ATOM

Number 153 / **July 1969**

MONTHLY INFORMATION BULLETIN OF
THE UNITED KINGDOM ATOMIC ENERGY AUTHORITY

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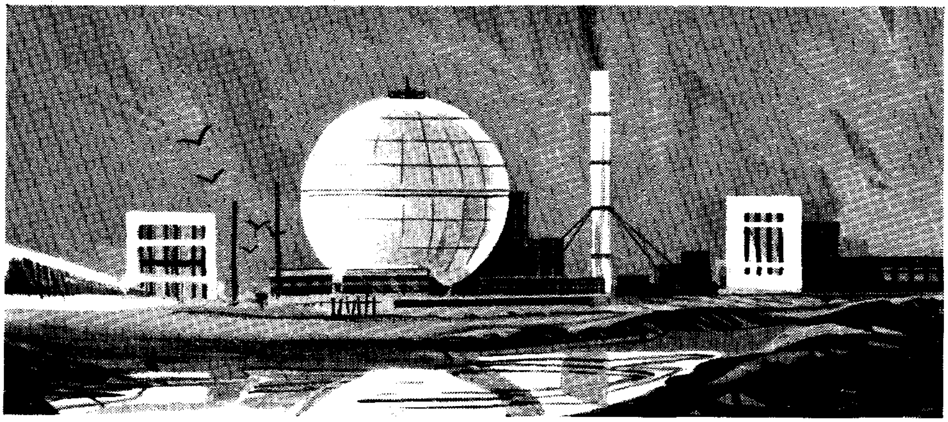

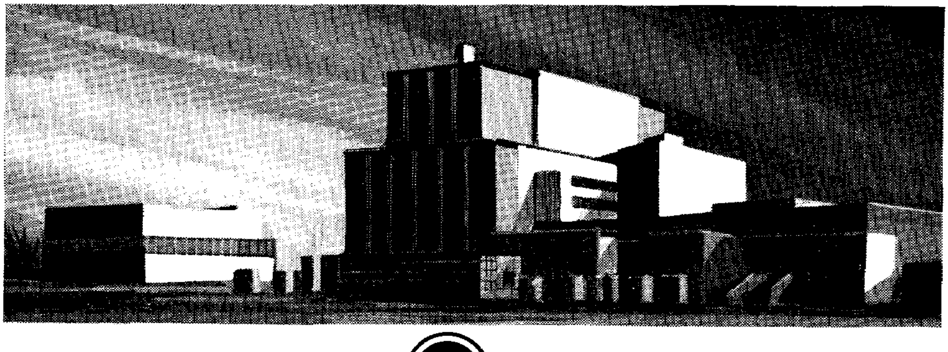

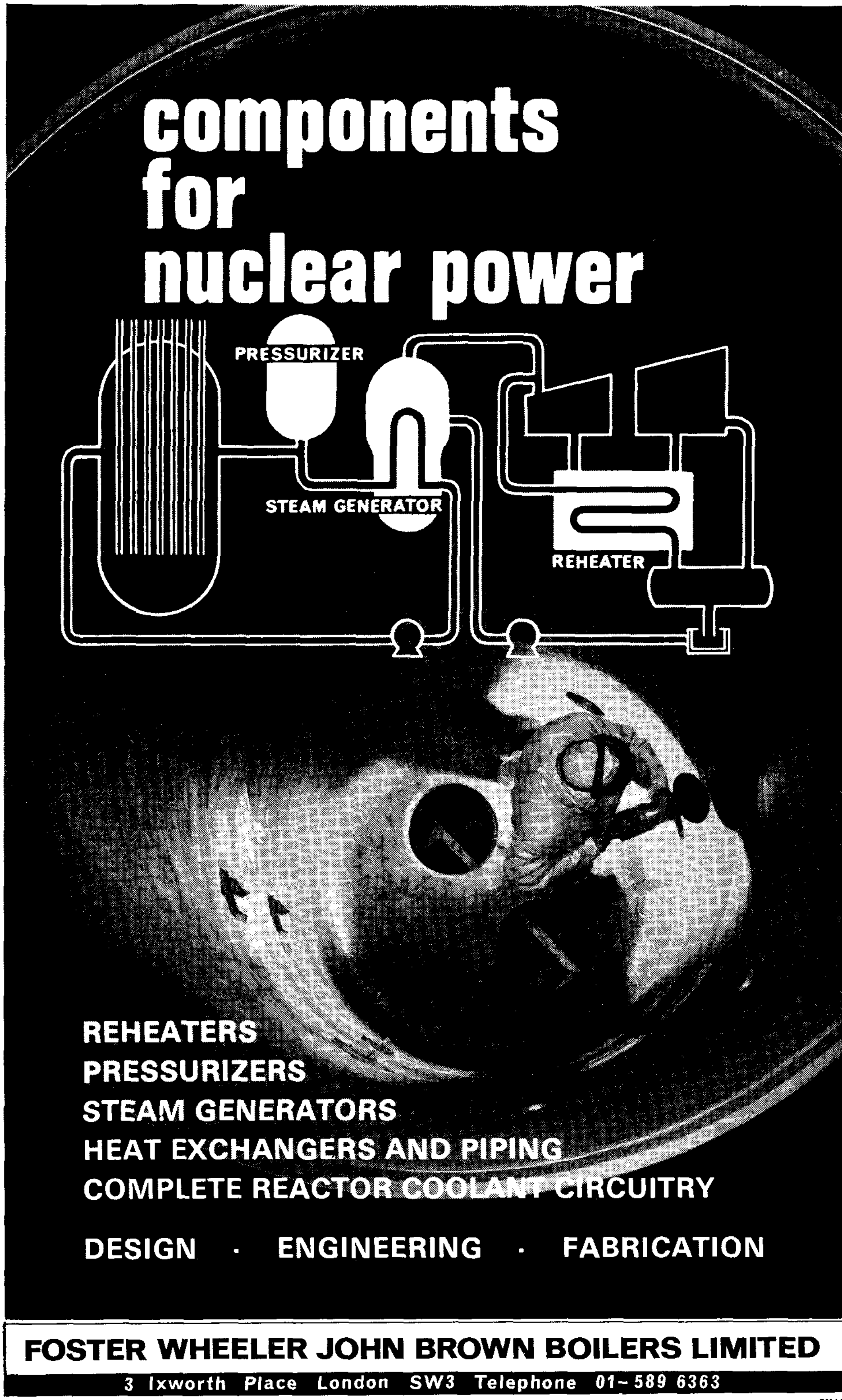
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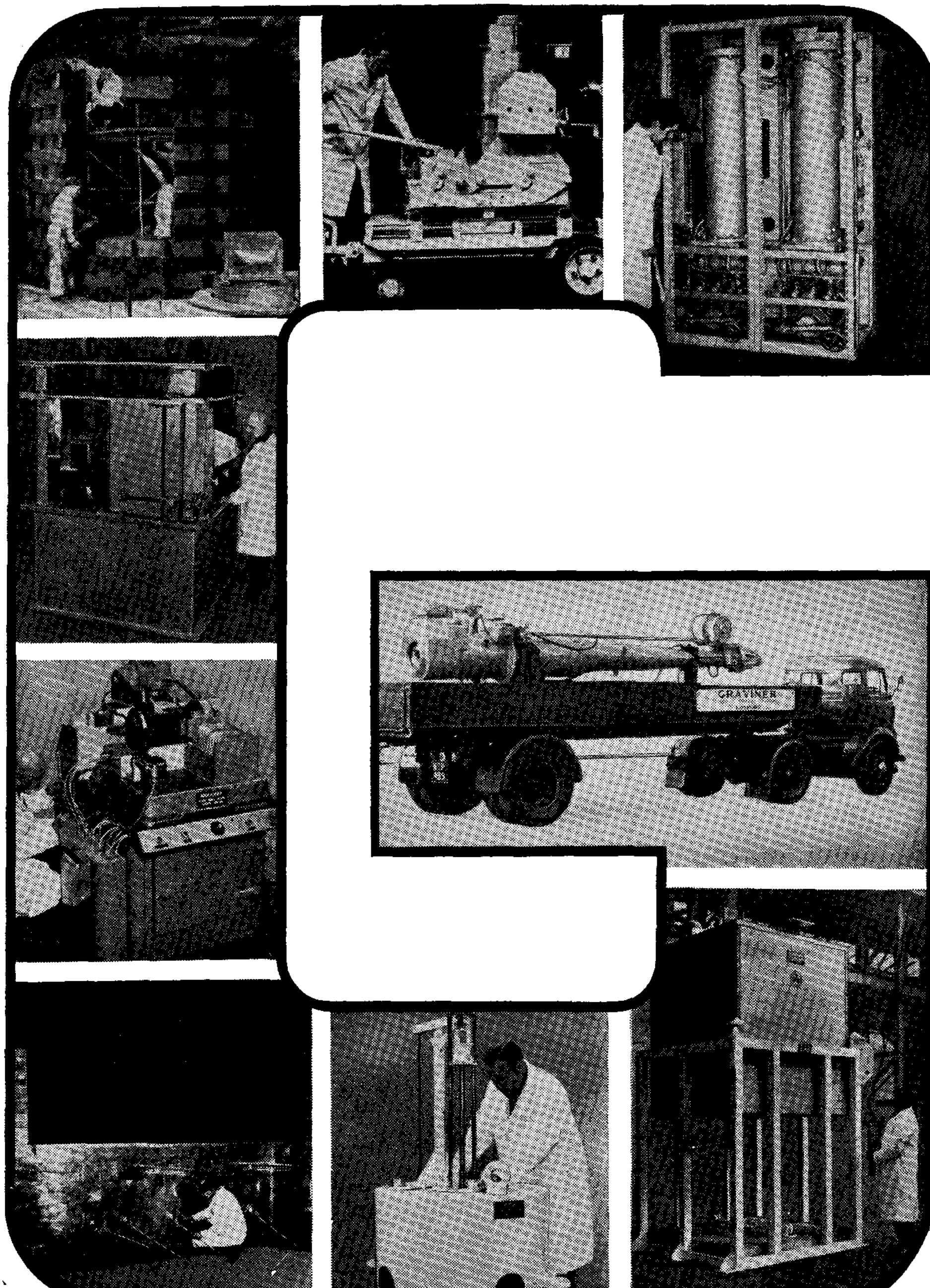
GRAVINER

ATOM

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ATOM
monthly bulleting of the UKAEA 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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Birthday Honours

The Queen has awarded Birthday Honours to the following U.K.A.E.A. staff:—

Knighthood
Dr. J. M. Hill, Chairman.

C.B.E.
Dr. W. P. Grove, Director, The Radiochemical Centre, Amersham.

O.B.E.
Dr. F. Morgan, Senior Superintendent, Chemistry Division, Weapons Group, Aldermaston.

M.B.E.
Dr. K. G. Eickhoff, Research Manager, Reactor Technology, Reactor Group, Risley.
A. S. Davidson, Works Manager (Chemical Separation) Production Group, Windscale and Calder Works.

B.E.M.
Miss Ruth Butler, Canteen Supervisor, Production Group, Springfields Works.

The Nuclear Power Group Ltd.

As part of the reorganisation of the nuclear industry, the Shareholding Companies of The Nuclear Power Group Limited, the United Kingdom Atomic Energy Authority, and the Industrial Reorganisation Corporation, have together formed a new company for the design and construction of nuclear power stations at home and abroad.

