# ATOM

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Contents



**ATOM**
monthly bulletin of the U.K.A.E.A. is distributed to the staff of the Authority, to similar organisations overseas, to industrial firms concerned with the exploitation of nuclear energy, to the Press and to others to whom a record of information of the work of the Authority may be useful.


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# New reactor company

*The following press release was issued by the Industrial Reorganisation Corporation, on Monday, 16th September, 1968.*

IT is announced by Babcock & Wilcox Ltd., English Electric Co. Ltd., Taylor Woodrow Construction Ltd., the U.K. Atomic Energy Authority and the Industrial Reorganisation Corporation that they have agreed to establish a new company to design and construct nuclear reactors and power stations at home and abroad. This company will be one of the two such companies envisaged in the Minister of Technology's statement of 17th July, 1968. It will take over the business of Nuclear Design and Construction Ltd., on terms to be agreed, and will bring together the appropriate reactor design and construction capabilities of the U.K.A.E.A. and of N.D.C. If the talks already begun between the C.E.G.B. and N.D.C. concerning the contract for the nuclear power station at Hartlepool are successfully concluded, it is anticipated that the C.E.G.B. will place the order with the new company.

The new company will have its headquarters at Risley and offices at Risley and Whetstone: the chairman will be Mr. Hector McNeil.

The new company's share capital will be held in the following proportions— Babcock & Wilcox Ltd., 25%; English Electric Co. Ltd., 25%; Taylor Woodrow Construction Ltd., 4%; U.K. Atomic Energy Authority, 20%; Industrial Reorganisation Corporation, 26%. If in accordance with the July statement of the Minister of Technology, a nuclear fuel company is formed, it is the intention that the A.E.A. shareholding should pass to this company. The proposal for an I.R.C. shareholding arose from a general wish to proceed with the reorganisation of the industry despite current uncertainties. The I.R.C. intends to dispose of its investment within 18 months to one or more of the other shareholders in consultation with them.

All necessary preparations are being made for the earliest possible establishment, staffing and operation of the new company.

# Hartlepool power station

*The following extract is from the press notice issued by the Ministry of Power on 21st August, 1968.*

On 21st August, 1968, Mr. Roy Mason, the Minister of Power, gave the Government's consent to the CEGB's application to build an additional nuclear power station at Hartlepool with a capacity of 1,250 MW.

It is hoped that construction work on site with the extra employment it brings will start in the late autumn or early winter, that the station will be operating in 1973/74 and will be fully commissioned in the year after that. Construction will provide employment reaching a peak of 2,400 men by 1971 and the station when commissioned will mean continuing employment for 450 men.

The Government gave careful and sympathetic consideration to the case for a coal-fired station and in examining the choice between the different fuels they took full account of the wider economic factors including in particular the effect of the decision on employment. Their conclusion was that in this particular case nuclear power clearly had the advantage over coal from the point of view of the nation as well as that of the CEGB.

This decision does not pre-judge how future stations should be fuelled. It must too be kept in perspective. There are 12 new coal-fired power stations being constructed or commissioned by the CEGB, at present with total capacity of about 20,000 MW and by 1973/74, 46,000 MW (70% of total capacity) will be coal-fired.

**Background**

The Government have decided that the CEGB should be authorised to start one new power station this year. Apart from the importance of ending uncertainty over the Hartlepool project, this will avoid a bunching of power station orders next year with probable higher costs and difficulties in getting stations finished on time; and the start will be made when there is a shortage of orders for the heavy electrical plant industry. It will bring additional employment to Teesside in the coming winter. And this additional very efficient generating capacity will lead to reductions in CEGB costs when it is commissioned.

The CEGB preferred Hartlepool for their next station because of the growing need for power in the Teesside area; if a new power station were not completed there by the mid-70's further grid transmission lines would be needed to bring in power from other parts of the country. This would mean extra cost and damage to amenities. The Government found this case compelling.

*Relative costs to the CEGB of coal and nuclear power*

It is important to bear in mind the following points.

First, the calculations for the Hartlepool stations have been done on the same basis as the comparisons of nuclear and conventional generating costs in the White Paper on Fuel Policy (Cmnd. 3438) and in the Ministry of Power's evidence to the Select Committee on Science and Technology; the Government have seen no reason to change the method of comparison.

Second, in considering the costs of coal-firing it is essential to take full account of " system " costs both to the CEGB and the NCB. A nuclear power station at Hartlepool will not displace any of the low cost coal that is available because this will be used elsewhere in the generating system. It will replace expensive coal from the most costly pits which would only be kept in production if a coal-fired station were to be built. The CEGB have stated that the coal offered at the specially low price of 3½d. a therm for Hartlepool is acceptable to them for use at other stations.

Third, running costs for nuclear power are only about a third of those for a coal-fired station, the exact ratio depending, of course on the relative prices of uranium and coal. But nuclear power stations are more expensive to build than coal-fired stations. Thus for a station at Hartlepool, it is estimated that with a capacity of 1,250 MW, the construction costs of a nuclear station will be £91 million as compared with £76 million for a coal station. Allowing for interest during construction and for the initial charge of nuclear fuel these totals would come to £125 million for the nuclear station and £89 million for the coal one.

With the very different capital and running costs for the two fuels it was necessary to work out total costs for the life-time of each station. This involved calculating how much use would be made in the CEGB system of the two types over their lifetimes. Under the system of merit order operation, in order to minimise costs, stations are brought into operation in ascending order of running costs so that the most expensive stations of all operate only at peak times. With the higher running costs of a coal-fired station it would not be loaded as highly as a nuclear station. While on base load it would burn about 3m. tons of coal; operating on merit order, the quantity would be much less.

The CEGB's assessment based on current prices is that nuclear power would give them a financial advantage over the life of the station averaging £3¾ millions a year, equivalent at present value to about £37 million. The cost per unit of a nuclear station assuming an average load factor of 75% would be 0.52d., and for a coal-fired station with the same load factor the cost would be 0.70d. per unit.

*The national advantage*

The Government has made a thorough examination for which the CEGB and NCB readily supplied much information. This examination covered not only the comparative costs of nuclear and coal-fired generating but also the wider economic factors involved, i.e., resource costs.

Full account has been taken of possible reductions in coal costs at relevant collieries indicated by NCB, of a higher price for the initial charge of uranium fuel, and of the effects on employment and on the railways. The estimates of nuclear costs included the royalty payable to the AEA on the Advanced Gas-Cooled Reactor process which should amply cover all forward avoidable costs likely to be incurred by the AEA in the further development work for the second nuclear power programme; this is the relevant consideration in calculating resource costs.

Full account has also been taken in the Government's overall assessment of the relative effects of a nuclear and of a coal-fired station in terms of employment both in the immediate future and further ahead. Construction work on a nuclear power station at Hartlepool will provide employment starting in the coming winter, and reaching a peak of 2,400 men by 1971. The greater part of the labour required during construction is expected to be recruited locally. To build a coal-fired station would require rather fewer men—at peak about 1,900. Such a station could probably not be started for about 12 months; so that it would not be till the middle and later 1970's that it would be burning coal and so affecting employment in the mines by which time there will be other developments in the Region as a result of Government regional policies. Both types of station need more than 450 men to operate them.

The Government's conclusion is that after taking into account all these factors entering into the total cost to the community, the net advantage to the community of a nuclear station at Hartlepool as compared with a coal-fired station remains substantial. The rate of return to be expected on the extra capital expenditure on a nuclear as compared with a coal-fired station is also substantially above the minimum looked for on such projects.

The cost figures are likely to vary with changes in prices and for other reasons; but the Government is confident that any likely rise in costs would not alter materially the relative advantages of nuclear power over coal in this case.

## Strontium-87m for bone scanning

Strontium-87m has proved an increasingly useful scanning agent for a variety of bone diseases and is an improvement on strontium-85. It has a short half-life (2.8 hours), emits monoenergetic gamma-radiation of 388 keV, no beta-particles, and decays to stable strontium. The gamma energy gives a reasonable balance between adequate tissue penetration and ease of collimation. The radiation dose to the patient is a very small percentage of that delivered by the same activity of strontium-85. Thus, much larger activities may be administered, leading to more rapid scanning (and hence minimum patient discomfort) and improved scan quality. The use of strontium-87m in bone scanning is described in Technical Bulletin 68/11, available from the Radiochemical Centre, Amersham, Bucks.

# Biomedical technology

*by F. E. Whiteway, Authority Project Officer on Medical Engineering, A.W.R.E., Aldermaston.*

The Authority has always maintained close collaboration with medical organisations such as the Medical Research Council on matters relating to atomic energy, for example on the biological effects of radiation. Radioisotopes and labelled compounds produced by Amersham have found widespread use in the medical field. Radiation instruments developed initially in the Authority and now marketed commercially, are being used in hospitals. There have also been various *ad hoc* contacts between individuals of the Authority and hospital staff, often in the nature of giving advice on materials or instrumentation. During the last few years, as part of their diversification programme, A.W.R.E. staff have been providing assistance to the Ministry of Health on non-nuclear research and development; this has now reached a substantial scale, and forms the subject of this article.

The first contract from the Ministry of Health was for the development of an artificial hand controlled by myo-electric signals.(1) This contract was placed at A.W.R.E. by the M.o.H. Limb Fitting Centre at Roehampton, and was followed by contracts to engineer the hand for production, to develop a compatible split hook, and to develop an improved prosthetic ankle joint.(2) In July 1965 a meeting was held between representatives of the Medical and Supply Divisions of of the Ministry of Health and the Authority to explore a much wider range of work which A.W.R.E. might undertake in support of the M.o.H. It was realised that A.W.R.E., being a large multidisciplined R. & D. establishment, could be of considerable help in the similarly multidisciplined field of Medical Engineering. Further meetings and visits followed and in April 1966, a sum of £20,000 was allocated by the M.o.H to cover support by A.W.R.E. in the financial year 1966-67. The programme increased rapidly, a sum of over £100,000 being made available during 1967-68; this figure is likely to double in the current financial year.

**Organisation of project**

The author was nominated as Authority Project Officer on Medical Engineering (now referred to as 'Biomedical Technology') in December 1965. Dental applications, which at first involved only the Chemical Technology Division at A.W.R.E., are the responsibility of a separate Project Officer in that Division. The officers responsible for the project in the Ministry of Health are Dr. G. E. Gale, Director of the Scientific and Technical Services Branch of the Supply Division, and Dr. Eley, a Principal Medical Officer in the Medical Division. The programme is controlled by a committee chaired by Mr. J. F. Hunt, Under-Secretary and Controller of the Supply Division. Individual tasks may be initiated in one of several ways. Firstly, problems arise within the National Health Service, for which the M.o.H. are either directly responsible, or are called in to help. Secondly, the M.o.H. initiate research and development work aimed at improving equipment and techniques used in hospitals, often on the advice of committees or consulted advisors. Thirdly, A.W.R.E. may submit proposals to the M.o.H. in the form of extensions to work already undertaken or on new work resulting from collaboration with hospital or university staff. In each case, the communication link between M.o.H. and the U.K.A.E.A. is between Dr. Gale and the Project Officer. It is part of the responsibilities of the Project Officer to discuss with the most appropriate Division within A.W.R.E. and elsewhere in the Authority new requests as they are received, to arrange and often attend initial meetings, and generally to act as a catalyst until the task has been initiated. As soon as possible, an officer is appointed in the Division most concerned to be responsible for the new task, including the enlistment of aid from other Divisions, the preparation of the financial estimate in collaboration with the Costs Branch, and the issuing of progress reports. The Project Officer keeps an overall watch on finance and progress, taking action where appropriate. He is responsible for keeping the M.o.H. informed on progress and expenditure, and reviewing the programme with them from time to time.

**Arrangement of staff**

As indicated above, staff remain in their original branches, instead of being extracted to form a special project team. This has the following advantages:

(a) Staff are close to their facilities. This is of particular importance in the Materials Department, where expensive facilities such as the stereoscan microscope and electron probe analyser are used on the medical programme.

(b) Staff benefit from the experience and stimulus of a much larger group in their own discipline.

(c) It facilitates the use of staff working part-time on other projects. For example, expert advice and assistance are being given to the M.o.H. on problems involving data handling and analysis, although the amount of work at present would not justify any full-time staff.

