OCTOBER 1979 NUMBER 276

ATOM

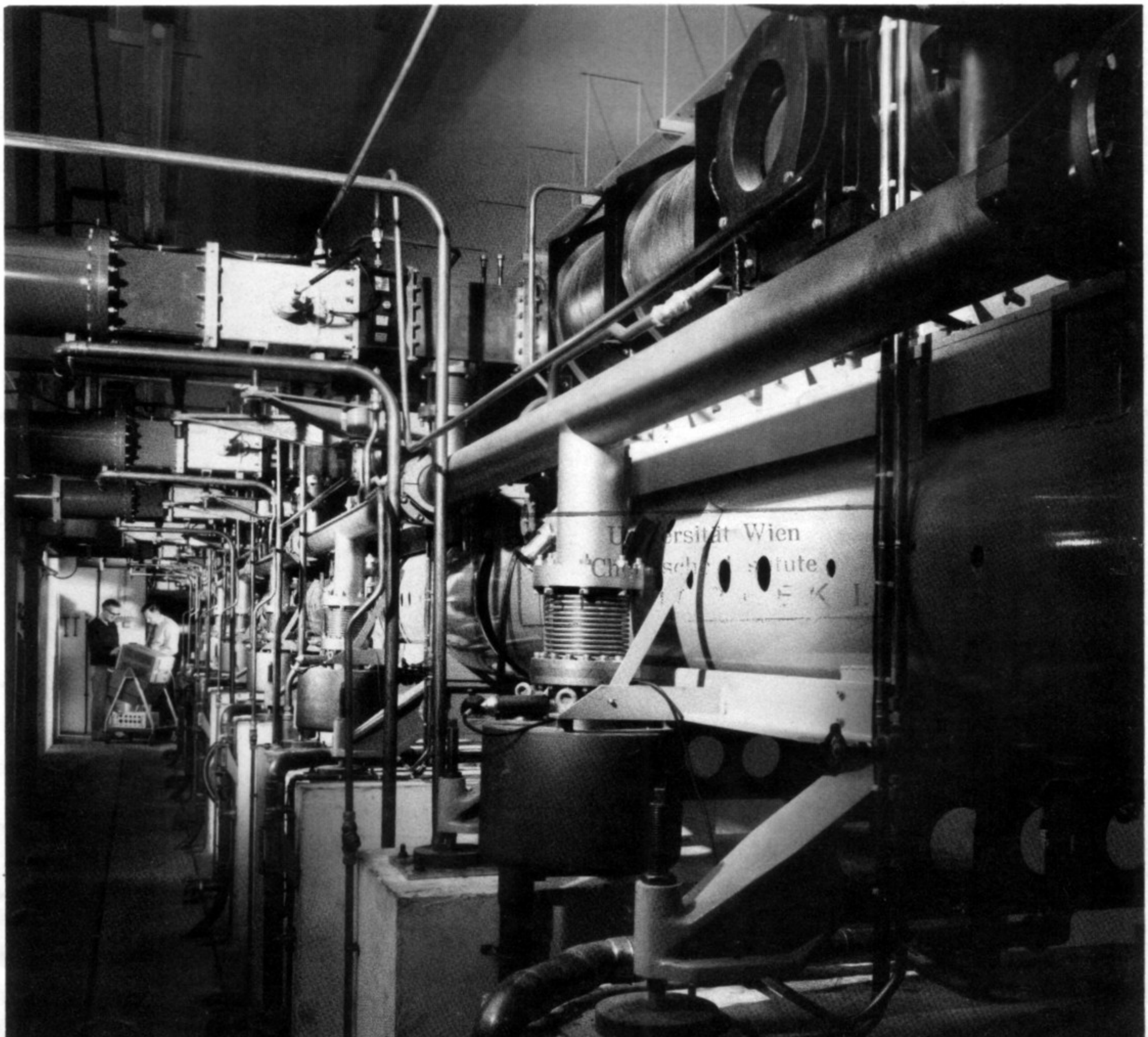
UKAEA ANNUAL REPORT

THE 136 MeV LINAC

TRCL ANNUAL REPORT

NUCLEAR POWER IN THE EASTERN BLOC

THE POTENTIAL OF CHP



OCTOBER 1979 NUMBER 276

ATOM contents

THE MONTHLY INFORMATION BULLETIN OF
THE UNITED KINGDOM ATOMIC ENERGY AUTHORITY

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Front cover: Accelerator sections of the new 136 MeV LINAC at AERE Harwell — a new research tool discussed in an article in this issue.

THE AUTHORITY'S YEAR

The 25th annual report of the UKAEA was published on 20 September. The following extract from the general introduction to it describes the Authority's activities and progress during the year.

July 1979 was the 25th anniversary of the creation of the Atomic Energy Authority. Over these 25 years the study of atomic energy has developed from a new and exciting branch of science to a mature technology with the capability of providing the world with a major additional source of power at an economic cost. Fossil fuel supplies are finite and will not be able in coming years to expand sufficiently to meet the needs of a growing world population and increasing demands for an adequate standard of life for all. Other new energy resources have yet to be adequately developed and proved technically and economically capable of making a commensurate contribution; their contribution to the world's energy supply this century seems likely to be small. The gap is capable of being filled only by nuclear power which is already an indispensable element of the world's energy supply. The UK's leading role in this development has been a considerable national achievement.

The closing months of the year 1978-79 brought into particularly sharp focus the issues of the contribution to be made by nuclear power to the solution of the world's energy problems. Public awareness of the energy crisis facing the world was acutely sharpened by the appearance of petrol shortages and significant price increases following the interruption of supplies from Iran during and after the revolution in that country. There were indications that adjustments of demand to match reductions in supply (even where the reductions were relatively small) would not be achieved easily and without friction. In these circumstances, the importance of maintaining the availability of nuclear power became increasingly apparent.

In March, however, there occurred the accident at the Three Mile Island reactor in Pennsylvania, USA: this led to fears that a major release of radiation might occur. In the event, the releases which occurred were minor but the widespread alarm which followed the early reports had a serious effect on public confidence in nuclear power in the United States and elsewhere in the world. The openness of the USA authorities in discussing the accident with the Authority and other nuclear organisations will ensure that the lessons to be learned from the accident are quickly assimilated by nuclear industry throughout the world.

In the United Kingdom, the Authority have continued to provide a technological base for the development of safe, reliable and economic generation of nuclear electricity. During the year they have supported the activities of the generating boards and the Nuclear Power Company (NPC) in relation to the Advanced Gas-cooled Reactor (AGR) programme, maintained a safety-assessment programme of Pressurised Water Reactors (PWR) against the possibility of the adoption of this system in the UK, and continued a broad programme in aid of future fast reactors and carried out programmes of general reactor safety research. Through a co-ordinated European programme under the auspices of Euratom, progress has been made towards establishing the feasibility of fusion reactors as a means of power generation in the next century. Working closely with British Nuclear Fuels Ltd (BNFL) and the Department of the Environment, the Authority have made advances in the development of processes for the safe handling of radioactive materials and disposal of radioactive waste. In all these programmes they have collaborated with other countries wherever appropriate. The knowledge and skills acquired in the Authority's work have, to an increasing extent, brought requests from nuclear and non-nuclear organisations for assistance which have led to further growth of repayment activities.

Nuclear power development

Support for the electricity boards' AGR stations has continued as the highest priority during the year. Following the Government decision to endorse the generating boards' plan to build two more AGR stations, the arrangements for providing close collaboration on technical matters between the Authority, NPC, the generating boards and BNFL have been revised. The generating boards have entered into a jointly-funded extension of the Authority's programme, including operation of the Windscale AGR until 1981. At the boards' request, Authority staff are also assisting with measurements in the boards' commercial reactors.

The emphasis in the AGR programme funded from the Nuclear Energy Vote has been on optimising the coolant composition. From this work proposals have been made for a coolant composition for the next phase of commercial reactor operation and for design measures which should further prolong moderator life in the Heysham II and Torness AGRs. The Vote-funded programme on the basic technology of the system now accounts for rather less than half of this work, the remainder being financed by the nuclear industry and generating boards under contract work placed with the Authority.

The Authority's programme on PWR safety development studies is designed to maintain and develop an independent body of expertise in safety-related technology pending finalisation by the UK nuclear industry of PWR licensing arrangements. Special attention is being given to topics raised by the Nuclear Installations Inspectorate (NII) in the main conclusions of their report on the Generic Safety Issues of Pressurised Water Reactors, published in July 1977. Contacts with overseas organisations have been strengthened in order to derive maximum benefit from the extensive PWR experience in other countries.

Within the fast reactor project, most emphasis has been given to the operation of the Prototype Fast Reactor (PFR) at Dounreay and its associated process plants. The reactor has given valuable service as an experimental facility, at power levels up to 600MWth. Experimental programmes performed on the reactor have given information which will be most valuable in the design of future commercial fast reactors. These programmes, and work on steam plant modifications, have limited power output for much of the year. Progress has been maintained on commissioning of the fuel reprocessing plant.

With the help of the Joint Committee on Fast Reactor Safety (on which NII and the Central Electricity Generating Board (CEGB) are represented), good progress has been made towards establishing agreed ground rules for the safety case for a Commercial Demonstration Fast Reactor (CDFR) in the light of experimental work in PFR, some of which was carried out in collaboration with overseas organisations, and further theoretical work.

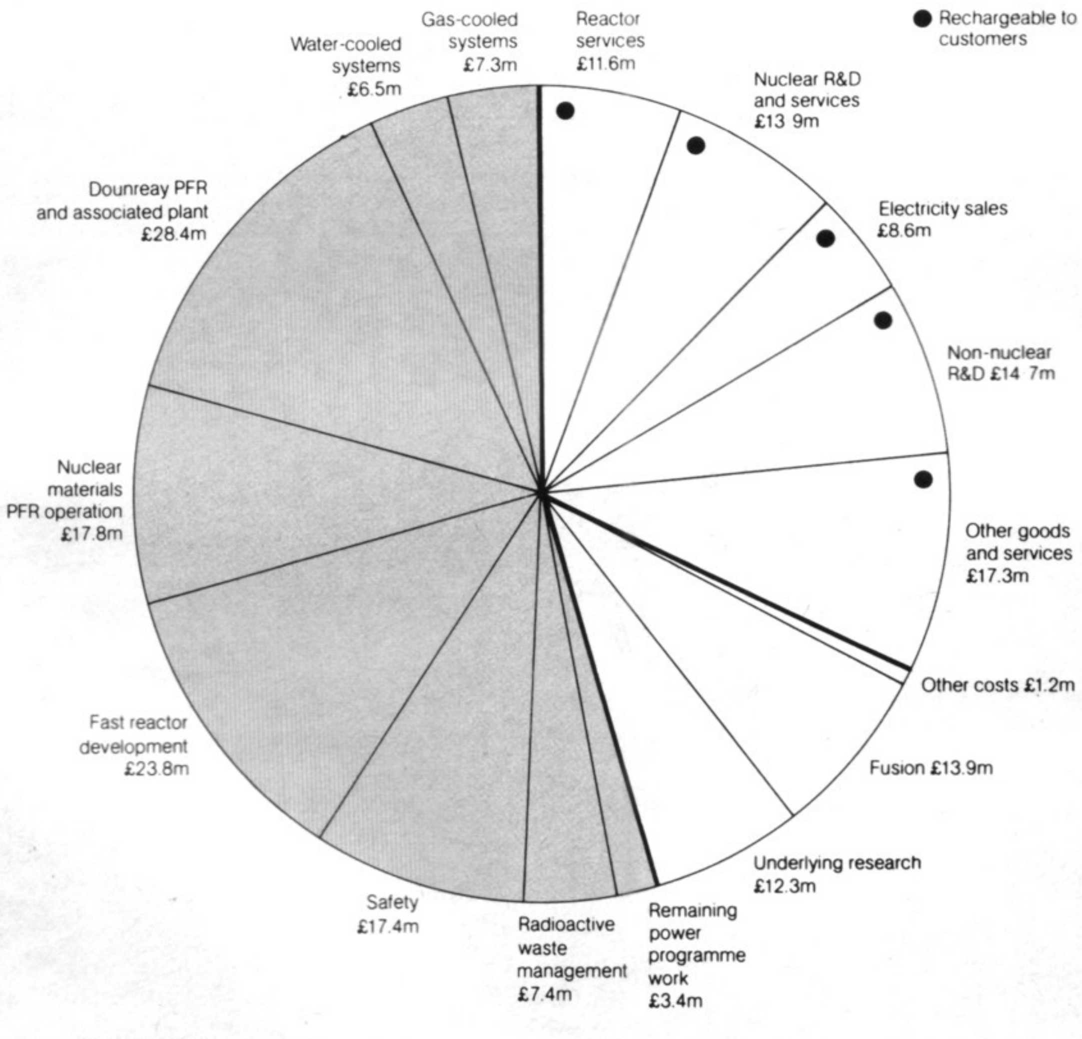
Discussions have continued during the year with the other organisations concerned in the UK to formulate policy on the development of the fast reactor, taking account of the time-scale on which the need for fast reactors is expected to arise, the interaction with thermal reactor work and the scope for international collaboration. It is expected that any decision to build a CDFR would be the subject of a public inquiry and the Authority have considered their contribution to the forms of procedure that have been suggested.

During the past year an extensive re-examination of the objectives of the research and development programmes on fuel processing has taken place. This has reflected the widespread interest in the treatment of nuclear waste, the wish to demonstrate closure of the total fuel cycle for a fast reactor on a single site and the buoyant business opportunities available to BNFL. As a result, there has been a significant shift of qualified manpower into the fuel processing areas. Important programmes of underlying research to provide the scientific base for future developments both in the Authority and in the nuclear industry have been maintained.

The International Fuel Cycle Evaluation Programme (INFCE) to which the Authority have been actively contributing is aimed at comparing the technical aspects of alternative reactor and fuel cycle concepts and exploring their merits against economic, environmental and weapons proliferation criteria. The Authority's contribution is closely co-ordinated with those of the Department of Energy, the Foreign and Commonwealth Office, the Ministry of Defence and BNFL. The evaluation has reached the stage of preliminary drafting and is expected to be reported to Governments early in 1980. There is a consensus emerging that there is no unique technical solution which will satisfy the interests of all participating countries. Their circumstances differ considerably depending on whether they are large or small energy users, net importers or exporters of uranium, and more or less advanced technologically. It seems probable that the world will need to move towards more advanced reactor systems and that breeder reactors will be an essential component of the world's deployed capacity in the next century, although the appropriate time for their adoption may vary from nation to nation.

Research into nuclear fusion is carried out with a high degree of international collaboration. Two significant landmarks during the year were the formal setting up of the JET Joint Undertaking at Culham where the large collaborative European fusion experiment is now being built and the record plasma temperature of 60 million degrees obtained in the Princeton Large Torus in the USA.

In addition to the general support given to the UK nuclear industry through the Authority's own programmes, a growing proportion of the Authority's effort is being deployed on con-



UKAEA expenditure 1978-79 by sector

tracts placed by the nuclear industries in the UK and overseas, the total value of nuclear work in 1978-79 being £25.9m. Among these, work for BNFL projects on process development, plant operation and control has been increasingly important.

Safety and the environment

The Authority's roles in the field of reactor safety are to provide advice based on R&D programmes and to comment constructively on the results of experiments and of experience. Increasing attention has been devoted to this area in the past year and is reflected in the continued expansion in the Safety and Reliability Directorate (SRD) and of programmes of work at several establishments. The incident at the Three Mile Island nuclear power station in the United States has naturally caused considerable public concern. This and all other events of possible safety significance are the subject of intensive study.

Responsibility for research into the management and disposal of radioactive waste has been transferred from the Department of Energy to the Department of the Environment, but the Authority continue to play their part in the programme and discharge their responsibilities for safe management of their own nuclear waste operations. The research programme to explore the feasibility of disposing of highly-active waste into geological formations continues. As part of this research the drilling of boreholes at a site at Altnabreac, Caithness, was completed in Spring 1979. The Authority have appealed against the refusal of planning permission to drill boreholes for research purposes in South West Scotland and Northumberland.

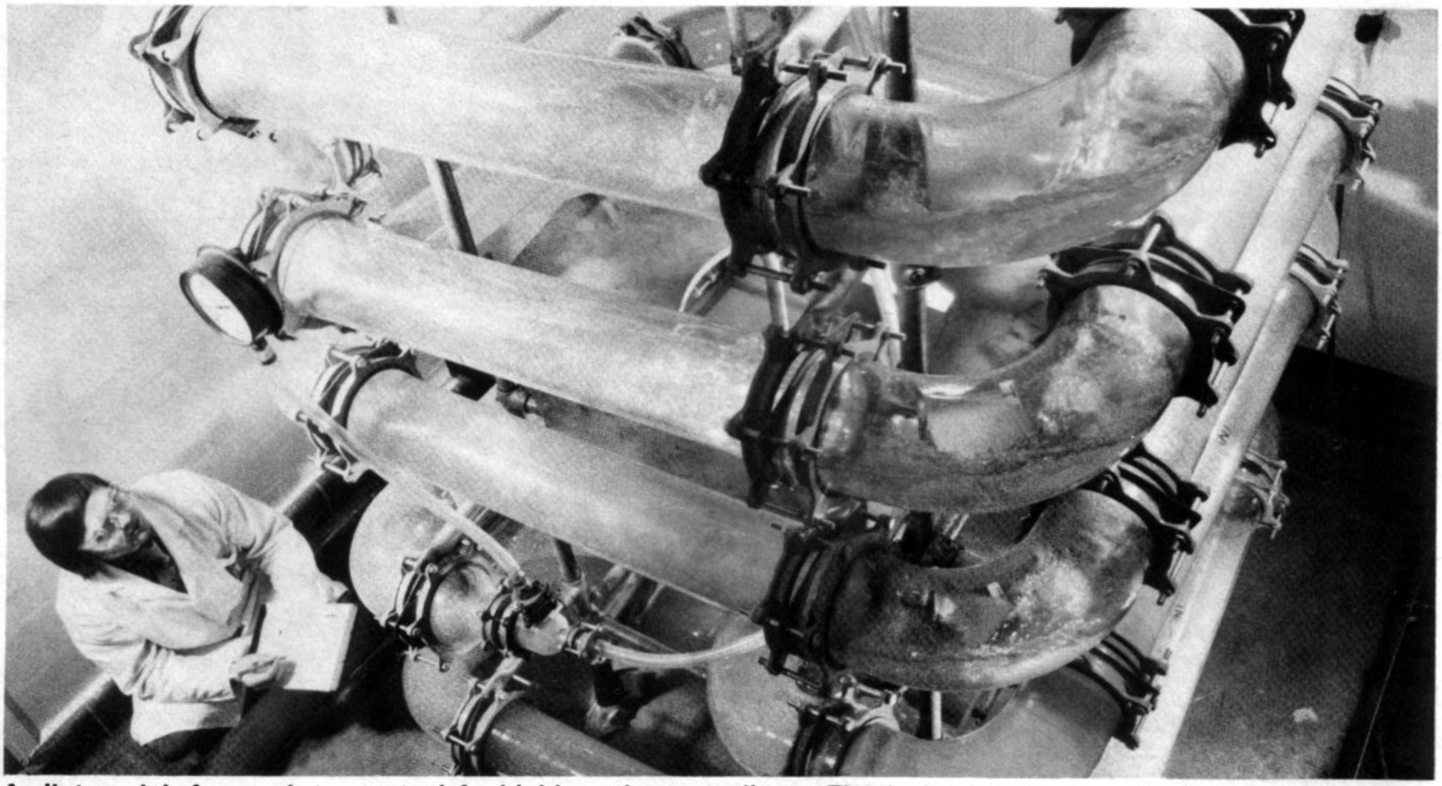
The Radioactive Waste Management Advisory Committee, under the Chairmanship of Sir Denys Wilkinson, Vice Chancellor of the University of Sussex, was set up in May 1978 to advise the Secretaries of State for the Environment, Scotland and Wales, on all the major policy issues affecting radioactive waste management. Dr L.E.J. Roberts, the Director of Harwell, is a member of the Committee. The Committee has held general meetings and is reviewing, as a matter of priority, the adequacy of the UK research programme and the present arrangements for controlling radioactive waste. Sir Denys Wilkinson has written to the Secretary of State for the Environment on behalf of the Committee concerning the need to drill boreholes as part of the research programme for the disposal of highly-active waste, informing him that the Committee would be unable to discharge its responsibility to advise Government on policy, unless it was in possession of all the relevant facts on each of the waste disposal options. In the vital matter of the disposal of highly-active waste to geological formations, these facts could only be brought to light by exploratory drilling.

Work outside the nuclear power programme

Requests for the Authority to undertake industrial R&D work have again increased involving a wide variety of projects which exploit the knowledge and experience of the Authority in fields outside the nuclear power programme. Most of the work is undertaken through contracts placed by a large number of different customers, including industry, Government departments, research councils, local authorities and universities. Longer term research aimed at providing new ideas and applications of potential benefit to industry is commissioned by the Requirements Boards of the Department of Industry. A notable feature was work by the Non-Destructive Testing Centre in collaboration with Rolls Royce Ltd on the development of the technique of dynamic radiography of aero engines (for which the two organisations gained a joint Queen's Award for Technological Achievement in April 1978).

During 1978-79, the Authority's non-nuclear work produced income of £15.3m of which £4.5m resulted from contracts from industrial and other organisations. Income from the Department of Industry's Requirements Boards totalled £5.1m and work for other Government Departments amounted to £5.7m.

Recommendations made by the Energy Technology Support Unit (ETSU) on the size and direction of the Research, Development and Demonstration (RD&D) programmes on the renewable energy sources were incorporated in the White Paper replying to the third and fourth



A pilot model of a novel storage tank for highly-active waste liquor. The design is being investigated as an alternative to the conventional tanks.

report of the Select Committee on Science and Technology. The White Paper announced that the total expenditure allocated to this work is £15.7m, of which some £13.3m will be managed at ETSU. In addition, the RD&D allocation to energy conservation for which the Unit is responsible amounts to a further £21.5m. The role of the Marine Technology Support Unit (MATSU) has become predominantly the management of a large programme of R&D projects concerned with the exploitation of the UK's offshore oil and gas resources and ship and marine technology for the Departments of Energy and Industry.