The new Company, which was registered on 31st March, 1969, is called The Nuclear Power Group Limited* with headquarters at Radbroke Hall, Knutsford, Cheshire. It has a share and loan capital of £10m. held as follows:

	%
United Kingdom Atomic Energy Authority	20
Reyrolle Parsons Limited ..	20
Sir Robert McAlpine & Sons Limited	15

*On 31st March, 1969, the Company formerly known as The Nuclear Power Group Limited and which has contractual responsibilities for the design, construction and commissioning of the A.G.R. nuclear power stations at Hinkley Point B and Hunterston B, changed its name to "The Nuclear Power Group (H.H.) Limited".

Clarke Chapman & Company Limited	10
John Thompson Limited ..	10
Industrial Reorganisation Corporation	10
Head Wrightson & Company Limited	5
Strachan & Henshaw Limited ..	5
Whessoe Limited	5

The Company has received contracts from the United Kingdom Atomic Energy Authority for the completion of the design and construction of the 250 MW(e) Prototype Fast Reactor at Dounreay in Scotland and for development work on sodium-cooled fast reactor systems. The staff of The Nuclear Power Group (H.H.) Limited are transferring to the Company. In addition a number of the United Kingdom Atomic Energy Authority staff engaged on the design and construction of the Prototype Fast Reactor are transferring to the Company.

Members

The Members of the Board of Directors of The Nuclear Power Group Limited nominated by the Shareholders are:

Sir Edwin McAlpine, Chairman
S. A. Ghalib, Managing Director
Dr. H. Kronberger, United Kingdom Atomic Energy Authority
C. Allday, United Kingdom Atomic Energy Authority
E. T. Judge, Reyrolle Parsons Limited
J. Bennett, Reyrolle Parsons Limited
K. McAlpine, Sir Robert McAlpine & Sons Limited
J. B. Woodeson, Clarke Chapman & Company Limited
Sir Humphrey Browne, John Thompson Limited
J. P. Berkin, Industrial Reorganisation Corporation
The Hon. J. D. Eccles, Head Wrightson & Company Limited
Colonel E. Ward, Strachan & Henshaw Limited
M. J. Noone, Whessoe Limited

Directors

The full-time Directors of the Company, under Mr. S. A. Ghalib, are:

R. D. Vaughan, Chief Engineer
W. Macrae, Projects Director
W. A. K. Wicks, Secretary.

U.K.A.E.A. PRESS RELEASES

Fuel sales in U.S.

The Authority have made an arrangement with Gulf General Atomic of San Diego, for collaboration on promoting sales of light water reactor fuel in the United States. The arrangement provides for the Authority's development and design experience to be made available to Gulf General Atomic.

Gulf General Atomic have announced that they are now offering nuclear reactor fuel assemblies and reactor cores for light water reactors to the electric utility industry.

In the longer term as warranted by the market it is planned that the Authority shall have a modest shareholding in a joint company to be established with Gulf General Atomic in the U.S. for manufacture of light water reactor fuel. *28th May, 1969*

A.E.A. team visits Japan

The United Kingdom Atomic Energy Authority and the Science and Technology Agency of Japan have agreed to hold annual meetings to discuss nuclear matters of common interest.

The first meeting is to be held on 9th and 10th June. The British team will be led by Dr. J. M. Hill, Chairman of the Authority, and will include: Dr. H. Kronberger, Member for Reactor Development, and Mr. D. E. H. Peirson, Secretary of the Authority. *6th June, 1969*

APACE Centre courses

APACE (Aldermaston Project for the Application of Computers to Engineering) is holding further courses for engineers:

Computer Appreciation Course for Engineers—4 days
FORTRAN Programmers' Course for Engineers—5 days
APT Part I Course—4½ days
2CL Users' Course—4½ days
Interactive Graphics Programming Coures—4½ days
Electronic Computer Aided Design Introductory Course—4½ days
Circuit Analysis Users' Course—3 days

Further information is obtainable from The Secretary, (Ref. A), APACE, U.K.A.E.A., Blacknest, Brimpton, near Reading, Berks. Telephone Tadley 4111, ext. 5951/5873.

IN PARLIAMENT

Gas centrifuge process

The following extracts are taken from the debate on the gas centrifuge process which took place in the House of Commons on 14th May, 1969.

MR. EDWIN BROOKS (Bebington): I wish to raise a matter which has excited a good deal of interest and anxiety both in this country and in many parts of Europe. I refer to the proposal for a gas centrifuge technology for the enrichment of uranium, a sophisticated scheme to be developed jointly by this country, the Netherlands and the Federal Government of Germany.

This is a most important proposal, both in the economic and military sense, and I feel that Parliament is owed a full explanation of the Government's objectives.

My questions fall into three main sections: the economic case for the gas centrifuge, the industrial structure of the tripartite venture, and the military potential of the uranium 235 which will be concentrated by the process and made available to the countries concerned.

The enrichment of uranium has been described as a key to the future development of nuclear power. Without such enrichment, we are told, the efficiency of future power stations would be handicapped.

On the borders of my constituency in Cheshire lies the older, original technology, the gaseous diffusion plant at Capenhurst. The electricity consumed in such a diffusion cascade is enormous, and Capenhurst, although much smaller than the United States Complex at Oak Ridge, Portsmouth and Paduca—which use, I understand, 6,000 megawatts of electricity when on full stream—is probably the greatest single industrial consumer of power in Britain.

Indeed, I understand that about half the price of processing the uranium by the diffusion process is in electricity costs alone. Therefore, a process, such as the gas centrifuge, which promises to use considerably less electricity could have a big influence on the future costs of enriched uranium. Some estimates I have seen suggest a power requirement only 10 to 15 per cent. of that needed for the diffusion plant, while a further bonus is that for a given throughput a centrifuge plant is believed to be marginally cheaper to build.

Against this, the centrifuges, which spin at 50,000 r.p.m. and generate centrifugal forces in excess of one million times gravity, may prove to be expensive and sophisticated devices on the very frontiers of our present metallurgical and engineering skills. I would be interested to know from my hon. Friend how far the obvious problems of such devices have yet been solved—for example, how to pass the gas in and out while the rotor is spinning at these tremendous speeds, the problems of the vacuum seals and the structural integrity of the outer walls of the rotor. Indeed, there is, I gather, a risk of a sort of chain reaction among the centrifuges themselves should one split and fly to pieces and bombard the others.

Further proposed investment at Capenhurst has been held back pending clarification of the centrifuge agreement, and I and people on Merseyside are naturally curious to know the latest state of play. Will one of the two proposed centrifuge plants be at Capenhurst? In view of the investment already made there, it is probable that a "hybrid" system would make economic sense.

In *Science Journal*, last February, it was suggested that the initial stages of the diffusion plant could perform the rough filtering, and the centrifuges, also connected up as a counter-flow cascade, would then bring the enrichment of uranium-235 up to the standard fuel figure.

This suggests that one major use of the centrifuge will be topping-up the capacity of existing filter type separation plants, and I therefore assume that Capenhurst is the probable choice of site.

The possibilities of growth seem substantial, for one attraction of the centrifuge system is that capacity can be expanded piece-meal.

There would seem to be undoubted advantages of having such successive centrifuge cascades alongside one another, and alongside the diffusion plant where the so-called rough filtering is carried out. But there seems to be a further prospect of the actual manufacture of the centrifuges being placed alongside as well. This also has great relevance to Merseyside. The scale of output of centrifuges would be very large, since estimates have been made that a production line capable of turning out one million rotors a year will be needed by the early 1970s.

Indeed, estimates of the Common Market requirements alone by 1975 suggest a figure of several million rotors. It has been claimed, and I would ask my hon. Friend to comment on this, that such production of a highly precise piece of engineering would be best sited near the centrifuge cascade, to avoid the possibility of damage being caused in transit over long distances. Capenhurst, on Merseyside, could mean an injection of highly skilled employment.

I am aware that such detailed considerations may lie in the future, but this brings me to my second major series of questions, the business side of the project, its administrative structure and the way in which decisions will be taken over purchases, siting of plant, pricing of the product and so on.

If I can take the pricing first, is it to be the case that uranium will be sold to the member countries at basic costs of production, or will there be a levy to meet the capital costs involved? I ask this because I understand that the operating costs of the centrifuge are relatively low—so little electricity being required—yet the capital investment plus the research costs at this stage, could be very substantial.

Furthermore, how is the market for the enriched uranium to be calculated and won? The huge diffusion plants in the United States and possibly their successors will presumably be competing with the centrifuge plants, in the E.E.C. countries as elsewhere, and I would be interested to know whether there is confidence that the centrifuge price will prove competitive.

New Scientist, on 20th March last, criticised the administrative arrangements as being "not very sensible", and designed apparently to appease all interested parties: the United Kingdom because of its vast and recently expanded investment in uranium enrichment at Capenhurst, the Dutch because they believe—I base this upon an *Observer* article on 16th March last—that they have a two-year lead over the other countries, and the Germans because of their growing need for nuclear fuel, quite apart from their hitherto undisclosed work on isotope separation methods.

Could my hon. Friend tell us which organisations and firms are actually involved in the scheme, and on what terms and conditions about profit margins and voice in decision making? In a Press statement issued on 11th March, it was announced that two organisations should be set up—a "Prime Contractor" for the manufacture of centrifuges and the construction of enrichment plants, and an "Enrichment Company" for the operation of enrichment plants. The headquarters of the former, the prime contractor, which will be responsible for research, design and construction of the extremely high performance centrifuges, is to be in Germany. I would like to know a little more about its rôle.

Mr. David Fishlock, in the *Financial Times* on 13th March, described it as "in effect, a central purchasing agency for some very high grade engineering-rotors, bearings, ultra-fast drives and vacuum systems, for example—and should soon find itself placing orders for components for some hundreds of thousands if not millions of machines a year. Those orders will go out to tender in private industry in the three countries, and, if others are admitted, in those countries, too."

Are we to have two, or more than two, assembly factories built for the manufacture of the centrifuges initially? Are these to be alongside the centrifuge cascades in the Netherlands and Britain, as I think would be sensible, or will they be in Germany?

What would be the position in general terms if a further country sought to join the consortium? Would participation on the part of other E.E.C. countries be desirable? It seems to me that we tend to pay far too much lip-service to the idea that anyone who wants to join in later can do so; but after all, it is not good enough for others to come in once the initial risks have been borne and the costs incurred, and simply help cream off the benefits.

The Minister of State, Ministry of Technology (Mr. J. P. W. Mallalieu): My hon. Friend the Member for Bebington (Mr. Brooks) has made not only an interesting but extremely balanced speech on what is a difficult question. He has asked a number of penetrating questions which I shall try to answer in the time available, but I ought to make clear to him and the House at the outset that so far no formal agreement yet exists between this country, the Federal Republic of Germany and the Netherlands to embark on the collaborative production of enriched uranium using the centrifuge process.

When my right hon. Friends met their colleagues from the two other countries in London on 11th March agreement was reached on a number of principles which would have to govern any collaboration, if it took place, but discussions have continued with the two other Governments and a number of issues have still to be settled before we can even be in a position to sign a formal agreement. I hope that my hon. Friend will understand that for this reason it will not be possible for me to be as precise as he might have wished me to be in dealing with some of the points that he has raised.

In his speech my hon. Friend concentrated on three main themes—the economic aspects of the project, the industrial organisation involved and the military implications—and I propose to try and reply to him in that order.

The first question he asked under economic prospects was related to the likely cost of the enriched uranium produced by the centrifuge process. This is one of those questions on which I cannot be precise, since until we have gone much further in our discussions with the other two countries, indeed, not until after a formal agreement has been concluded, will it be possible to estimate at all precisely what the economics of a design using the best ideas from the three countries would be.

However, all three of us are confident, on the basis of work which each of us has done in our own country, that the process is cheaper than the gaseous diffusion method, used at present at Capenhurst, and, moreover, that the tripartite venture will be able to compete with the U.S. Atomic Energy Commission's enrichment plants—and I hope that my hon. Friend will consider that this also answers the point that he made about the market potential for enriched uranium from the centrifuge project in competition with similar uranium produced by the gaseous diffusion process.