**Collaboration with hospitals and medical research groups**

To be effective, close collaboration must be maintained between A.W.R.E. staff working on the M.o.H. programme and hospital and medical research teams. This is important so that staff may gain a true appreciation of the clinical problems and the conditions under which equipment is used; also clinical and biological tests are required which need access to facilities which are not available at A.W.R.E. Staff in the Applied Physics Division are collaborating with a consultant at Guy's Hospital on the problem of clearing obstructions in the femoral artery, and with another at St. Martin's Hospital, Bath, on infra-red scanning techniques. They are studying patient monitoring systems for use in operating theatres and intensive care wards in collaboration with staff at the Middlesex Hospital; this has involved frequent visits to the hospital, including attendance at operations. Staff in the Materials Department are collaborating with a consultant at the Royal National Orthopaedic Hospital, Stanmore, on the corrosion of metal implants, and with staff at the Eastman Dental Hospital on the development of dental materials and instrumentation. Research and development on artificial kidneys is being carried out in association with Leeds University and Leeds Royal Infirmary. Many of the hospital staff involved are medical consultants, but there is growing collaboration with hospital physicists and biochemists, whose work is complementary to that at A.W.R.E.. For example, the development of solid state detectors for use in gamma cameras is a joint task involving physicists at both the Royal Marsden Hospital and A.W.R.E. Recently, a short symposium and exhibition was arranged at A.W.R.E. for the South Western Group of the Hospital Physicists Association.

**Collaboration with NRDC and industry**

Since most of the programme is almost new, very little equipment has reached the final prototype stage. An exception to this is a small hand-held audiometer for screening babies' hearing ability. This task arose prior to the present M.o.H. contract as a result of one of the *ad hoc* contacts referred to above, and is now being produced commercially. Engineered prototypes of the artificial hand and associated electronics have been produced with drawings, specifications and test equipment which would facilitate further quantities being made commercially. As future tasks approach the manufacturing stage, N.R.D.C. will be consulted concerning suitable firms to undertake production. N.R.D.C. will also hold most of the patents arising from work undertaken for the M.o.H. except where it is more appropriate for the Authority to carry out the exploitation, i.e., where the development has resulted mainly from experience in the atomic energy field.

Another aspect of the programme which will benefit industry, as well as providing direct assistance to hospitals, is the scientific and technical assessment of commercial equipment. For example, a number of artificial kidney systems and echo-encephalographs are at present being assessed at A.W.R.E. Although less exciting than some of the more fundamental research and development work, this type of work is equally important and requires high calibre staff. Its purpose is more than to provide a much-needed service of technical advice to hospitals; it is also aimed at determining what improvements could be made, and at drawing up specifications to guide manufacturers in the design of new models.

**Publicity**

A press statement(3) on the collaborative programme was issued by the M.o.H. in March 1968. This was followed by a press conference at A.W.R.E. attended by scientific correspondents of most of the leading papers, as well as one or two medical journals. In addition to talks by the Director of A.W.R.E., by Dr. G. E. Gale and senior A.W.R.E. staff amplifying the press statement, an exhibition of work in progress was shown. This was filmed by I.T.N. and B.B.C. camera teams. The resulting publicity has made the work known more widely, and should lead to collaboration with a wider range of hospitals. Also, it should have done much to dispel early misunderstandings of the role of A.W.R.E. in this field.

**Programme of work**

The present programme of work at A.W.R.E. involves 14 sections in 7 divisions, notably the Chemistry, Chemical Technology and Applied Physics Divisions. It is not possible to describe all the work in detail here; the following summarises the salient features of the programme.

*(a) Artificial kidneys*

Two senior personnel of the Chemistry and Chemical Technology Divisions are members of a M.o.H. Forward Looking Committee on artificial kidneys. As part of A.W.R.E. work on this committee, proposals were submitted for an R. & D. programme on sorption type materials (examples of which are charcoal and ion exchange resins) for removing metabolites directly from blood or from the rinsing fluid in a dialyser; this should lead to the development of more compact artificial kidneys. Proposals were also submitted for comparative studies on the nature of metabolites in normal and uraemic serum, with a view to identifying those of most importance for removal from the body. It is hoped that this would lead to a better understanding of the characteristics required of membrane and sorption materials to achieve more effective clinical treatment. These proposals were accepted, and work is now in progress on both problems in the Chemistry Division. Staff in the Chemical Technology Division are assessing commercial artificial kidney systems, with the aid of the Applied Physics Division in the electronic evaluation. They are also engaged in some component development work and on drawing up specifications for new systems. However, there are no plans for designing complete artificial kidney systems at A.W.R.E.

*(b) Corrosion studies on surgical implants* (2)

Staff in the Chemistry and Metallurgy Divisions are engaged in a research programme on the factors influencing corrosion and failure in metals and their alloys used for implants, which are finding increasing application in surgery. Electrochemical procedures are used for measuring the corrosive effect of physiological fluids, and the extent to which this is affected by composition, cold work and surface finish. Metallurgical techniques involving the use of the stereoscan and other advanced physical equipment are being applied to determine the mode of failure of implants where this has occurred in the patient. The main object of the programme will be to advise surgeons on the most suitable materials for implants and, where appropriate, to prepare specifications aimed at controlling manufacturing processes and subsequent handling techniques.

*(c) Toxicity of plastics*

Plastic materials are also being used in increasing quantity in implants (e.g. cardiac pacemakers), in equipment handling blood, and in disposable syringes. There is a need for more information on the possible toxic effects that may arise from the use of these materials. Following a feasibility study, staff in the Chemistry Division have begun an experimental programme aimed at identifying substances leached from the plastics, and determining the extent to which the extract is cytotoxic. This involves the use of cell and tissue culture techniques. The physical nature and surface structure of the plastic is another important parameter influencing the behaviour of the body, and arrangements are being made for a research worker, supported by the M.o.H.,

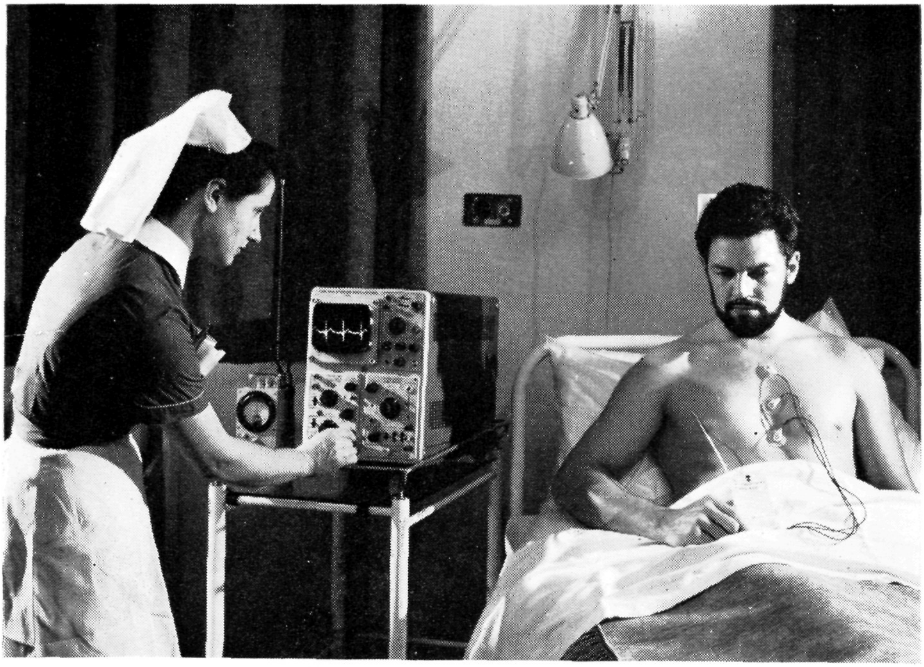


**Fig. 1.** *Patient monitoring: Radio telemetry equipment which is being developed to provide information about the functioning of a patient's heart before, during, and after surgery.*

to use the stereoscan microscope in this investigation. Ultimately, it is hoped to provide the M.o.H. with the information necessary to define specifications aimed at control of the material selection and manufacture of plastic products used in medicine, for which legislation is pending. The studies will also provide information on the type of composition most likely to withstand the body's environment.

*(d) Artery clearance*

Staff in the Applied Physics Division are investigating two proposed methods for clearing arterial obstructions. The first uses laser energy to vaporise the obstruction. The second method originated in A.W.R.E. and involves the use of a drill specially developed for the purpose. The design is analagous to an oil drilling rig, with a metal bit driven at high speed by a flexible drive shaft inside two concentric flexible plastic tubes. The drilling debris is removed by saline circulating down the inside tube and back between the two tubes. Animal experiments are in progress and appear to be encouraging.

*(e) Optical instruments*

Part of the expertise acquired by the Optics Branch is in the fabrication of coherent and incoherent fibre bundles. Members of this branch are currently engaged in developing a fibre gastroscope(2) with a controlled flexible distal end, and illumination from an external light source. They are also studying the feasibility of designing small diameter endoscopes for applications such as exploring arteries and veins. Other staff are skilled in holographic techniques, and have demonstrated that a group of radiographs taken from a series of different viewpoints can be multiplexed on to a single photographic plate using holographic techniques to provide a three dimensional reconstruction. They have applied similar techniques to ultrasonic images.

*(f) Patient monitoring*(4)

Studies are in progress in the Applied Physics Divison on patient monitoring systems for use in hospitals. Many types of equipment are already available commercially, including large, sophisticated systems. The objectives of this study are to establish the essential parameters which require monitoring, to investigate the feasibilty of establishing physical and electrical standards in order to provide compatibility between units, and to compare available transducers and methods for transmitting, analysing and displaying the data. A radio telemetry system (Figure 1) has already been designed to

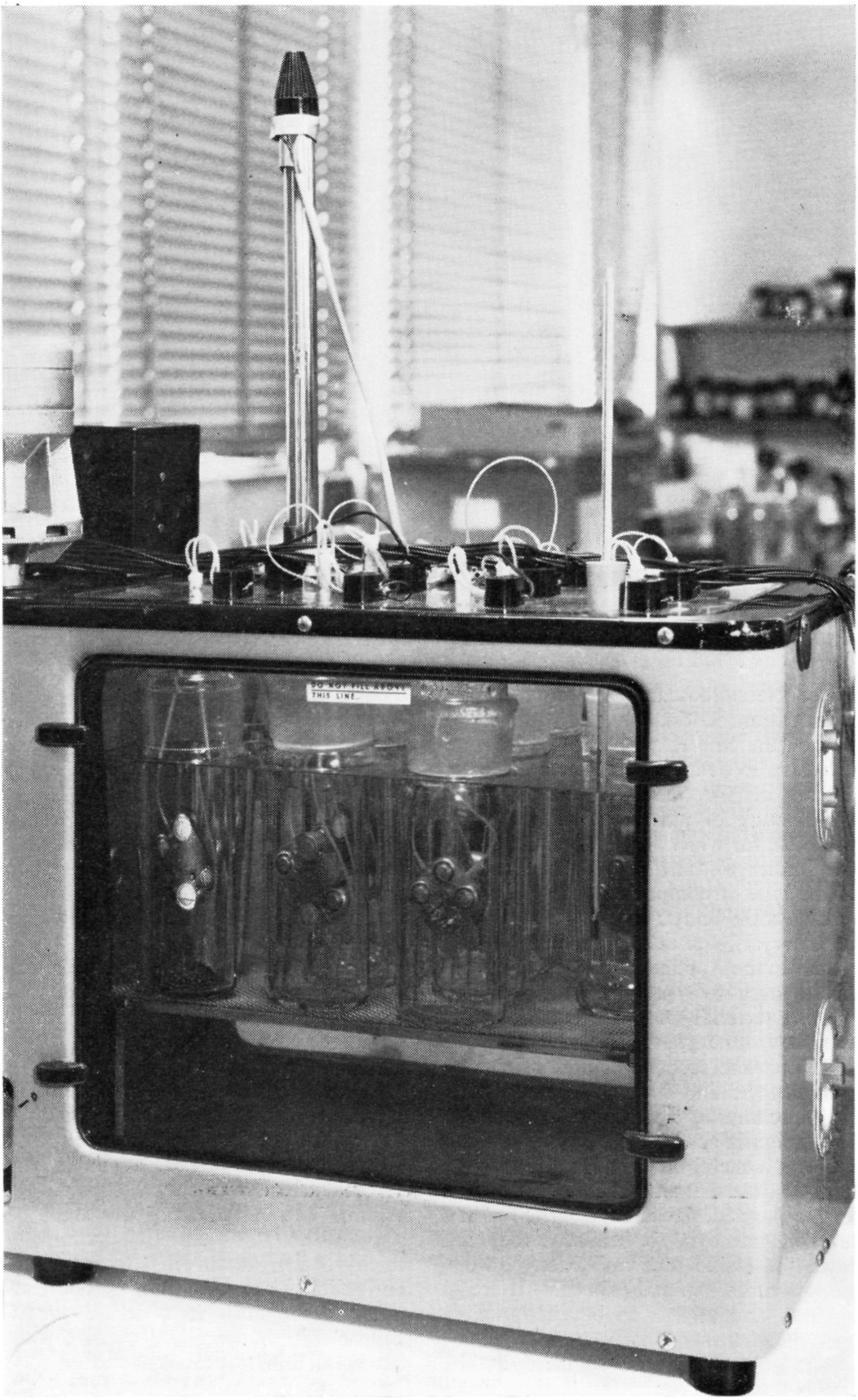


**Fig. 2.** *Test tank, with cardiac pacemakers undergoing life tests in simulated body environment.*

test the feasibility of transmitting essential parameters from a patient throughout movement from the ward, induction of anaesthesia, surgery, and movement to an intensive care ward.