The non-nuclear industrial programme is closely linked technically with the nuclear power and underlying programmes and may be broadly divided into work concerned with materials on the one hand, and on the other with process technology. In the former category is work of the Metals and Chemical Technology Centre, the Ceramics Centre, the Composite Materials Project and the Non-Destructive Testing (NDT) Centre where there are close links with the work in the nuclear programmes on fuel technology and the metallurgy of reactor components and plant. The non-nuclear industrial projects concerned with process technology include the Separation Processes Service, the Internal Combustion Engine Project, the Macromolecular Separation Processes Project and the Heat Transfer and Fluid Flow Service (HTFS) where there are links with reactor cooling and fuel processing.

Non-nuclear work in the field of environmental research and protection has continued under the support both of the Department of the Environment and of operating organisations ranging from local councils to manufacturing industry. Among the highlights of the year's work were substantial effort on lead pollution in the atmosphere, stratospheric pollution, and ozone layer stability; assessment of chemically-polluted urban sites for redevelopment; the measurements of water contamination by landfill waste sites. The technical synergy of work in this non-nuclear area with some of the problems of assessment of pollution hazards of the nuclear industry is close and much exploited.

The expertise of the Safety and Reliability Directorate at Culcheth is also applied to non-nuclear work, both by the research undertaken for industry through the National Centre of Systems Reliability and services provided to the Health and Safety Executive. The latter has included risk assessments of major potential hazards in the petroleum and chemical process industries.

Members, organisation and staff

The Authority are pleased to record that during the year Sir Brian Flowers, a part-time Member of the Authority, was raised to the peerage, Mr H Cartwright, Director of the Atomic Energy Establishment at Winfrith, was promoted to be Commander of the Order of the British Empire, Mr P I M Irwin, Director of Security, was appointed to be an Officer of the Order of the British Empire, Mr J C Hale, Operations and Engineering Technology Division, Dounreay Nuclear Power Development Establishment, and Mr W Archer, Risley Nuclear Power Development Laboratories were appointed to be Members of the Order of the British Empire, Mr J G Talboys, Lightning Studies Unit, Culham Laboratory, and Mr F Hindley, Personnel and Administrative Directorate, Northern Division, Risley, were awarded the British Empire Medal. Dr D C Robinson of Culham Laboratory has been awarded the Charles Vernon Boys Prize of the Institute of Physics. The prize is awarded annually for distinguished research in experimental physics.

There were no changes in the Membership of the Authority during the year, nor were there any major organisational changes.

During the year there was a very small increase in the Authority's total strength. The numbers of employees at the beginning and end of the year were:

	Qualified Scientists and Engineers	Other Non-Industrial Employees	Industrial Employees	Total
1 April 1978	2 588	6 223	4 536	13 347
31 March 1979	2 666	6 407	4 502	13 575

The deployment of qualified scientists and engineers to projects in 1978-79, in terms of man-years of effort, is set out in the table.

Deployment of Qualified Scientists and Engineers

		1977-78	1978-79
1	**Nuclear power programme**		
(a)	(i) Gas-cooled reactors	110	110
	(ii) Water moderated reactors	130	100
	(iii) Fast reactors:		
	(I) PFR and associated plants	245	220
	(II) Fast reactor development	420	380
(b)	Nuclear safety and the environment	325	320
(c)	Radioactive waste management	65	95
(d)	Processing nuclear materials and other work in support of the nuclear power programme	155	190
	Sub-total	1 450	1 415
2	**Other nuclear research and development**		
(a)	Applied	40	25
(b)	Underlying	195	210
(c)	Nuclear fusion and plasma physics	175	175
	Sub-total	410	410
3	**Nuclear R&D and services on repayment**	380	435
4	**Non-nuclear R&D**	355	360
		2 595	2 620

Pay

From 1 April 1978 increases were paid to non-industrial employees as consequentials of increases paid to non-industrial civil servants, in accordance with the Government's guidelines under Phase 3 of their pay policy.

For industrial employees agreement was reached for pay increases from 1 October 1978 which represented an average of 8.8 per cent on earnings. In December 1978 the Authority's National Joint Industrial Council agreed to the introduction of self-financing productivity schemes based on cost reductions for industrial employees at sites where the local Joint Industrial Councils so wished.

Health and safety of employees

The total radiation dose received by the Authority's radiation workers fell from 3 435 man rems in 1977 to 3 126 man rems in 1978. The average annual dose was 0.39 rem/year compared with 0.43 rem/year in 1977. There were again no serious radiation incidents.

There were no fatal accidents during the year. There were 184 lost-time accidents compared with 170 in the previous year. Sickness absence showed no significant change.

Both centrally and locally, Joint Health and Safety Committees, representing Management, Staff Associations and Trades Unions have been active in promoting arrangements to enable safety representatives to carry out their statutory functions at the Authority's establishments. Particular consideration was given to training requirements.

A review of the radiological protection arrangements at Authority establishments was put in hand following the publication of Sir Edward Pochin's investigation into radiological health and safety at the Ministry of Defence establishment at Aldermaston. The findings of the review will be discussed with the Joint Committee on Health and Safety.

The Authority decided in October 1978, in parallel with BNFL, to extend their mortality studies of all current employees by including former employees as far as is practicable. This decision followed a BNFL pilot study of former employees at the Windscale and Calder site. The data collected will be analysed by epidemiologists to be nominated by, and working under the aegis of, the Medical Research Council.

The work will be carried out in close consultation with the National Radiological Protection Board and will reinforce the data accumulating in the National Registry for Radiation Workers which was set up by the Board in 1976.

Consultation

During the year the Authority had regular consultation and discussion with Staff Association and Trade Union representatives, not only on pay and conditions of service but also on a wide range of topics including health and safety at work, training and the Authority's programme.

Energy conservation

Measures to reduce energy consumption have been given close attention during the year at all the Authority's establishments with cooperation between Management, Trades Unions and Staff Sides; savings of fuel consumption of 25 per cent, in comparison with 1974, have been achieved in some establishments. Improved insulation of buildings has made an important contribution to these savings and at Risley this was assisted by an aerial survey using infra-red detectors carried out by Harwell as part of its work under contract to the Department of Energy.

Information services

In response to the considerable public interest in nuclear power, the Authority provided a wide range of information on nuclear power subjects through films, slide tape programmes and leaflets and in the monthly journal ATOM.

Several hundred lectures were given to schools and other organisations and two seminars on nuclear power for science teachers were held at Harwell.

Authority staff also took part in public meetings in Scotland on research into the disposal of nuclear waste into geological formations, and participated in a symposium on "Atomic Waste and the Environment" organised by the Northumberland and Newcastle Society and held in Newcastle-upon-Tyne.

Some 1 800 people took part in public tours of the Prototype Fast Reactor at Dounreay during the summer months and some 20 000 people visited the Dounreay exhibition. Exhibitions attended by the public in which the Authority participated, included the Energy Show, held in February at the National Exhibition Centre, Birmingham where the Authority and the Nuclear Power Company mounted a joint display. Some 36 000 people visited the exhibition. The most significant commercial exhibition to include an Authority exhibit was Nuclex, held in Basle in October 1978.

Most of the results of the Authority's research work are published, either in scientific journals or in reports which are publicly available. In 1978-79, a total of 676 articles in scientific journals, about 100 unclassified reports and 12 books were published. Details of these publications can be obtained from the Authority's "Monthly List of Publications Available to the Public". They are also deposited with the International Atomic Energy Agency (IAEA) and included in the Abstract Journal INIS Atomindex published as part of the IAEA's International Nuclear Information System. Copies of the unclassified reports can be obtained from the British Library Lending Division at Boston Spar or from HMSO.

Finance

The Authority Estimates for 1978-79, as varied by Supplementary Estimates, provide for gross cash expenditure in the year of £217 791 220 and receipts of £89 100 020, leaving £128 691 200 to be financed by Parliamentary Grant. In the event there was a net underspend of about £1.5m against the grant.

The figure for cash expenditure includes expenditure on contracts for reactor design and component development let with the nuclear industry on behalf of the Department of Energy. This expenditure does not form part of the Authority's programme and the amount involved is therefore excluded from the Authority's Commercial Accounts. From 26 April 1978 the Electricity Generating Boards assumed financial responsibility for design and associated development work on the AGR and PWR previously funded under the Authority's contract with NPC. Contracts with NPC on fast reactor design and component development have been extended. R&D work at Dounreay and other development of the fast reactor and its fuel continues to represent the biggest single programme undertaken by the Authority.

The Authority's Accounts have been prepared on the historic cost basis and the cost of operations totals £126.7m. The Authority have examined the effect of applying the Interim Code of Practice agreed by the Nationalised Industries' Chairmen's Group. As the Authority are financed by monies provided by Parliament and have to surrender all revenues to the Department of Energy, any adjustment of the figures in the Operating Account to take account of the agreed code of practice would have no material effect so far as the Authority's finances are concerned. No supplementary Statement has therefore been prepared.

Income in 1978-79 totalled £77.9m of which £51.7m was received for R&D products and services chargeable to customers (including where appropriate income credited to Authority programmes). The Authority's products and services activities produced a surplus of £2.4m and in addition there was a royalty income of £1.8m. Sales to BNFL were £27m and to The Radiochemical Centre Ltd (TRC) £2m of which £1.7m was for isotope production.

The Authority are sole shareholders of BNFL and TRC. The Chairman of the Authority is also Chairman of both companies. Mr A M Allen, CBE, Authority Member for Finance and Administration, is a Director of TRC. BNFL's profit (before tax) was £13.7m compared with £5.4m in 1977-78, and they have declared a dividend of 6¾ per cent net. TRC's profit (before tax) was £6m compared with £6.7m in 1977-78 and they have declared a dividend of 12 per cent net on increased capital (1977-78 22 per cent). The Authority continue to hold a 35 per cent shareholding in the National Nuclear Corporation, of which the nuclear construction company NPC is a subsidiary.

Trends of Authority expenditure

Over the last 15 years the Authority's net expenditure on nuclear R&D has fallen in real terms to about half what it was in the peak year of 1963-64.

Computers

In September 1978 the Authority signed an eight-year agreement with International Computers Ltd for the supply of 2900 series systems to provide for the increased computing facilities required at the Risley, Culham and Winfrith establishments. Some of the new equipment is now installed and the remainder is due for delivery at various dates extending up to April 1982. □

HARWELL'S NEW RESEARCH TOOL

THE 136 MeV LINAC

On 6 July this year Dr Walter Marshall, Deputy Chairman of the UKAEA, officially opened a new 136 MeV electron linear accelerator at Harwell, in a ceremony which was one of a number of events marking 1979 as the Authority's Silver Jubilee Year. The new machine will enable scientists to pursue to new levels of understanding the area of nuclear physics that is of main relevance to the development of nuclear power.

In the following article Dr J.E. Lynn, of the Nuclear Physics Division at Harwell, traces the history and describes the purpose of the facility.

The construction of this accelerator — known as a LINAC for short — and its associated experimental areas was begun in 1975. The decision to embark on the project at an anticipated capital expenditure (at that time) of £2.8 million is a measure of the AEA's determination to carry out, down to a quite basic level, a vigorous programme of research in the nuclear physics necessary for current and future nuclear power technology. The main area of nuclear physics that is seen to be relevant to nuclear power is the study of neutron reactions from low to moderately high energies. The general aspects of the study of nuclear structure using a variety of charged particle beams is largely left to the Universities in this country, but conversely Harwell is now, and quite naturally, the main centre for neutron physics in the UK. The new LINAC will raise Harwell's facilities for doing this kind of research to the world front rank. It will also provide an important facility for advancing the Authority's interests in promoting the use of neutron beams for the study of condensed matter physics. The machine, which has been designed and constructed by Radiation Dynamics Ltd of Swindon, its beam control equipment and targets are 'state of the art' throughout, and the project cost has been controlled to the original approval, updated by the formally published Department of Trade inflation indices.

The main function of the electron linear accelerator, the overall layout of which is shown in Fig. 1, is to act as the driver of a pulsed neutron source. The LINAC is of the travelling wave type, in which a pulse of electromagnetic radiation is transmitted down a wave-guide of circular cross-section loaded with irises to break the guide into a series of resonant cavities. The dimensions of the cavities are such as to give the electromagnetic wave the right phase velocity to accelerate the electrons; these sit just ahead of the crests of the wave obtaining energy from the longitudinal component of

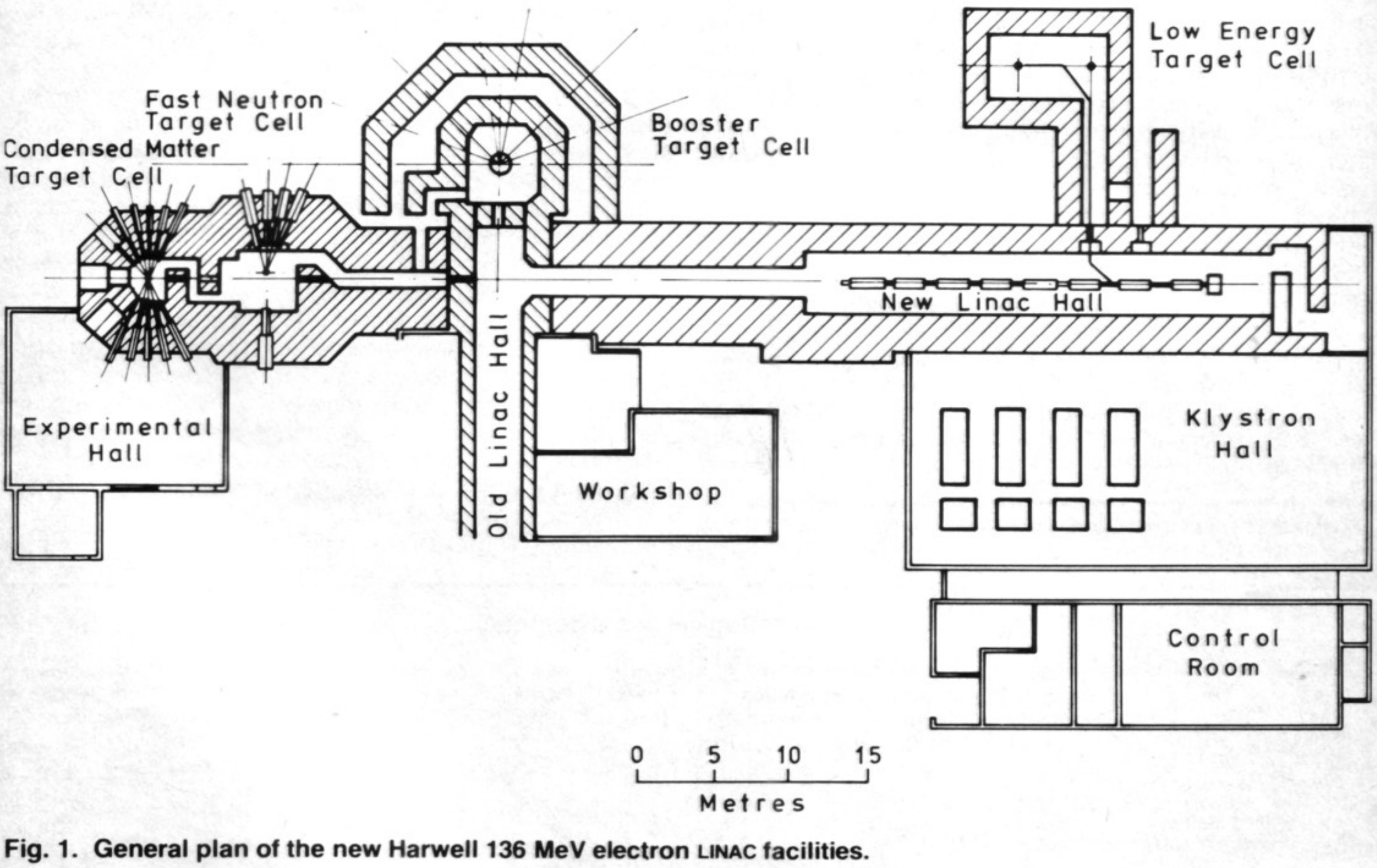


Fig. 1. General plan of the new Harwell 136 MeV electron LINAC facilities.

Table 1: LINAC parameters and performance

Maximum energy	136 MeV
Operating frequency	1300 MHz (L band)
Klystrons	Four Thomson-CSF type TV 2022 each giving 20 MW or 10 MW peak power and 40 kW mean power
Acceleration length	16 m (8 x 2 m)
Maximum pulse length	5 μs at $\leqslant$300 pps
Maximum pulse repetition frequency	2000 pps for pulse width $\leqslant$0.4 μs
Electron pulse duration	Variable from 5 ns to 5 μs
Maximum beam power	30 kW (short pulses), 90 kW (long pulses)
Maximum pulse current	6-11 A (short pulses), 0.6-1 A (long pulses)

the electric field. The technical parameters of the accelerator are given in Table 1.

Conversion from energetic electrons to neutrons is achieved in two stages. Interaction between the electrons and the atoms of a heavy element target yields bremsstrahlung radiation with energy up to the electron energy. These gamma-rays can then interact with nuclei in a photonuclear reaction that produces neutrons. The cross-sections for photonuclear reactions are highest for heavy nuclei, so both the bremsstrahlung production and the photoneutron reaction can be accomplished in the same heavy metal target. The bremsstrahlung and photoneutron reactions are essentially instantaneous, giving a primary neutron pulse at birth with the same time duration as the electron pulse from the accelerator. But extra broadening of the effective neutron pulse can occur as a result of the transversal of the neutrons across the physical dimensions of the target and the neutron interactions within the target materials.

At the high electron energies that the new Harwell LINAC will deliver, neutron production is almost linearly proportional to the electron beam power for a given target material. This is one reason for the comparatively high energy of the LINAC, increased electron energy being easier to achieve (essentially by increasing the overall length of the accelerator) than increased current within the pulse. The penalties incurred in going to much higher energy than that of the Harwell accelerator are the rapidly increasing volume of shielding required to screen the highly penetrating higher energy neutrons, and the increased target size required to exploit fully the neutron production capability of more energetic electrons.

Most of the neutron physics carried out with the LINAC will exploit the pulsed nature of the source. The neutrons emitted in the photonuclear reaction form a "white" spectrum, the explicit form being that of a Maxwellian with a characteristic temperature of nearly 1 MeV.* If uranium is used as the target material an appreciable fraction of the neutrons produced come from the photofission reaction. Again the spectrum approximates to a Maxwellian form with a temperature greater than 1 MeV. The energy of a neutron involved in an observed experimental event is measured by the time-of-flight principle; the resolution of the energy determination is governed by the length of the flight path between neutron source and event detector (which may be a neutron detector in the beam or a selective detector for a specific prompt reaction placed close to a sample material in the beam), the duration of the neutron pulse and the time jitter characteristics of the detector. The new Harwell facility has a flexibility that allows the choice of these factors to be optimised within wide limits.

*In nuclear physics temperatures are commonly stated in units of energy, multiplication by Boltzmann's constant being understood.

The electron pulse width of the LINAC can be varied from 5 nanoseconds (ns) to 5 microseconds (μs). The nominal electron energy of 136 MeV is the unloaded energy, i.e. that which would be obtained with negligible current in the electron pulse, so the energy, current and power characteristics of the electron pulse are interrelated and depend on the chosen pulse width. Details of these and the resulting neutron output from the three main neutron-producing targets are given in Table 2.

For very slow neutrons with long flight-times a resolution of 5 μs in the flight-time is adequate even over a flight path of a few metres (this is the minimum practical length, being governed by the size and shielding wall thickness of the target cell). A cell and target that normally accepts the highest powered pulses of 5 μs duration has therefore been constructed for experiments on neutrons of a few eV energy or less. Most of the interest in such neutrons is for studies on solids and liquids and this cell is therefore called the Condensed Matter Cell. Its relation to the accelerator is shown in Fig. 1 and layout in Fig. 2. The target is a series of heavy metal plates, ranging in thickness from 1 mm at the front to 1 cm at the rear, separated by 1.5 mm gaps which act as channels for the cooling water (see Fig. 3). The metal in the initial target will be tantalum. Later targets will be of uranium clad in Zircaloy. Considerable development effort has been put into the production of such plates by Harwell's Metallurgy Division; this is justified by the net gain in neutron production by a factor of two over that of tantalum. A large fraction of the neutrons from this target must be moderated into the very low energy range required for experiment. This is achieved by surrounding the target with slabs of material rich in light atoms (normally polythene) 4 cm thick. Slow neutron output is also enhanced by placing heavy water reflectors above and below the target. The shape of the neutron spectrum at very low neutron energies can be modified by choice of the moderator. For experiments at neutron energies below 0.2 eV a liquid nitrogen moderator is available to shift the thermal Maxwellian peak downwards. Sixteen beam holes on horizontal axes open onto the Condensed Matter Target, five of them not directly but rather on to the lower D_2O reflector.