If agreement is reached between the three countries to collaborate, we envisage that two plants would be built to enrich uranium—one in the United Kingdom, and the other in the Netherlands and the Netherlands have already nominated a site for the plant in their country. We have not yet decided where any British plant would be located. There are, of course, very strong *prima facie* arguments for building it at Capenhurst, but the final choice has not yet been made—and indeed does not need to be made yet.

But whether or not a centrifuge plant is erected at Capenhurst it will supplement and not supersede the gaseous diffusion plant there. That plant will continue to supply enriched uranium for many years to come. Both facilities will be needed to meet the growing need of the nuclear power programme of this country—and, we hope, of other countries too—for enriched uranium in the 1970's.

My hon. Friend asked a number of questions about the industrial organisation of the centrifuge project. Obviously, again, since we have not yet concluded a formal agreement I can only give an indication of the lines along which we are working and which are agreed by all the three countries involved. There are two distinct functions that the industrial organisation will have to perform: one is to develop and supply the centrifuge plants, and the other is to use the plants to enrich uranium. We think that two distinct international companies, jointly owned by the Government and/or industrial interests in the three countries should be set up.

One of these will be an enrichment company which will own and operate the enrichment plants. The other, which has been called the "Prime Contractor", will carry out research and development on the centrifuge and will design, develop, manufacture and construct complete enrichment plants ordered by, and to the specification of, the enrichment company.

These two international companies should have as much autonomy as possible in their day-to-day operations if they are to operate on a sound financial basis. They would, however, be supervised by a committee composed of representatives of the three Governments, which would decide on questions arising in the course of their business, concerning security procedures, the safeguards on the use of nuclear material, relations with other countries and similar matters.

As regards participation in the project by other countries, the communiqué issued after the Ministerial meeting in London on 11th March stressed the readiness of the three Governments to associate other European countries with he proposed collaborative venture after ts establishment, and went on to point out that a special working party was being set up to examine what form of co-operation might be envisaged.

I think that it is clear, therefore, that all three Governments would welcome the participation of other European countries in due course, but the discussions that have taken place up until now have been solely on a tripartite basis because the three countries concerned believe that they are the only ones in Europe who are in a position to exploit significant work on the development of the gas centrifuge process.

A.E.A. establishments costs

9th May, 1969

MR. MARPLES asked the Minister of Technology if he will give a breakdown of the £6 million interest, £9 million depreciation, £2 million superannuation and £1 million of other items, including insurance, respectively, between each of the Atomic Energy Authority's establishments.

Mr. J. W. P. Mallalieu: The Authority's accounts do not provide a detailed breakdown of the charges for depreciation and interest on a site basis. Approximate figures on a group basis are given below.

	Interest £'s million	*Depreciation £'s million*	*Superannuation £'s million*	*Other Items £'s million*
Reactor Group, including Winfrith, Dounreay, Risley and laboratories ..	3	5	0·6	0·4
Research Group including Harwell and Culham	2	3	0·6	0·4
Other sites	1	1	0·6	0·4
	6	9	1·8	1·2

Nuclear station for Greece

14th May, 1969

MR. WILLIAM HAMILTON asked the Minister of Technology what progress has been made on the sale of a steam generating heavy water power station to Greece; and to what extent the agreement is dependent on the British purchase of Greek tobacco.

Mr. Fowler: An agreement has been signed with the approval of the British and Greek Governments which provides that the U.K.A.E.A. and the Public Power Corporation of Athens will negotiate a contract for the sale of a nuclear power station to Greece, and that, in parallel, a separate contract will be negotiated for the supply to Britain of Greek tobacco.

Desalination of sea water

21st May, 1969

SIR D. RENTON asked the Minister of Technology what progress has been made with regard to desalination of sea water; which pilot schemes are in operation or have been planned; and whether he will make a statement.

Mr. J. P. W. Mallalieu: Considerable progress has been made by the Atomic Energy Authority and several industrial partners. Development of the multi-stage flash distillation process for export markets has consistently reduced costs, and other processes are under investigation.

Pilot plants exist or are planned to test these alternative processes, but there are no proposals at present for desalination schemes in the United Kingdom.

Miss Quennell: Is the hon. Gentleman aware that there is a predictable and foreseeable water shortage in this country, which, by the year 2,000 will be critical? Surely the Government should be doing a little more than this about it.

Mr. Mallalieu: This is a matter for the Minister of Housing, but he has been having a report prepared on it and it is now being considered.

Centrifuge process research

21st May, 1969

MR. GWILYM ROBERTS asked the Minister of Technology what further study his Department has made of the uses of gaseous centrifuge techniques and their application to separating uranium 235 and 238 and plutonium 239 and 240; and to what extent in the British/Dutch/German agreement account was taken of the availability of nuclear weapons to each of the participating Governments.

Mr. J. P. W. Mallalieu: The United Kingdom Atomic Energy Authority has been conducting research on the centrifuge process and its application for many years. In our discussions with the Netherlands and German Governments it has been agreed that any agreement between us to exploit the process must incorporate mutual undertakings and safeguards provisions consistent with our respective policies and international obligations regarding the non-proliferation of nuclear weapons.

Future of Orfordness

21st May, 1969

SIR H. HARRISON asked the Minister of Technology whether he will make a statement about the future of the Atomic Weapons Research Establishment at Orfordness, Suffolk.

The Minister of State, Ministry of Technology (Mr. J. P. W. Mallalieu): In the foreseeable future there is not likely to be an adequate work load to justify keeping the Orfordness station open. The Atomic Energy Authority is therefore studying the implications of closing the establishment and transferring to Aldermaston those test facilities which will continue to be required.

Sir H. Harrison: Why have we had to wait for this Question before we had a statement about this? There have been rumours in the Press. Surely this is a bad way of doing it. What steps is the hon. Gentleman taking to see that those employed here are given further occupation? Is his decision influenced by the building of the radar research station at Orfordness?

Mr. Mallalieu: On the latter question, the answer is, "No." An announcement has been made to the staff concerned that this prospect is before us. There are about 170, most of whom could be re-employed at Aldermaston, if they want it, or, otherwise, in establishments in the area itself.

Breakdowns

21st May, 1969

MR. EADIE asked the Minister of Technology if he will list the nuclear power stations in Great Britain operated by the Atomic Energy Authority which have been subject to breakdown during the last five years; and what were the additional costs and the loss of revenue involved.

Mr. J. P. W. Mallalieu: I have already given the hon. Member the information for which he asked in respect of the one reactor at Chapelcross which has been out of commission since May, 1967. The three other reactors at Chapelcross and the four reactors at Calder Hall, which is the only other power station operated by the Authority, have all operated successfully over the last five years.

Mr. David Price: Does the hon. Gentleman agree that the reactors operated by the Atomic Energy Authority are in the main prototype reactors and a fair comparison with coal-fired stations is in looking at the costs with the Central Electricity Generating Board and the South of Scotland Electricity Board? Will he confirm that the utilisation of British reactors by the two generating boards is higher than any reactors operating anywhere else in the world?

Mr. Mallalieu: Yes, I confirm that with pleasure.

D.M.T.R.

21st May, 1969

MR. HECTOR HUGHES asked the Minister of Technology why the Dounreay Materials Testing Reactor was closed down after 11 years; where and when its unfinished work will be resumed; what employment will be offered to the workers there; and what effect this will have on the employment conditions in the City of Aberdeen.

Mr. J. P. W. Mallalieu: The reactor was closed down because the Atomic Energy Authority decided, after careful consideration, that its needs for materials testing irradiation facilities could best be met by concentrating remaining work at Harwell. Staff will be transferred to other work at Dounreay, and employment conditions in Aberdeen should not be affected in any way.

Mr. Hector Hughes: Does my hon. Friend realise that this closing down is very serious from the point of view of not only interference with the valuable work carried on there but interference with workers who live there who will have to transplant their homes to another area? Will he therefore give the evidence on which his deep consideration was based?

Mr. Mallalieu: I understand that there will be no uprooting whatever. The staff will be transferred to other work at Dounreay itself.

Nuclear site development

23rd May, 1969

SIR F. MACLEAN asked the Secretary of State for Scotland what restrictions are placed by the Inspectorate of Nuclear Installations on industrial and residential development in the vicinity of nuclear power stations of the type of Hunterston A.

Mr. Ross: The Inspectorate advises me about the desirability of any proposed development near the Hunterston A station and the decision rests with me.

Each proposal is examined on its merits, and the considerations which I take into account vary according to the nature of the development.

Prototype Fast Reactor

9th June, 1969

MR. LUBBOCK asked the Minister of Technology if he will now give an estimate of the additional costs and the loss of revenue involved as a result of the welding defects on the prototype fast reactor now under construction.

Mr. J. P. W. Mallalieu: The additional cost of constructing the prototype fast reactor as a result of the delay in completion due to welding difficulties is estimated at £$\frac{3}{4}$ million. The estimated loss of electricity receipts is £1.2 million in 1971-72 and £0.85 million in 1972-73.

A.E.A. Reports available

THE titles below are a selection from the June, 1969, " 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.

AEEW-M 834
Lilly. A Computer Code for Calculating an Inferred K-Infinity from Reaction Rate Measurements in Thermal Reactor Systems. By M. J. Hibberd and K. C. Kendall. August, 1968. 24 pp. H.M.S.O. 4s. 6d.

AEEW-M 881
Progress in the Application of Solid-State Track Recorders to Reactor Physics Experiments. By C. B. Besant and S. S. Ipson. March, 1969. 26 pp. H.M.S.O. 6s.

AERE-M 2135
Some Chemical Methods for the Separation of High Purity Short-lived Fission Products. By R. J. Bullock and N. R. Large. March, 1969. 15 pp. H.M.S.O. 2s. 6d.

AERE-M 2145
7,000 Series CAMAC Controllers. By J. M. Richards. April, 1969. 24 pp. H.M.S.O. 3s. 6d.

AERE-M 2152
Minimum Fluidisation Velocities for Spherical and Irregular Particles Fluidised by Air. By B. A. Partridge and E. Lyall. March, 1969. 9 pp. H.M.S.O. 4s.

AERE-PR/HPM 13
Health Physics and Medical Division Progress Report, January-December, 1968. Edited by J. E. Johnston. March, 1969. 49 pp. H.M.S.O. 8s.

AERE-M 2199
Abundances of Long-lived Delayed Neutron Groups ($t\frac{1}{2} \rightarrow 1$ min) in the Fission of ^{235}U, ^{238}U and ^{239}Pu by Fission-spectrum Neutrons. By L. Tomlinson and M. H. Hurdus. April, 1969. 5 pp. H.M.S.O. 1s. 9d.

AERE-R 4657
Properties of Refractory Materials. By S. J. Burnett. 1964. Reprinted April, 1969. 325 pp. H.M.S.O. 42s.

AERE-R 5999
A Gravimetric Procedure for the Quantitative Determination of Zirconium and of Niobium as Phosphate. By C. G. Wallace. March, 1969. 18 pp. H.M.S.O. 2s. 6d.

AERE-R 6040
The Irradiation of Carbon Dioxide containing Small Amounts of Methane. The Formation of Hydrogen. By J. A. Hearne and R. W. Hummel February, 1969. 19 pp. H.M.S.O. 5s.

AERE-R 6056
Calculated Independent Yields in Thermal Neutron Fission of ^{233}U, ^{235}U, ^{239}Pu, ^{241}Pu and in Fission of ^{232}Th, ^{238}U and ^{240}Pu. By E. A. C. Crouch. March, 1969. 10 pp. H.M.S.O. 4s.