*(g) Assessment of echo-encephalographs*

These ultrasonic instruments are being evaluated for their application to the measurement of the mid-line position of the brain, which provides valuable diagnostic information in accident cases who may have sustained internal head injury. A.W.R.E. staff are responsible for carrying out engineering and functional assessments. As part of their programme they have designed a special test tank simulating the clinical application to permit the measurement of sensitivity, spacial resolution and other parameters. This design involved investigation into materials which are similar acoustically to the various tissues and structures present within the skull. The programme involves collaboration with the Sheffield Regional Physics Group, who will be responsible for arranging clinical assessment of the instruments.

*(h) Cardiac pacemaker development*

This is in three parts. The first consists of an investigation into the properties of materials used for encapsulating the electronic packages used in implantable pacemakers. Measurements are being made of shrinkage during cure, and permeability to water, with attendant changes in dimensions and resistivity. The programme includes life tests on pacemakers immersed in hot saline (Figure 2).

The second part consists of the development of a new ventricular triggered pacemaker in collaboration with the National Heart Hospital. The third part is the development at Harwell of an isotope power source for pacemakers as part of their isotope generator programme. The output voltage will be too low to drive existing designs of cardiac pacemaker, and the Applied Physics Division of A.W.R.E. have designed suitable voltage converters.

*(i) Thermographs*(2)

Measurement of the surface temperature of patients by infra-red scanning has a number of possible applications, including the diagnosis of breast cancer and vascular defects. Following an assessment made at A.W.R.E. on commercially available instruments, it was decided to proceed with the development of a new scanner with a quantitative display and a scan duration optimised for a single indium-antimonide detector. Techniques have been evolved for the production of inexpensive parabolic mirrors, several of which are incorporated in the design.

*(j) Gamma cameras*

Modern gamma cameras typically use a scintillation detector comprising a sodium iodide crystal viewed by an array of photomultipliers. These systems are now approaching the limit of performance capability, and a feasibility study is in progress at A.W.R.E. on the use of solid state detectors. These have the advantage of direct conversion of gamma photons to electrical output, and high quantum efficiency leading to energy resolution an order better than in scintillation detectors. Encouraging results have already been obtained using orthoganal strip counters. These are made by a newly devised technique involving the machining of grooves on either side of a semiconductor slab. Positional resolution of about $1\frac{1}{2}$ mm is feasible, a significant improvement on existing gamma cameras. Work has now started on developing suitable data handling and display systems.

*(k) Chemical analysis equipment*

Support is being given to the M.o.H. on the assessment of commercial automated biochemical equipment. Also a system has been developed in collaboration with the Churchill Hospital, Oxford, for measuring the coagulation time of blood when treated with various reagents (Figure 3). This information is important in the treatment of haemophilia. Proposals have been submitted to the M.o.H. on the measurement of trace elements in blood, and their possible correlation with ill-health.

*(l) Dental materials and equipment*

The main task on dental materials so far has been the development of new organic and inorganic materials for filling anterior teeth, existing materials having only moderate resistance to mouth acid. Work is now being concentrated on the use of reactive glass fillers from which acid phosphate can be leached to produce insoluble phosphate precipitates with other contituents of the cement mix. Preliminary results are encouraging, showing high strength and low solubility.

Following a successful feasibilty study,

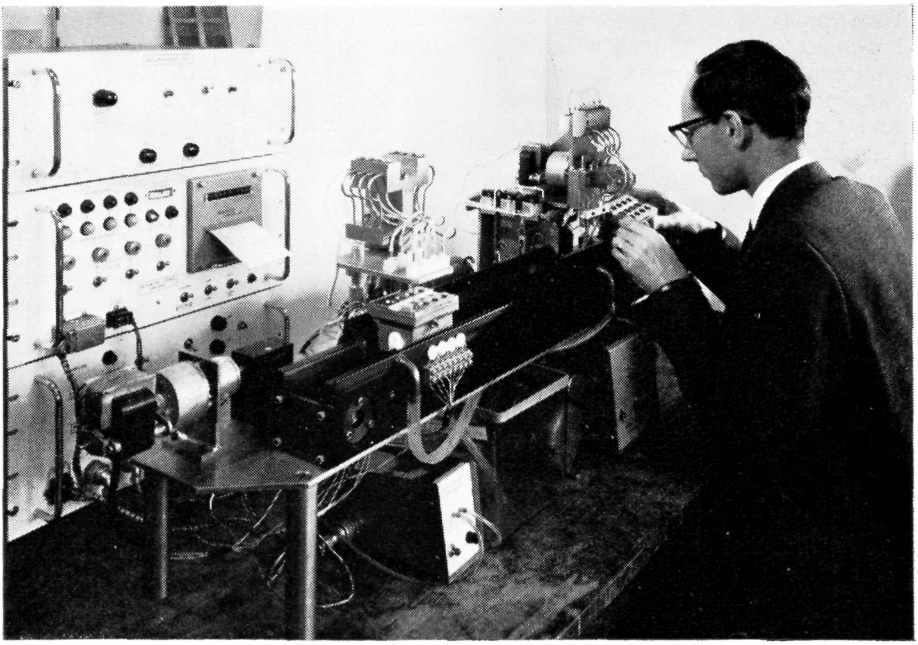


**Fig. 3.** *Automated chemical apparatus for the determination of the coagulation Factor VIII in blood which is significant in patients suffering from haemophilia.*

which led to patent action, work is now in progress on toughening dental porcelains by chemical modification of the surface. A feasibility study has also been completed on toughening denture base polymers by chemical modification to the polymer structure.

Close collaboration has been established with the Eastman Dental Hospital, with whom several studies are in progress.

**Other tasks at A.W.R.E.**

These include the development of an inflatable balloon system for assisting the pumping action of the heart (sponsored by the Medical Research Council), development of methods for assessing the performance of X-ray image intensifier systems, investigations into the use of lasers in surgery (Figure 4), assistance in the assessment of equipment for analysing cervical smears, and experimental work on the interaction of infra-red, visible and ultra-violet radiation on tissue.

**Involvement of other Authority groups**

Although the M.o.H. contract is placed with A.W.R.E. work may be subcontracted to other Groups where it is more appropriate. Proposals by Culham for a feasibility study on sources for neutron therapy have been accepted by the M.o.H., and work has commenced. Proposals have been submitted by A.E.R.E. Harwell for the development of a dialysing unit much smaller than those currently available. The possibility of applying Harwell experience on electro-hydraulic crushing to the removal of large bladder stones is also under investigation.

**Conclusions**

The diversification programme on biomedical technology described above is well matched to the multi-disciplined structure of A.W.R.E. and a wide range of tasks are already in progress. The present arrangement, whereby staff remain in their own Divisions, has proved effective. Further expansion of the programme is expected, with participation of other Groups of the Authority. Collaboration with hospitals and industry in the manner described should contribute significantly to the establishment of a viable biomedical instrumentation industry in the United Kingdom.

**References**


1. ATOM No. 112, Feb. 1966, p.29
2. AWRE News, Jan. 1968, p.18
3. ATOM No. 140, June 1968, p.143
4. AWRE News, June 1968, p.18

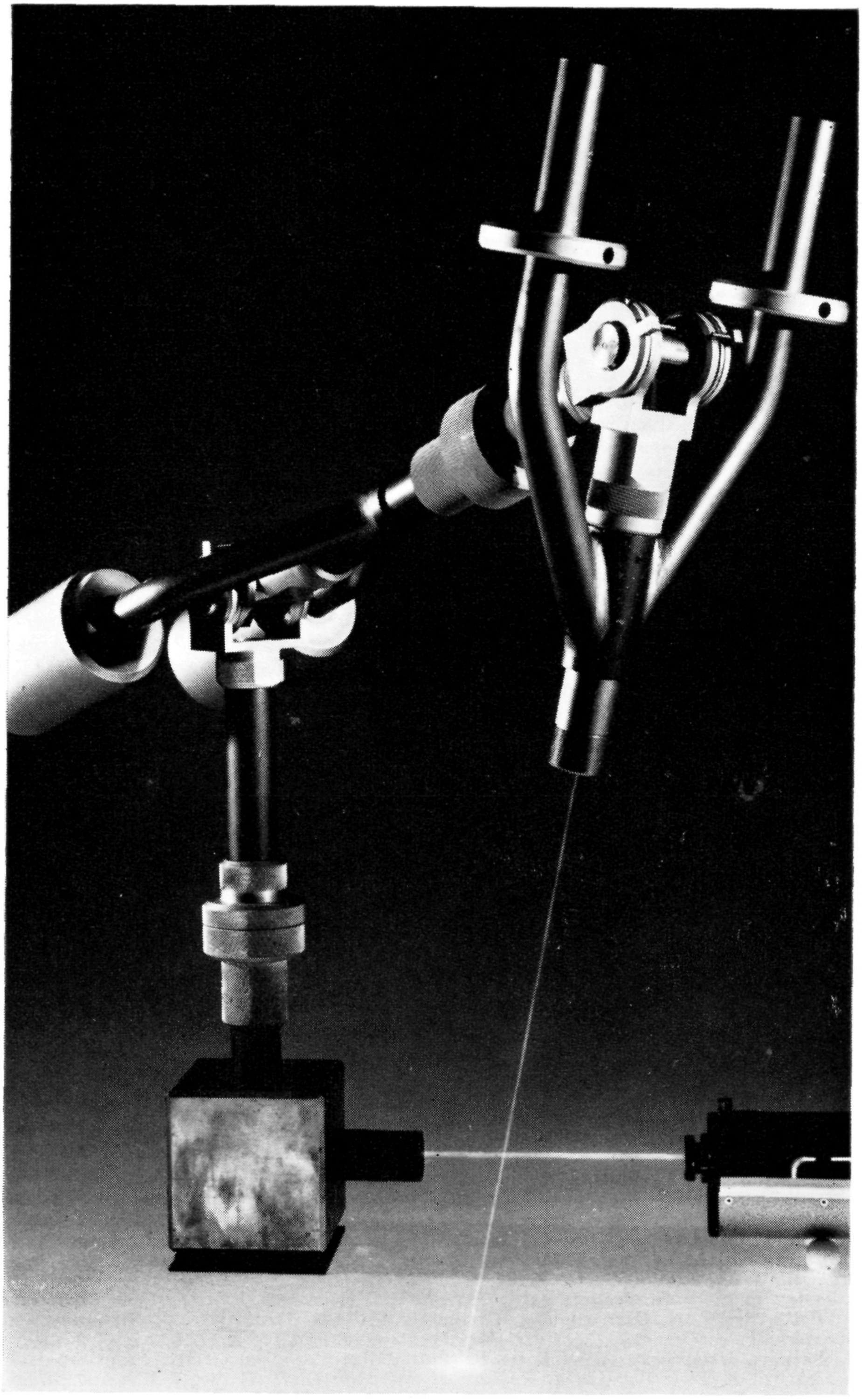


**Fig. 4.** *Laser beam manipulator: experimental apparatus enabling a laser beam to be guided in any direction. An improved model will be designed for surgical applications.*

# A.H.S.B. Reactor Safety Course No. 8

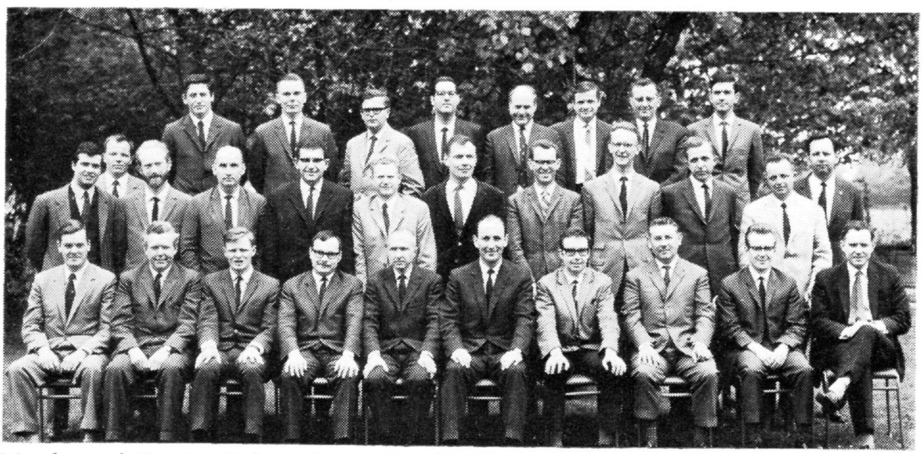
So many applications were received for the U.K.A.E.A. Reactor Safety Course this year that it was decided to hold an extra course in the autumn. The course which is organised by the Authority Health and Safety Branch in collaboration with the Post-Graduate Education Centre, Harwell, normally comprises a maximum of 10 U.K. students and 20 from overseas. By the end of this year some 200 safety specialists from 26 different countries will have attended.