At the opposite extreme fast neutrons with energies ranging from some tens of keV to several tens of MeV require long flight paths (up to several hundred metres) and the shortest possible pulses for adequate energy resolution. A Fast Neutron Target and Cell has therefore been constructed

Table 2: Typical target outputs

Target	Electron Pulse Duration	Mean Electron Energy (MeV)	Pulse Repetition Frequency (pps)	Peak Current (A)	Beam Power (kW)	Neutrons Per Pulse	Peak Neutron Output During Pulse (n/s)	Neutrons Per Second
Fast Neutron	5 ns	94	2000	6	5.6	1.1×10^{10}	2.2×10^{18}	2.2×10^{13}
Booster	100 ns	128	390	1	5	7.6×10^{11}	7.6×10^{18}	3×10^{14}
Condensed Matter	5 μs	60	300	1	90	1.2×10^{12}	2.4×10^{17}	3.6×10^{14}
Low Energy	2 μs	18	500	1	18	—	—	—

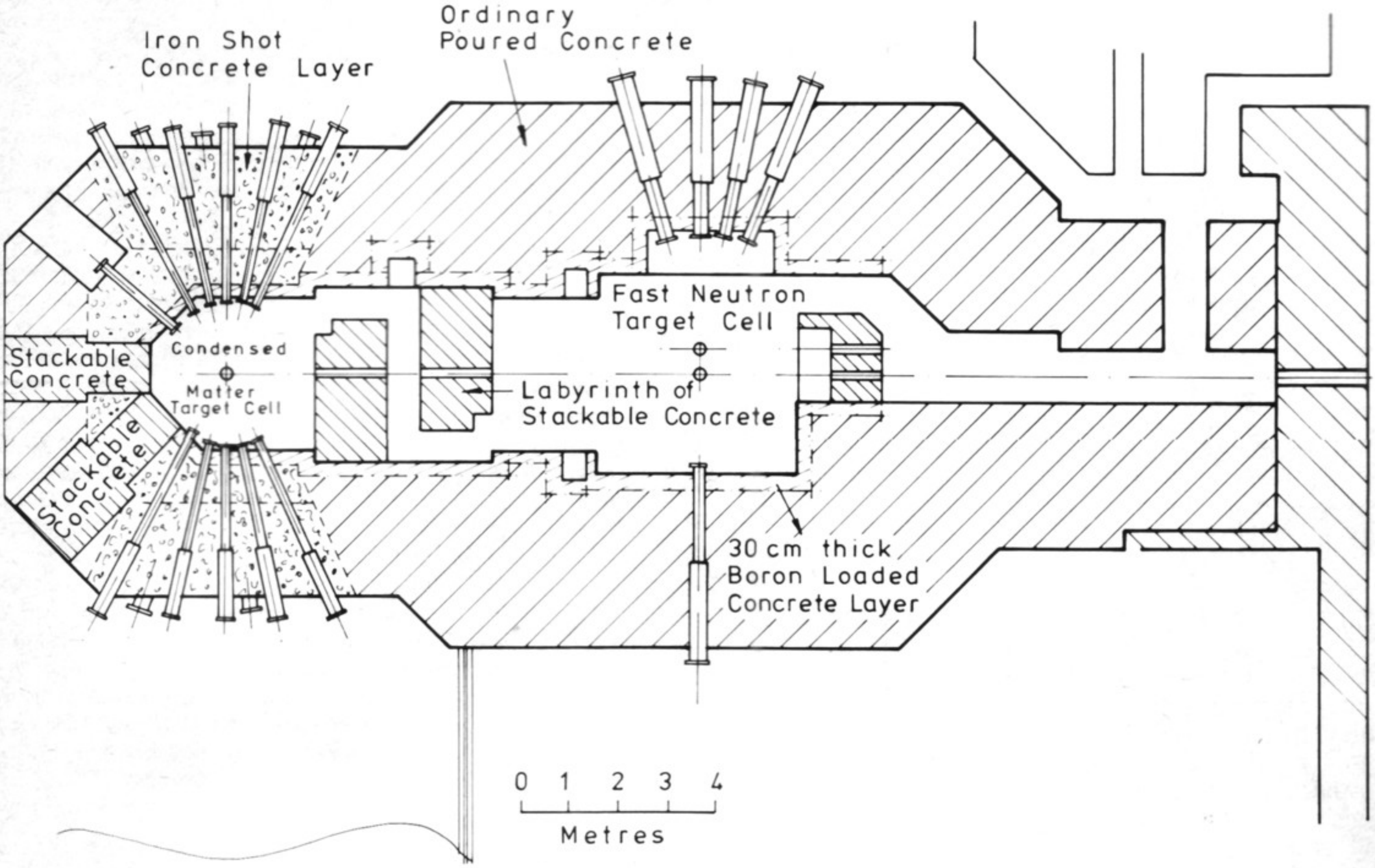


Fig. 2. Detailed plan of the Fast Neutron and Condensed Matter Target Cells.

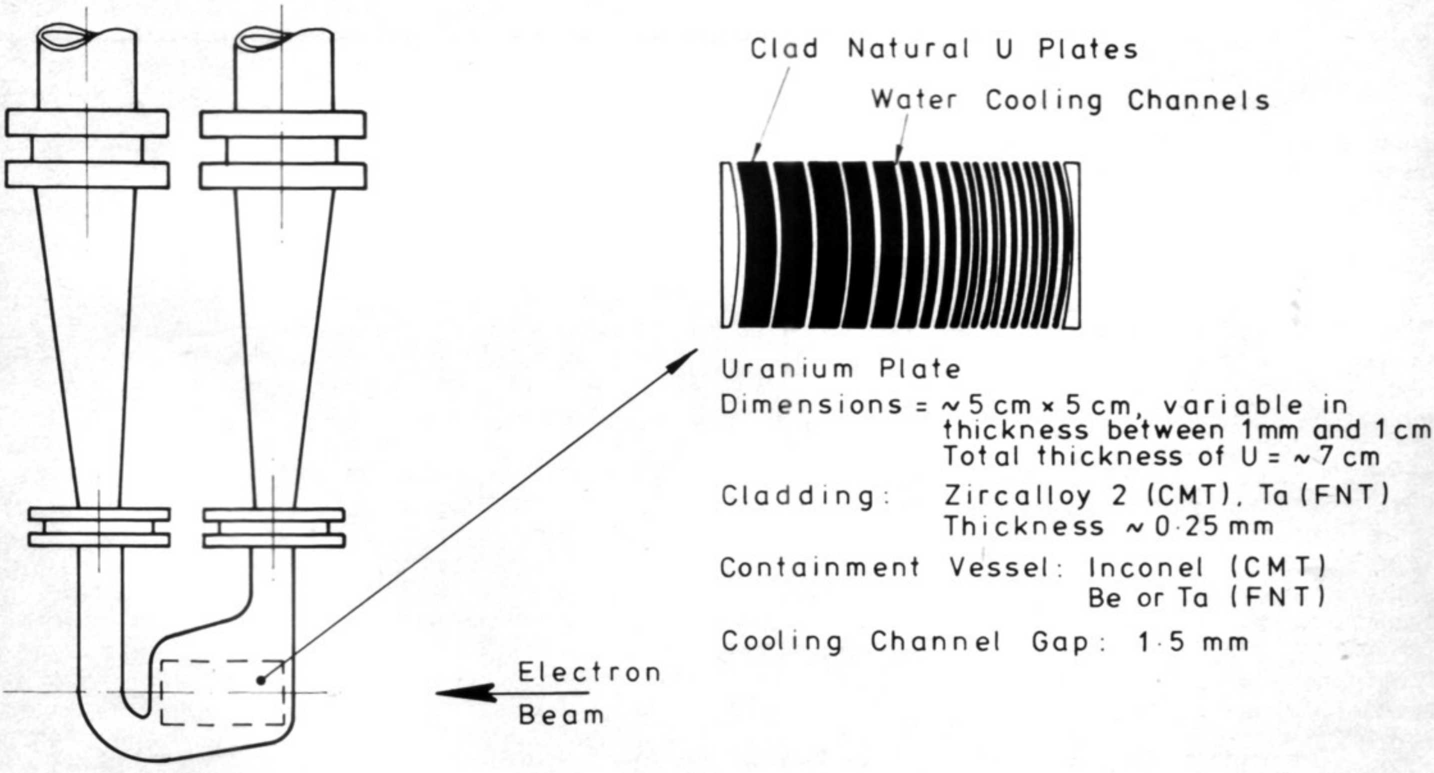


Fig. 3. Configuration of main neutron-producing targets in the Fast Neutron and Condensed Matter Cells.

to exploit the pulses in the 5 ns to 50 ns range of duration. The geometrical form of the target is similar to that of the Condensed Matter Target but the choice of materials can differ. The plates of the first target will be made of tantalum, but later targets will again be made of uranium. Because zirconium, the major constituent of Zircaloy contains widely spaced resonances in its cross-section at fast neutron energies, which would complicate the neutron spectrum and hence the analysis of experimental data, tantalum will be used for cladding the uranium. The pressure vessel material is beryllium (which contains almost no resonance structure in its neutron cross-section); this is in contrast to the Inconel of the Condensed Matter Target. No moderator will normally be placed around the Fast Neutron Target. Five beam ports penetrate the walls of the Fast Neutron Cell (see Fig. 2), and space is available beyond some of these for flight paths up to 400 m long.

For intermediate neutron energies (up to a few tens of keV) the ideal target has been *in situ* for the past 20 years. This is the Neutron Booster which was driven by the earlier 45 MeV electron LINAC. The Neutron Booster contains at its centre a primary target of U-235 which acts as bremsstrahlung and photoneutron source. Surrounding this core is a sub-critical assembly of highly enriched uranium which amplifies the primary neutron production by a factor of about ten. Surrounding this again are 2 cm thick slabs of hydrogeneous moderator to enhance the neutron spectrum in the epithermal range. One of the characteristics of the booster is that the stochastic chain of fission events involved in amplification of the primary neutron pulse give rise to an inherent pulse spreading of about 100 ns. Hence, from the point of view of energy resolution, it is not the best target for very fast neutron measurements, although it does have the very great advantage of shielding the bulk of the intense bremsstrahlung burst from the detector equipment. At the very slow end of the neutron range, where the spectrum of neutrons in time-of-flight is weak, the comparatively large background due to delayed neutrons from fission in the amplification process renders this target unsuitable for many experiments.

The Booster Target cell is equipped with a complete suite of evacuated neutron beam tubes ranging from 10 m up to 300 m in length. The beam tubes from the new target cells will not interfere with these, the axis of the new accelerator being some 60 cm above that of the old one.

Although the neutron target facilities described above provide for the principal uses of the Harwell electron accelerator there are some important secondary ones which require their own target cell facilities. These are principally concerned with electrons and gamma-rays at rather lower energies than the maximum the machine is capable of giving. Consequently the electron beam can be diverted out of the accelerator after traversing the first or the second of its eight sections. Maximum electron energies are then, respectively, 15 MeV and 32 MeV. The diversion after the second section has an additional valuable feature. The phase of the electromagnetic wave in the second section can be tuned so that the resulting electron energy is continuously variable between 2 and 32 MeV. A Low Energy Cell has been built to handle this electron beam for various experimental purposes.

Finally, a feature must be mentioned that allows for the maximum possible flexibility and economy in operation of the whole LINAC complex. This is the multiplexing system whereby a pattern of pulses can be scheduled amongst a set of target cells to allow them to be operated simultaneously for experimental work. The scheduling allows variation of pulse-widths according to target cell destination and a second version of the system now under design will allow variation of the pulse current amplitude too. The pulses are directed to the appropriate target cells by a set of pulsed magnets.

Nuclear reactions

The most important research programmes based on the new LINAC will be centred, like those of its predecessor, on the nuclear physics that is relevant to the technology of nuclear power. Broadly speaking, this comprises the physics of nuclear fission, the nuclear reactions initiated by neutrons up to at least 20 MeV neutron energy, and, to a lesser extent, the nuclear physics associated with gamma-rays in the same energy range. Charged particles ranging from protons to

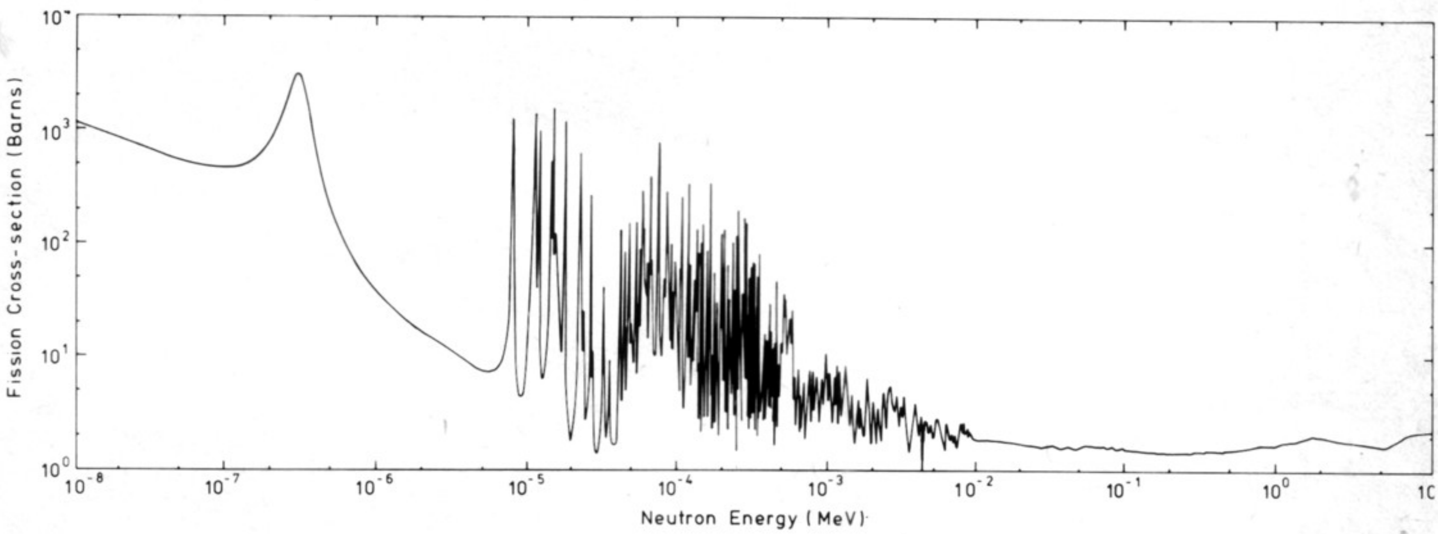


Fig. 4. The neutron fission cross-section of Pu-239. The fine-structure resonances that are apparent at low neutron energies apparently disappear at higher energies because of steadily worsening resolution; in fact this kind of structure is expected to persist to well above 1 MeV. Some of the structure at the higher energies (above 10 keV or so) is intermediate structure associated with highly deformed meta-stable shapes of the nucleus (see also Fig. 6).

medium heavy ions are becoming increasingly useful as tools for the materials aspects of nuclear technology, but the relevant physics is mainly studied on the set of three Van de Graaff accelerators at Harwell.

The most direct requirements on the LINAC for the nuclear power programme are for the detailed neutron cross-section data on the various nuclides present in the core of a fission reactor. The relevant neutron cross-section data on the principal nuclides in the core of a freshly-fuelled thermal reactor burning natural or slightly enriched uranium have been known well enough for most practical purposes for several years now. Some problems centre on the detailed energy variation of the cross-sections at low neutron energies, which could affect the moderator and Doppler temperature coefficients of reactivity (see below), and there is interest in the cross-sections of the fission products and higher actinides that are produced at higher degrees of burn-up, the former mainly because of their effect on neutron economy in the reactor core, the latter in order to be able to calculate the arisings of various heavy nuclides; these must be known for assessment of problems and design of schemes for fuel transport, reprocessing and waste management. Knowledge of their detailed neutron cross-sections at low neutron energies will allow the use of novel materials in control rods and in cladding of fuel elements and other structural materials. Neutron cross-sections (especially for capture, alpha-particle production and proton production) over the full energy range of the fission neutron spectrum (approaching 20 MeV) are also required to assess activation in core structural materials and radiation damage, and for various nuclides that can be used in neutron dosimeters by measuring their activation after residing in various parts of the reactor.

Neutron cross-section data are required for fast reactors for similar reasons but on a much grander scale. For example, present design criteria for the neutronics of a thermal reactor core can be met if the cross-section data of the fuel nuclide have an accuracy of ± ½ per cent for neutron energies up to about 1 eV, and such accuracy has largely been reached. But for the fast reactor this degree of accuracy should be met by the data from neutron energies of a few hundred eV up to more than 1 MeV. Given the complexity of the cross-section of a typical fissionable nuclide (see Fig. 4) this is a formidable undertaking, and at present the combined efforts of several laboratories have only reached an accuracy of about ± 3 per cent. How, then, have the present fast reactors, such as PFR at Dounreay, been designed? The answer is that the reactor physicists have made "integral" experiments to measure the neutron spectra and reaction rates in macroscopic assemblies of materials resembling parts of reactor cores; the neutron spectra generated in these assemblies are similar to those of the reactor under design. To interpret these data into the multigroup neutron cross-sections required for the neutronics calculations on a full reactor design a knowledge of at least the relative energy variation of the differential neutron cross-sections is required. Even so, it has been found necessary to make arbitrary adjustments to the relative differential cross-sections over certain energy ranges in order to reproduce by calculation the results of integral experiments. This suggests that there are still significant uncertainties in the multigroup data sets or the computational methods for neutronics calculations, and it is highly desirable for precise and economic design in reactor technology that these should be further tested and explored by great improvement in the accuracy of the basic differential cross-section data. The point is stressed by a recent international comparison of neutronics calculations on a reference fast reactor design; a range of 1½ per cent was found in the calculated values of reactivity, where only ½ per cent was expected.

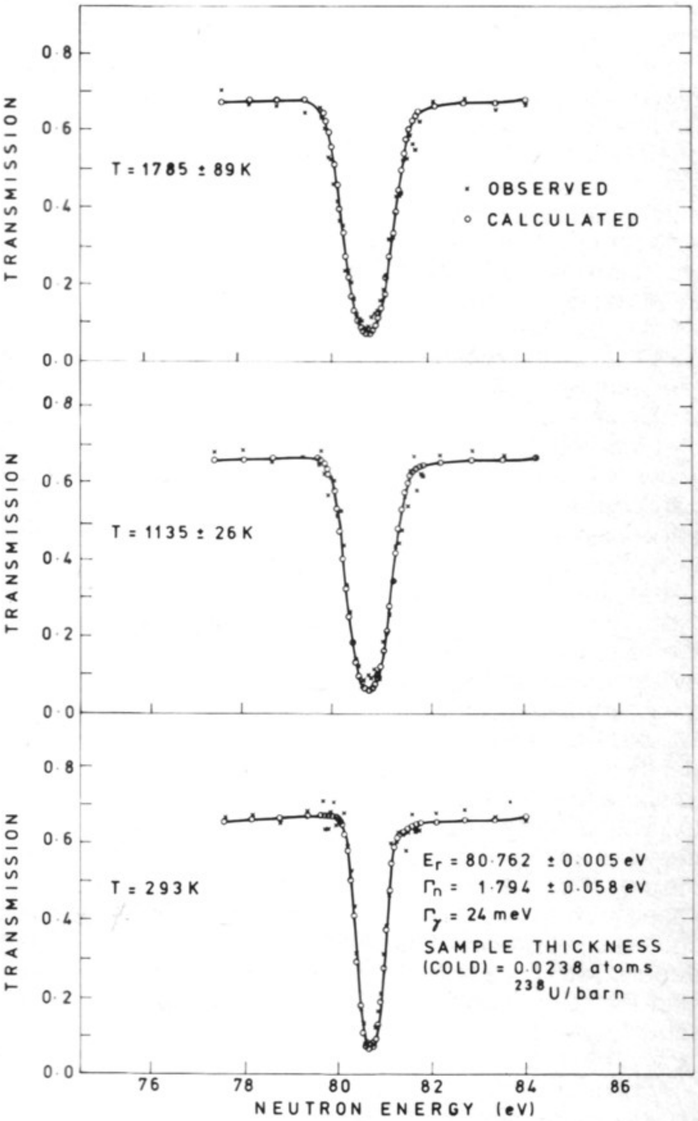


Fig. 5. Neutron transmission near the 80.8 eV resonance of U-238 showing broadening with increasing temperature.

Political uncertainties about the future programme of commercial fast reactors might seem to throw a doubt on the importance of pursuing a research programme on neutron cross-section data specifically related to fast reactor requirements. In fact prudence dictates that such a programme should be pursued; the large range of requirements and the problems to be overcome in improving accuracy imply that there are many years of work in this field alone for a machine such as the new LINAC. And once the political decisions have been made to implement vigorously a fast reactor programme in this country lead time will be lost if the measurements are only then to be made with the care and accuracy that is needed.

This is particularly important for data concerning safety. One of the inherent safety factors of a fast reactor is a nuclear effect, the Doppler temperature coefficient of reactivity. This effect arises from the resonances that occur in neutron cross-sections (as apparent in Fig. 4) at different neutron energies for different nuclides. The energy variation of the cross-section over such a resonance has a typical form, the so-called Breit-Wigner form, with a characteristic line width for a stationary nucleus. Thermal motion of the nuclei in a macroscopic sample of material will cause the effective cross-section in the sample to deviate from this form, the effective line width being greater the higher the temperature. This is Doppler broadening and a typical example of the change is shown, for neutrons in transmission, in Fig. 5. For a reactor the importance of this effect resides in the fact that as the reactor fuel heats up neutrons with energies in the wings of a resonance of a given nuclide will undergo relatively more events of the kind associated with that resonance than with other kinds of nuclide that are present.† The main nuclide present in a fast reactor core is U-238, the resonances of which correspond to neutron capture leading to U-239. This, then, has a negative effect on the reactivity as the temperature rises. The resonances of the fuel nuclide correspond to both fission and capture giving rise to positive and negative temperature coefficients of reactivity, respectively, which, it is calculated, cancel approximately. The total Doppler effect in a fast reactor is therefore negative but it is important to know its magnitude accurately to determine to what extent it can be relied upon to overcome any positive temperature effects that may arise from other sources, such as possible loss of coolant.

The Doppler temperature coefficient of reactivity can be calculated from the resonance parameters, if known, of all the relevant nuclides. In fact the resonances of the U-238 cross-section have only been resolved to a neutron energy of a few keV and resonances up to much higher energies contribute significantly to the effect. To help remedy the deficiency an experimental programme of investigating the temperature dependence (to more than 2000°K) of the transmission of neutrons through heated samples of UO_2 at energies above the resolved resonance range was begun at the old LINAC. It is intended that this programme shall be continued with the new LINAC. It will be extended to materials such as iron and plutonium, and to the temperature dependence of the capture yield of heated samples. In addition the much greater intensities of the new machine will allow improvement of resolution and the measurement of individual resonance parameters up to higher energies.