AERE-R 6061
The Use of Gamma Radiation in Soil Research. By P. A. Cawse. April, 1969. 15 pp. H.M.S.O. 3s. 6d.

AWRE O-15/69
The Determination of Natural Radioactive Impurities in the Raw Materials of Li-6 Loaded Cerium Scintillation Glasses and their Removal. By L. P. O'Connor. April, 1969. 14 pp. H.M.S.O. 2s. 6d.

Harwell and industrial research

The following paper was presented as the Maurice Lubbock Memorial Lecture by Dr. W. Marshall, Director of Harwell and the Research Group, U.K. Atomic Energy Authority, at the Department of Engineering Science, University of Oxford on 9th May, 1969.

It is the custom of these Maurice Lubbock Memorial Lectures to appoint as speaker a man of high reputation, outstanding ability and undisputed merit. It is a good custom, much to be applauded, and therefore I am in some difficulty to explain to you why, in this case, the organisers saw fit to depart from such an excellent precedent. Nevertheless I was delighted and honoured to accept the invitation to address you here today, because the subject suggested to me is the contribution that Harwell can make to industry and the problems to be faced in making this contribution effective. This subject has been the central part of my own personal task over the last few years and though I and my colleagues would not claim to have solved all the problems, we think we have made a promising start; what I have to say to you is thus an interim report on how a large Government-funded laboratory diversifies into direct industrial involvement.

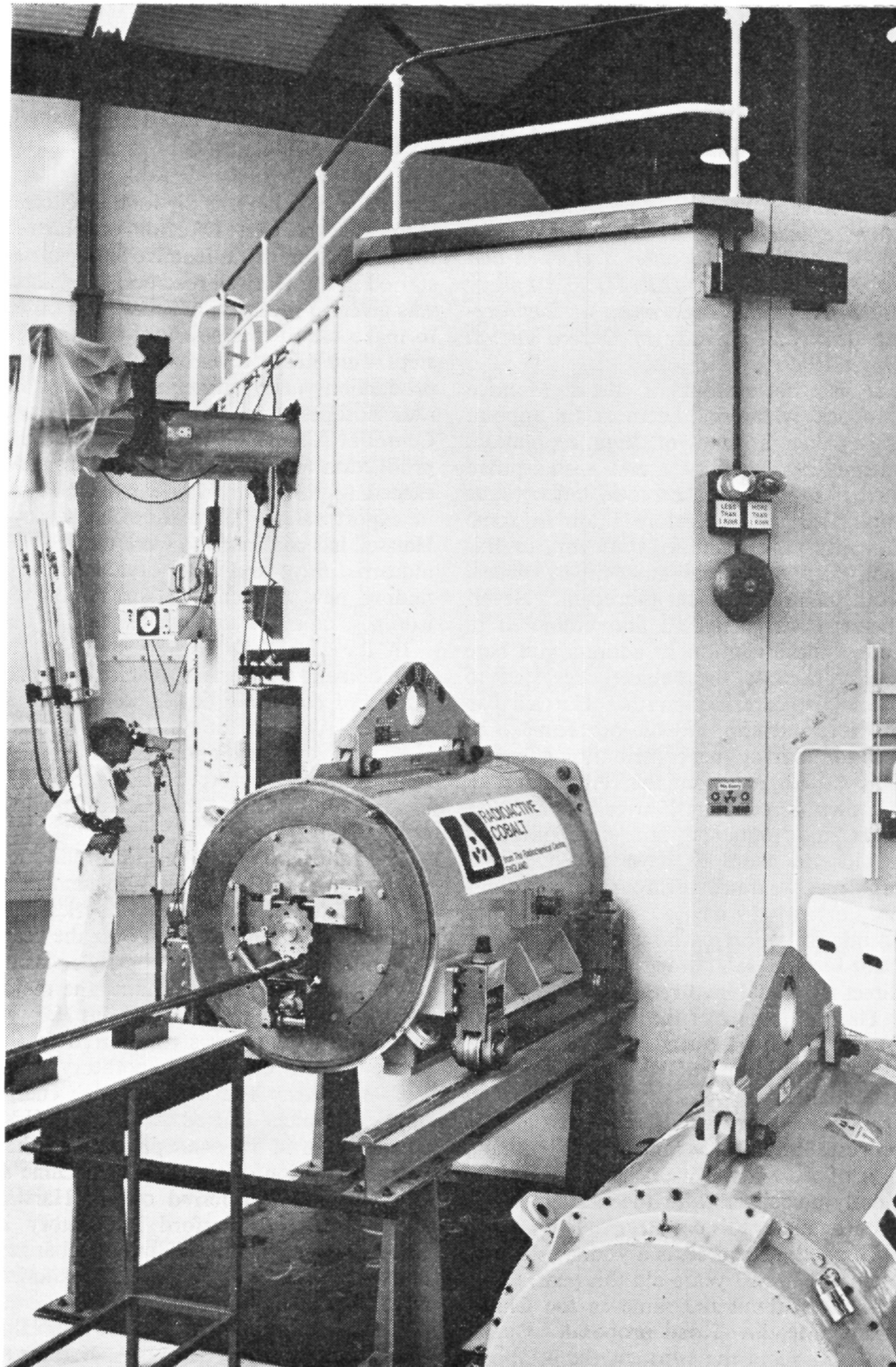
Harwell is part of the United Kingdom Atomic Energy Authority and employs about 5,500 staff, of whom about 1,200 are qualified scientists and engineers; it spends altogether about £15m. per annum on research and development. The major part of the Harwell work is directed at or closely associated with the nuclear power programme in this country.

Harwell, of course, is a young establishment; we are 23 years old this year, which makes us about the same as the Christchurch Meadow Road proposal. During those 23 years the work of the establishment has undergone several major changes. During the first few years, until the 1950's, the main task was to establish the scientific background required for the design and construction of the production plants for fissile material at Windscale, Capenhurst and Springfields. As soon as possible, under the leadership of Sir John Cockcroft, who was the first Director of Harwell, the production of radioactive isotopes was started in the Harwell reactors. Assistance was given to industry, hospitals and others to make use of this new tool and the first steps were taken towards establishing the production and marketing industry for radioisotopes. Later the Radiochemical Centre at Amersham took over all isotope production and they now have a turnover exceeding £3m. of which over 50% is in export sales. Since those early days, Harwell has continued to work closely with industrial firms and other organisations in finding new applications for radioactive isotopes, radiation and nuclear techniques.

In the 1950s the earliest steps in the development of nuclear reactors as producers of economic power were taken at Harwell. Amongst the systems then studied were the fast reactor and the high temperature gas-cooled reactor, which are today in the forefront of the U.K.'s nuclear programme.

The rapid growth of reactor studies led to the formation of a new establishment at Winfrith to which reactor physics and engineering were transferred over the years 1958-60. Similarly, the Authority's plasma physics and fusion programme, the major part of which was concentrated at Harwell in the early years, was transferred to the newly-formed Culham Laboratory from 1960 onwards. The work on high energy physics, which started with the U.K. participation in the CERN project and then the construction of the 7 GeV machine at Harwell, was transferred out of Harwell and into the Rutherford Laboratory in 1961. From all these major changes, Harwell emerged as primarily a materials research and development establishment.

I hope you will have gathered from this brief sketch that there has been at Harwell a continuous change in the research programme and consequently a high degree of mobility amongst the staff. This tradition of mobility has been retained, the average half-life of our scientists is about 8 years and this has kept us a young laboratory. Our close connection with the



The Isotope Production Unit, located at Harwell is the Department of the Radiochemical Centre, Amersham, Bucks.

A transport container ready for loading with cobalt-60 at the Unit.

applications of science, through radioisotopes and radiation but primarily through the nuclear power programme, has involved us in the many problems of transforming scientific knowledge into technology rapidly. We have found from this experience that the rapid development of a sophisticated technology, such as nuclear power, requires a co-ordinated multi-disciplinary attack on the problems. For example, the development of a fuel element requires chemical, physics and metallurgical studies on the materials used, fabrication studies, engineering design and testing (especially from the heat transfer point of view), studies of the radiation effects on the materials and attention to impurities which may have a profound effect on radiation behaviour and on physical properties. Frequently unsuspected problems are met which may affect the whole of the technological development programme; thus the ability to switch effort rapidly and in particular to bring in new disciplines and approaches may be vital if the development is to succeed both technically and economically. This participation in the development of nuclear power has provided Harwell with an exceptional range of resources which are capable of application to other technologies, and also with a group of scientists and engineers who have experienced the tight scheduling of technologically oriented projects.

Tonight I wish to talk, not about the nuclear power programme, but about the way these resources, physical and intellectual, can be exploited for other purposes of economic value. Nowadays it is generally conceded that nuclear power is proven and established—though possibly the Maurice Lubbock lecturer of 1965 would register a violent dissent to such a statement—and therefore the need for a continued "big push" of research into nuclear power is diminished. A considerable effort will still be required to develop the third generation of British power reactors, due to come on stream after 1975, but the scale of the total effort can be diminished. When this first became clear we began to consider what the future role of Harwell should be. It was quite apparent that this country needed more research and development oriented to industrial problems but nevertheless it was not at all easy to decide that this was what Harwell should do. We knew we could undertake scientific research on a wide range of problems, we knew that we could use the resources of Harwell to develop ideas rapidly and we saw that this was essential to meet international competition. Furthermore, and perhaps this was the most important factor of all, we knew that the Laboratory as a whole could rapidly change its orientation and objectives—after all that is something we had done several times before in our short history.

But on the other hand, the simple idea that national growth and innovation were linked closely with R. & D. was largely discredited. We knew that research and development were largely worthless unless done as an integral part of an operation linking them closely to design, production and marketing. This point was subsequently emphasised in the report of the Central Advisory Council for Science and Technology on "Technological Innovation in Britain" (the Zuckerman report). Indeed, it is noteworthy that, in summarising the "Conditions for Successful Innovation", the report uses the word "research" once and the word "market" or "marketing" no less than five times.

The question we faced some two years ago was therefore quite clear: could Harwell work so closely with industry that the research was strongly market-oriented and that there was a close link between all the parts of an innovative chain? At the time it was not obvious that the question deserved a positive answer and the decision to go ahead with the industrial programme was very much an act of faith by the Authority and by the Ministry of Technology. The decision was, of course, consistent with the policy of the Minister of Technology to redeploy Government resources and funds to more immediate and short term research.

When this decision was taken, we embarked on another major change in Harwell's programme. As I have stressed earlier it is not difficult to change emphasis or orientation in a multi-discipline and multi-purpose laboratory like Harwell, and I'm quite sure that the present change will not be the last for us. But, it is worth commenting that it is more difficult to bring about change in a single discipline, single objective laboratory: such laboratories have many attractions but it is difficult to know what to do when their objective or mission has been achieved.

Having decided to seek industrial research, our first task was to determine what resources could be spared from the Reactor R. & D. programme—which remains our central task—and how much underlying scientific research we should continue to do. We have so far been able to free about 20% of our resources for new work and we have also been able to re-orient a further 10% of existing work towards more direct industrial objectives. The total makes about 30% on direct industrial objectives outside the nuclear power field. In practice the demand for reactor R. & D. is not falling off as rapidly as we expected and the industrial programme has grown more rapidly than we expected—thus our resources at the moment are under heavy pressure.