The Eighth Course in this series will be held at Harwell from 2nd June to 27th June, 1969. It is intended primarily for senior engineers and scientists, preferably with several years' experience in reactor design or operation, who are, or will be, engaged on the safety assessment, regulatory control, or inspection of nuclear reactors. It provides an opportunity for safety specialists of different countries to exchange views on reactor safety problems and presents the safety principles and evaluation techniques developed in the U.K.

The principal sections of the course cover the safety aspects of gas-cooled, water-cooled and fast reactor systems; containment engineering; control and instrumentation; and fission product release. Other topics covered are: quantitative techniques of reactor safety assessment; U.K. legislation and safety organisation; siting policies and problems; the analysis and reporting of reactor accidents, and reactor accident simulation techniques. The lecturers are drawn from the U.K.A.E.A., the Central Electricity Generating Board, the nuclear industry and the Universities.

In addition to the lectures, the course comprises discussion periods, films and visits to U.K.A.E.A. reactors and laboratories and C.E.G.B. nuclear power stations. A manual containing notes on some 60 lectures given during the course is sent to participants well in advance of the start of the course for preliminary study.

The course fee is £160, excluding travel to Harwell and accommodation. Some accommodation will be available at Harwell. Further details of the arrangements for the course and application forms may be obtained from D. A. French, U.K. Atomic Energy Authority, Authority Health and Safety Branch, 11 Charles II Street, London S.W.1. The closing date for applications is 28th February, 1969.



*Members of Reactor Safety Course No. 6 held at the Post-Graduate Education Centre, Harwell, from 6th to 31st May, 1968. Back row—left to right: W. Fürste, Germany; A. P. Vuorinen, Finland; A. Isola, Finland; S. Lanes, U.S.A.; B. W. Emmerson, C. E. G. B. Bradwell; S. J. Stachura, U.S.A.; G. H. M. Fieuw, Belgium; A. Valdeyron, France. Centre row—left to right: G. Belardi, Italy; H. Holtbecker, Euratom; P. J. Turton, A.P.C. Ltd; W. Pollis, Brazil; N. Chrysochoides, Greece; W. Ullrich, Germany; P. K. G. Emmersen, Denmark; P. A. Carter, C.E.G.B. Hinkley Point; G. R. Cullington, U.K.A.E.A. Winfrith; H. Hekman, Netherlands; C. N Beets, Belgium; J. Tsomlexoglou, Greece. Front row—left to right: E. A. Pickering, Lloyds Register of Shipping; D. H. Brown, U.K.A.E.A. Aldermaston; A. F. Wylde, New Zealand; P. Böttger, Germany; G. A. Rϕnneberg, Norway; F. Abbey, A.H.S.B. (Course Manager); N. McNair, S.S.E.B. Glasgow; B. Toner, Australia; F. H. Passant, C.E.G.B. London; B. J. Hardy, I.N.I. London.*

# Carbon fibres

*by Dr. J. B. Morris, A.E.R.E., Harwell*

**Introduction**

At the beginning of the year the Minister of Technology, acting under Section IV of the Science and Technology Act 1965, directed Harwell to carry out a non-nuclear research and development programme on carbon fibres. Seventeen professional scientists and engineers are engaged on this project which is expected to cost about £250,000 per annum. The purpose of this article is to explain how Harwell's interest in carbon fibres began and developed, and also to give an elementary account of the technical perspective of this new material.

**Work at R.A.E., Farnborough**

For some years a small team of scientists led by W. Watt at the Royal Aircraft Establishment, Farnborough, had been working on the problem of how to make fibres with superior engineering properties. They reasoned that, provided certain structural features were controlled, it should be possible to produce a carbon fibre having excellent mechanical properties. This work was crowned with success about 3 years ago when the R.A.E. scientists were able to make in the laboratory bundles of carbon filaments about 8 microns (0.0003 inches) in diameter which have a mean tensile strength of 300,000 psi and a mean Young's modulus of 60 x $10^6$ psi. Although carbon fibres had been available commercially in the U.K. for some time prior to this, they had been developed for their insulating rather than mechanical properties. Material intended for structural applications was on the market in the U.S.A., but its Young's modulus was only 25 x $10^6$ psi and moreover it was a pretty expensive commodity, being offered at $500 per lb, say £180 per lb, in 1965. (The Americans have since improved their material and carbon fibres with a modulus of 50 x $10^6$ psi are now available in the U.S.A. at $550 per lb, say £230 per lb.) Thus in 1965 the position was that R.A.E. had invented a better process for making carbon fibres; these fibres were (and still are) superior to any other similar known material; and the production costs were likely to be below that of any competitive carbon fibre.

**Entry of Harwell**

Clearly the next move was to evaluate this new material rapidly and thoroughly as a preliminary to industrial exploitation, and it was at this point in the Autumn of 1965 that Harwell first became involved. Farnborough had by now set up their own substantial research and development programme, but in order to support it, R.A.E. required the preparation of much larger quantities of the new carbon fibre than was possible in the laboratory-scale apparatus. The Farnborough process entails starting with a man-made fibre of the acrylic class and heat treating it under carefully controlled conditions in several stages up to a final temperature of about 2,600°C. The Experimental Graphite Plant at Harwell includes medium-sized furnaces which can be operated under well-controlled conditions over the full temperature range relevant to the carbon fibre process. Also the team of scientists and supporting staff which operates the Graphite Plant had long experience in handling carbons and graphites in other forms, and so for these two reasons it was considered that Harwell was in the best position to achieve a rapid scale-up of the production process. A contract was therefore placed by R.A.E. at Harwell, and within a few months we completed the necessary plant modifications. There were some initial problems but close liaison with Farnborough staff enabled these to be overcome, and we were then able to supply R.A.E. with kilogram quantities of carbon fibres, compared with the 100 g per run possible from laboratory apparatus. The quality of the product was very close to that achieved in the laboratory at Farnborough, namely, a tensile strength of 250,000 psi and a Young's modulus of 55 x $10^6$ psi. Figure 1 shows a batch of carbon fibres being unloaded from one of the Graphite Plant furnaces.

The National Research Development Corporation was made responsible for

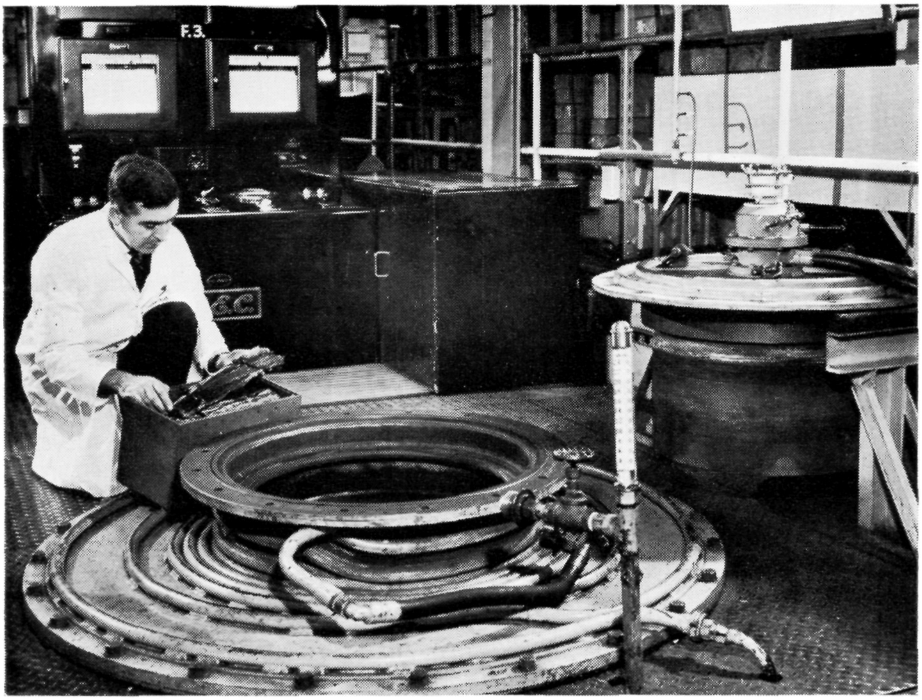


**Fig. 1.** *Bundles of carbon fibres being unloaded from the heat treatment furnace of the Experimental Graphite Plant at Harwell.*

sponsoring the commercial production of the new material, and the Corporation approached Courtauld's Ltd., Morganite Research and Development Ltd., and Rolls-Royce Ltd. with this end in view. Rolls-Royce had themselves independently embarked on a research and development programme on carbon fibres and so an informal collaboration emerged, at first with the R.A.E., and later including Harwell as well. For example, we have made available to all three industrial firms the "know-how" we acquired during our scale-up work. Meetings are held periodically at which N.R.D.C., R.A.E., A.E.R.E., and the three firms informally discuss topics of mutual interest.

**Structure of carbons**

At this stage it is appropriate to leave the historical account for a moment and indicate the technical significance of the new carbon fibre. The word "carbon" is unfortunately used in the technology in more than one sense, and so perhaps this ought to be clarified. On the one hand "carbon" is the sixth element in the periodic table. It is normally a solid and exists in either of two crystalline forms, diamond and graphite. On the other hand "carbon" is more narrowly used to signify a graphite of poor crystallinity, the word "graphite" generally being reserved for a material of high crystallinity. This is the meaning adopted in this article.

The first point to note regarding the R.A.E. carbon fibre is that its Young's modulus of $60 \times 10^6$ psi is very high, there being very few other materials of engineering value having a comparable modulus. (Tungsten and molybdenum are perhaps the best examples with E about $50 \times 10^6$ psi. The modulus of elasticity for steels is about $30 \times 10^6$ psi.) All "carbons" have a structure based on the graphite lattice, see Fig. 2. The carbon atoms are arranged in parallel planes, the disposition within any one plane being an hexagonal array. The atoms in each plane are 1.42 Å apart and are bonded together by strong covalent forces. However, the distance between one plane and the next, which is 3.35 Å, is much greater because the atomic forces involved are of the much weaker van der Waals type. This crystal structure is highly aniso-

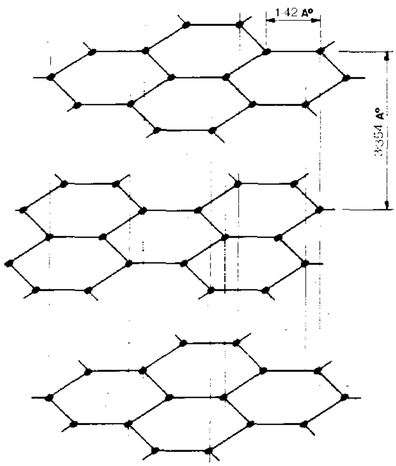


*Fig. 2. Structure of graphite lattice.*

tropic; the thermal conductivity along the layer planes is about 200 times as great as that in the perpendicular direction, whilst the ratio of the corresponding electrical conductivities is even greater, about $10^5$. The elastic constants mirror this anisotropy, with the two principal Young's moduli being equal to 140 x $10^6$ psi and 5 x $10^6$ psi.