Accompanying programmes of this type, which have quite specific objectives in the development of nuclear power, there will be an underlying programme of nuclear physics. The principle that governs this in a large applied science laboratory like Harwell is the general one that research should be carried out to seek improved understanding and insight into the fundamentals of subjects from which extensive applications are made. Applied to neutron physics, this principle has the pragmatic consequences of enabling improved methods of data measurement to be devised (and weaknesses in old ones to be uncovered); of building up or contributing to bodies of knowledge that could well be called upon for application in the future (the variation of neutron capture gamma-ray spectra with neutron energy is one example); of enabling the laboratory's physicists to keep closely in touch with the basic nuclear physics in such a way that they can rapidly assess the potentiality of any radical application that is proposed, or the significance of nuclear problems that might arise or be anticipated in existing or developing technology; of devising and exploring completely new applications of nuclear techniques; and of being able to calculate the neutron cross-section data that might be required on materials or reactions that are exceedingly difficult to measure.

The last concept is the most closely related to the principle of an underlying programme so I shall discuss this first. Important examples of fast neutron cross-sections that are difficult to measure are those of the fission products and the higher actinides. Although the high neutron intensities from the new LINAC will enable many of the background problems due to the high radioactivity of these nuclides to be overcome, and a systematic programme of measurement will be undertaken as suitable samples become available, the problems of preparing samples of such nuclides will be arduous, and the calculational tool for obtaining such cross-sections is therefore a most valuable one to develop. The higher actinides present a particular problem. From a nuclear industry that is designing and developing efficient plant for a large-scale expansion of fuel cycles based on fast breeder concepts (or, perhaps, more futuristically, accelerator breeder or fission-fusion concepts) the main requirements will be for the neutron capture cross-sections of these nuclides to enable their arisings from successive neutron capture and alpha and beta decay to be calculated. Their fission cross-sections are not of overriding importance, but to calculate capture cross-sections the competition in the nuclear processes from fission and inelastic scattering must be understood in detail. The rate, relative to other processes, of prompt fission decay of a compound nucleus excited by absorption of a neutron is controlled by a potential barrier with a complicated double-humped form as a function of the nuclear deformation. In the lighter actinides the barrier form may be even more complicated than this. The several parameters that describe the fission barrier must be accurately known to allow the fission rate to be properly calculated. The detailed neutron fission cross-sections show remarkable structure with intermediate-scale and giant resonances, in addition to the conventional fine-structure resonances, and these give important information on the fission barrier parameters, the intermediate resonances representing excited states of the compound nucleus in an extremely deformed meta-stable shape (see Fig. 6). An important part of the underlying programme on the new LINAC will be the detailed exploration of these structure phenomena.

Intermediate structure in neutron cross-sections is not confined to fission phenomena, but few examples of other kinds are known. Part of the reason for this is probably overlap of intermediate resonances with differing angular momentum quantum numbers. The complexity of such problems can be reduced if the neutron beam and target nuclei are polarised and angular distribution measurements are made on the reaction products. Intermediate levels, which have much simpler structure than the true compound levels corresponding to resonance fine structure, are certain to play an important role in neutron reaction mechanisms, and it is hoped therefore that polarising neutron filters can be introduced onto certain neutron beam lines of the LINAC to fulfil this part of the future underlying programme.

A possible new technique that will be explored with the new accelerator is resonance neutron radiography. In conventional neutron radiography thermal neutrons in a well-collimated beam are passed through an object with a converter foil and photographic film placed immediately behind. Neutrons, in varying density that depends on the thermal cross-sections of the material they have passed through, activate the foil which in turn exposes the film by beta-ray emission. The degree of contrast thus achieved will depend (somewhat accidentally) on the relative values of the thermal cross-sections, and information on the constituents of the radiographed object will not be unambiguous. The idea in resonance radiography is to use a position sensitive neutron detector with good time response, in place of the converter foil and film, at the end of a well-collimated beam from a pulsed neutron source, and make a simultaneous analysis of neutron position and neutron energy (from time-of-flight) by

†Neutrons with energy at the centre of the resonance will also undergo relatively fewer events, but because the energy range involved is much smaller, and the peak cross-section is normally so high, gobbling up virtually 100 per cent of those neutrons whether or not the resonance is temperature broadened the net effect comes from the wings.

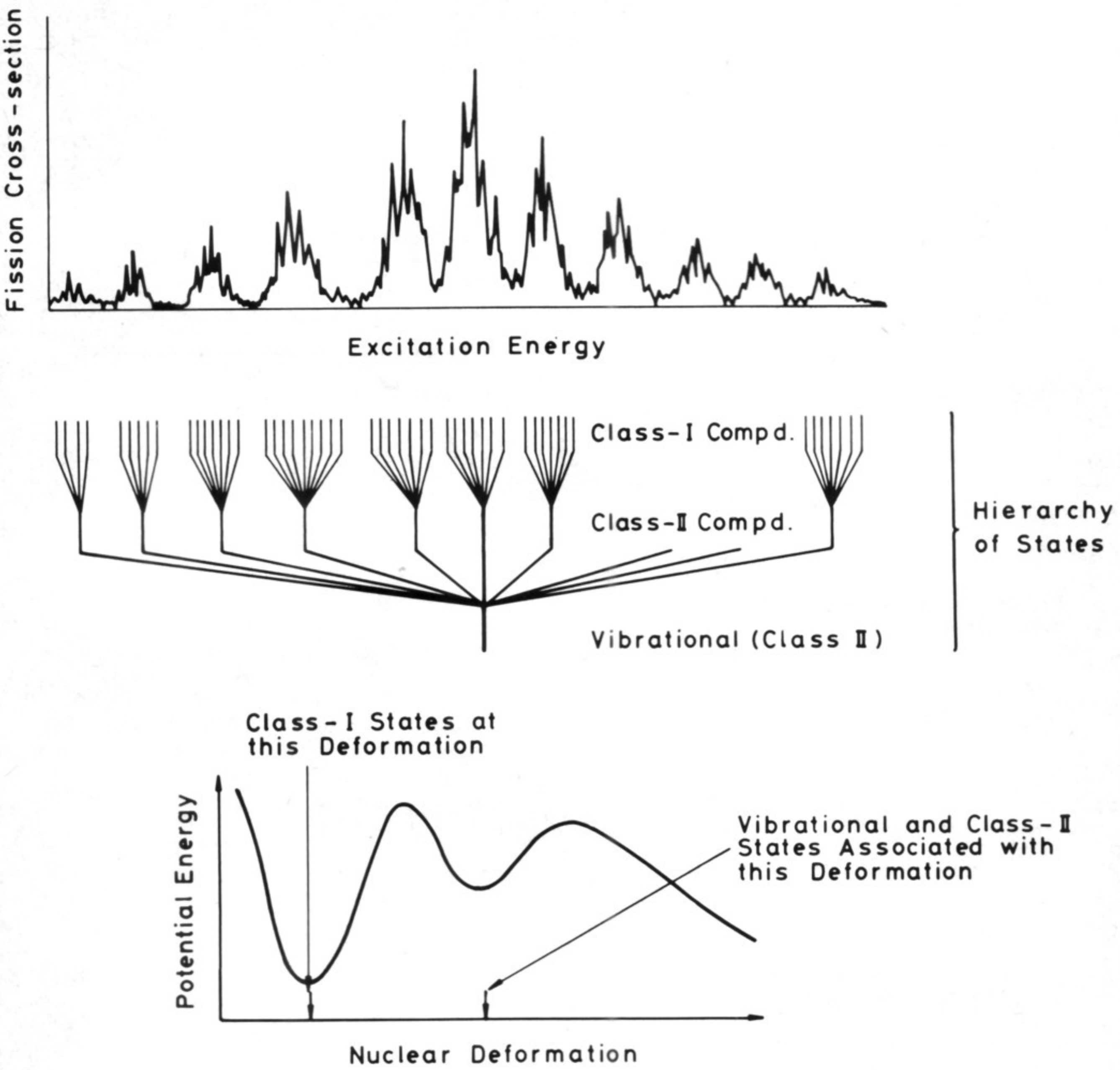


Fig. 6. Schematic diagram of fine and intermediate structure in a fission cross-section.

on-line computer. Nuclides of specific interest can then be located in the object by visual display of the radiographic information at the characteristic neutron resonance energies of the nuclide concerned. The system is illustrated schematically in Fig. 7. There are many conceivable uses for radiography of this kind. The location of higher actinides or fission products in reactor fuel elements after high burn-up is one possibility, the search for inclusions in steel ingots another. A third is dynamic radiography of rotating or vibrating machinery, the pulse repetition frequency of the LINAC being matched to that of the radiographed object.

Photonuclear reactions

Other parts of the underlying neutron programme will be concerned with the gamma-ray production following neutron inelastic scattering and radiative capture. The study of photoneutron reactions is a useful complementary tool in understanding the latter process, but it also seems possible to develop it in such a way that completely new information relevant to the calculation of nuclear cross-sections can be obtained. This information concerns the nuclear level density, a key quantity on which theoretical calculation abounds but there is little direct confirmatory evidence. The experimental evidence on most nuclides consists of nuclear spectroscopic information in the first one MeV or so of nuclear excitation and the density of neutron resonance states for one or two values of the angular momentum at the neutron separation energy several MeV higher. It is possible to extend the latter kind of information to higher excitation energies and other angular momentum by high resolution studies of photoneutron emission to excited states of the residual nucleus (see Fig. 8). The key to determining to which excited state a resonant neutron group is emitting is to look at the group simultaneously at backward and forward angles with respect to the incident gamma-ray beam. The energy separation in the laboratory reference frame is a kinematic effect of the recoil of the gamma-excited compound nucleus, which depends on the excitation left in the residual nucleus.

The photonuclear process is also a useful tool in understanding fission. The ratio of photoneutron emission to photofission can give important statistical information on the properties of the fission barrier (described above); it is par-

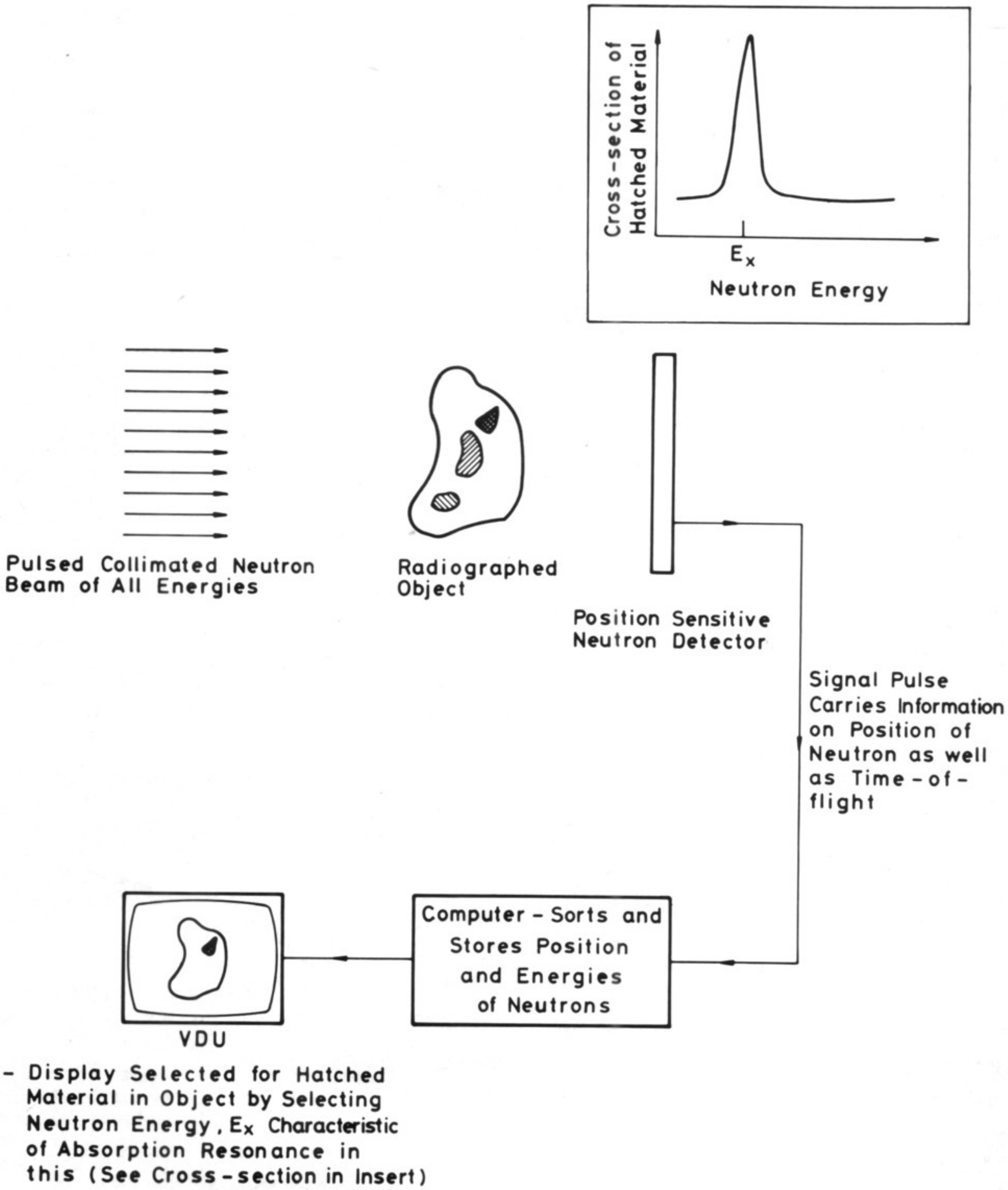


Fig. 7. Scheme for neutron resonance radiography.

ticularly valuable because the compound nucleus is excited to a very limited range of angular momentum states (essentially spin-parity = 1^- in the case of an even target nucleus). A very large neutron detector, consisting of a set of long BF_3 counters immersed in an oil-bath, has been constructed at Harwell to measure the neutrons from both these processes; the ratio of single to multiple detected neutrons is a measure of the photoneutron to photofission ratio. Much will also be learnt about the problems of detecting multiple neutron events from fission in large moderating neutron detectors; this will be invaluable in future design of instrumentation for nuclear materials safeguards. This will be one of the first experimental programmes to get underway on the new accelerator.

Condensed matter and other studies

Outside nuclear physics, the linear accelerator will find considerable applications. Some of these are straightforward electron irradiations, others use the gamma-rays from the bremsstrahlung process. Of the latter an important programme, originally started on the 45 MeV LINAC, is analysis of materials by gamma-activation. This is a particularly useful method of analysis for many light nuclides, and a fast rabbit leading to a small chemical laboratory for separating activation products with short life-time will be available.

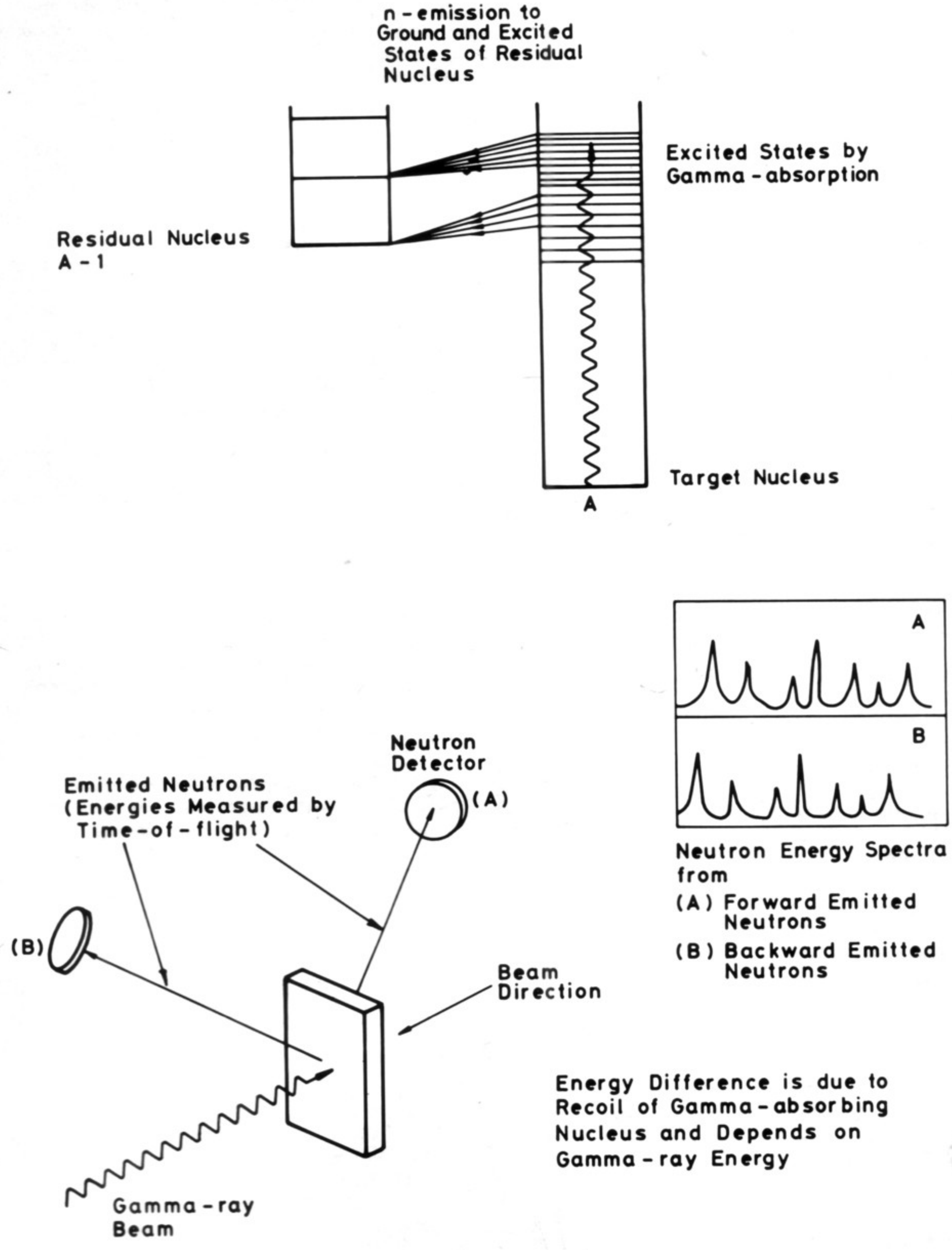


Fig. 8. Principle for measuring threshold photoneutron phenomena.

Electrons from the new accelerator could also be used for new research in electron pulse radiolysis to investigate processes on the 100 picosecond (ps) time-scale. This is because the macro-pulses of the LINAC are composed of a sequence of micro-pulses each about 40 ps long and separated by about 750 ps.

But the largest programme employing the accelerator, other than nuclear physics, will be the study of the solid and liquid states of matter using pulsed neutron beams and many university scientists will be participating in this work. Continuous thermal neutron beams from reactors have been used for many years in this field with great success. But monochromation devices on reactors become increasingly inefficient for higher energy neutrons, so for these the in-built monochromation afforded by the time-of-flight principle allows experimental work based on the LINAC to explore efficiently aspects of the subject which depend on short-wave length incident neutrons with high momentum and/or energy transfer to the sample material.

Both structural and dynamic properties of condensed matter are of interest, and several instruments to study various aspects of each are being installed in experimental halls covering the 16 beam holes of the Condensed Matter Cell.

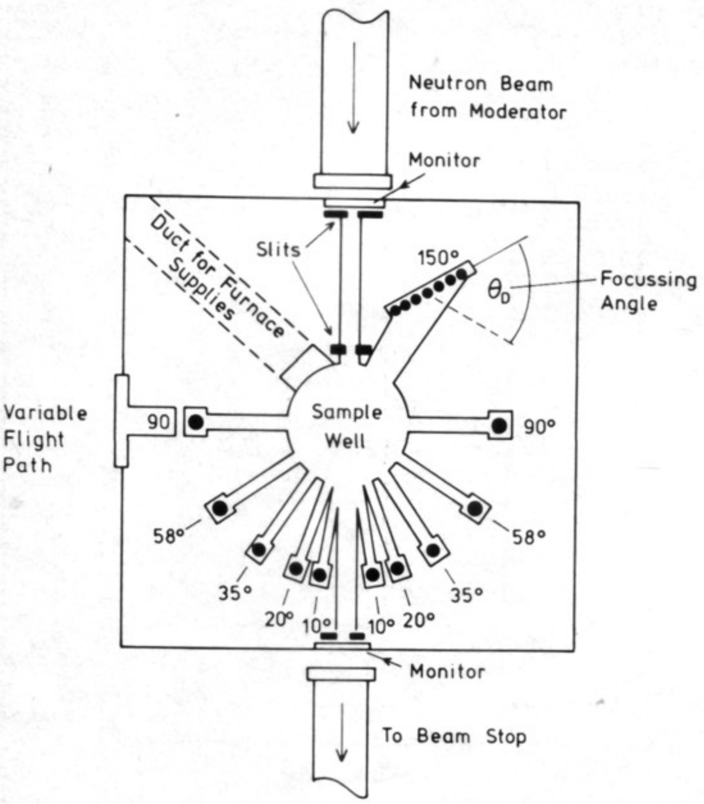


Fig. 9. The Harwell LINAC Total Scattering Spectrometer.

A typical instrument for structural studies is the total scattering spectrometer (see Fig. 9) which is designed for the examination of amorphous materials, molecular liquids and powders. Banks of neutron detectors (^{3}He proportional counters) are placed at various angles around the incident beam path, each bank defining a portion of a Debye-Scherrer cone. The scattered neutron energy (hence wavelength) is measured by time-of-flight. For a powdered crystalline sample this would allow the determination, simultaneously, of a wide selection of the spacings of the crystal-lattice planes, using the Bragg law, and the wide range of angles greatly increases the coverage of the lattice spacings. For amorphous materials the structural quantity of interest is the correlation function describing the density variation of atoms relative to a chosen origin atom, and this is obtained from the momentum transfer of the scattered neutrons. The Harwell total scattering spectrometer has a very high value of maximum momentum transfer (60 $Å^{-1}$) (much higher than that of a high-flux reactor), allowing the determination of the pair-density correlation function down to quite small values of radial separation. A typical result taken with the spectrometer on the old 45 MeV LINAC is shown in Fig. 10. On the new LINAC the instrument will have higher momentum transfer resolution and very much higher count-rates.