To construct a portfolio of industrial projects we took two basic decisions which were related in an important way to the legal powers possessed by the Atomic Energy Authority under the Act of 1954. That Act had empowered the Authority to do a wide range of nuclear work including industrially oriented nuclear work outside the main nuclear power programme. Typically this applied nuclear work would be concerned with the use of isotopes or radiation for various economic or social objectives. We examined this work very carefully and came to the conclusion that it was primarily of a "missionary" type: it was directed at industry but only in the sense of demonstrating how isotopes, radiation and other nuclear tools could be used for general purposes. We decided that this was no longer satisfactory and that the research should be given sharper and more direct objectives; each project should be chosen to give an identifiable economic benefit and, save in exceptional circumstances, pursued in close partnership with an industrial company. In brief we decided to change the work from a "missionary" to a "mission oriented" character.

The second basic decision concerned research outside the Atomic Energy Authority Act of 1954. Anticipating that it would be in the national interest for the Authority to take on wider responsibilities, the Science and Technology Act of 1965, which set up the new Ministry of Technology, included a clause empowering the Minister of Technology to "require" the Authority to undertake research into "matters not connected with atomic energy". We decided to take advantage of this new Act to seek a wider remit for industrially oriented work by asking the Minister for several of these "Requirements". All our work covered by the 1965 Act we refer to as non-nuclear work and so far we have requested and received sixteen Requirements. Each Requirement is couched in very general terms, for example, to do research on ceramics, on quality control, on computer software. And before we request a Requirement we ask ourselves very searching questions. What research, broadly speaking, would we do? Is it really needed in the national interest? Is Harwell the most appropriate laboratory to undertake it? Are we sure it does not overlap or conflict with the objectives of other Government Laboratories or of the Research Associations? On all these points both the Authority and the Ministry must be completely satisfied before any proposal is put to the Minister himself. This examination is done very thoroughly and the average time needed to satisfy ourselves and then obtain a Requirement is about 12 months.

The general purpose and reason for this non-nuclear work is sometimes misunderstood by outside observers who see it primarily as a device to continue Government support to scientists who would not otherwise have justifiable employment. I can reply only that this is neither our motivation nor that of Min. Tech. I personally regard these non-nuclear Requirements as essential legal steps to enable us to manage the industrial programme by simple objectives: if we set out to solve a particular problem we must solve it by whatever research is appropriate and best; if we confine ourselves to the 1954 Act then essentially we have nuclear solutions looking for problems to solve. It is better management to identify the problems and objectives first, and then look for the solutions to those problems and objectives: this seems self-evident for any organisation but in our case it does involve seeking the appropriate legal powers. For example, our work on analytical sciences uses all techniques, including nuclear techniques, for the atomic energy programme; but under the 1954 Act only the nuclear techniques can be used to help industry generally. Therefore, to make all our analytical resources available to industry, the legal powers of the 1965 Act are necessary.

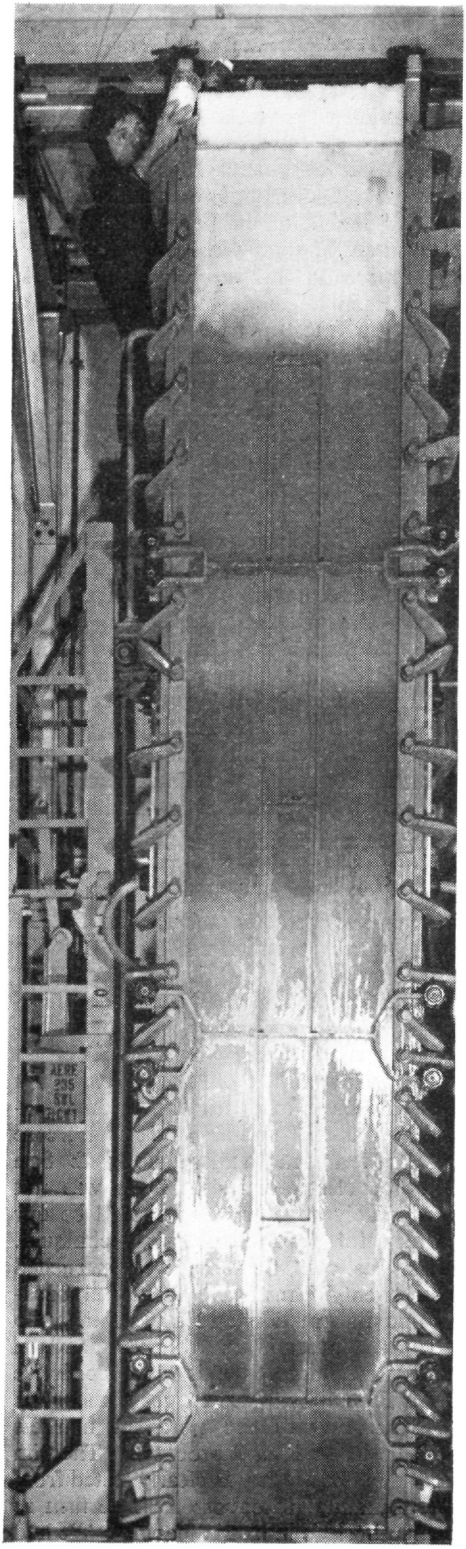
Where, then, have we got to in setting up these industrial projects? About 30% of the staff are involved and they spend about 25% of Harwell's budget—say £4m. a year. Naturally what I would best like to do is to talk about individual projects in some depth. Unfortunately this is not possible because of the need to keep a major part of the work in confidence. Therefore I shall be able to describe the projects only in general terms. In describing the projects I shall try to illustrate the ideas we are developing for interacting with industry and some of the problems which face us.

Some of the projects we undertake are of a national benefit type. These are projects undertaken to develop a new technology, for example high temperature fuel cells, or for purely social reasons, for example atmospheric pollution. For these projects the commercial exploitation aspects are either completely absent or not a major factor determining the way we work. But for most projects the commercial aspects are extremely important and in talking about these I shall begin with the desalination programme, because it is the largest single non-nuclear enterprise in the Authority.

The desalination programme has been undertaken by the Authority at Min. Tech. request in order to maintain the U.K.'s position in a competitive and expanding market. It is much the biggest of our non-nuclear programmes and is carried out jointly by the Reactor and Research Groups, thus it is an example of the use of the Authority's resources as a whole to make a major impact in industrial innovations—just as was done in the case of nuclear power. The size and aims of the project have been substantially influenced by an early study made by the Programmes Analysis Unit on the national benefit to be gained from research and development on desalination techniques.

The first objective was to exploit multi-stage flash distillation (M.S.F.) to the fullest possible extent so as to maintain the U.K. share of the market. M.S.F. is, of course, a U.K. invention and is the process used in the majority of present desalination plants. To achieve this objective, the Authority entered a joint development programme with Weir Westgarth Ltd. and were able to help them in improving their current designs. This has had a substantial effect on the prices that can be quoted overseas for plant and it is encouraging to find today that the market penetration being achieved by Weir Westgarth is again very impressive. However, the full benefit of the programme cannot be realised for some years yet. One of the key aspects in this project has been the development of computer programmes to speed up the optimisation of present M.S.F. designs so permitting more time to be spent on the project engineering aspects of tenders. The Reactor Group of the Authority have played the major part in this collaboration with Weir Westgarth. The Harwell work has concentrated upon a new design principle in which the thermal energy of the flashing brine is used to lift the brine upwards to the next stage in a vertical flashing plant. The principle employed is not dissimilar to that used in the coffee percolator and we expect that this should result in large savings in pumps. A single stage rig has shown that this is feasible and work is now going on to demonstrate feasibility in a multi-stage system. We are also working on improved methods of preventing corrosion and scale.

The second objective for the desalination programme is to explore processes which might eventually supersede M.S.F. Freezing, reverse osmosis and electro-dialysis offered most promise and after a study of the application of these processes to desalination and of the crucial technical questions to be resolved, we sought industrial partners with whom the processes could be developed on a joint basis. It was not difficult to identify Simon Engineering Ltd. as the natural partner for freeze desalination and William Boby & Son Ltd. for electro-dialysis, but it was not immediately apparent who should be our partner for reverse osmosis techniques. In this last case, therefore, we approached over twenty firms, gave them full background information and invited them to study the possibilities with us. Sixteen took advantage of this and collective discussions took place to get a thorough understanding of the potential markets and the technological problems. The aim of these discussions was clearly stated from the beginning: to choose a single firm as the Authority's industrial partner. We had



expected in this case that the choice would be difficult but indeed, in this as in other projects, we have found the selection process almost automatic: indeed firms tend to choose themselves by their willingness to invest their own effort and money in a joint programme. After the first 12 months of collective discussion we entered into an agreement with Portals Ltd. for the reverse osmosis part of the desalination programme.

This very brief summary of the desalination programme serves to illustrate three general points which apply to most of our work. The first general point concerns the participation of the Programmes Analysis Unit. This Unit was set up, jointly by Min. Tech. and the A.E.A.; it is located at Harwell but, very properly, it is not part of the Laboratory and operates as a completely independent and impartial study group. We have established the general rule of referring our major projects to them for comment; they take each idea, as they did for desalination, and analyse the national benefit to be gained from it, assuming success, and only if they and we agree there is a substantial national benefit and that the cost/benefit ratio for the research is reasonable, do we consider it is worth going ahead at all. This involvement of the P.A.U. is not a substitute for making our own decisions because there are many reasons, technical, commercial or managerial why a project can fail, and an assessment of these is not formally part of the P.A.U.'s study: but their involvement does establish from the outset that the potential benefit is there to be won and this is important in itself. Their help is valuable and it is a pleasure to acknowledge it publicly.

The second general point illustrated by the desalination example is that for each specific idea, if it involves substantial risk and a considerable research and develop-

The U.K.A.E.A. have equipment at Harwell for studying freezing techniques for desalination of sea water. These experiments use a refrigerant (butane), which is immiscible with sea water, to freeze it. The ice appears as small crystals in the crystalliser units. The crystals are then separated and washed free of traces of salt in a wash column. The ice is subsequently melted, by condensing butane vapour, to provide the fresh water product.

The photograph shows separation of the ice from salt water in a large experimental wash column.

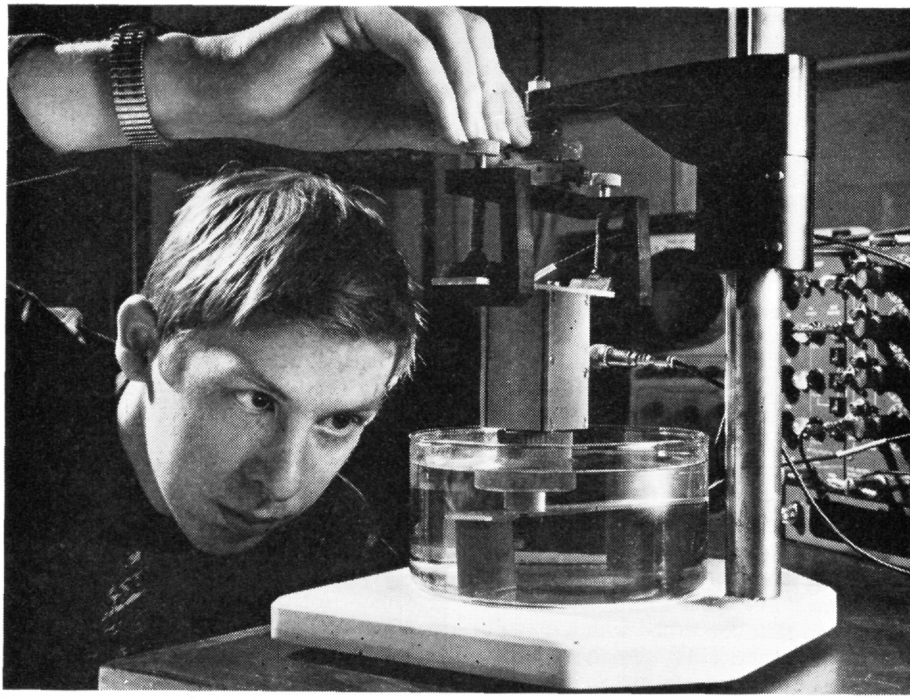
ment programme, we usually search for a single industrial partner with whom we collaborate on an exclusive basis. This has been called the application of "maximum unfairness" and in a sense this description is true; but in practice we discover that industrial companies are quite happy about the logic of it because it follows from the realisation that it is the final market opportunities, and the problem of penetrating that market, that dictates what industrial research is worth attempting. If for any specific idea we worked with several firms, then inevitably the final market must be divided between them, the incentive to each firm is reduced correspondingly and the probability of true commercial success is reduced sharply. Furthermore, the firms are then obliged to compete primarily with each other instead of with foreign competitors. Naturally this general argument must be qualified by the remark that there is a range of research, particularly that concerned with the evolution of techniques, that should be widely applied throughout industry: in such cases a co-operative effort between the individual firms of an industry can be a good approach.

