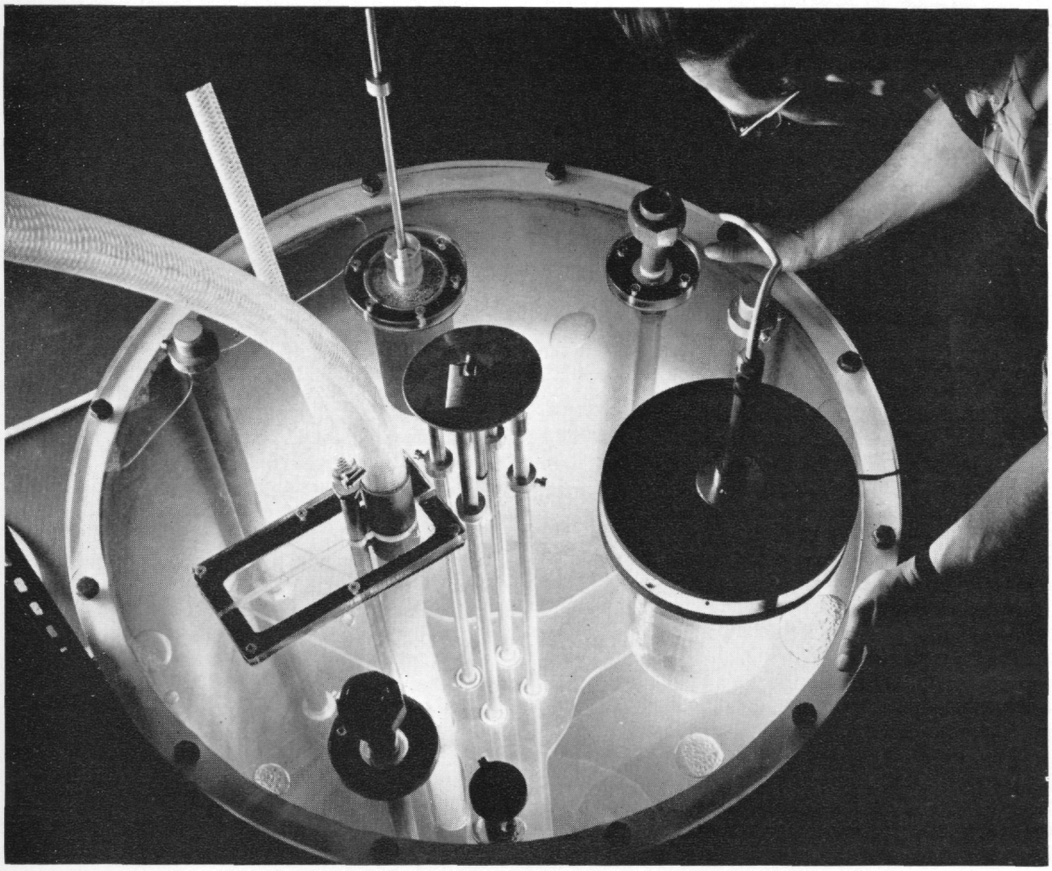
Several new methods with commercial potential for processing uranium ores were developed at Aldermaston and in extramural studies at the



SEPARATOR. Lintott Engineering Ltd, have been licensed to produce the Harwell Mark IV Separator and Ion Implantation Facility. A number have been installed in Japan, Germany and the U.S.A.



"CURIFAX". A walkway of Harwell's corrosion-resistant "Curifax" wood at BP Chemical's chlorine plant in Wales.



ANALYSIS. A californium-252 installation for activation analysis at Harwell. Radioisotopes provide reliable, compact and relatively cheap neutron sources for activation analysis.

Warren Spring Laboratory, the Microbiological Research Establishment at Porton and Imperial College, London. Strong acid leaching was found to be applicable to several types of ore and promises substantial savings in capital and operating costs. Other promising developments include a continuous ion exchange process, a new principle for upgrading ores by lump sorting and a bacteria-assisted leaching process for mill grade ore.