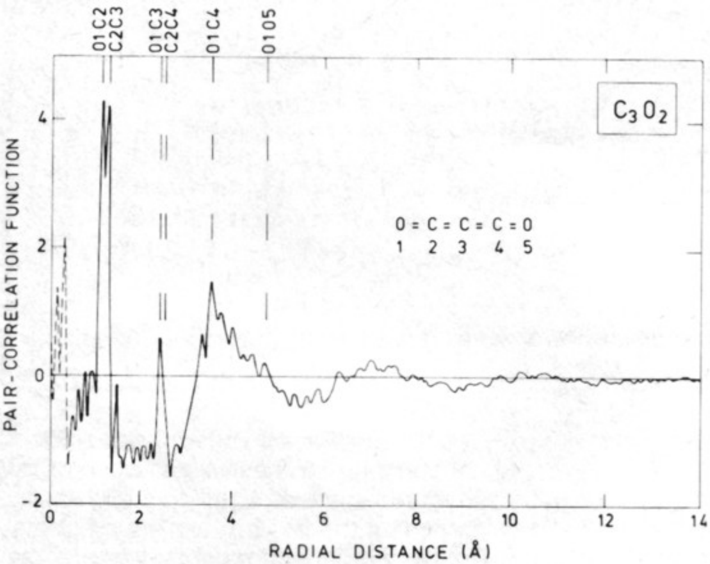


Fig. 10. The pair-correlation function for carbon sub-oxide deduced from Total Scattering Spectrometer data. Notice the resolution achieved at about 1 eV, showing clearly the difference in bond length between oxygen and nearest carbon atom and two nearest-neighbour carbon atoms.

Other instruments now installed, or being installed, for structural studies at the condensed matter target include a Back Scattering Spectrometer for high resolution at high momentum transfer, and an active sample diffractometer in inverted geometry (the sample will be situated within the Condensed Matter Cell). A Small Angle Scattering instrument will be included for investigation of structures with relatively large-scale order.

Dynamics studies of condensed matter require the simultaneous measurement of momentum and energy transfer, so in addition to the basic time-of-flight measurement, a second energy analyzing or monochromatisation system is required for the scattered or incident neutron. One of the first completely new spectrometers to become operational on the Harwell LINAC will be the constant Q spectrometer (Q denoting momentum transfer). This is the pulsed source and time-of-flight equivalent of a triple axis spectrometer on a steady state reactor, designed for the purpose of obtaining the energy dispersion relations of phonons or magnons at a position of high symmetry in a crystal. The analyzer is a crystal placed with its important lattice-planes parallel to the incident neutron beam; this ensures that, for a given analyzer lattice-spacing, the component, perpendicular to the incident beam, of momentum transfer is constant for scattered neutrons reaching the detector bank. For a detector at a given Bragg scattering angle relative to the analyzer plane the neutron time-of-flight can then be selected to correspond to the incident neutron energy that gives the constant momentum transfer vector, and this in turn determines the energy transfer. A particular advantage of this instrument compared with a reactor-based triple-axis spectrometer is that it extends the range of study to high incident neutron energies and hence high energy transfer.

The other spectrometers for inelastic scattering studies will initially include an Inelastic Rotor Spectrometer to measure scattering at high energy transfer and low momentum transfer, and, later, a Resonance Detector Spectrometer, to measure inelastic scattering with very high energy transfer, and a Beryllium Filter Spectrometer to measure high energy molecular modes of vibration.

Conclusion

The new facilities afforded by the 136 MeV electron accelerator at Harwell offer scope for new and highly interesting investigations in neutron physics and related sciences. The variety of target areas and flexibility of operation expected of the new accelerator will enable scientists outside the Atomic Energy Authority to join in these studies, and in many ways we see this as being another national, or, indeed, European, major facility for the exploration of the physical sciences. Enquiries from interested scientists will be welcomed and we hope they will be a prelude to mutual collaboration in exciting scientific studies. □

DEVELOPMENT CONTINUES

The eighth annual report and accounts of The Radiochemical Centre Ltd were published on 2 August. The report includes the following review of the year by the Company's Chairman, Sir John Hill.

The Radiochemical Centre Limited has had eight years of successful trading operations and rapid growth since it became a private limited company in 1971. This growth has continued this year, though with results which reflect some special factors referred to later in this report. The Company is now approaching the completion of a major programme of investment in a new production facility in the UK which will come into use during the next twelve months. As expected, the heavy launching costs of this project are currently affecting profitability and may be expected to continue to do so throughout the current financial year and into the following year.

The parent Company is now on the threshold of a period of considerable change, fortified by its record of forthright conduct of its affairs and its well-established reputation for technical excellence and commercial integrity. The board places great store on the character which The Radiochemical Centre has developed over many years of successful trading and the robust constitution it has acquired through forward looking investment programmes planned and consistently carried through in spite of occasional vicissitudes in trading conditions or performance. Its past record stands as a testimony to its capacity for further success.

There must be a touch of sadness that the hand of Dr Patrick Grove will no longer be guiding its fortunes at the start of this stage in its development. His inspiration and leadership from its inception has made the business what it is today and his influence will undoubtedly pervade the whole organisation for many years to come. Following Dr Grove's retirement in May, Dr J Stuart Burgess, hitherto Group Marketing Controller, has been appointed to succeed him as Chief Executive and Group Managing Director.

Organisation

The nature of the Group's operations is changing from a United Kingdom home and export concern to an international enterprise whose activities must reflect the economic and business circumstances which prevail in each of its markets, and the scope of the opportunities each one provides. To this end development overseas is continuing, including the setting up of Amersham France which began operating in January. The managements of our subsidiaries are making an increasingly important contribution to the business planning and product development strategy of the Group.

Undoubtedly a period of considerable organisational development lies ahead to reflect the new pattern which is taking shape, both in the parent Company and in its subsidiaries, as the whole undertaking adapts itself to meet the increasing size and complexity of its activities throughout the world.

We shall be seeking to exploit the augmented resources of the Group to the full to retain our position both as the broad-est-based supplier of radioactive materials in the world and as leader across substantial parts of the market. The task must be to convert the considerable new opportunities which are becoming available into the reality of achievement.

Business performance

Over virtually the whole range of products the growth of demand was up to plan and in some cases better than expected. Particular success was achieved with the Company's diagnostic products used in obstetrics and gynaecology where the range of kits we offer, having established a predominant position worldwide, is making a valuable contribution to sales and market share in very competitive market conditions, particularly in Europe and the United States. The Radiochemical Centre's well-founded strength in research chemicals has again been demonstrated by our success in the demanding American market, whilst sales of radiopharmaceuticals continued to be encouragingly buoyant. After the record level reached last year, which resulted in the parent Company once again receiving The Queen's Award for Export Achievement, the proportion of Group sales made overseas showed a further increase to 84 per cent. However Group profit fell below expectation, reflecting more arduous trading conditions and the influence of two particular adverse factors.

Firstly, in America the domestic market for smoke detectors reached its peak sooner than expected so that sales of alpha foil levelled off and then declined. Consequently this exceptional source of earnings in 1977-78 did not continue its growth through the recent financial year.

Secondly, with so high a percentage of its sales made abroad, Group results converted back into sterling are specially sensitive to the effect of movements in exchange rates and in the last quarter of the financial year this effect was mainly unfavourable as major world currencies weakened against the pound. In the preceding months the particular strengthening of sterling against the dollar strongly influenced Group trading results through its American subsidiary.

The substantial growth in the balance sheet figure for the parent Company and the Group reflects the considerable increase in fixed assets now taking place, but cash flow in the United Kingdom became heavily negative under the influence of high investment in the construction of the new plant at Cardiff, and of pre-production revenue expenditure there in the period before commissioning takes place. The board is confident that the benefits of current investment programmes will begin to show in Group results in 1980-81.

To help finance investment in the UK the remaining calls were made on the recent £5 000 000 share issue to the United Kingdom Atomic Energy Authority and borrowings from the banks increased under arrangements negotiated during the year. On an historical cost basis the Group achieved a 23 per cent return on average capital employed in the year. The total payment in dividend now proposed shows an increase from £719 000 to £752 000 reflecting the Company's confidence in the future. The dividend recommended by the directors, including the interim already paid, is equivalent to 15.8 per cent on average paid-in share capital for 1978-79.

UK operations

Substantial progress was made towards the completion of the new site at Whitchurch, Cardiff, and by the end of the year planning for commissioning the production buildings was being put in hand. The extra capacity is urgently needed as pressure on present production facilities is now becoming very heavy indeed.

A long-term plan for the future development of the Company's business operations in the Amersham area has been prepared. We have long recognised that the capacity of the present Amersham site is already near its maximum and that the aim must be to employ the facilities there as efficiently as we can so as to provide an integrated production facility with a working population of about its present size. The intention is that, after the move of two production departments to Cardiff in late 1979 and early 1980, the present site will be progressively re-developed, in a way which is consistent with its place in the neighbourhood and as an attractive place at which to work. To help towards this objective we have acquired land in an excellent location nearby for a new headquarters building to which we shall move a large part of the office work now carried out on the present site.

The demands made on staff, especially those engaged in manufacture and distribution, were particularly exacting during the last year not least due to the disruptive effect of the prolonged bad weather. The steadiness and determination of our own staff kept this to a minimum, in spite of the additional problems caused by industrial disputes which dislocated so many of the essential services on which we rely.

Careful attention continued to be given to energy saving. A special survey of this aspect of efficiency was carried out under the auspices of the Department of Energy's Industrial Energy Thrift Scheme.

Following recent advances in the technology, a second cyclotron has been ordered for installation at Amersham in 1980. Major improvements to computing and communications resources are also being made.

Products and processes

The product development programme has continued to bring good results. I am particularly grateful to the academic and research staff in the numerous universities and hospitals in many parts of the world who have collaborated with us in development and investigational work and in clinical trials. Their contribution has been of great value to the continuing technical endeavour which will always be the cornerstone of an enterprise of this type.

Six new reagent kits for clinical chemistry assays were introduced this year. For thyroid function testing a radioimmunoassay for thyroid stimulating hormone (TSH) and a new T3 uptake test, cheaper and more convenient than the established product Thyopac*-3, have been added to the product range. For obstetrics and gynaecology there is a new radioimmunoassay for alpha-foetoprotein in maternal blood or amniotic fluid as an indication during pregnancy of neural-tube defects such as spina bifida. A further radioimmunoassay, for luteinizing hormone, for the study of infertility in both sexes is an essential complement to our suc-

*trademark

Part of the facility for the production of alpha-active foil at the Amersham base of The Radiochemical Centre Ltd.
Copyright: TRC

A close-up of glove-box work in foil manufacture at TRC. *Copyright: TRC.*

cessful assay for follicle stimulating hormone. For the clinical research market we have introduced a radioimmunoassay for testosterone and dihydrotestosterone.

A new system has been launched for use in the treatment of uterine cancer with special caesium-137 sources. This enables improved positioning in the patient's body and reduces radiation exposure to medical staff.

More than 50 new labelled compounds for biochemical research have been added to the catalogue. Special attention is being given to high specific activity phosphorus-32 nucleotides and other products for research in molecular biology. Meanwhile improvements to the quality of products and to the efficiency of manufacturing processes have continued, with some notable advances in this direction. For example, particular attention was directed towards the increased use of high performance liquid chromatography in the preparation and analysis of the whole range of labelled compounds and of certain constituents of radioimmunoassay kits, and there was a further major increase in applications of microprocessor controls in technical departments.

Staff

The balance of staffing in the Group is changing significantly with over 25 per cent of its manpower employed outside the United Kingdom. This was another good and fruitful year in the further development of staffing policies and relationships both in the parent Company and in its overseas subsidiaries, which have been developing or revising their salary structures and pension schemes to suit their own circumstances.

In the United Kingdom the Group has a particularly close involvement with organised representatives of its employees and the parent Company strongly believes that such representation is to be encouraged. In other countries the relationship between its subsidiaries and their employees is based on the relevant legislation and customs of the countries concerned. Employment practices in the subsidiaries are determined by their managements in accordance with local considerations but it is the general intention that these should be of high standard and in line with the best practice in the country concerned.

An excellent safety record has again been sustained throughout this period, and indeed showed a further improvement over the good standard built up over many years. Minor incidents are inevitable but the level of lost-time accidents is very low indeed, a tribute to the care with which our employees carry out their tasks and the high quality of safety management which is maintained. Strict regard is paid to these important aspects of our responsibility to our employees, our customers, and to the public. Training for safety was further extended this year and the involvement of staff and their representatives in these aspects of our operations in the United Kingdom has significantly increased.

Board membership

In May 1979 Dr W P Grove retired from the board on his retirement from the Company's service. Dr J S Burgess accepted an invitation to rejoin the board following his appointment as Chief Executive. □

NUCLEAR POWER IN THE SOVIET UNION AND EASTERN EUROPE

BY THE OVERSEAS RELATIONS BRANCH, UKAEA

The USSR has substantial reserves of fossil fuels but great emphasis is placed on their effective utilisation and conservation. Therefore a large nuclear programme, which is centred predominantly in the European part of Russia where fossil fuel is scarce, forms an important component of Russian energy plans. In 1978 the Soviet Union had a total installed electrical capacity of 246 GW, of which 73 per cent was supplied by fossil fuel power stations, 4 per cent by nuclear power stations and 23 per cent by other types. The current five-year plan (the tenth) envisages that 35 per cent of new plant built in European Russia should be nuclear.

The first Russian power station, the small 5 MWe plant at Obninsk, came into operation in 1954 and was followed in 1958 by the six 100 MWe units at Troitsk in Siberia. These reactors were of the natural uranium-fuelled, graphite moderated pressure tube type known as RBMK. Considerable development of this system has taken place. Units of up to 1500 MWe are now under construction and units of 2000-2400 MWe are contemplated. Small 12 MWe RBMK reactors are being successfully operated in the far north of the USSR at Bilibinsk.

In 1964 the commissioning of a 210 MWe pressurised water reactor (known as a VVER) at Novovoronezh initiated an alternative system for thermal nuclear power stations. The system was successfully enlarged and in the early seventies two units of 440 MWe each were brought into operation at the same site. This unit size has been adopted as the standard for medium-sized nuclear power stations; it is understood to be competitive with fossil-fuelled power stations virtually everywhere in European Russia and has been adopted extensively by Russia's east European neighbours. In 1978 a 1000 MWe PWR came into operation at Novovoronezh and further units of this size are under construction and planned. It is intended that this larger size will eventually become the standard.

The Soviet Union also has a substantial fast reactor programme. The first unit to produce power, the BOR 60, was commissioned in 1969, some ten years after the first Soviet experimental fast reactor, the BR5, at Obninsk. It was followed by the BN350 which produces 120 MWe and 50 000 cubic metres per day of desalinated water. A full-sized fast reactor, the BN600 of 600 MWe, is under construction at Beloyarsk and is expected to be commissioned shortly. Design studies are also being undertaken for a 1600 MWe fast reactor. The Russian development programme is exploring alternative fast reactor designs: BR5 and BN350 are loop-type reactors in which the primary coolant circulates through a series of loops in which the main pumps and intermediate heat exchangers are located; BOR60, BN600 and the planned BN1600 are of the pool-type (like PFR and Phénix) in which the pumps and intermediate heat exchangers are located in the same large pool of coolant as the reactor core.

Table 1 sets out the nuclear stations in the USSR in operation, under construction and at an advanced planning stage.

A major bottleneck in the Soviet Union's reactor construction programme has been a lack of production capacity. Additional capacity is now being provided by the construction of

Table 1: Nuclear Power Stations in the USSR

Name	No. of Units	Type	Unit capacity MWe	Commissioned
In operation				
Obninsk	1	PTR	5	1954
Troitsk	6	PTR	100	1958-1962
Beloyarsk 1	1	PTR	100	1964
Beloyarsk 2	1	PTR	200	1967
Leningrad	2	PTR	1000	1973, 1975
Bilibinsk	4	PTR	12	1973-1976
Chernobyl	1	PTR	1000	1977
Kursk	1	PTR	1000	1976
Novovoronezh 1	1	PWR	210	1964
Novovoronezh 2	1	PWR	365	1969
Novovoronezh 3, 4	2	PWR	440	1971, 1972
Novovoronezh 5	1	PWR	1000	1978
Kola	2	PWR	440	1973, 1974
Armenia	1	PWR	405	1976
Ulyanovsk (BOR 60)	1	FR	12	1962
Shevchenko (BN350)	1	FR	*120	1973
Under construction				
Leningrad	2	PTR	1000	
Kursk	2	PTR	1000	
Chernobyl	1	PTR	1000	
Smolensk	1	PTR	1000	
Ignalino	2	PTR	1500	
Kola	2	PWR	440	
Armenia	1	PWR	405	
Kalinin	1	PWR	1000	
South Ukraine	1	PWR	1000	
Rovno	2	PWR	440	
Beloyarsk (BN 600)	1	FR	600	
Planned				
Kursk	1	PTR	1000	
Chernobyl	2	PTR	1000	
Smolensk	1	PTR	1000	
Kalinin	3	PWR	1000	
South Ukraine	3	PWR	1000	
West Ukraine	4	PWR	1000	

*This reactor also produces 50 000 m^3 of distilled water per day.

Notes:

1 There is a small, experimental boiling water reactor of 50 MWe at Ulyanovsk.
2 There is an experimental fast reactor of 5 MWe at Obninsk.
3 Total MWe in operation is: 8825 MWe
Total MWe under construction is: 13765 MWe
Total MWe planned is: 14000 MWe
Total: 36590 MWe
4 PTR refers to pressure tube reactors of the RBMK type
PWR refers to pressurised water reactors of the VVER type

a purpose-built nuclear power equipment plant called Atommash, near Vologodonsk in the Rostov area. It is designed to manufacture 1000 MW PWR reactor components and ancillary equipment using batch production techniques and will take advantage of the transport facilities afforded by the Volga and the Don Rivers. The first section of the plant has been commissioned; it will eventually consist of three factories, offices and housing covering some 1600 acres.

Although this article deals mainly with Russia's fission reactor development and construction programme, it is worth mentioning briefly the Soviet effort on thermonuclear fusion. Russian work in this field has been extensive and successful. Much has been done at the Kurchatov Institute of Atomic Energy where the tokamak system for containing the plasma required for thermonuclear reactions was first developed. This system is currently recognised throughout the world as that most likely to lead to a demonstration of practical fusion and is the basis of several major experiments now being built including the Russian T-15, TFTR in the USA and the European Communities' JET project at Culham.

The Soviet Union's east European neighbours, all of whom have a firm commitment to nuclear power, in general rely upon the Soviet reactor systems described above. Table 2 sets out the nuclear programme in these countries.

In 1971 construction work began on Bulgaria's first nuclear power station which consists of two 440 MWe VVER-type PWRs at Kozlodui on the Danube. The first unit was commissioned in 1974 and the second in 1975. Two further units of the same type are planned at this site.

Czechoslovakia was among the early-comers to reactor construction with the start in 1958 of a 144 MWe gas-cooled, heavy water moderated, natural uranium fuelled reactor, known as A1, at Bohunice near Bratislava. The reactor was based on a Russian design and proved extremely difficult to bring into operation. It was not completed until 1972 and has not been replicated. Instead, Czechoslovakia opted for the Russian-designed 440 MWe PWR. Three power stations, each comprising four units of this model, are currently under construction at Bohunice (where the first unit was commissioned this year), Dukovany and Mochovice. For the future, Czechoslovakia intends to adopt the Russian-designed 1000 MWe PWR and a station consisting of four units is planned for Malovice in southern Bohemia. Present Czech energy plans envisage 9000 to 10 000 MW of nuclear capacity by 1990. It is worth noting that with the development of nuclear component manufacturing capacity, principally at the Skoda heavy engineering works, Czechoslovakia has become a major nuclear supplier to the Soviet Union and her east European neighbours. Future plans include the supply of nuclear components for the 4000 MWe PWR station in the Ukraine which will be linked to the Czechoslovak, Hungarian and Polish electricity distribution grids.

The German Democratic Republic currently has the largest nuclear power capacity in operation in eastern Europe outside the Soviet Union. Their first commercial reactor, which was built at Rheinsberg, North of Berlin, was a 70 MWe BWR of Soviet design. A large station with four units of 440 MWe PWRs has been built at Lubmin, near Greifswald on the Baltic coast; three of its units are now in operation. It is understood that a twin 440 MWe station is planned at Magdeburg.

Hungary is constructing a single station of the 4 × 440 MWe PWR type at Paks on the Danube. The first unit entered service in January of this year.

Preliminary design work is reported to have started in mid-1978 on a nuclear power station at Zarnowiec on the coast of Poland, near Gdansk. The initial plan is to install 2 × 440 MWe PWR units but it is understood that a third unit of 1000 MWe capacity may follow.

Romania has as yet no operating nuclear stations, but construction of a single 440 MWe PWR of the standard Soviet type is planned to begin this year at Olt. Romania has recently negotiated with Atomic Energy of Canada Limited the supply of four 600 MWe CANDU units to be built at Cernovada on the Danube. Construction is expected to begin in early 1980. Use of CANDU will enable Romania to make use of the indigenous uranium deposits in Transylvania. □

Table 2: Nuclear Power Stations in Eastern Europe

In operation

Country	Name	No. of units	Type	Unit capacity (MWe)	Total capacity (MWe)	Commissioned
Bulgaria	Kozlodui	2	PWR	440	880	1974,1975
Czechoslovakia	Bohunice	1	—	144	144	1972
Czechoslovakia	Bohunice	1	PWR	440	440	1979
GDR	Rheinsberg	1	BWR	70	70	1966
GDR	Lubmin	3	PWR	440	1320	1974-1979
Hungary	Paks	1	PWR	440	440	1979
					3150	

Under construction

Country	Name	No. of units	Type	Unit capacity (MWe)	Total capacity (MWe)
Czechoslovakia	Bohunice	3	PWR	440	1320
Czechoslovakia	Dukovany	4	PWR	440	1760
Czechoslovakia	Mochovice	4	PWR	440	1760
GDR	Lubmin	1	PWR	440	440
Hungary	Paks	3	PWR	440	1320
					6600

Planned

Country	Name	No. of units	Type	Unit capacity (MWe)	Total capacity (MWe)
Bulgaria	Kozlodui	2	PWR	440	880
Czechoslovakia	Malovice	4	PWR	1000	4000
GDR	Magdeburg	2	PWR	440	880
Poland	Zarnowiec	3	PWR	2 × 440 1 × 1000	1880
Romania	Olt	1	PWR	440	440
Romania	Cernovada	4	CANDU	600	2400
				Total	10480

Totals by Country

Country	MWe in operation	MWe under construction	Planned	Total
Bulgaria	880	—	880	1760
Czechoslovakia	440	4840	4000	9280
GDR	1390	440	880	2710
Hungary	440	1320	—	1760
Poland	—	—	1880	1880
Romania	—	—	2840	2840
	3150	6600	10480	20230

COMBINED HEAT AND POWER

THE POTENTIAL OF CHP

Harnessing energy wasted in the form of heat discharged to the atmosphere as a by-product of power generation could eventually provide 30 per cent of Britain's space heating and hot water needs and save up to the equivalent of 30 million tonnes of coal a year.