The third general point which is brought out by this example is that, while the national benefit may arise fairly rapidly (increased export sales by Weir Westgarth), it is more likely to do so some years after the research (as for freezing or reverse osmosis) and in neither case will royalty payments cover the cost of the Authority's research except on a timescale of the order of ten to fifteen years. Therefore most industrial projects involve a significant risk element because, in effect, the Authority recovers expenditure by royalties or levies only on success. It follows that, for all projects of this type, we must make our own assessments of the market and the likely market penetration because without such assessments we cannot sensibly orient the research nor check that the discounted cost/benefit ratio is high enough to justify the risk involved.

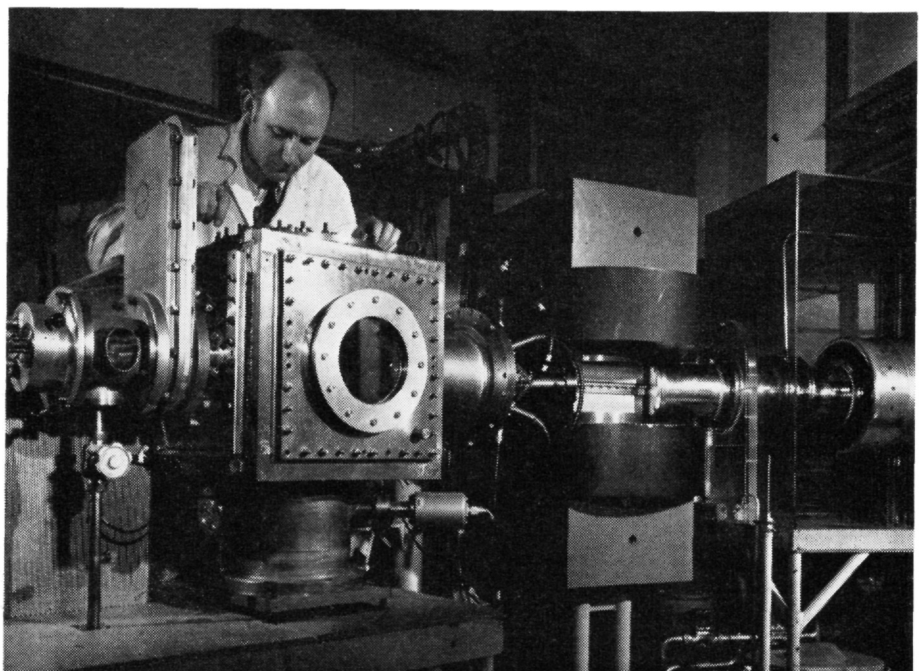
Many of our projects involve a careful market assessment and the Harwell sol-gel projects gives a good example of this.

We have developed some expertise in a method (or family of methods) of preparing oxide powders of closely controlled crystallinity, particle size and shape by using a colloidal stage in the manufacturing route —the so-called "sol-gel" method. This method was developed at Harwell for the fabrication of fuel elements but also has wide potential for the preparation of refractory feed material, pigments, catalysts, ferrites and so on. Because this was one of our early attempts to initiate direct commercial exploitation, it is not too surprising that we started off on the wrong foot using a "missionary" type of approach. We attempted to stimulate general industrial interest by lectures, discussions and the wide dissemination of samples of various types. Many firms displayed polite interest—and all requested further samples and time to assess them—but the results in terms of hard contracts or licences were negligible. We decided that either our technical ideas were no good or we were setting about the commercial problem incorrectly. We therefore set for ourselves a deadline for obtaining genuine industrial interest and commissioned a market survey for ourselves. The market survey enabled us to pinpoint the most promising applications of the technique and this in turn identified a few firms who should benefit materially by using it. We then made a new approach to these particular firms, but this time with an assessment of both the technical and marketing position and were able to negotiate the outline of several industrial agreements within a few days. This example, with many others, has reinforced the lesson that the final market is of such great importance that in most cases we must be prepared to make our own market study and our own assessment of it. For these particular agreements, now the objectives have been set, we have placed the content of the further Harwell research programme directly under the control of our industrial partners and furthermore we charge them immediately for the costs of it. We estimate that the cost of the initiating research will be sensibly covered by a royalty on success. The very simple idea, of placing the Harwell research programme directly in the control of our industrial partner, is another way of insuring that the research is properly oriented, that there is an efficient two way flow of information, and the N.I.H. factor (Not Invented Here) is minimised.

The next example I would like to describe concerns a new production process for the refractory bricks used to line steel



Since it was set up in 1967, the Nondestructive Testing Centre at Harwell has carried out sponsored research and development work for many industrial organisations, thus enabling them to improve quality control. Setting up a 100 MHz cadmium sulphide ultrasonic transducer to obtain reflections from a thin metal sheet.



Part of the work of the Metallurgy and Electronics and Applied Physics Divisions at Harwell involves the development of techniques for injecting selected ions, including radioactive tracers, into solids, particularly semi-conductors. Observing a silicon specimen during an implantation with phosphorous ions.

furnaces. Some early work on the manufacture of nuclear fuels suggested a production method which ought to have some attractions for the refractory industry and an analysis of the potential market and the penetration likely to be achieved showed that it would be worthwhile mounting a sizeable research and development effort. We therefore entered discussions with some large refractory firms. The problem we met in this case was primarily one of technical credibility. It was hard for our industrial colleagues to believe that the same technique developed for the fabrication of small pellets of expensive nuclear fuel could be used for making large refractory bricks cheaply. In advance of of the event it was hard for us to believe it also. We agreed therefore to work on their behalf for six months, without any commitment from them, in order to produce some technical progress. Furthermore we agreed in advance that after six months, the research would either be abandoned or would be pursued jointly with an assignment of staff and money from industry. Needless to say, or else I would not be telling this story, the six months work was successful and the joint research begun: it involves two firms in this case. A mixed team of scientists, half from Harwell and half from industry, work on the project either at Harwell or at the industrial firms, whichever is appropriate. After a two-year programme a pilot plant is now operational at Harwell and similar pilot plants will now be constructed in industry. To do this Harwell staff will move to industry for some months to make sure the installation and operation go smoothly. The form of the commercial agreement in this case is interesting; assuming the new process is a success, royalties will be collected and divided between the partners in proportion to their contribution to the R. & D. programme. This gives each partner a real incentive to contribute to the research and also a real incentive to look for additional markets and applications outside their own speciality.

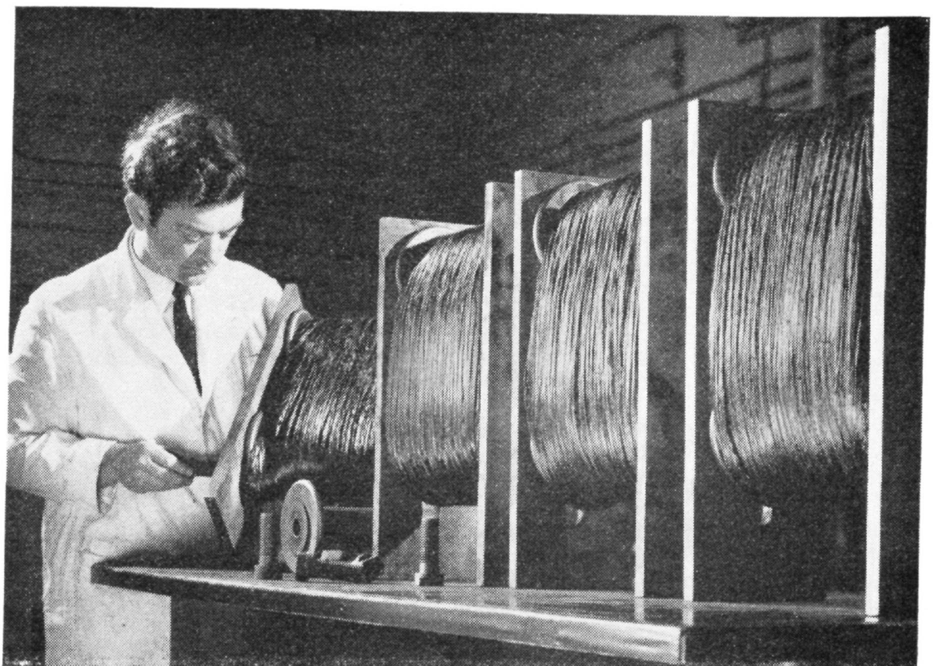
This refractory project can be used to illustrate a further point. In some projects, such as this one, the problem arises of transferring know-how from Harwell to the industrial partner. The difficulty of doing this sometimes inhibits firms from using an outside research organisation but we are satisfied that the difficulties are exaggerated. Provided all partners have a genuine commitment and incentive to achieve success then the research phase and development phase of the work is automatically dealt with in the most appropriate manner, whether in Harwell or in industry, and the staff involved can move from one to the other in a natural and planned way, and in moving, transmit the know-how efficiently.

As another example, I shall discuss the carbon fibres project and I shall be brief because there can be few of you who have not heard about carbon fibres already. The technique of making high strength carbon fibres was discovered at the Royal Aircraft Establishment at Farnborough. The general idea was that these fibres could be used to strengthen plastics and other materials and so generate a whole family of entirely new materials with high rigidity and high strength coupled to low density. Farnborough invited Harwell to assist them in their programme; they had in mind to make use of Harwell's special knowledge of carbon and graphite and to use the pilot plant equipment set up in the first place for research into the graphite moderators of gas-cooled reactors. I shall not review today the development of the Farnborough-Harwell collaboration because the entire subject has recently been the subject of an enquiry conducted by the Select Committee on Science and Technology on which there has been wide public comment. I wish to use this project to illustrate only one point: the interlinking and synergetic effect of research programmes being carried out in the same place and, in many cases, by the same people. Harwell was originally interested in graphite because of the use of that material as a moderator in gas-cooled reactors; because of the expertise and equipment developed for that problem it was natural for us to join in the production research for carbon fibres of various types. Now that is properly launched we see a range of uses for carbon fibres in the atomic energy field—and we are currently examining these ideas. Thus a laboratory like Harwell can have a large number of objectives without fragmenting the whole. It is the scientific content of the research which links all the projects together and indeed, from the scientific point of view, the Harwell programme forms one coherent whole although the total programme has many defined objectives and is divided up into nuclear and non-nuclear categories for legal purposes.

As you would expect, Harwell has a wide range of industrial research based on the use of radiation or radioactive isotopes. Some years ago we developed package irradiation plants using intense sources of radioactive cobalt-60. The use of these plants for sterilisation is now well established and ten plants built under licence from the Authority are now in operation throughout the world. Our own plant is still in use for sterilising medical supplies for the Armed Forces, industrial firms and individual hospitals. We are also using it to establish new markets; for example sterilised food for laboratory animals (150 tons were processed last year). A promising market is also developing on improving the hardness and water resistance of wood by first impregnating with a plastic resin which is then polymerised *in situ* by the use of radiation.