A conference on uranium prospecting methods sponsored by the NATO Science Council and organised jointly by the Authority and IGS was held in September, 1971; newly developed prospecting instruments were also demonstrated in field trials in S.W. England attended by representatives from 22 countries.

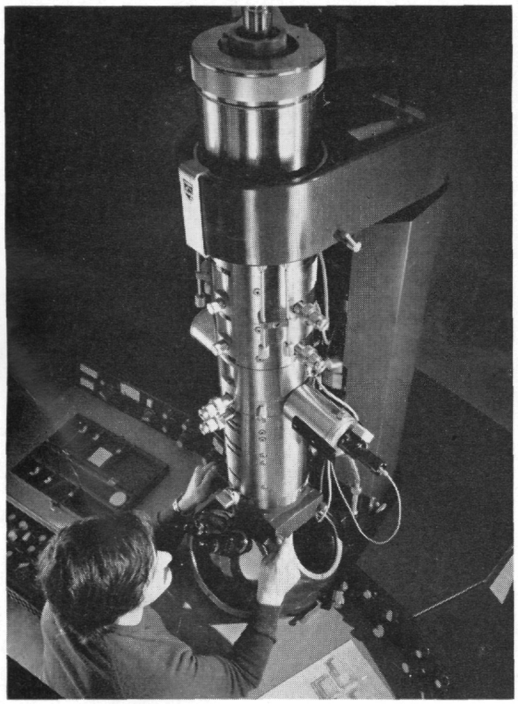
The aims of the Nuclear Techniques in Mining and Quarrying Project (NUTMAQ) are to develop and apply nuclear techniques in raw materials exploration, extraction and processing. Sea trials were carried out off the Scottish coast of the **gamma spectrometer** developed under sponsorship from IGS for radiogeological and mineral exploration surveys upon the Continental Shelf; good correlation was shown between measured radioactivity and the known geology of the sea bed. The ability to maintain continuous contact with the sea bed when the spectrometer was towed at 3-6 knots demonstrated the potential of these techniques for marine sedimentology, especially in relation to the erection of structures on the sea bed.

Four mining companies formed a group to develop the use of nuclear instruments in mineral exploration and mining operations, in collaboration with the Authority and IGS. A prototype X-ray tube unit and energy selector were constructed for the non-dispersive X-ray fluorescent equipment and **Nuclear Enterprises Limited** were appointed the licensee. A series of portable borehole logging equipments are being developed for international mining companies to measure the concentrations of metals such as copper, zinc, lead, tungsten and molybdenum in mineral deposits, e.g. for grade control in open cast mining.

Electronic Instrumentation

The systems of modular electronic units developed by the Modular Unit Schemes and Equipment Project (MUSE) at Harwell permit the rapid assembly of complex systems for measurement and control. Modules are available in several standardised formats, the most recent (the Harwell 7000 series) being compatible with the newly adopted international CAMAC specifications of the European Standard of Nuclear Electronics (ESONE). The endorsement of the CAMAC standard by the USAEC Nuclear Instrument Module Committee has ensured a world market and **Nuclear Enterprises Ltd.,** who are licensed to manufacture to Harwell designs, have for sale a larger range of modules than any other firm. Many government and industrial concerns are turning to standardised modules for interconnecting measuring and control equipment including computers; this project accordingly continued to introduce new hardware designs, to procure equipment and advise on its use for systems applications.

NON-NUCLEAR



MATERIALS. The EM.300 transmission electron microscope is used by Metallurgy Division at Harwell to study tiny voids or dislocations in materials.

The Science and Technology Act 1965 makes provision for the Authority to undertake **non-nuclear research and development** subject to authorisation in the form of Requirements issued by the Secretary of State for Trade and Industry. A requirement defines an area of study, e.g. Ceramic Materials, Quality Control. Authorisation of a specific project within the scope of a Requirement and with clear objectives, is given by the Department of Trade and Industry (DTI) in a Programme Letter which usually sets a limit on the manpower, expenditure and duration of the project. These projects form a non-nuclear programme that is **based on the expertise built up in the Authority to meet the demands of the nuclear power industry.** The work is carried out in close concert with industrial companies, or with other government funded bodies.