This is a principal concluson of a report* prepared by the Combined Heat and Power Group, set up at the end of 1974 by the then Secretary of State for Energy and chaired by Dr Walter Marshall, Deputy Chairman of the UKAEA and former Chief Scientist at the Department of Energy. The report of the Group, and their recommendations, are now being considered by the Government.

In a foreword to the report Dr Marshall notes that in the normal method used for the generation of electricity only about a third of the primary energy input — whether this is from coal, gas, oil or nuclear sources — emerges as electrical energy. The remaining energy is rejected to the environment as low-grade heat, as an inescapable consequence of the laws of thermodynamics and an inevitable result of operating power stations solely for the production of electricity. However, it is possible to operate power stations in the "combined heat and power" (CHP) mode, in which the reject heat is made available at a higher temperature and is useful for industrial processes and for commercial and domestic space and water heating. Though operation in the CHP mode leads to a reduction in electricity production — again as a consequence of the laws of thermodynamics — the overall efficiency of the power station in terms of efficiency of energy conversion is greatly increased.

The objective of the work of the CHP Group was to examine the current status of the use of CHP generation in the UK, and to make judgments on its economic role in the future and on ways of encouraging its further development.

"The Group spent a great deal of time discussing the application of CHP in industry," Dr Marshall wrote. "I was pleased to discover that CHP generation was already very widely used. Therefore the potential for further development of industrial CHP was relatively limited . . . Our main conclusion on industrial CHP is that, if the Government decides to provide capital grants to industry for further energy conservation measures, then CHP should be high on the priority list for such grants.

"In contrast to industrial application of CHP, there has been relatively little use in the UK of combined generation for domestic and commercial space and water heating using district heating networks, notwithstanding its potential for saving primary energy. This contrasts with the situation in a number of other countries (e.g. Sweden, Denmark and Germany) and the Group has been much exercised in identifying the factors which have militated against the use of CHP in this role in this country. Though there are many relevant factors, the consideration which far out-weighs all others in inhibiting the use of CHP for domestic and commercial space and water heating is the existence, at the present time, of a convenient and highly-competitive alternative, namely natural gas. The existence of an elaborate distribution network for natural gas, coupled with the latter's current availability from the North Sea, provides the UK with an enormously valuable asset. But heat from CHP stations can only be competitive with natural gas in the rather special circumstances of highly concentrated heat loads (e.g. in densely populated cities), and in all these circumstances natural gas is already supplied to customers, is well established and is cheap and convenient. The supply of gas from the North Sea will terminate when the gas fields are exhausted in the first part of the next century. However, gas supplies can be renewed beyond that by the introduction of substitute natural gas produced from coal. This is, obviously, more expensive and CHP generation then becomes more widely competitive with it.

"In the situation of competition with gas, there is obviously a temptation to forget about CHP or, alternatively, to defer any action, at least for a number of years. However, the majority of the Group were satisfied that this would not be for the best. CHP generation could form an important option for space and water heating in the future, and this option will not be available at the time required unless action is taken fairly soon; the reason for this is that the building-up of a sufficiently large network for the supply of hot water to commercial and domestic premises takes a long time (typically 10-15 years). Initially the hot water supply could come from small heat-only boilers and the areas served by these would be linked up at a later stage to the main CHP plant. There is little experience of the building-up of such large-scale networks in the UK. The majority of the Group, therefore, considered it important that experience be gained in the near future in setting up a major CHP scheme, despite the competition with natural gas. We consider that Government action is required to initiate such a scheme since market forces are such as to make it unlikely that schemes will be set up as a result of normal commercial considerations. Although there is no strong economic incentive toward such schemes at the present time, our calculations show that they are a reasonably efficient use of national resources provided that large areas of high density heat load, such as might be found in many cities, are chosen."

The majority of the Group favoured an early start on the planning and institution of a "lead scheme or schemes", leading ultimately to a full-scale demonstration of district heating from CHP applied to a major conurbation. Dr Marshall noted that probably the most important question to be settled before such a lead scheme could be embarked upon was that of public response. Heating users within the lead city would have to be persuaded to use heat from the scheme, rather than using a pre-existing natural gas supply: the district heating option could be economically viable only if it captured a major part of the potential market in the area it served. The issue of "freedom of choice" was therefore vital. "I consider this marketing question of the utmost importance and one which, if the Government accepts our suggestion of setting up a lead scheme, must be taken very seriously," he wrote. "Clearly, any Government would look at schemes differently depending on the extent of the subsidy required to initiate them. And, if we assume that no UK Government or local authority would use coercion, the extent of that subsidy would be both uncertain and large without the most careful planning and market surveys beforehand. An important purpose of the initial planning is therefore to determine the probable extent of the subsidy needed to launch a scheme — and minimise it as far as possible."

A majority of the Group proposed that a new Heat Board should be set up with the specific charge of ensuring the implementation of the lead scheme and later developments. Its function would be one of coordination, pro-

**Combined Heat and Power Generation in the United Kingdom.* Energy Paper No. 35, 82 pp. HMSO, £3.75. ISBN 0 11 410761 0.

motion, planning, standardisation and research; it need be of only relatively modest size to fulfil these roles.

Dr Marshall noted that there were two main differences between the recommendations of the majority report and those of a minority of the Group. In brief, these were:

- In the long term the main competitor to CHP/District Heating might well be substitute natural gas, coupled with heat pumps. The minority report gave weight to this: majority opinion was reluctant to rely on SNG heat pumps proving a feasible and preferable option when oil and gas were exhausted;
- they were all agreed that the next step for CHP/DH was to make detailed market and implementation studies for one or more lead schemes. If those studies were to be done purposefully, the majority opinion was that a decision in principle was needed now, so that it was clear that a scheme or schemes would be implemented *unless* the detailed studies revealed unacceptable difficulties. The minority report wished those detailed studies to be done and a decision then taken in the light of the results obtained. The majority felt that, in practice, that would be simply a recipe for indefinite delay.

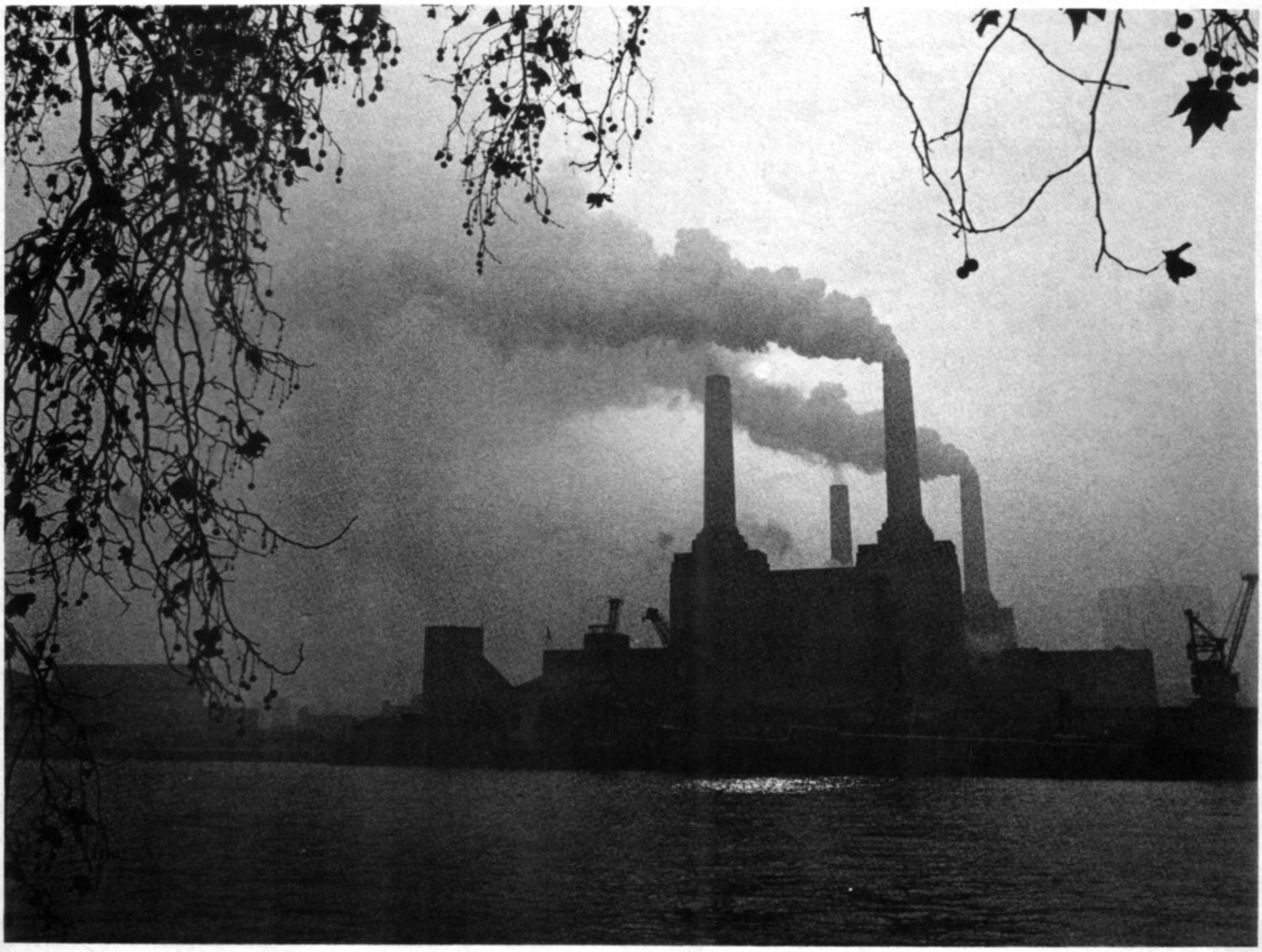
Dr Marshall said the area studied by the Group had been extremely difficult to consider: "it is certainly not one in which facile judgments should ever be made."

Industrial generation

Separately, the Department of Energy published on 26 July — the day on which the CHP report was published — a survey report on an "Inquiry into Private Generation of Electricity in Great Britain 1977". This showed that industry, transport and public administration produced 14 per cent of their own electricity from plant at 235 establishments. The electricity generated totalled 17 terawatt hours — some 60 per cent of the establishments' own consumption of electricity. Steam plant accounted for 90 per cent of the 4.3 GW of generating capacity and for 92 per cent of the electricity generated.

The report noted that a large majority of establishments (193) had some form of combined heat and power or heat recovery plant. CHP plant accounted for 65 per cent of capacity, and for a similar proportion of electricity generated from steam plant. Some 42 per cent of capacity and 79 per cent of electricity generated from non-steam plant was from diesel or gas turbines fitted with heat recovery facilities. The industries with most private generating plant were chemicals, oil refineries, iron and steel, and paper and printing. These four industries accounted for two-thirds of both capacity and electricity generated. A small number of establishments with plant capacities of 25 MW and more accounted for 75 per cent of total capacity and 80 per cent of the electricity generated; most of these were in the four industry groups named.

Copies of this report — whose main results are presented in the form of statistical tables — are available from the Department of Energy. □



Battersea power station at dawn . . . illustrated here in recognition of its seldom remembered role as the provider of heat to a residential complex across the Thames.

REVIEWS

Nuclear power and the *Groupe de Bellerive*

The *Groupe de Bellerive* held a Colloquium on 'Nuclear Energy — Implications for Society' in February 1979. The booklet by Amory Lovins 'Is Nuclear Power Necessary?', reviewed in the September issue of ATOM (No. 275), was presented, pre-publication, as a paper. Concern for the problems of the under-privileged peoples of the world was the main stimulus for the establishment of the *Groupe* and they have taken a special interest in the application of low technology to the solution of the problems of the poor countries.

The *Groupe de Bellerive* believe that their colloquium represents a watershed "in the recognition of the profound changes a nuclear world poses for society" — a quotation from the *Bulletin of the Atomic Scientists*, which the *Groupe* has included in the opening paragraph of a declaration that they issued in Geneva on 31 May this year.*

It is, in fact, not so much a declaration as a questionnaire of loaded questions. It starts by begging some very big questions and damning the pro-nuclear speakers at the colloquium with faint praise: it is said that they simply gave "the orthodox case for nuclear power" which "rests on assumptions made several years ago, which more recent research has subjected to severe and reasoned criticism". What that research is the declaration does not say; neither does it say in what way the "orthodox case" (whatever that is) is out of date. The declaration goes on to say that the nuclear case risks going by default. We are being lulled into a false sense of security by a number of favourable decisions and events — agreement to proceed with the oxide reprocessing plant at Windscale, the construction of Superphenix and the expansion of the reprocessing plant at La Hague, says the declaration. "While the governmental momentum . . . continues, the public is becoming increasingly aware that the criticism of the 'orthodox case' . . . is today being put forward by an increasing number of highly competent scientists and economists, and with more sophistication and greater objectivity than the case for nuclear power". This judgment that the anti-nuclear case has "greater objectivity" than the pro-nuclear case seems itself to be a highly subjective one, since no arguments or facts are advanced to support it.

The declaration warns us that this situation will lead the public into doubting whether they are being democratically governed and into believing that they are simply pawns being manipulated by "a military industrial complex" which seeks only more power and aggrandisement for itself. The *Groupe* declares that we must do better than this. We are called upon to make our case again — this time "with the objectivity and elaboration which the situation today demands". In particular we must answer a series of loaded questions, most of which are preceded by some false premises.

Energy forecasts and gaps

The *Groupe* ask "now that official energy demand forecasts (and more particularly forecasts of future energy gaps) have been . . . scaled down . . . to a fraction of what they once were, is it still valid to base energy policies on extrapolations of past total demand rather than on a detailed analysis of the specific demands for different kinds of energy to be expected from different sectors of consumption, in the light of realistic assumptions about fuel prices, consumption patterns, and technical and commercial developments?" This is an example of a question of the "Have you stopped beating your wife yet?" sort. If we answer "no" we appear to agree that energy forecasts have been scaled down to a fraction of what they once were and that we have been guilty of simple-minded trend extrapolation that takes no account of the important factors toward the end of the question. If we answer "yes" we appear to be defiantly voting for sin and rejecting all the virtuous practices at the end of the question. The fact is that energy forecasts had to be scaled down because there has been insufficient response to the message in the earlier forecasts — with the result that economic projections have had to be tailored to the present and near and medium future energy situation — and especially the energy price situation. Official forecasts are *not* based solely on simple trend extrapolation. They do take account of all the factors listed in this question as well as heeding the lessons of the past. Moreover those writers who reject past history as having any bearing and argue that highly disaggregated analysis is the *only* way to project future demands do not, by any means, always make "realistic assumptions about fuel price consumption patterns, etc, etc." Finally, and perhaps most importantly, it is much too restrictive to base policies upon rather narrow considerations of needs. Man's progress has been much more a matter of using his imagination to respond to opportunities than of simply setting out to satisfy his immediate needs — which would not have taken us very far past the Stone Age. Cheap oil presented the world with a great opportunity 30 years ago. We have all benefited from it. We now have a new opportunity — the prospect of cheap electricity from nuclear energy.

The all-electric future

The second question asks "Given that the use of electricity for domestic and commercial space heating is an extremely inefficient user of primary fuels, is it wise to continue to base any national energy policy on the all-electric house, office or factory?"

Here, the initial premise is wrong. Whilst there may be better uses for electricity, it is not "an extremely inefficient use [ ] of primary fuels" to use electricity for space heating. The charge of extreme inefficiency ignores the high end-use efficiency with which electricity can be converted into useful heat and the fact that local central heating boilers usually consume high grade, scarce fuel whilst for the most part power stations burn low grade, less scarce fuels.

The question implies that it is national policy to go for "the all-electric house, office or factory". As fossil fuels become scarcer and more expensive and as electricity becomes relatively cheaper as more of it is produced from nuclear energy there will, no doubt, be a continuation of the past trend for electricity to take a larger share of the energy market; but no government, as far as I know, has a declared policy of going "all-electric".

Can nuclear power substitute for imported oil?

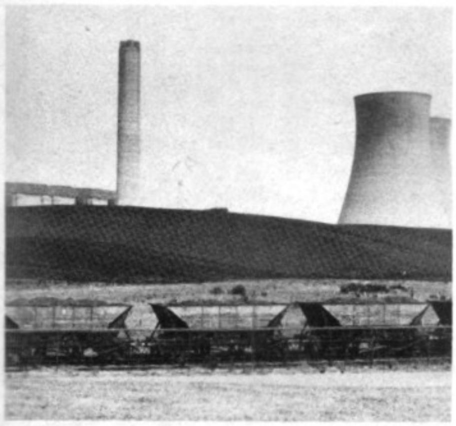
The question in the declaration is worded rhetorically: "How can nuclear power stations which generate elec-

Groupe de Bellerive, 122 rue de Lausanne, CH-1202 Geneva, Switzerland. The members of the *Groupe* are: Sadruddin Aga Khan, Jacques Freymond, Martin Kaplan, Lew Kowarski, Niall MacDermot, Paul Sieghart, Olivier Reverdin, Denis de Rougemont, William A. Visser't Hooft and Victor F. Weisskopf.

tricity substitute adequately for imported oil, at all events in those Western European countries where the greater part of such oil is used for transportable liquid fuel in road, rail and air vehicles?"

Many opponents of nuclear energy argue that coal will take the place of oil. They conveniently close their eyes to the fact that large quantities of coal (and oil) would be released for other purposes if nuclear energy replaced fossil energy in power production. If all large power stations were nuclear, the oil so released would provide direct relief to pressures upon the world oil market and coal could be used for many purposes for which oil is used today. The Friends of the Earth are always telling us that fluidised bed boilers make it possible to burn coal for steam-raising and other purposes in factories with a relatively low level of atmospheric pollution. There could well be a substantial switch to coal-burning for many purposes for which higher grade fuels like oil and gas are used today over the period of 30 years or so that it would take for nuclear energy to take over from the large oil and coal burning power stations as they are retired or relegated to very low load factor roles. Even if we confine ourselves to present levels of fossil fuel consumption by the world's power stations the direct and indirect savings of oil would be equal to two thirds of OPEC's entire present output. This saving would be achieved without looking beyond the fuel consumption of existing power stations. If, as seems very likely, electricity continues to expand its share of the energy market the saving would be even greater.

I would agree with the implication that, in the foreseeable future, nuclear-fired electricity is unlikely to substitute to any extent for the oil burned for transport purposes. But if we can relieve oil of the many other duties that it is required to perform there will be a lot more of it available for transport. (I would not, incidentally, accept the *Groupe's* estimate that "the greater part of . . . oil is used for transportable liquid fuel . . .". In most cases the proportion is substantially less than half.)



Coal as an energy source . . .

Energy conservation

The *Groupe* ask "Is it true that the potential gains from energy conservation, without any reduction in standards of living, are as great as are now claimed for them, given appropriate energy policies?"

Claimed by whom? And what are we to understand by an "appropriate" energy policy?

The most publicised claims for the benefits of energy conservation in the recent past have been those in the book by Gerald Leach *et al.* — "A Low Energy Strategy for the United Kingdom" — which was reviewed in the March issue of ATOM (No. 269). The simple answer to the question as far as that study is concerned is "no". The conclusions follow from assumptions of a highly unlikely future structure of the UK economy — and from the assumption that all fuel consumers in all sectors will give high priority to saving fuel, even at very long payback periods for their investment — in circumstances in which, according to the authors of the report, there will be ample supplies of familiar fuels.

Sensible energy policies need to provide for additional supplies of fuel as well as greater efficiency in its use. If we were to confine ourselves to going all out for more efficient methods of using energy, without providing for additional supplies of fuel at acceptable prices, we would end up making each barrel of oil more valuable to us and thus raising the level to which the cartel may force the price before consumers cut back their demands. Where a large part of the market is not controlled by a cartel, we have the paradox that the more successful energy conservation is the more the pressure is taken off the market and the more the price falls so as to discourage energy conservation! Thus it never offers the complete solution to the problem that its more extreme proponents claim for it.

Relative economics

The *Groupe* ask how the allocation of "scarce economic resources to large nuclear power programmes compares, in terms of future public and private utility, with the allocation of the same resources to other patterns of energy supply and distribution?" The answer is "very well". Investment in a nuclear power station calls for a somewhat larger initial capital outlay than for a fossil-fuelled station. In return the investor enjoys a reduction in fuel costs by a factor of three or more — and since fuel accounts for something like two-thirds of the cost of power generation the saving is absolutely as well as relatively very large. The payback period on the extra capital expenditure is typically four years or less — which any investor in any sector of the economy would regard as a handsome return on his money.

The fast reactor

"Even assuming a present and future need for some base-load electricity generated from nuclear reactors", says the *Groupe*, "what case is there for deciding *now* to build fast breeder reactors, let alone actually starting to build them?"

It never ceases to puzzle me why people who sincerely believe that fuel conservation is important lose all interest in it when the fuel to be conserved happens to be uranium. What would the *Groupe* say if I applied their question to coal- and oil-fired stations, and asked them "what case is there for deciding *now* to build coal- and oil-fired stations that use fuel more efficiently, let alone actually starting to build them?" They would surely say that there was every case — yet the saving in uranium fuel achieved by using fast reactors instead of thermal reactors is far and away greater than anything that could possibly be achieved by improving the thermal efficiency of fossil-fuelled stations.