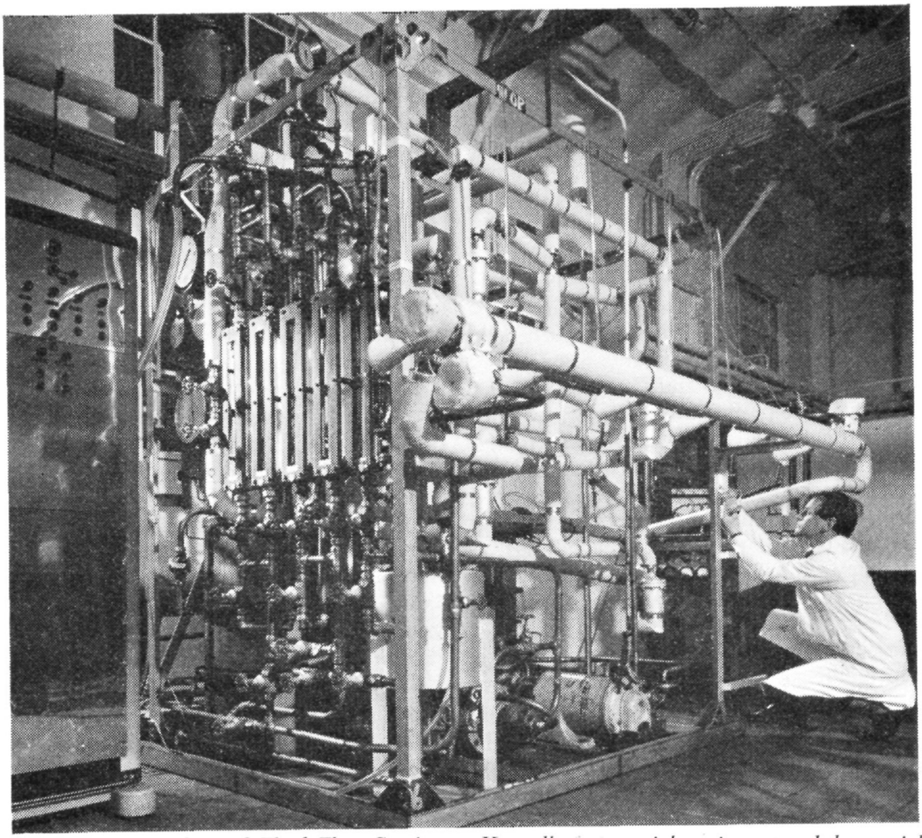
It is worthwhile examining the financial figures applicable to our cobalt-60 plant which was built in 1960 and has operated continuously since then. The total commercial cost of the plant, including depreciation, overheads and interest has been £403,000 over the 9 years. Over this period we have directly recovered our costs and made a small profit of £30,000. However, what is more important is that with licences from the Authority, the ten industrial plants have been built by U.K. industry to a total value of £500,000 and have led to sales of cobalt-60 from Amersham worth £710,000.

Radioisotopes are in regular use for various industrial projects, as hydrological tracers in field studies of water flow and sedimentation research in harbours and rivers. A large programme on electrical generators for use in remote locations is approaching a successful conclusion: the power is generated by strontium-90 and uses the thermoelectric effect. Five prototype generators are installed on evaluation trials. Recently a new thermoelectric



Using equipment and expertise available within the Ceramic Centre and Process Technology Division at Harwell, the original Royal Aircraft Establishment, Farnborough carbon fibre process was scaled up so that hundredweight quantities of commercially acceptable fibres were produced. Reinforcement of aluminium, copper, and white metal by carbon fibres has been carried out. The problem of getting good adhesion between the surface of the carbon fibres and a resin matrix has been solved, resulting in the establishment of a surface treatment process for fibres. When these treated fibres are made up into composites the product has a high interlaminar shear strength.

The picture shows continuous lengths of carbon fibres after final batch heat treatment.



The Heat Transfer and Fluid Flow Service at Harwell uses special equipment and the special knowledge gained by the Authority in this field, to solve specific industrial problems under a confidential consultancy and testing scheme operated on a rechargeable basis. A view of two-component condensation experimental apparatus—one of many engineering rigs available for use in this service.

source powered by plutonium-238 has been developed for heart pacemakers.

There is a continuing and growing demand from industry for the neutron activation analysis service which is operated as a commercial entity; we continue to investigate the use of accelerators and the ion implantation techniques for making new electronic materials. Many of these industrially oriented projects using nuclear techniques are well established and we expect some of the newer non-nuclear projects to mature in the same way.

Some of our projects involve giving a substantial amount of consultancy and advice: the Materials Technology Bureau, a small project, dealt with 160 enquiries last year. The Nondestructive Testing Centre received more than 400 visitors and answered 750 enquiries last year. These projects fulfil a national role, we believe, but how to recover costs without discouraging use of the service is a problem we have yet to solve. Last year we started the Heat Transfer and Fluid Flow service. This project gives consultancy and design reports to those firms which join a subscription service. The project seems likely to be popular with industry and this method of aiming for cost recovery seems feasible and attractive. In this case the industrial subscribers are paying, not for a literature search, but for the assessment of published and Harwell results, and their transformation into practical design reports and computer programs. The project has drawn such interest that we are now thinking of extending it to overseas customers.

For all our work, but particularly for this type, we naturally look for collaboration with our colleagues in other Government-funded laboratories and we have research programmes jointly with the National Engineering Laboratory, the Warren Springs Laboratory, the Royal Aircraft Establishment at Farnborough, the Royal Radar Research Establishment at Malvern, the Water Pollution Research Laboratory, the Hydraulics Research Laboratory and a number of the Research Associations.

We are specially pleased to note that, increasingly industry is bringing its problems and ideas to us. In the long term this is quite essential if we are to make a real success of industrial involvement. As my last specific example I shall take an item which might be of direct interest to a university audience. Some time ago we were approached by two university engineers with a neat idea for a ceramic heater, which has possible applications in the chemical industry and therefore Harwell first sponsored some more University research, then bought the commercial rights to the idea, and now we have established a collaborative project involving an industrial firm, Harwell and the University. In this further development the financial risk is shared by industry and Harwell but we have arranged for the inventors to direct the technical work of the entire project. The project sponsors further research in the University and to overcome the problems of commercial security in a University and to supplement their technical and engineering resources as the more advanced prototypes are developed, we have placed Harwell offices and laboratories at the disposal of our University colleagues. But the most important point, to my mind, is that the inventors have a continued interest and participation in their idea right up to the final market exploitation. This particular way of enabling interested University departments to get close to the market place is an organisational experiment which may or may not succeed in general, but we are interested in exploring this type of collaboration further because of the promise of this particular case, and we are always open to new ideas.

By discussing various examples I have tried to illustrate the type of industrial research done by Harwell, the lessons we have learnt so far and the problems we have met. I would like now to add a few more comments.

It has sometimes been argued that Government research is expensive compared to research in industry. We have found very little evidence for this assertion; some of our collaborative projects involve audited statements of research costs in Harwell and research costs in the laboratories of our industrial partners. These show that the true costs of a scientist at either laboratory are approximately the same: all costs as usually quoted must be treated with reserve because of different accountancy conventions in different organisations.

One substantial advantage of a large laboratory like Harwell is, we believe, the ability to construct sizeable pilot plants rapidly. This has shown up several times in the last year or so. But the main advantage of a large laboratory is the synergetic effect of all its activities and the ability to bring a wide range of disciplines and a wide range of techniques to bear on any specific project.

The main problem we face in the future, nad this is a personal and partially intuitive view, is the problem of maintaining a good standard of scientific literacy. Any success we do achieve is strongly dependent on our scientific standing and know-how. It is not easy to maintain a good scientific standard in the face of heavy day to day demands from the reactor and industrial programmes. The problem is, of course, parallel to that of a University department which has to teach while simultaneously maintaining quality by doing basic research.

In view of the fact that Maurice Lubbock had a special interest in management consultancy, it is appropriate to say something of the management decisions we have made to organise this new programme. One obvious decision was that we needed a larger commercial office to negotiate and draw up agreements with our industrial partners. In this next year we hope to sign, on average, one substantial agreement each week and, because the research is varied and the results difficult to predict in advance, each agreement deserves careful thought. However, it was more difficult to decide exactly how much responsibility this central office should carry: should they provide the main drive for commercial business or should this be left to the scientists themselves? We decided to place the full responsibility for projects directly and unambiguously on the individual scientists leading the projects. We think this was the correct decision because it means that each scientist is directly concerned with the market and final application of his work: this gets him thoroughly involved, committed and enthusiastic to make his work a success.

On this occasion it is interesting to note that one of Harwell's consultants on the organisation of this industrial work happens to be one of the first engineers recruited by Maurice Lubbock when he founded and became Chairman of Production Engineering Ltd.

At the beginning of this lecture I said this was an interim report on Harwell's industrial activities. According to my newspaper reading, it is usual for a company's interim report to include a summary by the Chairman of the good progress the company has made and the still better prospects he foresees. That I consider I have given you tonight. But also an interim report includes the hard figures of expenditure and income and those I have not yet given you.

Our total industrial programme will grow to a level of about £4m. per annum in the financial year 1969-70. Because much of the research produces an economic benefit after a delay of several years, we would not now expect to have a cash income comparable to that figure. Indeed our income from these activities is small compared to the expenditure but it has doubled in the last two years and for 1969-70 we estimate it will be about half-a-million pounds. We expect it to rise fairly fast after this.

These figures have taken no credit for the fact that some of the programmes, atmospheric pollution for example, are aimed at a dispersed national benefit and therefore we would not expect to receive any income from them. Nor do these figures allow for the fact that most programmes have a substantial orientation to the national interest and not just to immediate commercial objectives.

We regard these figures as reasonable in view of the fact that the major cash returns to Harwell must come in the future in the form of royalties assessed on the use or sale of products. Furthermore, as a Government funded organisation, it is proper for us to look primarily to the national interest; and we look for direct cash returns in addition primarily because this is the most positive test that our research really is needed and commercially oriented. It will be several years before we can draw up a proper balance sheet of expenditure weighed against immediate income plus discounted future income to us. The most important balance sheet for us to draw up in the future will be expenditure weighed against the total national benefit identified directly with the Harwell research. Of course, the proper time to judge all these activities will be when these figures are available; it is in the nature of research that this will take several years, and in the meantime we claim only to have made a promising start.

Calibration Service

THE Mechanical Standards Laboratories at A.E.R.E., Harwell, and A.E.E., Winfrith, have been authorised by the British Calibration Service to issue certificates for the calibration of mechanical measuring equipment. They will form part of a national network sponsored by the Ministry of Technology to provide a calibration service to industry.

The Harwell Mechanical Standards Laboratory will carry out tests on measuring instruments, gauges and tools, by comparison against reference standards traceable to national standards. It is intended to provide a prompt service, so that valuable equipment need not be out of use for long periods, and charges will be competitive. It is the second calibratioh service to be offered by Harwell.

The Winfrith Mechanical Standards Laboratory will undertake measurements of size and form on gauges and precision assemblies, in either imperial or metric units. The Standards Laboratory has a length interferometer; also a range of N.P.L. calibrated standards from which all certified measurements are derived.

AB.C.S. Certificate of Calibration will be issued stating the uncertainty of measurement. The Certificate will also state the conditions under which the tests were conducted, many of which will be in accordance with the appropriate British Standard.