Most of the non-nuclear projects fall into six broad areas of technology, namely:

- plant performance and reliability;
- process development;
- materials development and quality control;
- electrotechnology;
- computing and computer software;
- and environmental research.

Some work mainly for government departments is also undertaken in other fields, e.g. biomedical technology and space research.

SYSTEMS RELIABILITY

The Systems Reliability Service based at Risley makes available to industry the Authority's wide knowledge and long experience on reliability and safety derived from their work with reactors and other nuclear installations. It acts as a focus for activities in the systems reliability field, provides a Reliability Data Bank service and undertakes research and training. Some 230 people from the United Kingdom and overseas attended courses and seminars. Several more organisations from the United Kingdom and from **Europe, South Africa and the USA** became associate members.

Investigations of plant availability ranged from evaluation of various water cooling and drive systems for **Pilkington Ltd.** to die-casting machines for DTI. Safety assessments were concerned with both personnel and plant as, for example, an investigation for **Monsanto Textiles** of the reliability of a chemical emission and fire alarm system and another for the **Fire Research Station on automatic sprinkler systems.**

NON-DESTRUCTIVE TESTING

The Non-destructive Testing Centre provided direct assistance to industry in solving numerous problems concerned with the quality, reliability and serviceability of manufactured products. During the year over 100 calls from a wide spread of industries were made on the NDT field force which was set up to help evaluate difficult inspection problems or provide on-the-spot consultancy; this service involves both Research Group and Reactor Group staff. The number of special ultrasonic, eddy current and X-ray systems developed and supplied to solve specific industrial problems of quality assessment doubled during the year.

PROCESS TECHNOLOGY

The expertise of the Harwell High Temperature Chemical Technology Project in chemical plant design and knowledge of high temperature reactions was used in developing several new and improved chemical and metallurgical processes. More than half the work involved sponsored or collaborative programmes with industry. A joint development programme with the **British Oxygen Co.** expanded into a number of fields where a detailed understanding of process mechanisms could lead to significant cost reductions.

Helical extrusion is a new technique for reducing billets directly to wire. It is a combination of three forming stages, hydrostatic extrusion, conventional extrusion and an intermediate stage similar to the lathe turning process, and as all three take place simultaneously it is in effect a single operation. Helical extrusion has attracted world wide attention and part of its development is being carried out by the Authority, on repayment, for British and US companies. The technique is particularly suited to working copper; plain and stepped strip, cruciform and plain round wire sections were extruded. Overall extrusion ratios for copper billet to wire of up to 15,000:1 were achieved and development progressed from small scale experimental work to the design and installation of a production scale machine to process large billets; this is undergoing commissioning trials prior to use under a year's contract with an association of copper producers. Various silver alloys, 70:30 brass, 6 per cent phosphorus/copper, and beryllium/copper were also successfully extruded on the small scale equipment at Springfields.

ENVIRONMENT. Airborne dust and rainwater are collected on Plynlimon, Wales, for analysis at Harwell. The station is one of seven set up in Britain for checks on the atmosphere.

MATERIALS DEVELOPMENT

The Ceramics Centre continued to find important new industrial outlets through R and D programmes on new ceramics for engineering applications, advanced ceramic processing and glow discharge electron beam devices.

Development work on silicon nitride, based on ceramics-plastics technology was pursued under contract to **Advanced Materials Engineering Ltd.** New fabrication techniques were established, some being taken to a pilot production stage, that extended the scope of silicon nitride technology and led to products with improved physical properties. Industrial applications were also identified for "Refel SiC" the advanced silicon carbide ceramic developed at Springfields as a reactor cladding material.

Glow discharge electron beam devices were developed for welding and an agreement was reached with **Energy Beams Ltd.** on the marketing of "one-shot" ring welders in close collaboration with the Ceramics Centre and industrial users.

The Carbon Fibre Project provides support to British industry in the technology of carbon fibre production, in particular to improve the quality of fibres and to provide design data to help in lowering production costs of fibres and composites. The project is also involved in the testing and evaluation of fibres and composite materials and development of applications.