Sensible planners add other dimensions — economics and operating experience for example. We need to make a fairly early start with fast reactors in order to gain experience in operating them and to help us find ways of reducing their cost.

Plutonium and proliferation

This is another one of those questions where the sting is in the premise rather than in the question itself. The *Groupe* says:

> "Given the exceptional dangers of plutonium, especially in terms of the proliferation of weapons, as well as of national security and therefore of the survival of civil liberties and democratic societies under the rule of law, what case is there for deciding now to build nuclear reprocessing plants which will separate that substance from the highly radioactive materials with which it is mixed when it leaves the current reactors, and which protect it from illicit use in atomic weapons, either by States or by sub-national groups?"

Let us answer the question first. Plutonium is an extremely valuable fuel.

Moreover, when it is separated, along with depleted uranium, from irradiated fuel elements returned from reactors, waste storage and disposal is greatly simplified. There is thus every reason for reprocessing fuel without too much delay.

There is hardly any space in an article of this nature to give an adequate reply to all the charges that have been made about the dangers of plutonium, the risk of weapons proliferation and the alleged threat to civil liberties arising from nuclear power operations that have been made by the various sections of the anti-nuclear movement. Taken simply as a toxic substance, plutonium is no more hazardous than many industrial materials and a good deal less hazardous than some.

The argument about the threat to civil liberties is greatly over-done. The benefits of living in highly-developed, highly-organised societies inevitably requires some ceding of freedom of action and subjection to some form of surveillance to protect honest citizens from the activities of criminals. Terrorism — not nuclear power or air travel — has made it necessary for us to accept some new, rather irksome, restrictions. Fears about hostile acts by other countries have always played some part in the conditions under which we live. There is no reason to suppose that reprocessing of nuclear fuel will make any noticeable difference.

It is interesting to see that the *Groupe* is giving support to the idea that "a technical fix" (in this case leaving fuel unreprocessed) can protect nuclear materials from illicit use. Many nuclear opponents have argued that technical fixes will not work and that the only solution is to reject nuclear energy altogether. We would argue that even this would not remove the spread of weapons proliferation. There is no example of a nuclear weapon having been developed as an offshoot of civil nuclear power. In every case the weapon has either preceded the use of civil nuclear energy or it has been developed quite independently with materials developed from other sources. "Technical fixes" can certainly be used to make it more difficult for civil nuclear materials to be diverted for weapons purposes but, in the end, the political problem of the spread of nuclear weapons has to be dealt with primarily by political measures of one sort or another.

Conclusions

It has taken me longer to discuss the declaration of the *Groupe de Bellerive* than it took them to make it. This is first because the declaration largely takes the form of the series of questions listed above, which need to be given in full if the reader is to follow the discussion of them; but mainly because the declaration was remarkable for what it did not say rather than what it did. All the real questions were begged and — unlike the *Groupe* — I have had to take up space discussing these.

My main conclusion has to be that broad, generalised, unsubstantiated accusations followed by loaded questions offer very little to greater understanding of nuclear power issues.

L.G. Brookes
Economics Adviser, UKAEA

Nuclear Energy — What are the Choices?

A report by the Quaker Nuclear Energy Group, May 1979. *Available from the Book Centre, Friends House, Euston Rd, London NW1; 22 pp; 45 pence.*

All sorts of pamphlets and leaflets to do with nuclear energy have been produced by all sorts of organisations and special interest groups. This is a distinguished addition to their ranks.

The Religious Society of Friends — the Quakers — have, of course, a long history of concern about social issues. In February 1978 their "Meeting for Sufferings" set up a group "to carry forward the thinking on [the nuclear] issue and present to the Meeting a report on the spiritual and moral issues on which the judgment of the Society should be sought". The group had among its members several scientists and engineers who have special knowledge of nuclear energy; and a number of non-scientific people whose particular knowledge of the subject came through either their participation (as lay witnesses) in the Windscale Inquiry or their membership of the group itself. They set themselves a daunting task — an assessment of nuclear power in the light of world-wide needs and dangers rather than in the context of UK policy alone — though they stress in the preface to their report that they hope Friends will realise that the spiritual and moral issues presented by the existence of nuclear armaments "are much more immediate and far-reaching than the issues involved in the development of nuclear energy for civil purposes."

The group see four choices ahead of us: rapid development in the use of nuclear energy; further development "with the utmost caution, as a necessary measure to bridge the gap between the effective exhaustion of fossil fuels and the harnessing of long-lasting or renewable enough sources"; putting off taking any decision; and urging the government to halt nuclear development. "None of the choices is 'safe'; each of them implies something about our view of human society, what it is and what we should strive to make it," they say. "None of the choices offers an easy way through because there *is* no easy way through the situation with which the world is faced."

They then discuss what they see as the two major issues which must be faced in formulating a judgment on nuclear power — the proliferation of nuclear weapons, and the gap between rich and poor — and a number of "subsidiaries": energy policy, health hazards, reactor accidents, the disposal of radioactive waste, the health hazards of uranium mining and of mine tailings, the fast reactor and the theft of plutonium; and alternative sources of energy. The ground they cover is well-worn, and it is to their credit that they go over it in an admirably matter-of-fact way.

At the end of the day the group plumps for caution: in effect, they choose their second option. At the risk of abusing a reviewer's licence, I think it is worth quoting their conclusions in full (the full pamphlet merits reading):

> "We would remind Friends that whether we like it or not we live in a society that relies on technology for the sustenance of life, and with world population at its present levels our technology cannot be abandoned without risk of major disaster. While small groups of people may attempt to 'opt out' from this society even they depend in some measure on present technology, and such a retreat is not available to more than a small minority. It would be comforting to be able to say 'Nuclear Power — No Thanks', but it would also be comforting to say 'Coal mining, factory farming, chemical plants, motorways, pesticides, production lines, oil tankers, advertising — No Thanks'.
>
> "There are risks in any technological process, and the risks associated with the use of nuclear power for civil purposes are such that this course could be accepted only with great caution, but if the alternative were the failure to sustain the energy needs of the whole world, a limited nuclear power programme is an option that cannot be lightly laid aside. So we refer Friends back to a consideration of the choices set out in the opening pages of this document".

Or, freely translated, "moderation in all things".

J. Daglish

Safety testing of radioactive consumer products

In 1976 the National Radiological Protection Board established a laboratory for testing consumer products containing radioactive materials. The work of the laboratory is described in a report* published on 23 August 1979.

Experimental appraisal and measurement play a substantial role in the development both of a coherent philosophy on the safety of consumer products and rational radiological protection standards. At the NRPB tests have been designed to simulate credible and extreme abuse and mishandling of products and include burning, freezing, puncturing, immersion in water, vibrating and dropping from a height of 10 metres. Each type of product is assigned an individual test programme which may then be modified in the light of experience.

The types of consumer product which have received most attention have been ionisation chamber smoke detectors and liquid crystal digital watches containing gaseous tritium light sources; the results obtained on these two types of device are the main subject of this report.

Most of the smoke detectors performed entirely satisfactorily in the mechanical tests, although there were some shortcomings in construction and in the cutting and mounting of the radiation sources. The fire tests — carried out at 600°C — produced the most interesting results and several problems of materials incompatibility leading to leakage of radioactivity in excess of the limit specified in the standard were identified and solved.

Liquid crystal watches also performed creditably under the Board's test programmes, although shortcomings in construction were initially relatively common. The main problem concerned the gaseous tritium light sources, rather than the watches themselves. The need for stricter quality control during manufacture, and monitoring with regard to release of activity, was particularly evident.

The NRPB say a feature of this work has been the willingness of manufacturers to undertake the necessary modifications as a result of the Board's findings. Products are submitted for testing at the prototype stage.

Further information is available from the Information Officer, National Radiological Protection Board, Harwell, Didcot, Oxon OX11 ORQ. Telephone: Abingdon (0235) 831600 ext. 410.

*NRPB-R85 *The Radiological Testing of Consumer Products: 1976-78*, by B T Wilkins and D W Dixon. HMSO, £1.00.

Radiological Protection Code of Practice

AERE Harwell has published a new code of practice for designers, installers and operators of radiological protection systems — believed to be the first of its kind to be drawn up in the United Kingdom.

The code* has been prepared under the auspices of the Advisory Committee on Radiological Protection Instrumentation which was set up in 1974 to review radiological protection systems, drawing its members from the country's major nuclear establishments.

The protection of personnel against radiological hazards is one of the most important requirements in work in nuclear energy, and depends heavily on well-designed and reliable instrumentation. While there has been comprehensive documentation concerning instrumentation for nuclear reactors, there has until now been no comprehensive guide for designers and installers of radiological protection equipment.

The Advisory Committee on Radiological Protection Instrumentation, whose members have considerable experience in the nuclear field, turned their attention to this problem and identified the main requirements of a suitable guide. The result is a Code of Practice which is intended to cover the field comprehensively and to serve also as a reference guide on particular points. Sections of the code deal with specifying and satisfying instrumentation requirements, and also with installing, operating and maintaining equipment. It defines a standard of good practice, taking the form of recommendations which should prove of value both to the experienced engineer and to the newcomer to radiological protection. □

**Code of Practice and Design Principles for Installed Radiological Protection Systems*, by R.G. Powell, AERE-R-9374, 101 pp. Obtainable from the HMSO, £2.50. Technical enquiries and comments on the code may be addressed to Mr Powell at the Marketing and Sales Department, Building 329, AERE Harwell, Didcot, Oxon OX11 ORA. Tel: Abingdon (0235) 24141 ext. 2942.

Ion implantation licensed to industry

AERE Harwell has licensed Hawker Siddeley Dynamics Engineering Ltd of Hatfield, Herts., to manufacture a machine for the ion implantation of machine tools and other components.

Ion implantation is a means of changing the surface properties of components so that their wear life increases, by the controlled injection of electrically accelerated foreign atoms into the surface of a component in a vacuum environment.

The R&D phase of the project at Harwell was funded by the Engineering Materials Requirements Board of the Department of Industry. The technique has been shown to have widespread application in engineering: it has been used already to increase the life of tungsten carbide wire drawing dies, injection moulding equipment, press tooling dies and cutting edges.

It is believed that ion implantation may be applied to a wide variety of steels under both adhesive and abrasive wear conditions. Additionally, it may be used to implant either gaseous or metallic ions into carbide and stellite materials. As the process is carried out at only slightly above room temperature there is no danger of distorting the components being treated.

For Hawker Siddeley Dynamics Engineering, production of ion implantation machines is a natural development from their present production of electron beam welding systems. □

UKAEA courses

Condition monitoring — a maintenance aid?

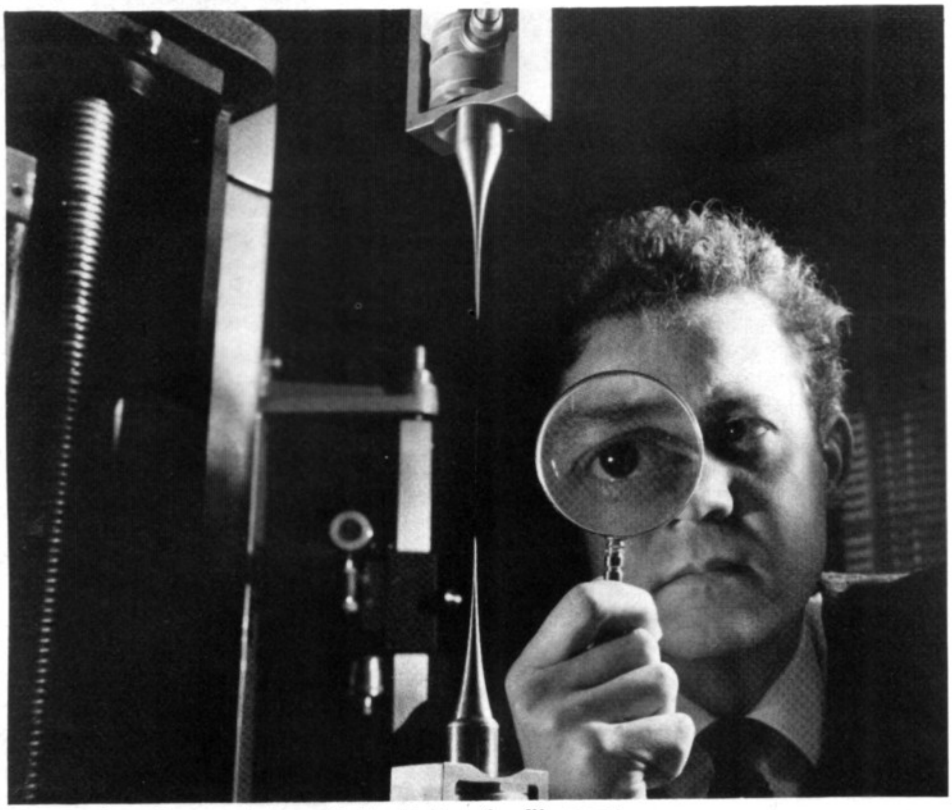
A one-day training course on condition monitoring is to be held at the National Centre of Tribology, Risley, on 31 October. Its objective is to describe the methods and apparatus available for the monitoring of the condition of plant and machinery, and to give some examples from practical experience so that engineers concerned with both design and maintenance can be better able to decide "what's in it for them."

The course fee inclusive of notes and refreshments is £52 plus VAT. Application forms and programmes are available from the Course Organiser, National Centre of Tribology, UKAEA Risley, Warrington WA3 6AT.

Two-phase flow and heat transfer

An intensive course covering fundamentals and applications of two-phase flow and heat transfer is to be held at the UKAEA establishment at Winfrith, Dorset, from 14 to 18 January 1980. The course, for which the fee is £275 plus VAT, is aimed at engineers and research workers in the process chemical, petrochemical, power generation and nuclear industries.

Further information may be obtained from the Education and Training Centre, AERE Harwell, Oxon.



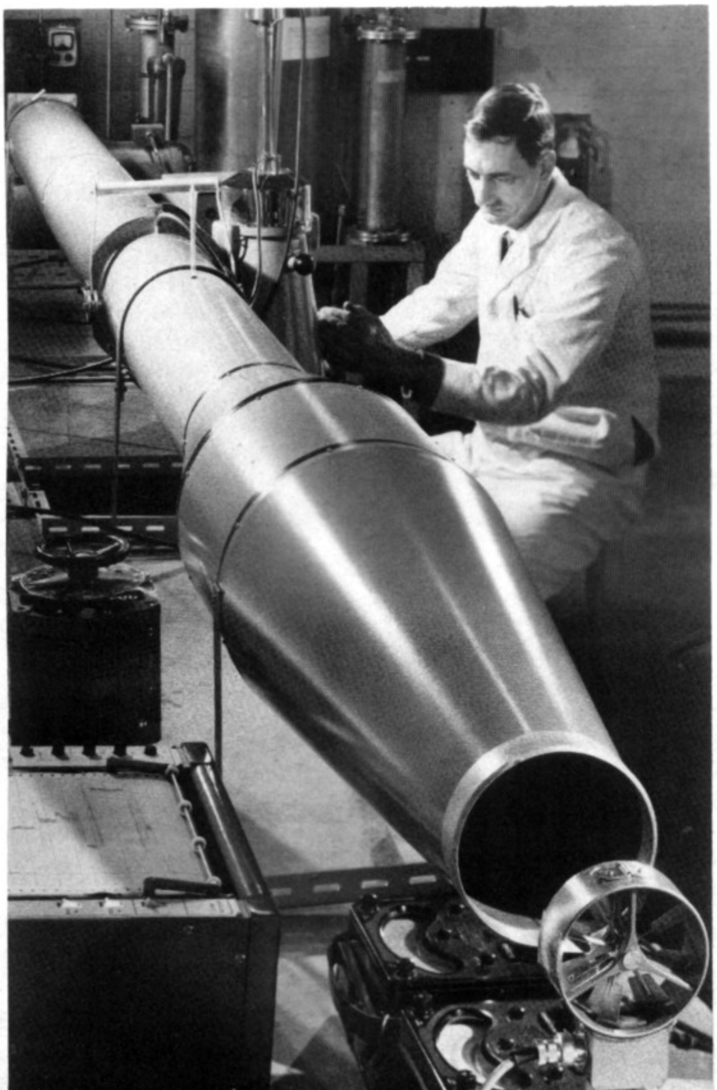
Measuring the modulus of elasticity of a filament . . .

ATOM IN CAMERA

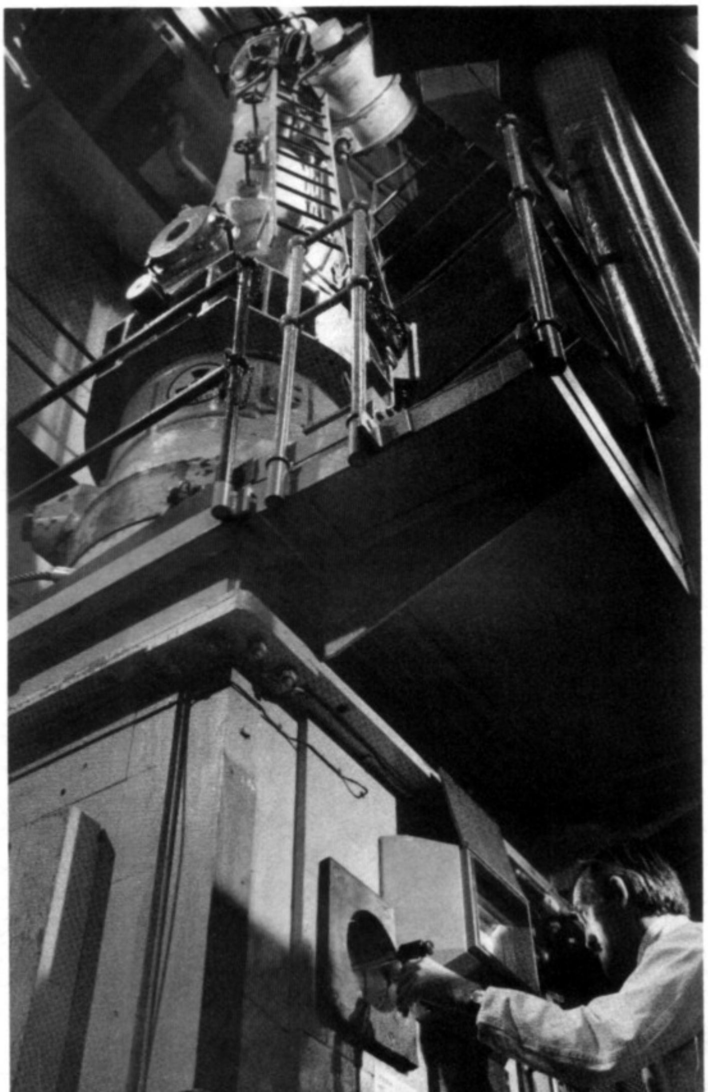
Outstanding photographs from 25 years of Atomic Energy Authority press and industrial photography will be on display at the Ceylon Tea Centre, Regent Street, London SW1 for the first two weeks of October.

The pictures are a random selection from the 25 years of Atomic Energy Authority activities being celebrated this year. Most are by the Authority's prize winning staff photographers Eric Willmott and Brian Goodman, both of whom have won top awards in the *Financial Times* industrial photography competition. Other pictures have been contributed by the Authority's establishments around Britain.