All " carbons " and " graphites " are polycrystalline in that they consist of an assembly of crystallites having the structure shown in Fig. 2, the difference between a carbon and a graphite being one of degree only. In practice some C atoms will be in disordered positions, perhaps cross-linking one crystallite to another; a carbon has proportionately more of such atoms than a graphite. A more important distinction between a carbon and a graphite is that the crystallite size in the latter is much larger, 500 Å to 1,000 Å as compared with 50 Å to 100 Å for a carbon. The perfection of the crystallites also is greater in a graphite. It should be understood that although the individual crystals are highly anisotropic, an ordinary piece of bulk carbon or graphite may well be much less so, since the method of manufacture may have ensured that the constituent crystallites are oriented in all directions. But, if all the individual crystallites were oriented so that their layer planes are parallel to one particular direction, the Young's modulus in that direction would be 140 x $10^6$ psi. Thus a key part of any process to make high-modulus carbon fibre is the procuring of a high degree of alignment of the individual crystallites. Hence the modulus of the R.A.E. fibre is only about 50% less than the maximum theoretically possible, after allowing for porosity of about 15% by volume.

**Comparison of fibre-reinforced resins with other materials**

Why are the new carbon fibres so important? The short answer is that they extend the range of available fibre-reinforced materials. The best known examples at the moment of this class are the glass fibre reinforced plastics. These materials were developed after it was discovered that molten glass spun or drawn into fine filaments was much stronger (tensile strength ~ 300,000 psi) than bulk glass (10,000 psi). When these fibres are incorporated into a suitable matrix such as a resin, the resulting tensile properties of the composite are to a first approximation proportional to the volume fraction of fibres oriented in the given direction. Thus a resin reinforced by 50% by volume of unidirectional glass fibres would have an ultimate tensile strength of about 150,000 psi and a Young's modulus of about 5 x $10^6$ psi.

**Table 1** Mechanical properties of some structural materials

| | Density ($lb/in^3$) | Tensile Strength (psi) | Young's Modulus (psi) | Specific Strength (in) | Specific Modulus (in) |
|---|---|---|---|---|---|
| Glass fibre/resin .. | 0·076 | 150,000 | $7 \times 10^6$ | $2·0 \times 10^6$ | $90 \times 10^6$ |
| Carbon fibre/resin .. | 0·056 | 120,000 | $30 \times 10^6$ | $2·1 \times 10^6$ | $540 \times 10^6$ |
| High tensile steel .. | 0·283 | 200,000 | $30 \times 10^6$ | $0·7 \times 10^6$ | $110 \times 10^6$ |
| Aluminium .. .. | 0·100 | 85,000 | $10 \times 10^6$ | $0·85 \times 10^6$ | $100 \times 10^6$ |
| Titanium .. .. | 0·170 | 150,000 | $17 \times 10^6$ | $0·9 \times 10^6$ | $100 \times 10^6$ |

(The Young's modulus of glass itself is 10 x $10^6$ psi.) The result is therefore a pretty strong material, made more attractive by its low density which is only about 25% of the value for steel.

Table I compares the mechanical properties of a typical glass reinforced plastic (G.R.P.) with some other structural materials. The comparison on the basis of specific strength is particularly interesting. Specific strength is defined as $S/\rho$ where S is the tensile strength and $\rho$ the density of the material. Specific strength is a measure of the ultimate tensile load which a beam of given weight and length can support. We see that the specific strength of a G.R.P. is at least twice as great as that of metals. This means that a structure fabricated in G.R.P. will weigh less than one-half of an equivalent one made in metal. This weight advantage accounts for the aviation industry's keen interest in fibre-reinforced systems. Carbon fibre reinforced resins possess the same specific strength as glass systems, and so on this basis alone carbon fibres have no obvious advantage over glass fibres. The real advance offered by carbon fibres is apparent when one takes into account its Young's modulus and specific modulus. Specific modulus is analogous to specific strength, and is a measure of the tensile load a beam of given weight and length can support without exceeding a given tensile strain.

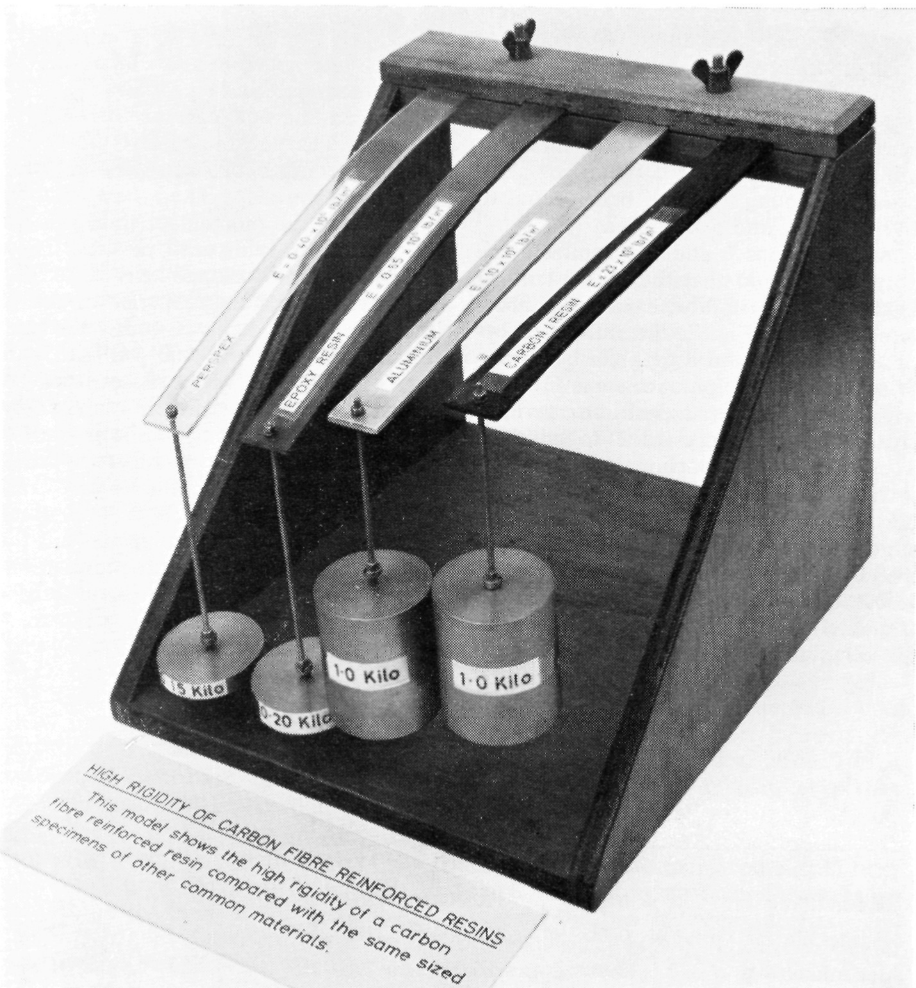



**Fig. 3.** *Model demonstration of the rigidity of a carbon fibre reinforced plastic composite.*

Looking at Table 1 again it is seen that the specific modulus of carbon-reinforced plastics is more than 4 times that of G.R.P. or the metals. This means that a structure made with carbon-reinforced resin will be over 4 times more rigid than one of the same weight fabricated in either G.R.P. or the metals. In other words, the deformation under tension of such a structure will be over 4 times smaller than the equivalent weight in G.R.P. or metal. The weight factor makes this carbon fibre system of obvious attraction to the space and aviation industry and it opens the way to building very light-weight components which are required to be extremely stiff, such as turbine blades in aeroengines. Rolls-Royce Ltd. are developing such a power unit in which the compressor blades are made from carbon fibre reinforced resin. This engine, the RB 211, is the one for which the company has recently won the very large order from the U.S.A.

Fig. 3 shows a demonstration of the high rigidity of a carbon fibre reinforced resin as compared with other materials. Geometrically identical cantilever beams are subjected to the loadings shown, and the superiority of the carbon system is clearly visible.

The higher stiffness of carbon fibre reinforced resins leads to other advantages over the corresponding glass fibre materials. For a given applied load the strain on the resin matrix is correspondingly less, which should improve the fatigue properties. In a glass reinforced system the resin has to be strained to the comparatively high value of about 3% to permit the full strength of the composite to be called into play. Glass fibre systems are also affected adversely by moisture, a problem not expected to occur with carbon which is generally chemically inert except under strong oxidizing conditions. The advent of carbon fibres also opens up the possibility of fabricating composite materials which retain good mechanical properties up to very high temperatures, e.g. 2,000°C. Another useful property not possessed by glass fibre is the electrical conductivity of carbon fibres. Thus it does appear that in addition to its outstanding mechanical properties, carbon fibres have a number of other advantages over glass which are worthy of exploitation.

**Boron fibres**

The U.S. space and military programmes have fostered an enormous amount of research and development into materials of construction for space vehicles and high-speed aircraft, and an important product from this effort is the boron filament. This is not strictly a boron filament as such but consists of a core of tungsten wire 12 or 25 microns (0.0005″ or 0.001″) in diameter on which boron has been deposited by a vapour phase process to yield a fibre about 100 microns (0.004″) in diameter. It has a higher transverse modulus than carbon fibre, but otherwise its mechanical properties are about the same as the British carbon fibres. Although the price has come down from $6,500 per lb (£2,300 per lb) 5 years ago, it is still a relatively expensive material at $330 per lb, i.e. £140 per lb. Because of its larger diameter, boron fibre yields reinforced resins which are more resistant to compressive/buckling forces, but by the same token, filament winding of small components is more difficult than with the finer carbon fibre. A further disadvantage of boron is its restricted high temperature potential.

**Current contribution of Harwell**

It is now appropriate to return to the account of how Harwell became involved in carbon fibre research and development. During the scale-up work for Farnborough we gradually came to the conclusion that the potential of this new material was so great that its development should not be restricted to the aircraft industry. Moreover, here was a British invention whose exploitation the nation ought to press with urgency if we were not to see repeated the all too familiar story of overseas commercial rivals beating us at the application of our own discovery. We felt that the U.K. should invest more of its scientific and technological effort in this new material, and that the skills and expertise in particular fields which existed at Harwell could well play a rôle, complementing the effort already deployed by R.A.E. Accordingly discussions took place between Harwell and Farnborough, and a joint programme of work was drawn up. Naturally those parts of the programme having a direct bearing on aviation applications will continue to be carried out by Farnborough. The joint project is co-ordinated by a Ministry of Technology Working Party on which R.A.E., A.E.R.E. and N.R.D.C. are represented. The recent directive of the Minister, referred to at the beginning of this article, formally requires Harwell to implement its part of this collaborative programme.

Our initial scale-up work was geared to produce relatively short-length carbon fibre in lengths of about a few feet. However our production capacity is not excessively large and as soon as the commercial firms were able to market this type of fibre we ceased its manufacture and turned our attention to the production of "continuous" carbon fibre. Harwell has developed equipment for making 1,000 ft. lengths, and Figure 4 shows such a batch made by the Graphite Plant. We intend in the near future to extend our operations to produce 10,000 ft. long material. Whilst short-length fibre is perfectly satisfactory for making laminate structures, continuous fibre is necessary to fabricate structures and vessels by filament winding. We are also making a broad study of the chemical engineering of the manufacturing process in order (a) to provide the data required for the design of a large commercial plant and (b) to optimise the original R.A.E. route. Some process improvements have already been found.

In order to support both the research and the production parts of the carbon fibre development programme it has been necessary to set up a laboratory to monitor the mechanical properties of the fibres. Sampling poses some severe statistical problems, but nevertheless an attempt is being made to relate the properties of individual filaments to, for example, the characteristics of the raw material. In a full-scale commercial plant it would be most convenient if quality control of the carbon fibre could be achieved by an *in situ* method, and the Nondestructive Testing Centre at A.E.R.E. is engaged on this problem. Ultrasonic and X-ray techniques are, for example, being examined and a certain amount of success has already been gained.