ANALYTICAL R AND D

The Analytical R and D Unit was set up to promote industrial use of the analytical techniques pioneered in the nuclear energy field. Over 80 industrial companies and 20 government and university laboratories have placed contracts with the Unit.

The time-shared computer system developed in collaboration with **Computer Technology Limited** is being extended under a DTI contract to suit a wider range of analytical instruments and to provide feed-back control. Software was developed for **Twentieth Century Electronics Ltd.** for a

SERVICES

gas chromatograph/quadrupole mass spectrometer/computer system at Queen Mary College. New instrument development included an initial study for **Measuring and Scientific Equipment Limited** of sample loading techniques for their new centrifugal analyser (GeMSAEC) which is designed to provide a high throughput of clinical and chemical analyses.

PCMU

The Physico-Chemical Measurements Unit provides a service of measurement and interpretation to universities and to government and industrial establishments, based on a range of advanced instruments. These measurements are used mainly to determine the molecular structure of new chemicals. The universities, financed by the Science Research Council, continued to be the major customer and the Unit is installing new nuclear magnetic resonance spectrometers to meet their requirements for more advanced types of measurement. Also, during the year more than 50 industrial companies, many in pharmaceuticals, sent a wide range of materials for examination including gas samples from sealed electronic devices and ships holds, condensed chimney-fumes from a paint-stoving plant and spoiled or contaminated products such as foodstuffs and tin-cans.

ELECTROTECHNOLOGY

The Industrial Electrotechnology Project at Culham attracted substantial financial support from industry. Forty contracts were carried out for customers in the computer hardware, metal refining and fabrication, aerospace, printing, shipping and electrical industries, as well as for a number of government departments and universities. One large contract from the Ministry of Defence was to set up a test facility to investigate the effects of lightning strikes on aircraft. Tests on aircraft structures were also carried out for UK aircraft manufacturers.

A Laser Applications Group was set up, also at Culham, to study the application of high power lasers to industrial processes and contracts were undertaken for customers in the textiles, paper, glass, plastics, rubber and food industries.

COMPUTERS

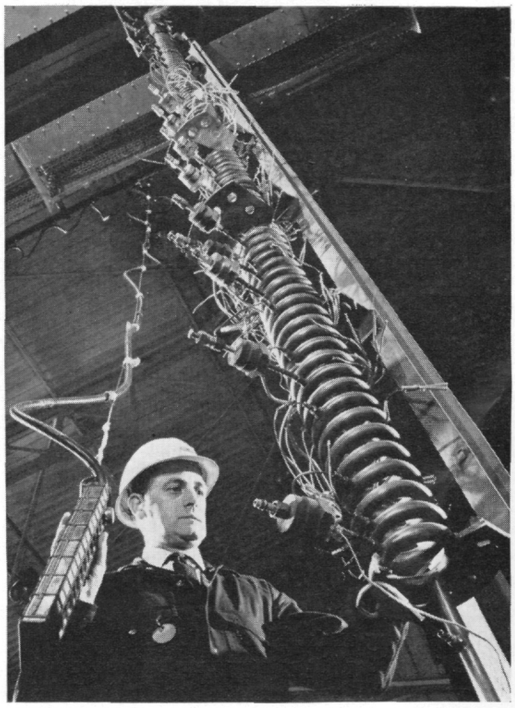
The Computer Optimisation Project aims to apply Harwell's experience in large scale computer programming to optimisation problems in industry. A program was developed in collaboration with **Seabridge Shipping Ltd.** to optimise the scheduling of bulk cargo fleets; it is used to control day to day operations and also as a means of medium term profit forecasting and strategic planning. The company continue to sponsor development of this program. Scheduling trials were also completed with the fleets of two Oslo based companies and another UK company; these trials indicate that the program can be generalised to cover the special problems of many bulk carrier operators and new trials are planned to test the system with oil tankers and passenger vessels.

Another project, sponsored by the **Heating and Ventilating Research Association,** aims to optimise the design of district heating systems. Tests with existing sites indicated that substantial savings could be achieved and trials were initiated at sites which are still at the planning stage.