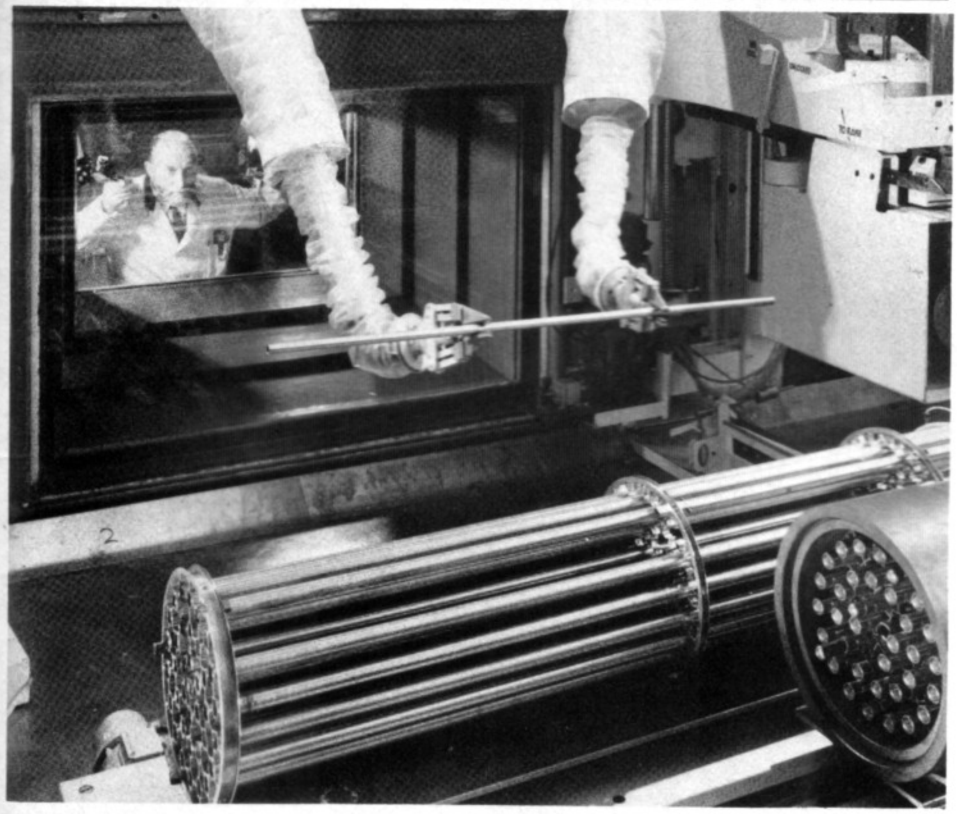
The photographs throw an often unexpected light on the Authority's work from radioisotopes to nuclear reactors. □



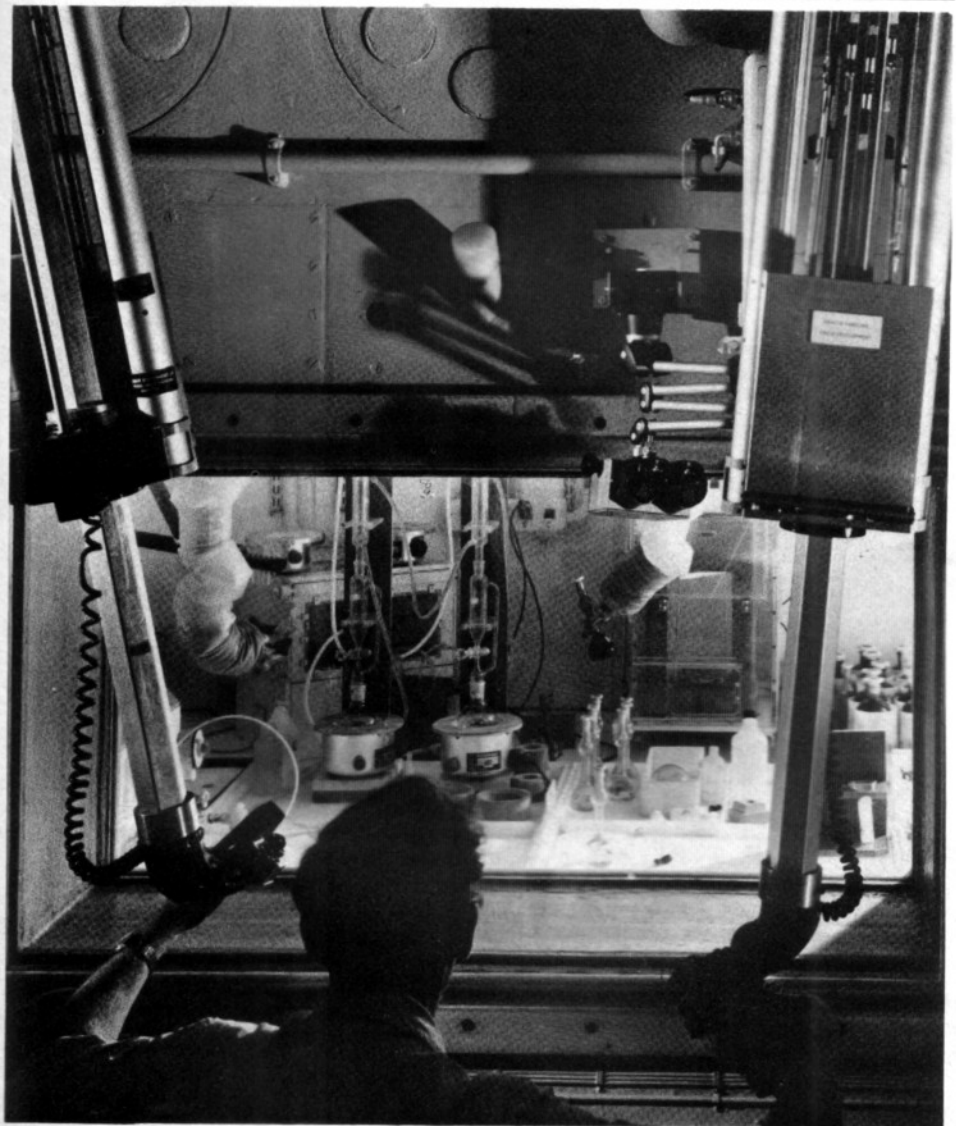
Calibrating an anemometer for heat exchanger tests



. . . and experimental work on the PLUTO reactor.



Working with a remote manipulator on fuel elements



. . . and preparing for chemical analysis of spent fuel samples.

Design-phase contracts for new nuclear plant

The CEGB announced on 1 August that it had awarded the design-phase contract for two 660 MWe turbo-generators for the Heysham II advanced gas-cooled reactor (AGR) station to NEI Parsons. The machines will be of the six-flow exhaust design.

The South of Scotland Electricity Board also announced on 1 August that it had awarded the design-phase contract for two 660 MW machines for its Torness AGR station to GEC, selecting the four-flow exhaust system.

The decisions were taken after both Boards had invited competitive tenders for both four-flow and six-flow exhaust 660 MW machines.

The Boards will be involved in the approval of the designs submitted by both manufacturers and the resulting turbine hall layouts, so that either Board could use either turbine with its associated standard layout for future AGR stations. The contracts for the manufacture of the turbo-generator plant will not be placed until work on the design contract has been completed. The CEGB has also made it clear that it would not wish to place the hardware contract until the restructuring of the nuclear design and construction industry, at present being considered by the Government, has been satisfactorily resolved. □

Torness: questions answered

The South of Scotland Electricity Board has produced a series of leaflets explaining the need for the building of the Torness nuclear station, on which work has begun at a site near Dunbar, east Lothian.

One notes that growth in demand for electricity comes partly from industrial expansion and partly as a result of rising standards of living. "Demand for electricity in the South of Scotland has grown to be three times what it was 20 years ago. It is expected that, after taking into account greater use of house insulation and other conservation measures, the demand will continue to increase", it says. "In addition, some old generating plant has reached the stage when it has to be taken out of service. Forecasts for the longer term can never be precise, but the predicted level of demand in the late 1980s is likely to exceed present levels by some 50 per cent, and this cannot be met without new generating plant."

The leaflet explains that the Board now burn about eight million tonnes of coal a year, and have sufficient modern coal-fired generating plant to burn all the coal that is likely to be made available at economic prices in the future. Nuclear power, with fuel costs about a quarter of coal and oil fuel costs, is a valuable hedge against inflation.

"The consensus of informed opinion in this and other countries is that the development of nuclear power, along with other existing and potential energy sources, is essential for the wellbeing of future generations. . . . Nuclear power is being developed because it ensures an abundant supply of energy, because it is safe and economical and because it will assist the preservation of valuable oil reserves for transport and other special purposes. The AGRs to be built at Torness, to basically the same design as those at Hunterston, are the most economical means of securing future electricity requirements in Scotland."

The planned output of the Torness station is 1300 megawatts, from two identical 650 MWe AGR units. It is expected to enter service in the late 1980s.

A second leaflet outlines the main factors which influenced the SSEB's proposals for connections from Torness to the transmission system; and a third is in the form of a series of questions which have been raised about the project, and answers to them.

Each leaflet is available from the South of Scotland Electricity Board, Cathcart House, Glasgow G44 4BE; and from the Information Services Branch of the UKAEA. □

Demand for coal increases

Sir Derek Ezra, chairman of the National Coal Board, noted increased demand for coal not only for electricity generation but also in domestic and industrial markets when he presented the Board's annual report and accounts on 2 August.

"Less than a year ago we were criticised for over-producing, but now we are being pressed to mine more coal to meet the demand," he said. "It is impossible to develop an industry like coal, with its long lead times, in an opportunist way; the vital element must be consistency in investment, exploration and research."

This thinking lay at the heart of the Board's *Plan for Coal*, agreed between the government, management and unions in 1974, he said. A great deal of progress had been achieved in implementing the plan since then — some seven billion tons of coal in the ground had been fully explored (it was the NCB's objective to have at least 50 years of explored reserves ahead at any one time, out of the 300 years' worth, 45 billion tons, of technically recoverable reserves known to exist); they had committed investments for over 40 million tons of new capacity, some of which was already being operated; and they were obtaining important results from intensified research activities. In coal research they had moved forward significantly in such important fields as coal blending, fluidised combustion and conversion technology.

"All these efforts are designed to provide the country with an expanded and technologically advanced coal industry as we move toward the end of the century and are called on increasingly to substitute for other fossil fuels which may then be in diminished supply in relation to demand," said Sir Derek. "The *Plan for Coal* is an essential element in building up security of energy supplies in the longer term — it is an insurance policy for the future. It is a vital objective which justifies the heavy cost of the investment. The damage caused by a possible shortage of energy is infinitely greater than the disadvantage of possible temporary surpluses."

The NCB report says electricity sales in 1978-79 were 4.5 per cent higher than in 1977-78 and this led to an increase of 3.4 million tons of coal equivalent (3 per cent) in total power station fuel use. Technical problems depressed the output of nuclear electricity, and the use of natural gas was restricted; coal and oil therefore met all the increase in power station fuel requirements. The coal burn was 4.4 million tonnes or 5.7 per cent up on 1977-78 and represented more than 70 per cent of total power station fuelling. □

INSTITUTION OF NUCLEAR ENGINEERS CELEBRATES TWENTIETH BIRTHDAY

October marks the 20th anniversary of the formation of the Institution of Nuclear Engineers.

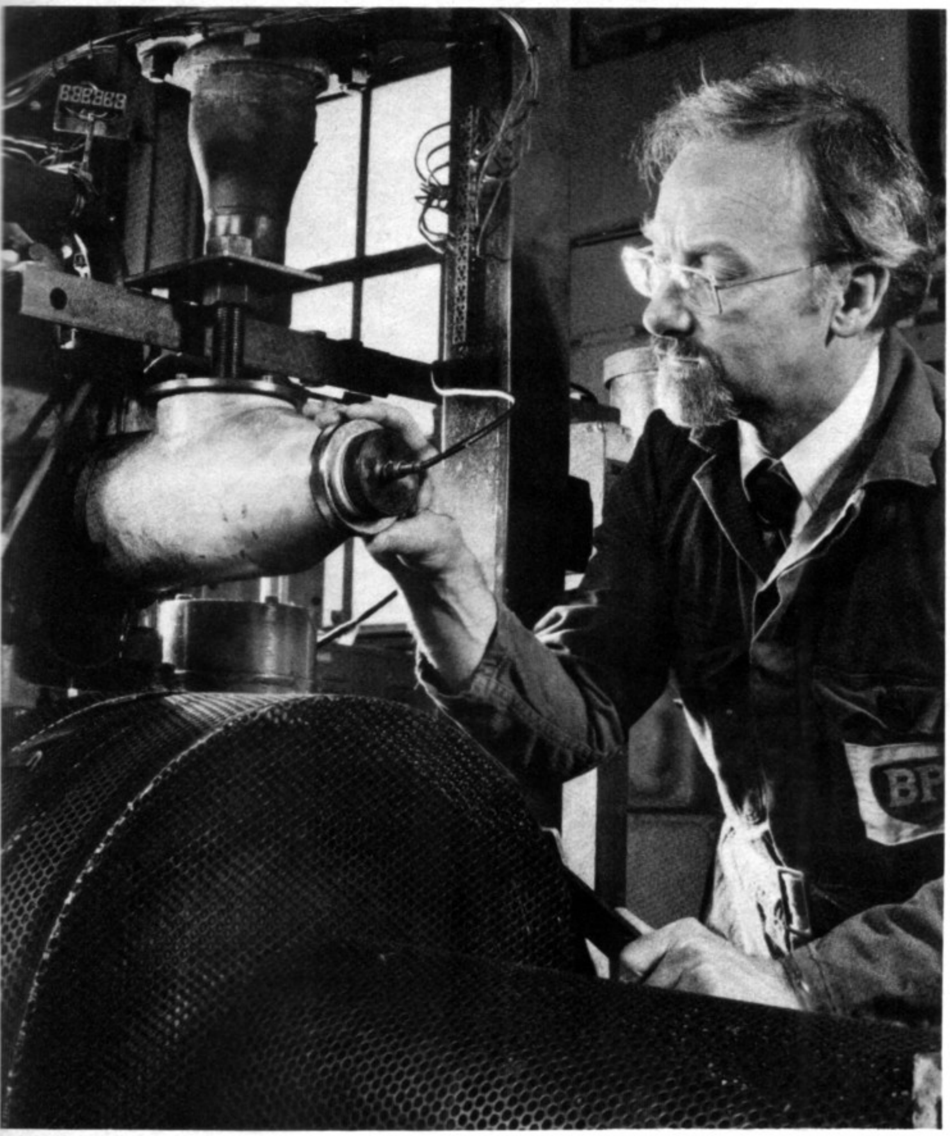
In a special message to the Institution — which is to be published in the October issue of its *Journal* — Sir John Hill, chairman of the UKAEA, recalls his pleasure at being elected an honorary Vice-President of the Institution. "I have the greatest regard for the part the Institution has played in the development of nuclear power and, in particular, the contribution it has made to the better understanding of nuclear power among informed opinion in this country," he writes.

"1979 is also a significant anniversary year for the UKAEA — our Silver Jubilee, in fact — and you were kind enough, with the British Nuclear Energy Society, to invite me to give a lecture in April to mark this occasion. These anniversaries remind us that the study of nuclear power is no longer a new science. We have already a history behind us — a history which we can, I think, look back on with some pride. We have been able to bring to fruition a new source of power which has shown itself to be economically attractive and I am sure environmentally preferable to alternative energy sources. This has been achieved just at the time that the world is facing the prospect that supplies of the fossil fuels will be unable to meet the needs of a world population growing by 100 million a year and increasingly intolerant of the hardship under which so many are obliged to live.

"There have been difficulties and accidents too, in the course of this development. There will no doubt be others in the future. There are risks involved in the use of nuclear power as there are in the use of other forms of energy and, indeed, in all human activities. The 'invisibility' of radioactivity however makes it difficult for people to make their own assessments of risks to set against the benefits of abundant energy supplies and it is the public attitude to the acceptability of nuclear power and not the pace of technical development that now controls our rate of progress. Public acceptance of nuclear power depends upon public understanding of the issues or at least their being satisfied on all safety matters. It is here particularly that the Institution of Nuclear Engineers, and similar bodies, have a vital role to play."

The anniversary falls on 23 October; on the evening of 25 October there is to be an Anniversary Lecture at the Royal Institution, Albemarle St, London, on 'The World Energy Situation and the Response of the European Community' given by L. Williams, Director-General for Energy in the Commission of the European Communities. The Institution's AGM is to be held the following day.

Further information may be obtained from the Secretariat of the Institution at 1 Penerley Rd, London SE6 2LQ, tel. 01 698 1500. □



Tribologists at the BP Research Centre, Sunbury on Thames, are finding that the Thin Layer Activation method of wear measurement developed at Harwell gives them highly accurate results far more rapidly than previous methods they have used for cylinder liner wear testing.

Using TLA they are able to obtain wear rates to within 0.01 μm per hour after running Caterpillar diesel engines for only ten hours. This compares with 120 hours running — plus a week for stripping down and rebuilding — needed using previous test techniques in which piston rings were measured for wear.

They also find TLA a more accurate method of testing wear because they can change the oil or fuel in the engine without interfering in any other way with the lubricant regime. Using the previous techniques, which included stripping down and rebuilding the engine, they found that there was an inherently high variability in test results because of small variations in the new parts and subsequent variations during the running-in period.

An alternative technique, neutron activation of parts of interest, which had been used regularly at BP, needs a specially equipped laboratory because radiation levels are higher. TLA has the advantage that it uses only very low levels of activity. Only 5 microcuries of activity are induced in each cylinder liner, by irradiation in the Tandem accelerator at Harwell. The difference in activity caused by wear at the spot which has been irradiated is then measured by means of a scintillation counter mounted against the engine. Wear is calculated from the difference figure.

The BP Research Centre is one of half a dozen or so leading UK research laboratories that are using the TLA method for the rapid and accurate measurement of wear rates. Other labs include the Shell Thornton Research Centre [see ATOM, July 1979, No. 273, p. 194] and the SGRD laboratories of the Lucas Group.

The BP Sunbury team is using TLA as well to measure cam follower wear in a test rig. Here again, they find that TLA has the two advantages of involving a very small amount of activity, and having good repeatability as a result of being able to perform short tests under unchanged conditions. □

AEA REPORTS

The titles below are a selection of the reports published recently and available through HMSO.

AEEW-M1663 *Absolute calibration of the Rh-103 (n,n') Rh-103m reaction rate.* By W.H. Taylor, M.F. Murphy and M.R. March. May, 1979, 18pp. HMSO £1.00. ISBN 0 85182 043 3

AEEW-M1684 *A simple method of fitting ill-conditioned polynomials to data.* By A.N. Buckler and J. Lawrence. April, 1979. 16pp. HMSO £1.00. ISBN 0 85182 045 X

AERE-R 9266 *A Harwell 6000 series microprocessing system.* By G.I. Phillips. February, 1979. 38pp. HMSO £1.50. ISBN 0 70 580860 2

AERE-R 9441 *Radioactive fallout in air and rain. Report to end of 1978.* By R.S. Cambray, E.M.R. Fisher, K. Playford, J.D. Eakins and D.H. Peirson. May, 1979. 50pp. HMSO £1.50. ISBN 0 70 580601 4

SRD-R-149 *World-wide data on the incidence of multiple-fatality accidents.* By L.S. Fryer and R.F. Griffiths. April, 1979. 34pp. HMSO £2.00. ISBN 0 85 356122 2

AERE-R 9024 *Chemical studies of the upper atmosphere using Concorde aircraft. Part 1. Design, construction and testing of air sampling equipment.* By F.J. Sandalls. February, 1979. 32pp. HMSO £1.50. ISBN 0 70 580840 8

AERE-R 9298 *Transmutation and activation of fusion reactor wall and structural materials.* By O.N. Jarvis. January, 1979. 82pp. HMSO £2.00. ISBN 0 70 580800 9

ND-R-259(R) *The safe transport of radioactive materials.* By W. de L.M. Messenger. February, 1979. 17pp. HMSO £1.00. ISBN 0 85 356120 6 □

IN PARLIAMENT

IN THE COMMONS

LWR timetable

27 July 1979

Mr Skeet asked the Secretary of State for Energy what is the timetable for the acceptance, construction and commissioning of the UK's first light water reactor for power generation.

Mr John Moore: The intention to build a pressurised water reactor in the UK is subject to satisfactory completion of design work and to all necessary Government and other consents being obtained. The Central Electricity Generating Board and the Nuclear Power Company are still considering the options for licensing PWR technology in the UK and the earliest date for a start on site would be 1982. It is too soon to say how long construction would take.

New generating capacity

27 July 1979

Mr Marlow asked the Secretary of State for Energy if he would give comparisons of the capital cost of new generating capacity in p/kWh for oil-fired, coal-fired and nuclear generators, breaking down the costs into loan, depreciation and maintenance and setting out the period of write-off in each case.

Mr Lamont: Calculations of the capital costs of new generating capacity in p/kWh depend upon the method used and assumptions made. I am advised by the CEGB that, as an example, on the basis of the capital costs of Heysham II and of completing Drax . . . converted into annuities at the required rate of return of 5 per cent and divided by units supplied at an assumed annual load factor of 75 per cent give:

	p/kWh
Heysham II	0.80
Drax completion	0.40

The annuity covers the cost of depreciation and return on capital over the writing-off period which in the case of Heysham II is taken as 20 years and for Drax completion 25 years.

The CEGB has not ordered an oil station recently. There is no reason to think that the maintenance costs per kWh will differ significantly from those shown for different types of station in 1977-78.

Government assistance

27 July 1979

Mr Michael McGuire asked the Secretary of State for Energy if he would give details of the total amount of money which the coal industry and the nuclear power industry have received from various Governments since 1955.

Mr Lamont: The total amount of net identifiable grants voted and paid to the National Coal Board from 1954-55 to 1978-79 inclusive was £1086.9 million.

The total amount of loans made to the National Coal Board between 1 January 1955 and 31 March 1979 and either written off or outstanding on 31 March 1979 was £1349.1 million.

Sums paid to private coal mining companies have been negligible. The net total of grants voted and paid to the UKAEA from 1954-55 to 1978-79 inclusive was £1626.7 million. This sum includes a repaid loan of £4 million and small amounts of expenditure on grants in aid, subscriptions to international bodies and so on.

The figures of voted payments for 1978-79 included in those shown above are provisional and subject to minor amendment.

Radioactive waste disposal

27 July 1979

Mr Paul Dean asked the Secretary of State for the Environment what area of Somerset is to be involved in the geological research programme connected with the disposal of high-level radioactive waste.

Mr Heseltine: It is too early to say. I will, however, ensure that Mr Dean is informed if and when a specific site is selected for geological investigation. As I said in reply to a question on 24 July, exploratory work, including test borings, will be the subject of appropriate planning procedures and publicity will be given to the proposals.

IN THE LORDS

Air transport of plutonium

24 July 1979

Lord Hylton asked what would be the probable consequences of a crash at take-off, landing or during flight of an aircraft carrying plutonium fuel from Windscale to Dounreay and what plans are in existence to deal with such a contingency.

The Earl of Gowrie, Minister of State at the Department of Employment, said: The nuclear fuel assemblies for PFR which are carried by air between Windscale and Dounreay enclose numbers of fuel rods containing heat resistant ceramic pellets of uranium with approximately 30 per cent of plutonium oxide. The assemblies are carried in containers specially constructed, tested and certified to international standards designed to ensure that material would be contained in an accident. It is therefore considered that even in an extreme accident the pellets are unlikely to be released.

Contingency plans exist to deal with any air crash. Should such a crash result in a possible radiation hazard to the public prompt specialist assistance would be provided under the National Arrangements for Incidents involving Radiation (NAIR) scheme.

Fuel transport

26 July 1979

Lord Hylton asked what contingency plans exist to cope with a derailment or collision affecting trains carrying radioactive waste from nuclear power stations to Windscale; what would be the probable consequences if such an accident occurred in the thickly-populated parts of London, through which the trains pass; and what consultations have recently been held with local emergency services, especially in London.

Lord Bellwin: Irradiated nuclear fuel is transported from power stations to Windscale in accordance with very high safety standards laid down in international regulations. These regulations require the massive flasks used to meet the specified performance standards which would enable them to withstand severe impact and fire conditions. A derailment or collision of a train carrying such a fuel flask in a thickly-populated part of London would thus not put public safety at risk.

Nevertheless, there are detailed plans to cater for the unlikely event of an accident. These plans, which have existed for many years, are nationally applicable and are rehearsed and kept under constant review. Each rehearsal involves the emergency services in the area concerned, who are subsequently consulted about the lessons to be learned from the exercise and about any needs which may emerge to modify the national plans.