In most applications of fibre-reinforced composites the adhesion between fibre

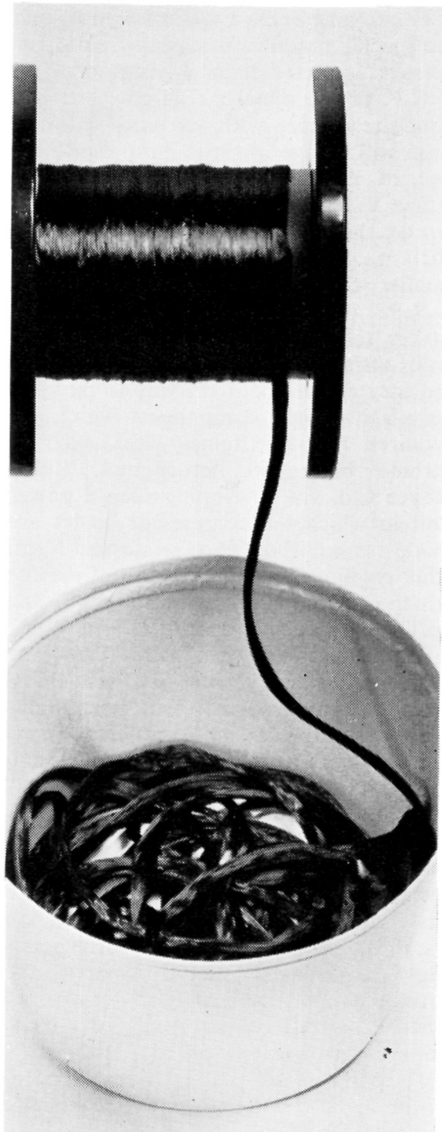


**Fig. 4.** *Sample of continuous carbon fibre made at Harwell.*

and matrix is important. During the development of glass-reinforced plastics it had been found necessary to use coupling agents such as silanes to obtain adequate bonding between glass and resin. A similar situation exists with carbon fibres and both R.A.E. and A.E.R.E. have developed processes for treating the fibres which raise the inter-laminar shear strength of a resin composite from 2,500 psi to the satisfactory level of 10,000 psi. Although the major part of the effort on reinforced plastic development in the joint programme rests with Farnborough because of its immediate application to the aerospace field, particular aspects are being examined at Harwell. The nature of the resin/fibre bond and its relation to fibre structure is being studied, using electron microscopy. The internal structure of the fibre is being explored by field-ion microscopy.

A further break-through in the potential of carbon fibres will be made if they can be used to reinforce metals and ceramics, and accordingly a significant portion of the Harwell contribution is concentrated in this area. The usefulness of aluminium is sometimes compromised by its relatively poor mechanical properties, and we are therefore investigating the effects of incorporating carbon fibres into the metal. Copper and bearing materials are other metals being studied. The incorporation of carbon fibres should also improve the high temperature properties of these metals. Turning to non-metallic matrices such as magnesia and glass, we have found that toughness, i.e. the ability to withstand thermal and mechanical shock, is considerably improved by incorporating carbon fibres, and so we are pressing ahead with the research in this area.

Whilst the A.E.R.E. contribution to the joint Farnborough/Harwell programme outlined above has the general objective of assisting the exploitation of carbon fibres by British industry, there are also potential applications in the nuclear field. "Rabbits" are small capsules which are used to contain specimens for irradiation in a reactor. Some experimental "rabbits" are now being made in carbon fibre reinforced resin and it is expected that superior mechanical performance will result. Another application to be tested soon is the use of a carbon fibre reinforced rotating disc in place of a glass fibre unit in a neutron chopper system. The neutron chopper is employed to produce mono-energetic pulses of neutrons for experimental purposes, and the higher speed of revolution permitted by the more rigid carbon fibre reinforced component should improve the control over the neutron energy distribution.

**Summing up**

A review of the development of a new material is obviously incomplete without some reference to its cost. It is impossible to say much on this score in this article since this is really a matter for the commercial producers. At the moment the price of carbon fibres is undoubtedly expensive when compared with, say, glass fibres. This of course is partly due to the limited scale of production, but even so the British prices are competitive with any other supplier's figure. And if a much larger demand can be stimulated the cost will fall considerably. One of Harwell's objectives is to promote such a demand by practical demonstration of the virtues of the new carbon fibres.

Although the U.K.A.E.A. has now been involved with carbon fibres for nearly three years, it is clear to us that the wave-front of this project is still enlarging. In this time we have seen the national effort grow until it now involves two major government research establishments and three large industrial concerns to a considerable extent, as well as many other laboratories and firms to a smaller extent. The first major practical application of the new material is going to be in the aerospace field but its potential is so great that other important uses will follow. Harwell is doing its share to ensure that the nation gets the best out of carbon fibres.

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More detailed information on the R.A.E. carbon fibres is given in:—

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3. J. P. Giltrow and J. K. Lancaster, "Nature", June 10th, 1967.
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## Ripple

A revised version of a leaflet "Radioisotope Powered Thermoelectric Generators" has been published by the U.K.A.E.A. Copies are available from Public Relations Branch, U.K.A.E.A., 11, Charles II St., London, S.W.1.

# A.E.A. Reports available

THE titles below are a selection from the September, 1968, "U.K.A.E.A. list of publications available to the public". This list is obtainable free from the Librarian, A.E.R.E., Harwell, Didcot, Berkshire. It includes titles, of all reports on sale, translations into English, books, periodical articles, patent specifications and reports which have appeared in the published literature. It also lists the Depository Libraries in the U.K. and the countries with official atomic energy projects which receive copies of U.K.A.E.A. unclassified reports.

AERE-AM 107
*The Determination of Hydrogen in Zirconium Alloys by Hot Vacuum Extraction.* By M. Robinson. August, 1968. 7 pp. H.M.S.O. 1s. 9d.

AERE-AM 108
*The Determination of Nitrogen in Titanium Carbide by the Dumas Technique.* By B. J. Hambridge and A. Parker. August, 1968. 6 pp. H.M.S.O. 2s. 6d.

AERE-Bib 151A
*Compendium of References to Studies of the Properties of Liquid Metal Binary Systems Which Relate to their Structure.* By B. W. Mott. July, 1968. 46 pp. H.M.S.O. 7s.

AERE-M 2086
*The Use of Massive Foamed Polystyrene in Radioactive Transport Packaging.* By F. E. Dixon, F. K. Olley and L. R. Cohen. July, 1968. 8 pp. H.M.S.O. 7s.

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AERE-R 5324
*A Radiometric Method of Continuously Measuring the $^{11}C$ Concentration in $CO/CO_2$ Mixtures.* By W. C. T. Munnoch and D. Williams. July, 1968, 20 pp. H.M.S.O. 6s.

AERE-R 5701
*Type A Packaging for Liquids and Gases. A Proposal for Amendment of the Additional Tests Specified in 1-3 Annex IV and of Design Requirement in II—1-6 Annex II, I.A.E.A. Safety Series No. 6 (1967 Edition).* By F. E. Dixon, F. K. Olley and L. R. Cohen. August, 1968. 25 pp. H.M.S.O. 20s.

AERE-R 5790
*The Production of $^{236}Pu$ and $^{235}Np$ in the Harwell Variable Energy Cyclotron.* By I. L. Jenkins and A. G. Wain. July, 1968. 7 pp. H.M.S.O. 1s. 9d.

AERE-R 5799
*A Versatile Spectrographic Method for the Analysis of a Wide Range of Materials.* By M. S. W. Webb and M. L. Wordingham. June, 1968. 33 pp. H.M.S.O. 4s. 6d.

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*The Design of a Ventilated and Mechanical Shield for a Heavy Lead Shielded Flask Which Contains a Heat-Emitting Source.* By F. E. Dixon. July, 1968. 26 pp. H.M.S.O. 10s.

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*Scattering Law $S(\alpha\beta)$—Values for a Mixture of Light Water and Heavy Water.* By D. I. Page. July, 1968. 34 pp. H.M.S.O. 5s.

AERE-R 5841
*Further Calculations of Neutron Scattering Cross Sections of Point Defects in a Relaxed Lattice.* By D. G. Martin. July, 1968. 10 pp. H.M.S.O. 3s.

AERE-R 5875
*Anodic Oxidation of Silicon.* By A. Wilkins. August, 1968. 11 pp. H.M.S.O. 3s.

AHSB(RP) R77
*Occupational Hygiene Standards for Natural Uranium.* By N. L. Spoor. July. 1968. 19 pp. H.M.S.O. 3s. 6d.

PG Report 837(W)
*The Preparation and Properties of Thermoluminescent Lithium Borate.* By R. T. Brunskill. 1968. 9 pp. H.M.S.O. 4s.

TRG Information Series 678(R)
*Nuclear Power Reactor Engineering Selected and Annotated References.* By J. C. Hartas and J. C. C. Sharp. 1968. 16 pp. H.M.S.O. 2s. 6d.

TRG Report 619(C)
*Use of Small Isothermal Calorimeters to Measure the Radiation Dose Rate in $CO_2$/Graphite Rigs.* By J. Standring. 1964. Reprinted 1968. H.M.S.O. 4s.

TRG Report 962(D) (1st revision)
*Analytical Method for the Determination of 137-Caesium in Fission Product Solutions Using a Carrier-Free Extraction Procedure.* By W. Davies and W. R. Diggle. 1968. 7 pp. H.M.S.O. 1s. 6d.

TRG Report 1547(S)
*Theoretical Analysis of Some Forces, Stresses and Strains Produced in Nuclear Fuel Element Cladding by Thermal Expansion of Cracked Fuel Pellets.* By J. H. Gittus. 1968. 20 pp. H.M.S.O. 3s. 6d.

TRG Report 1720(D)
*Movable Personnel Shield for Access to Hot Cells.* By E. Edmonds and I. H. Thomas. 1968. 4 pp. H.M.S.O. 2s.

# An 'S' curve to forecast electricity demand

*by L. G. Brookes, Economics and Programming Branch, UKAEA.*

*Traditionally, demand forecasting in the electricity industry has been done on the combined judgements of the Area Boards, the C.E.G.B., and the Electricity Council. In the early 1960s the C.E.G.B. introduced trend extrapolation as a check and a stabilising influence on the more empirical methods, fitting an exponential curve to the data for this purpose. This paper makes a general case for trend extrapolation and recommends a method of forecasting electricity demand using the more fashionable "S" curve.*

Economic forecasting to establish the growth pattern of any particular ingredient in the economy—energy consumption, for example—invariably presents the forecaster with the problem of estimating changes in other economic factors, such as the gross national product or the energy coefficient. These may be just as difficult to forecast as the main object of the exercise. The case for the indirect approach is that certain key factors—GNP growth in particular—are the " controllers " of the economy: other factors—electricity usage, for example—are no more than symptoms of what is being done to the economy. In the short term, moreover, an ounce of real knowledge (for example, about credit restrictions or plans for major industries) is worth a ton of conjecture.

However the case for believing we have more than a modicum of control over what the economy will be like in, say, 20 years' time is very slim indeed. Long-term economic changes in individual countries are very much under the influence of macro-economic effects on a world scale. We have seen what happens if an attempt is made to push the growth of the economy ahead too fast: it becomes " over-heated "; balance of payments problems ensue; we may be subject to economic retaliation by competitor countries. Perhaps the best our national economic management can do for us is to see that we achieve the limit of the potential for growth that world economic forces allow us. In the long-term, the range between the results of good, bad and indifferent national management may not be very great. If this argument is sound, the long-term effects on our economy will show themselves over a long period in major indicators of economic growth like energy consumption. These very basic economic forces will almost certainly have a great deal of inertia about them, and it should be possible to find reasonably satisfactory mathematical models of their effects—not forgetting that the technique is only applicable to long-term trend forecasting; short-term effects may cause quite substantial oscillations about the trend line though, if the theory is sound, the trend will eventually re-establish itself just as if there had been no perturbation.

Unfortunately for the electricity industry, their requirement is for a forecast six years ahead—the time it takes to plan, build and commission new plant. This is too long for a forecast based on known facts and immediate intentions and too short for the trend line to be adequate for their purposes. Nevertheless, they have found it helpful to extrapolate the trend: it does, as they have said, act as a check and a stabilising influence on their other methods of forecasting.

The Authority has an interest in forecasts anything up to 30 or 40 years ahead. In drawing up long-term plans for research and development on nuclear power it is useful to know how demand for power will build up because it has implications for plant and station sizes and for the eventual economic " pay-off " for the R. and D. work. These considerations promoted the attempt, related in this paper, to find a more enduring model of electricity demand than the one used by the industry.