Harwell assisted the R and D authority **(Royal Radar Establishment, Malvern)** for the Linesman Project for air traffic control, and made a substantial contribution to the data processing system on sub-contract to the design authority **(The Plessey Co. Ltd.)**.

POLLUTION

The objectives of the Atmospheric Pollution Project at Harwell are to study the physics and chemistry of atmospheric gases and aerosols in order to identify the causes of pollution phenomena and help to overcome them, and to provide, in collaboration with the Warren Spring Laboratory, the scientific data needed to establish permissible limits of pollution. Field studies confirmed the high rate of photochemical oxidation of sulphur dioxide demonstrated previously in the laboratory. During the summer of 1971, measurable quantities of photochemical ozone were observed in Southern England, formed by a smog reaction of the Los Angeles type arising from unsaturated hydrocarbons and oxides of nitrogen, mainly emitted from motor vehicle exhausts.



HEAT TRANSFER. A fully-instrumented test section (at Winfrith) to simulate a helical coil from a boiler. (Photo: Courtesy Clarke-Chapman Ltd.).

An ultrasonic technique to measure continuously and without obstruction the total volume of water flow down rivers was successfully demonstrated on a small tributary of the Thames; the first full-scale equipment will shortly be installed on the Thames at Sutton Courtenay. Output data will be on punched paper tape, compatible with the computer operated by the Water Resources Board who commissioned the tests. This flowmeter can also be used to gauge rivers which are too sluggish for measurement by conventional techniques. Its use by other river authorities in the Severn, Dorset Avon, Lincolnshire Ouse, Mersey and Weaver areas is under consideration.

Space technology

The National Centre of Tribology at Risley was established to assist industry in solving problems of lubrication and wear. Response was encouraging to the Retainer Consultancy Scheme which was launched during the year to meet the demand for services on a continuing basis and to enable subscribers to gain access to the Centre's services speedily and at reduced rates. Industrial contracts were signed with firms in the aircraft, chemical, computer, diesel engine, electric motor, food, general engineering, glass, shipbuilding, textiles and telecommunications fields. Nearly 50 per cent of the Centre's clients commissioned further work during the course of their initial contracts.

The Centre was awarded a contract by the **European Space Research Organisation** (ESRO) to study the requirement for a tribology laboratory for space applications. Following this study contract, ESRO formally approved the setting up of a European Space Tribology Laboratory, within the National Centre, to be built and operated at their expense. Its objectives are to establish the long-term reliability of satellite mechanisms, to improve that of existing mechanisms and to develop new bearing systems, slip rings and lubricants for future satellite components.

Teams from Aldermaston have, over the past four years, launched and telemetered about 80 PETREL and 45 SKUA rockets on behalf of the Science Research Council. Payloads are shared between the SRC and British and overseas universities and are used to study phenomena in the upper atmosphere at heights of up to 100 miles. The launchings are mainly from South Uist and Kiruna, Sweden, and also from South India and West Pakistan.

Tape recorders designed and assembled at Aldermaston, together with electronics by GEC, were installed in the satellite "Prospero" launched by the British Black Arrow rocket from Woomera, Australia, in October, 1971 and the satellite "Ariel" launched by the US "Scout" rocket from California in December 1971. "Prospero" is mainly testing space techniques and systems and "Ariel" is observing space phenomena for the Universities of Birmingham, Sheffield and Iowa, and for Jodrell Bank and RSRS Slough.

Risley is assisting the SRC in the design and construction of radio telescopes. The Cambridge telescope for which the Authority acts as Architect Engineer is substantially complete. Collaboration continued with Manchester University and with the consulting engineers, Husband and Co., on modification of the Mk I Telescope at Jodrell Bank and on the design of the proposed Mk VA Telescope at Meifod in Wales.

TRIBOLOGY. Commissioning an ultra high vacuum unit in the European Space Tribology Laboratory at Risley.