It hardly seems any time ago that we were all being frightened by the bogeyman of exponential growth. Everything was said to be rising exponentially: world population, and hence the demand for food, housing, etc.; expenditure on

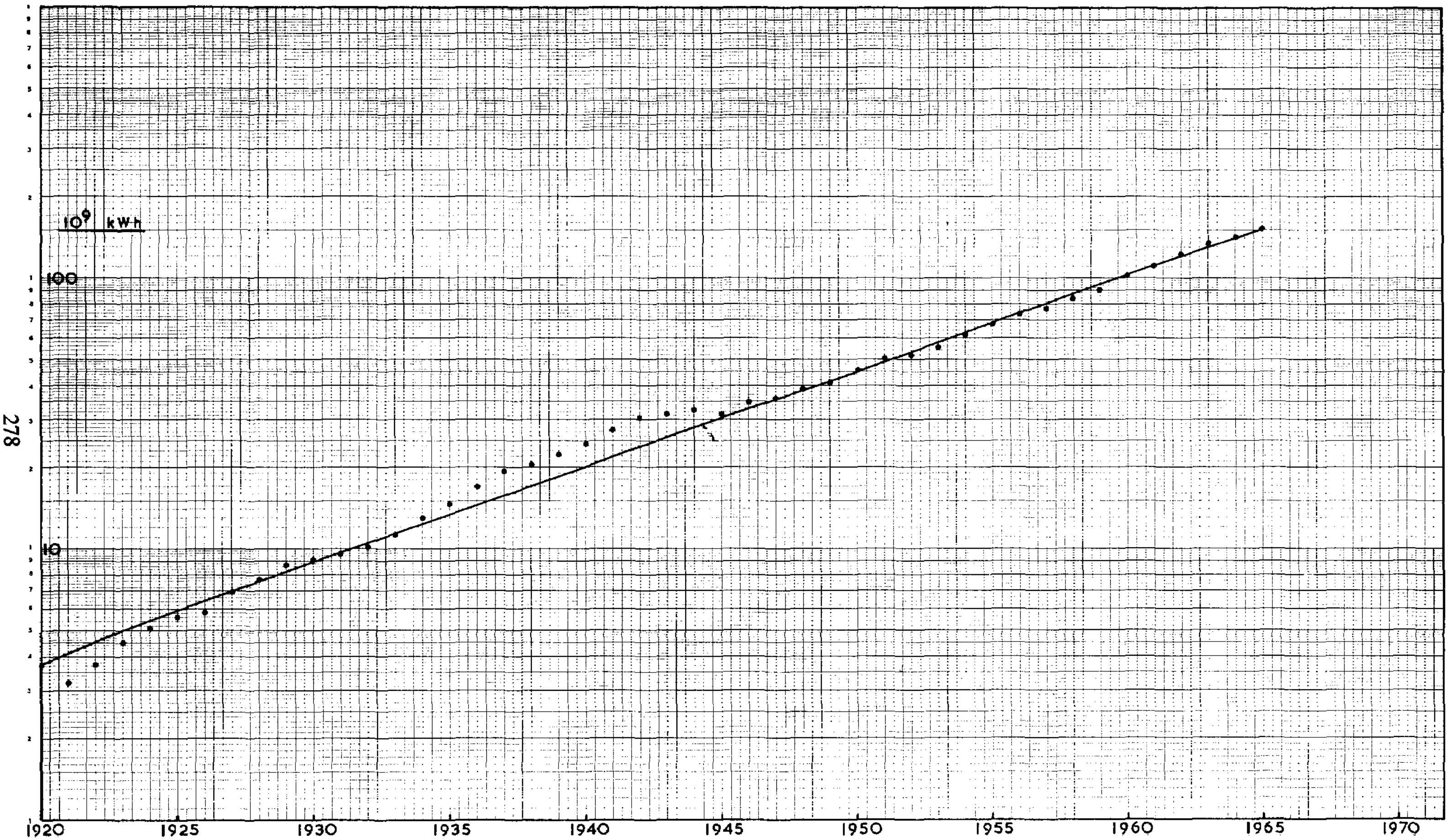



Figure 1 - United Kingdom Sales of Electricity 1920 to 1965

science and the demand for scientists—at the present rate of growth, so it was said, it will not be long before the country is wholly populated by scientists; even the issue of scientific papers and the number of scientific journals was supposed to be rising exponentially. One of the more silent revolutions in recent years has been the change to "S" curves. Originally recognised as very adequate models of biological phenomena (including, for example, human growth from embryo to adult) they are now applied to a wide variety of demographic and marketing situations. The merit of the logistic function ($y = \frac{k}{1 + me^{-at}}$, the most commonly used "S" curve) is that its growth rate starts by being exponential but gradually flattens until the curve finishes as a negative exponential tending to an upper asymptote. It is therefore a good model of situations where initial exponential growth is subsequently flattened as the function increasingly comes up against the constraints that are liable to affect its growth. In the real world, things are much more likely to grow in this way than exponentially, because they are bound to be checked by something in the end—even if it is only the size of the earth. For electricity, it is argued that population growth levels off; domestic consumers become surfeited with applications of electricity; that increasing efficiency in its use brings about a levelling in the demand for it; and so on.

Fig. 1 shows annual electricity consumption from 1920 to 1965 on a logarithmic scale. The points just after the first world war and during the ten years from 1935 to 1945 that included the second world war are somewhat erratic. Otherwise growth is fairly steady. A smooth curve drawn through the points is slightly concave to the X axis, showing the steady decline in percentage rate of growth that is characteristic of the logistic "S" curve.

The equation was fitted to the curve by first finding approximate values for a and m of about .08 and 20 respectively, by a method that need not be detailed here. Combinations of a and m in the vicinity of the approximate values were then plotted for selected points on the curve, as shown in Fig. 2. From these plots the most likely values of a and m emerged as .08175 and 26.6. m is a location constant: it depends upon the value of k (the upper asymptote) and the choice of $t_0$. This had been taken as 1965, giving a value for $y_0$ of 151 and hence a value for k of 4160. On the first round, therefore, the equation emerged as

$$y = \frac{4160}{1 + 26{\cdot}6e^{-0{\cdot}08175t}}.$$

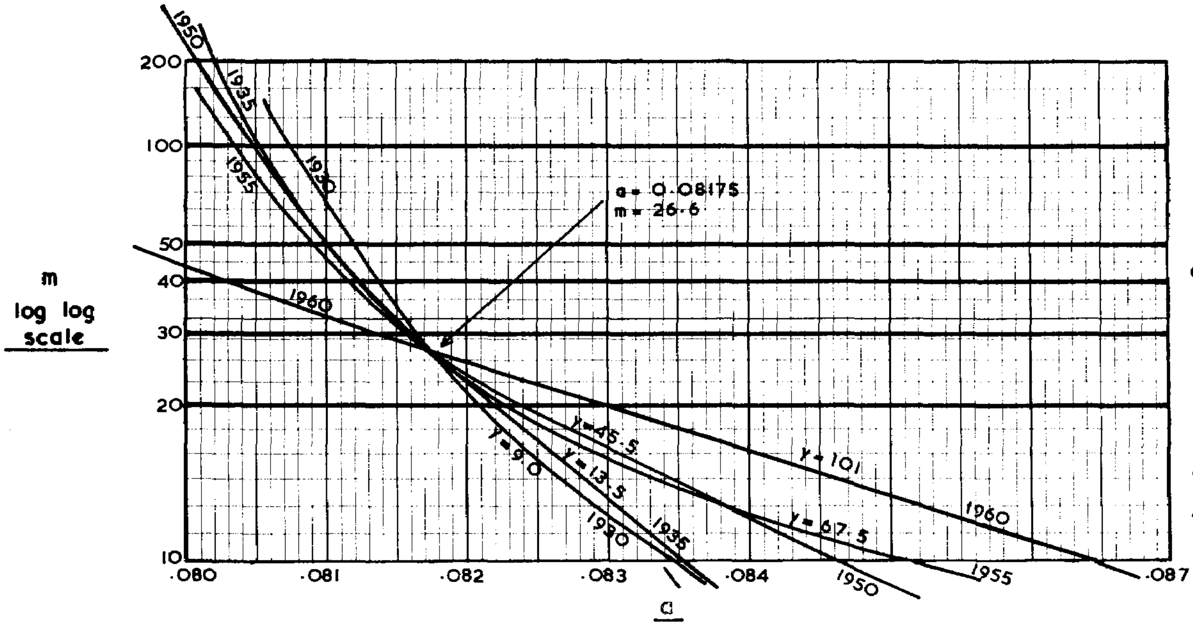
This formula was then used to produce predicted values of y for all years between 1924 and 1935 and between 1946 and 1965. The periods 1920-23 and 1936-45 were omitted as being clearly unrepresentative of the trend. A quick check to see how well the curve generated by the equation was centred between the points was then made by calculating the log differences between the actual points and the points predicted by the equation. The algebraic sum of these had a small residual so the prediction line was moved very slightly parallel to itself to reduce this sum to zero. This was done by substituting a value for k of 4152.4, making the complete equation:

$$y = \frac{4152{\cdot}4}{1 + 26{\cdot}6e^{-0{\cdot}08175t}}$$

This is not, of course, a true fit by the method of least squares. However, tests made with values of a of .0817 and .0818 both showed poorer fits than with a = .08175. The values given above must, therefore, be very close to the best obtainable fit. This was confirmed by calculating the correlation coefficient linking actual and predicted values. It came out at .99937. Fig. 3 shows the recorded values of actual consumption, points predicted by the logistic equation and various extrapolations into the future—a simple exponential extrapolation, the "S" curve extrapolation and two forecasts made in the Authority by the more traditional methods:*

For the year 2010 the "S" curve prediction is less than half the exponential but nearly twice the larger of the two previous Authority forecasts. The argu-

*Reported in "U.K.A.E.A. Study of the Economic Background for the Assessment of Future Nuclear Reactors" presented at the National Conference on Technological Forecasting, Harrogate, July 4 and 5, 1968 (organised by the University of Bradford, Ministry of Technology and The Times).




$$a = \frac{-1}{t} \log \left( \frac{\frac{y_0}{y}(1+m) - 1}{m} \right)$$

$y_0 = 151$

$t_0 = 1965$

| Values of m | Values of a | | | | |
|---|---|---|---|---|---|
| | 1960 | 1955 | 1950 | 1935 | 1930 |
| 9 | 0.0867 | 0.0858 | 0.0851 | 0.0837 | 0.0837 |
| 19 | 0.0833 | 0.0824 | 0.0826 | 0.0823 | 0.0821 |
| 39 | 0.0804 | 0.0812 | 0.0812 | 0.0813 | 0.0814 |
| 99 | 0.0804 | 0.0804 | 0.0805 | 0.0805 | 0.0808 |
| 199 | | 0.0800 | 0.0803 | | |
| Observed values of y (TWh) | 101 | 67.5 | 45.5 | 13.5 | 9.0 |

Figure 2 - Logistic Curve $y = \frac{K}{1 + me^{-at}}$

Applied to Electricity Consumption

Identification of Constants 'a' and 'm'