Desalination

The Authority continued to be responsible for the national research and development programme on desalination. A second report from the Programmes Analysis Unit confirmed **the national benefit obtainable from export of desalting plant** and analysed **longer term benefit from application in the UK.** The major experimental objectives of the earlier programmes having been met, the work concentrated on process demonstration and investigation of plant reliability in the field. The expertise gained in R and D, plant operation and cost analysis over the past seven years enables Authority staff to offer to consultants and Government Departments **expert advice on the status, operation and economics of desalination and water renovation processes.**

The advanced multiple effect distillation technology developed within the Authority over the past four years reached commercial application in a contract awarded by the **Gibraltar Government** to **Aiton & Co** to build a 300,000 g/d vertical tube evaporator to meet the growing water demands of the tourist trade. Plant manufacture proceeded satisfactorily and the double fluted tubes for the evaporator were produced by **Yorkshire Imperial Metals.**

The Authority undertook to oversee the successful completion and commissioning of the plant.

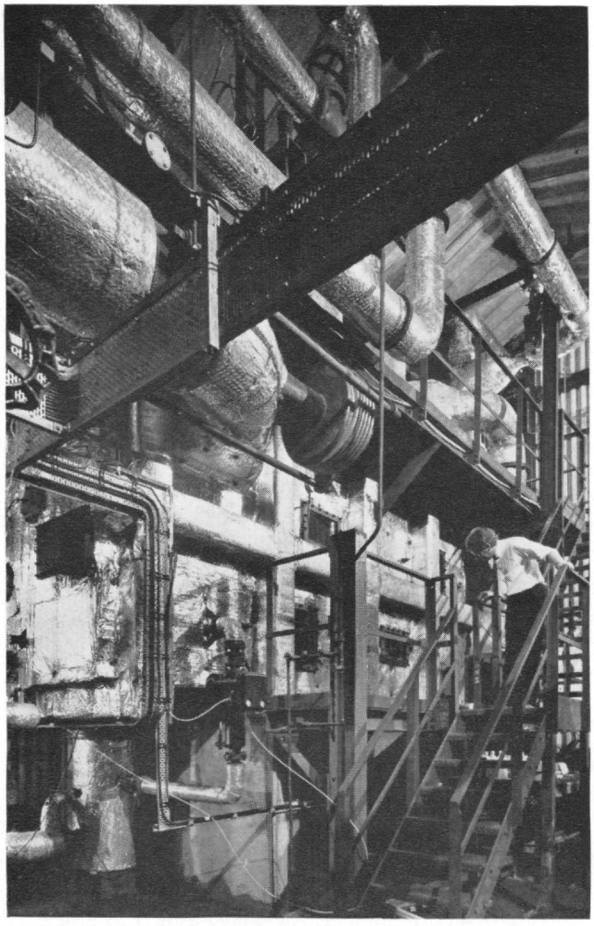
The 100,000 g/d prototype unit of another variant of the multiple effect evaporator (the horizontal falling film), developed in collaboration with **Aiton & Co,** was commissioned and successfully operated at the **CEGB's Dungeness A** site; the design parameters which had been determined in earlier laboratory studies were confirmed and sufficient confidence was obtained for Aiton & Co to offer commercial units up to 2.5 mgd capacity. The unit produced extremely pure distillate which augmented the supply at the power station.

The exploitation of surfaces with enhanced heat transfer properties (such as the fluted tube and profiled condenser tubing developed as part of the desalination programme) is being pursued with tube manufacturers. Distillation techniques are also being applied to the disposal of **sewage plant effluent** and **industrial liquid waste.**

The R and D programme on the multi-stage flash distillation (MSF) process with **Weir Westgarth** was drawn to a close as this process is now well established; two of the large rigs at the Troon R and D facility were put in a standby condition for use by Weir Westgarth as occasion arose. The corrosion monitoring programme on the Jersey MSF plant continued and will make a valuable contribution to the design of the units which are operated only intermittently.

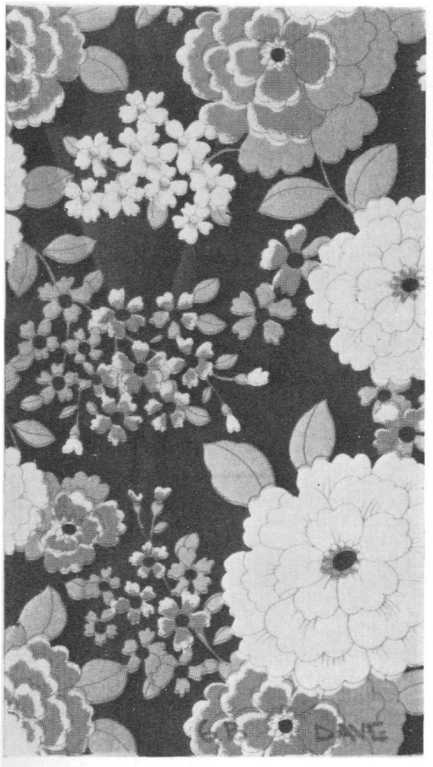
The Department of the Environment approved the construction at Ipswich of the 1 mgd plant using the freezing (SRF) process but a reassessment of the timetable for the introduction of desalination on a large scale in the UK together with increasing development and plant costs and delays in obtaining site approval led to a decision to cancel the project in January, 1972. However the work on the SRF process was taken sufficiently far to provide a sound basis for future exploitation.

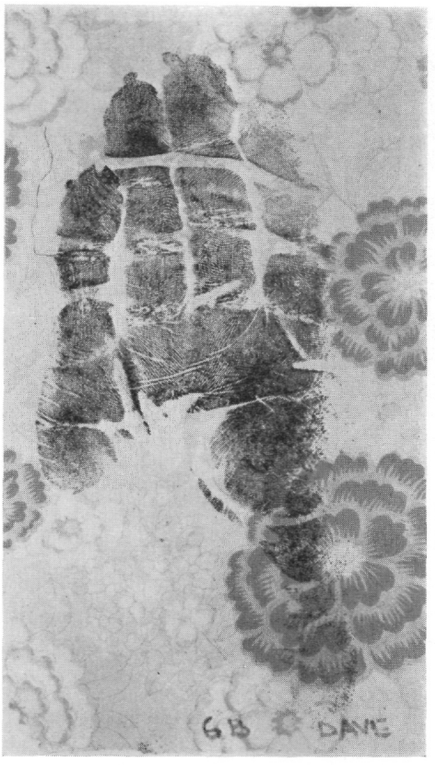
Reverse osmosis offers considerable promise as an economic method for the **desalination** and **recycling** of salt and brackish water and also for **treating sewage effluents.** Tubular supported membrane units have been developed with **Paterson Candy International Ltd.** for exploiting this process for water renovation; a second and complementary design was developed in which the membrane is laid on the outer surface of a cylindrical support. The latter design is very reliable and well suited for the treatment of brackish water, whilst the tubular system is preferred for liquids with suspended solids. Both systems are being used in extensive field trials and with a variety of feeds including treated sewage effluent, the latter in collaboration with the Water Pollution Research Laboratory.



DUNGENESS. Multiple-effect evaporation plant built by Aiton & Co., Ltd. (in collaboration with UKAEA) at the CEGB nuclear power station, Dungeness.

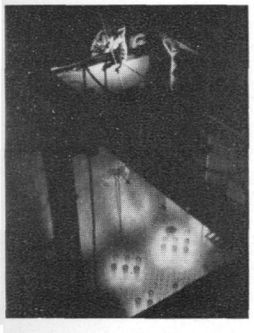
GIBRALTAR. Manufacture of the desalination plant being built by Aiton & Co., Ltd. for the Gibraltar Government. Aiton's have a collaborative agreement with the Authority for the development of advanced equipment.



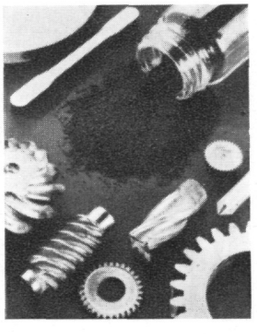


FINGER PRINTS

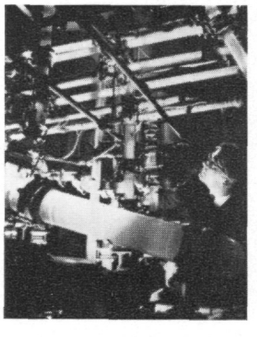
Until recently it was impossible to reveal finger-prints on fabrics. A new technique, developed by Harwell under a Home Office contract, shows promise for dealing with such materials. The technique depends on the greater reactivity of sulphur dioxide gas with deposited skin excretions than with the basic material.