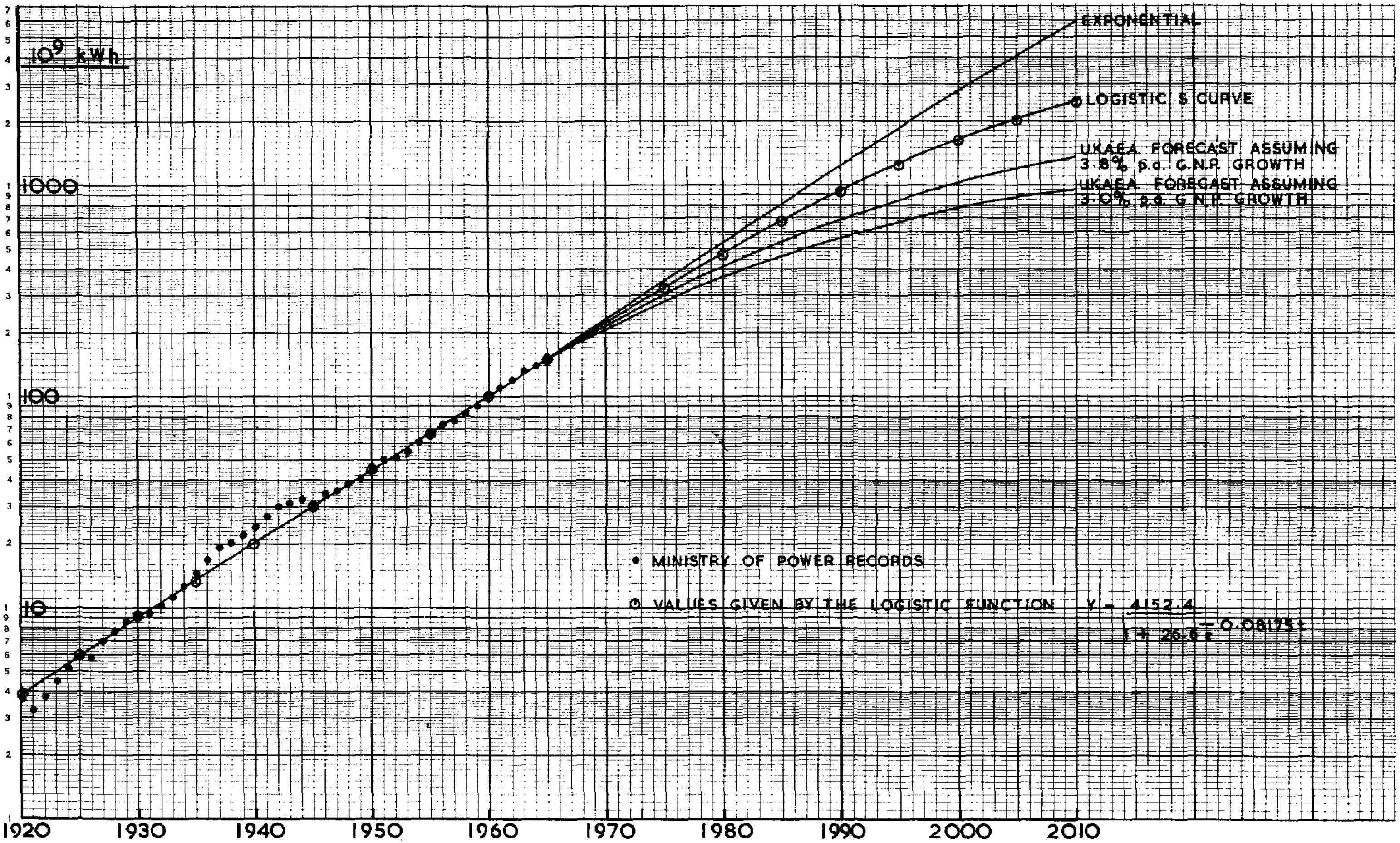



Figure 3 - Records and Forecasts of Electricity Consumption in the U.K. 1920 to 2010

ments in favour of the "S" curve extrapolation are as follows:

(1) There is no question that the general trend has been for the percentage rate of growth to fall off steadily over the years. The growth curve is not, therefore, exponential. The C.E.G.B. found that they could not produce satisfactory trend lines by fitting a single exponential function to the whole of the past data. They have adopted the device of taking the last 10 years' growth as exponential and projecting it for the further six that they need for their forecasts. This device makes some allowance for the falling percentage growth rate. It has the disadvantage (if the object is to inject stability into forecasts) that it gives undue weight to the recent pattern of growth and if this happens to be uncharacteristic of the trend the six-year extrapolation can be badly out as a trend indicator.

(2) The Authority forecasts correctly make provision for a falling percentage growth rate, but the fall they predict is much steeper than what has been experienced up to date. The only special reason that could be advanced for a sharper contraction in the percentage growth rate is the advent of natural gas. This might very well make inroads into the use of electricity for industrial and domestic heat, but—if there is only a finite amount of it available—demand for electricity will eventually come back on to the trend line. It is, in any case, arguable just how much natural gas will affect electricity demand: it is likely to have its main effect on the use of other primary sources of energy.

(3) In 1962, the Electricity Council predicted an annual increase in demand of 8.6% up to 1968 (extrapolating experience in the 10 years up to 1962). This has turned out to be a substantial over-estimate. With 'S' curve forecasting, 8.6% would have been recognised immediately as uncharacteristic of the trend. With the values of a and k found above, the percentage growth rate at any time is given as $8.175\left(1-\frac{y}{4152.4}\right)$. An in-trend rate of growth can never be higher than 8.175%, and a rate of growth as high as 8.6% would not be extrapolated.

Summing up, trend extrapolation seems as good a method as any for long-term predictions of electricity demand. The equation found in this study is a remarkably good model of past experience and therefore stands a good chance of being a useful predictor of future demand.

# A.E.R.E. Post-Graduate Education Centre

THE following courses are due to be held at the Post-Graduate Education Centre, A.E.R.E., Harwell, Didcot, Berks. Further information and enrolment forms can be obtained on application.

**Commissioning, Use and Maintenance of Reactor Instrumentation**

*21st October to 1st November, 1968*

This course is intended for commissioning, operation and maintenance engineers working on nuclear reactor instrumentation. Participants should have some knowledge of the basic principles of nuclear reactions and reactors, electronics and the measurement of physical quantities. Fee: £80 exclusive of accommodation.

**Process Instrumentation**

*21st October to 1st November, 1968*
*10th to 21st March, 1969*

This course is intended for graduates who are working on the instrumentation of process plant, nuclear reactors and scientific apparatus or who have a direct interest in the subject. A visit will be arranged to a process plant or a power station where modern control techniques are being applied. Fee: £80 exclusive of accommodation.

**Introduction to Production Control by Computer**

*30th and 31st October, 1968*
*4th and 5th December, 1968*
*31st March and 1st April, 1969*

A new system of production control (WASP) which ensures better loading of machine tools has been devised at Harwell. The course will show how "WASP" may be used on its own, or in conjunction with other computer control systems. Fee: £25 exclusive of accommodation.

**Radiological Protection**
*4th to 8th November, 1968*
*24th to 28th February, 1969*
*9th to 13th June, 1969*
This short course aims to give users of radioactive substances and radiations in industry, research or teaching a broad introduction to the principles and practice of radiological protection, with a strong emphasis on practical considerations. Fee: £40 exclusive of accommodation.

**Magnet Design**
*18th to 22nd November, 1968*
*14th to 18th July, 1969*
This course is intended to be suitable for both design engineers and scientists with or without experience in the field.

It will cover basic theory, magnetic materials, Fabry factors for coils, forces on coils, digital and analogue computation and computer calculations; field-measurement techniques, technology of low temperature and cryogenic magnets, practical winding design and construction techniques, superconducting magnets and pulsed magnets. Fee: £40 exclusive of accommodation.

**Seminar on Harwell's Multi-access Computing System**
*10th and 11th December, 1968*
The objective of the seminar is to describe and discuss the multi-access computing facilities developed at Harwell for use on the IBM system/360 computer. The system is designed to operate efficiently with conventional batch-processing. Participants will be given the opportunity to use it. Lectures will describe how it is implemented, giving particular emphasis on what is required for similar systems to be implemented on other computers. Fee: £16 exclusive of accommodation.

**Two-Phase Heat Transfer**
*6th to 10th January, 1969*
*9th to 13th June, 1969*
The subject will be approached in a fundamental way and although the problem of nuclear reactors will have some emphasis, the material presented will be useful to those requiring a knowledge of the problems inherent in two-phase heat transfer and of current solutions, theories and developments. Fee: £40 exclusive of accommodation.

U.K.A.E.A. SCIENTIFIC AND TECHNICAL NEWS SERVICE

## The best way to use uranium

Britain's nuclear energy requirements to the end of the century—one million megawatt years—could be provided by about one thousand tonnes of uranium, if utilised completely.

Achieving complete utilisation was the theme of a paper presented by the U.K.A.E.A. at the World Power Conference in Moscow, 20th-24th August. The authors were Mr. J. C. C. Stewart, Member for Reactors, U.K.A.E.A., Dr. N. L. Franklin, Deputy Managing Director, Production Group, U.K.A.E.A., and Dr. T. N. Marsham, Director, Technical Operations, Reactor Group, U.K.A.E.A.

The key to U.K. uranium requirements is the proportion of various types of reactor constructed here in the future and the extent to which effective use can be made of the substantial quantities (2.5 tonnes per year) of plutonium which will be produced by nuclear stations already built and under construction.

The introduction of fast breeder reactors would particularly improve the utilisation of imported uranium—from less than 1% achieved by present reactors to over 70%. Depleted uranium available from ore already imported into the U.K. to meet thermal reactor requirements will be sufficient for a large fast reactor programme continuing well into the next century.

In a comparison of the fuel requirements of different types of reactor the authors said, " For the gas-cooled reactor, refuelling is carried out continuously while the station is in operation. For typical load factors, enriched uranium fuel is fed in at a rate of about 35 tonnes per year per 1000 MW(E), and this requires a feed of ore to the separation plant of 160 tonnes $U_3O_8$ per year, the difference being available as depleted uranium, waste material low in fissile content but suitable for conversion in a fast reactor to plutonium.

" The fuel discharged from the reactor after processing yields further depleted uranium and also 180 kg of plutonium per year. These figures are typical for the AGR; for Magnox reactors ore usage is higher, but so also is the plutonium production rate.

"The plutonium-fuelled fast reactor requires 2.8 tonnes of plutonium for its initial fuel charge, equivalent to the output of a 1000 MW(E) station (e.g. AGR) for 16 years, but thereafter it requires an input of only 25 tonnes per annum of waste uranium from the isotope separation or spent fuel reprocessing plant of which about 24 tonnes can be recycled.

" In the fast reactor, small batches of fuel from the core are changed approximately every three months. Processing of this, together with the blanket material which is discharged less frequently, produces an annual surplus of 200 kgs of plutonium, which is used to meet the requirements of further fast reactors."

The correct strategy for the installation of thermal and fast reactors depends on many factors additional to uranium utilisation.

However, such are the advantages of fast reactors, that the authors state that, " The U.K. conditions strongly favour the early introduction of fast breeder reactors to take full advantage of the plutonium being produced by the present large installation of gas-cooled reactors, and so the fast reactor development programme is related to the introduction of commercial stations in the late 1970s."

They also state that " The earliest date for the first fully commercial fast reactor to come on power in the U.K. is judged to be about 1976."

*23rd August, 1968*

## Conference on fracture

The Second International Conference on Fracture will be held in the Winter Garden of the Metropole Hotel, Brighton, Sussex, from Sunday, 13th April, to Friday, 18th April, 1969. The Conference will cover all aspects of the science and technology of fracture and fracture mechanisms concentrating particularly on: the prevention of failure by using composite and multiphase materials; the growth of cracks in fatigue and at high temperatures; design with materials, that is, the application of basic fracture knowledge to the design of engineering components; the chemical effects due to environment.

Over 300 delegates from industry, universities and other organisations in 20 different countries (including for example most European countries, the USA and Japan) are expected to attend and about 80 papers are to be presented at the Conference. The official language of the conference will be English.

The First International Conference on Fracture was held at Sendai, Japan, during December 1965, following an earlier international meeting at Swampscott in April 1959, devoted to the same topic. At the Sendai conference an International Congress on Fracture (Chairman: Professor Takeo Yokobori, Tohuka University, Sendai, Japan) was formed, having as one objective the promotion of a series of international conferences on fracture phenomena. The executive committee of the International Congress on Fracture authorised the formation of an organising committee to arrange the Second International Conference on Fracture in the U.K., and the arrangements for the Conference are now proceeding rapidly.

Mr. R. W. Nichols, (Deputy Head of Laboratory, Reactor Materials Laboratory, U.K.A.E.A., Culcheth) is chairman of the organising committee and Professor P. L. Pratt (Imperial College of Science and Technology, University of London) is chairman of the papers committee and editor-in-chief of the proceedings which are to be published by Chapman and Hall Ltd.

The Conference is being supported by the Ministry of Technology, by contributions from the International Congress on Fracture, by a guarantee from the British National Committee on Materials and by a wide range of industrial organisations in the United Kingdom. Delegates will be welcomed to Brighton at a reception given by the Mayor and Corporation of Brighton and will be invited to attend a government reception at the Royal Pavilion, Brighton.

The Conference fee is £15 exclusive of accommodation and the registration closing date is December 31st, 1968.

Further information about the Conference may be obtained from: Dr. A. H. S. Matterson, Secretary, Fracture Conference Office, B.77, A.E.R.E., Harwell, Didcot, Berkshire, or Mr. J. K. Johnson, Secretary, Papers Committee, C.E.G.B., Sudbury House, Newgate Street, London, E.C.1.

*28th August, 1968*