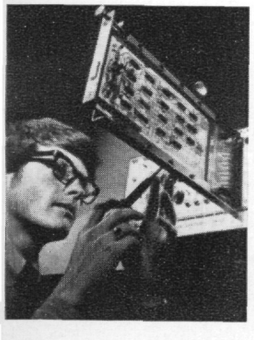
1



2

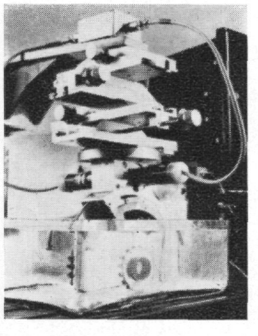


3

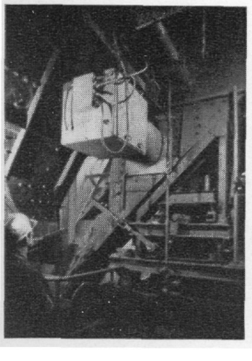


4

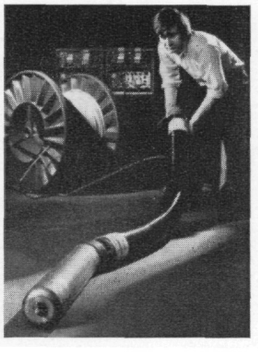
5



6



7



8

9

Front cover : Looking into the core of the Prototype Fast Reactor now under construction at Dounreay.

The illustrations on the back-cover represent a cross-section of the extensive services which Harwell provides to industry.

1 **Applied Radiation Chemistry.** While spent fuel elements from the DIDO reactor are stored for some weeks under water they can be used to irradiate materials for research or pilot-scale industrial trials. One of the irradiated materials currently attracting great interest is "Curifax" (see page 18).

2 **High Temperature Chemical Technology.** Special powder metallurgy: the sintering of micron-sized powders produces fully-dense components at lower temperatures. The photograph shows some components and the granulated metal powder from which they are made.

3 **Materials Development.** Harwell undertakes a widely based research programme geared to the needs of British industry. The rig shown, which circulates water at high speed, is used to study corrosion of profiled tubes in brine.

4 **Instrumentation.** The HARWELL 6000 series has been introduced by the Instrumentation Systems Laboratory to enable rapid and economic development of instrumentation systems. Picture shows a 4-channel counting system for a californium-252 neutron activation facility.

5 **Ceramics.** The Ceramics Centre continues to find important new industrial outlets through R & D programmes. Glow discharge electron beam devices (see illustration) have been developed for welding and an agreement has been reached with Energy Beams Ltd, on the marketing of "one-shot" ring welders.

6 **NDT.** The Non-Destructive Testing Centre provides direct assistance to industry in solving problems concerned with the quality, reliability and serviceability of manufactured products. Picture shows the automated ultrasonic goniometer currently applied to the study of composite materials and an understanding of surface adhesion.

7 **Isotopes in Industry.** The illustration shows the British Steel Corporation/Nuclear Enterprises Atomat on-line gauge for measuring the moisture in coke in one of the hoppers serving the blast furnaces at the British Steel Corporation Llanwern Works. (Photo: Courtesy British Steel Corporation and Nuclear Enterprises Ltd).

8 **The Sea-Bed.** The sea-bed gamma spectrometer shown has been developed jointly by Harwell and the Institute of Geological Sciences for mineral exploration on the Continental Shelf.

9 **CAMSPEK** is a laboratory microwave spectrometer developed jointly by the Analytical R & D Unit and Cambridge Scientific Instruments Ltd, under a CSIL contract.

Published by Public Relations Branch, UKAEA, 11 Charles II St., London S.W.1. Printed by The White Rose Press, Mexborough and London.