Enquiries should be addressed to:—

Harwell The Chief Inspector, (J. H. Bicknell), Mechanical Standards Laboratory, A.E.R.E., Harwell, Didcot, Berks. Tel.: Abingdon 4141—Ext. 2294

Winfrith The Chief Inspector, (E. J. Gervasio,) Mechanical Standards Laboratory, Building A22, A.E.E., Winfrith, Dorchester, Dorset. Tel.: Dorchester 3111 —Ext. 2412.

The peaceful use of nuclear energy

The following paper was presented by Dr. Michael Davis, Technical Adviser to the U.K.A.E.A. Finance and Programmes Officer, to the Turkish Economic Research Foundation International Seminar on Technology and Economic Development, held at Istanbul, from 5th to 8th May, 1969.

Introduction

Almost a quarter of a century has passed since the power of the atom's nucleus was introduced cataclysmically to the world just a few days before the end of the Second World War. But, within five years of that event, scientists and engineers had prepared designs of prototype nuclear reactors to harness this power to the generation of electricity for peaceful purposes. These early reactors in U.S.S.R., U.K., U.S.A. and France came into operation within a year or two of each other and of the first U.N. Geneva Conference on the Peaceful Uses of Atomic Energy in 1955. Since then the technology has developed rapidly and nuclear generation of electricity has, during the sixties, progressively become competitive with conventional generating methods in many parts of the world.

Several technologically advanced countries have invested heavily in developing their own nuclear technology. A few less developed countries, such as India, have decided to allocate a high proportion of their scarce technological resources to the same objective. Other countries hope to reap the economic benefits of nuclear power without such heavy investment. In the case of Switzerland, for example, though there has been no massive national research and development programme, there is sufficient confidence in the acquisition of the necessary technology, mostly from others, to be able to claim temporarily a higher nuclear generating capacity (0.149 kWE) per head of population in the early seventies than any other State.

In this paper I shall describe the course of developments so far; attempt to forecast the pattern of the future; and suggest how individual countries may benefit from developments carried out by others.

The present situation

Some 11,000 MWE of nuclear generating capacity is currently operating and this represents about $1\frac{1}{2}\%$ of the total world electrical generating capacity*. In the United Kingdom about 13% of all electricity generated comes from the 26 nuclear power reactors we have in operation.

Nuclear power reactors today fall into three main systems characterised by the choice of moderator, i.e. graphite, light water or heavy water. As such they are known as "thermal reactors" because the nuclear reaction, involving the fission

*Exclusive of U.S.S.R.

Table 1: *Nuclear Generated Electricity* (*to end of* 1968) (*Gross*)

Country	Nuclear Generating Capacity (MWE)	Nuclear Generated Electricity (Millions of kWhr)
U.K.	4,782	119,747
U.S.A.	2,827	45,754
France	1,106	11,106
Italy	631	15,687
W. Germany	430	3,789
Canada	225	1,748
Japan	179	1,900
Spain	153	95
Holland	54	28
Belgium	11	261
Sweden	10	148
	Total exclusive of U.K.:	80,516

of the uranium isotope, U-235, is maintained by slowing-down, or "moderating", the fast, high energy fission neutrons to the "thermal" energy corresponding to the moderator temperature. The light water reactors in which ordinary water serves both as a moderator and as a coolant have been developed mainly in the U.S.A. They divide into two variants: in one, boiling is suppressed, the so-called Pressurised Water Reactor (P.W.R.); in the other, the Boiling Water Reactor (B.W.R.) boiling is permitted and the steam arising drives the turbine. Figure 1 shows the present installed nuclear generating capacity by reactor type. It will be noted that the British and the French are the chief protagonists of gas-cooled, graphite moderated reactors. The heavy water generating capacity is much smaller than that of the other types, but about five variants of heavy water reactors exist. Each variant can be designed to be fuelled with natural uranium*, although in some cases slight enrichment of the U-235 isotope gives design advantages and certain economies.

Table 1 shows the electricity so far generated from nuclear power stations. Experience in U.K., where more nuclear electricity has been generated than in all the rest of the world, indicates that load factors better than the estimate of 75% are consistently achieved after the initial year or so of operation.

*i.e. uranium with 0.7% of the fissile isotope, U-235 as occurring in nature.

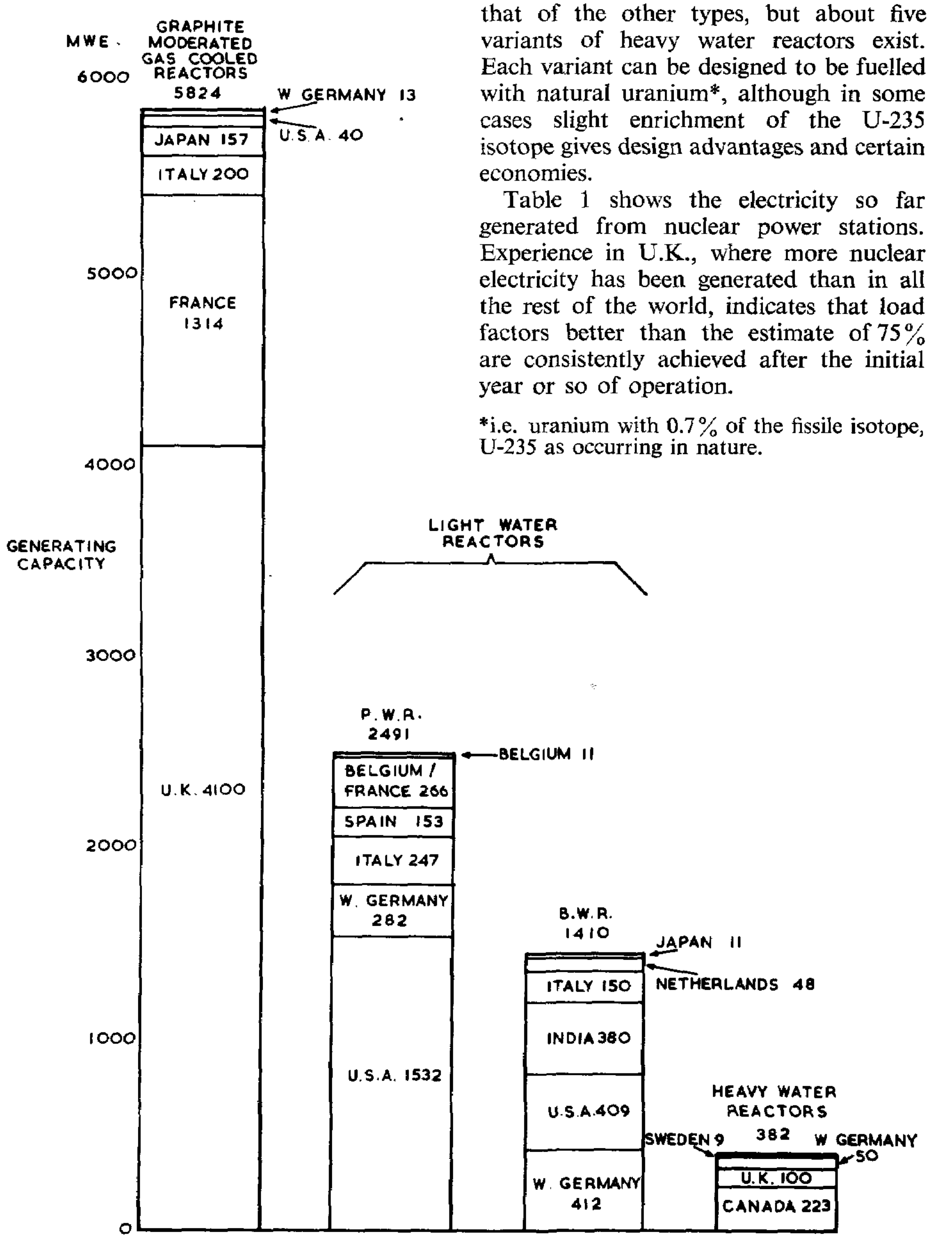


Figure 1. *Nuclear generating capacity by reactor type—March* 1969.

Table 2: *Recent Annual Orders for Nuclear Power Stations in U.S.A.*

Year	Number of Stations Ordered During Year	Capacity (MWE)
1966 ..	21	16,618
1967 ..	31	25,570
1968 ..	17	15,555

The future

The favourable operating experience coupled with attractive economics (to which I shall refer again) has led to various forecasts of the nuclear generating capacity to be expected in the future. There has been a tendency to revise these forecasts upwards with the passage of time, particularly in the U.S.A., where at the present time some 60,000 MWE or so are being constructed or are on order. The rate of ordering in U.S.A. is shown in Table 2, from which it will be noted that the remarkably large annual ordering rate in 1966 and 1967 was less in 1968. This reduction is attributed to:

(a) some earlier nuclear stations being late in coming into operation;

(b) suppliers having full order books;

(c) prices having escalated;

and, in consequence, the utilities have been more reticent in ordering nuclear stations.

It seems probable that the world nuclear generating capacity (other than U.S.S.R., for which figures are not readily available) will attain some 25,000 MWE by 1970 and that this figure will have increased four or fivefold by 1975; and by tenfold or so by 1980. Figure 2 is an attempt to predict what growth may occur by the end of the century. Of course, such a long term prediction is attended by many uncertainties (even though the views of various national experts have been taken into account). Therefore Figure 2 shows a range of uncertainty which diverges from the best estimate curve as the date becomes more remote from the present.

During the next ten years it is likely that thermal reactors will predominate in this considerable growth of nuclear power. Doubtless, later stations will make more efficient use of their uranium inventories, but in spite of this, the growth of nuclear power is bound to be reflected in a marked growth in the demand for uranium. Figure 3 illustrates the likely range of cumulative demand corresponding to the growth of nuclear power in the preceding Figure. In terms of existing low cost*, proved uranium reserves, Figure 2, suggests their exhaustion by the early 1980's. It is possible that additional resources of low cost uranium at least as plentiful as the known reserves will be discovered before reasonably assured resources of more costly uranium have to be exploited. (Reference 1).

Plutonium

I have already referred to the source of energy in a nuclear reactor as being due to the fission of the isotope U-235. When such an atom undergoes fission, two fission product atoms and at least two neutrons are formed. The fission products eventually become a nuisance and have to be removed, because they capture more and more of the neutrons required to maintain the chain reaction. However, while the nuclear fission reaction is going on, a certain proportion of neutrons is captured by the nuclei of the preponderant uranium isotope, U-238, and this results in the formation of the element plutonium, which does not occur in nature. As with uranium, there are several different isotopes of plutonium, some of which are, like U-235, capable of undergoing neutron-induced fission. Although some of these plutonium isotopes can be used in thermal reactors—and hence cause some diminution in uranium requirements—there are considerable attractions in isolating the plutonium for use in fast breeder reactors.

The operation of separating plutonium and unused uranium from spent nuclear fuel whilst at the same time rejecting unwanted fission products is known as "re-processing". This process is technologically complex, largely because of the intense radioactivity of the discharged nuclear fuel, and calls for remote operation protected by heavy shielding. Nevertheless, reprocessing has now been mastered and is carried out on a fully-industrial scale. The U.K. Atomic Energy Authority's reprocessing plant at Windscale has an annual capacity of well over 2,000 te for example. Reprocessing becomes quite uneconomic in small plants.

*Taken as less than $10 per lb. U-308.

Fast breeder reactors

These reactors of the future are distinguished from the "thermal reactors" by the fact that high energy or "fast" neutrons direct from fission are arranged to induce fission in other fissile isotopes *without* being slowed down to "thermal energies" by a moderator. Plutonium makes an excellent fuel for such a "fast reactor" because more of its isotopes undergo fission by "fast" than by "thermal" neutrons.

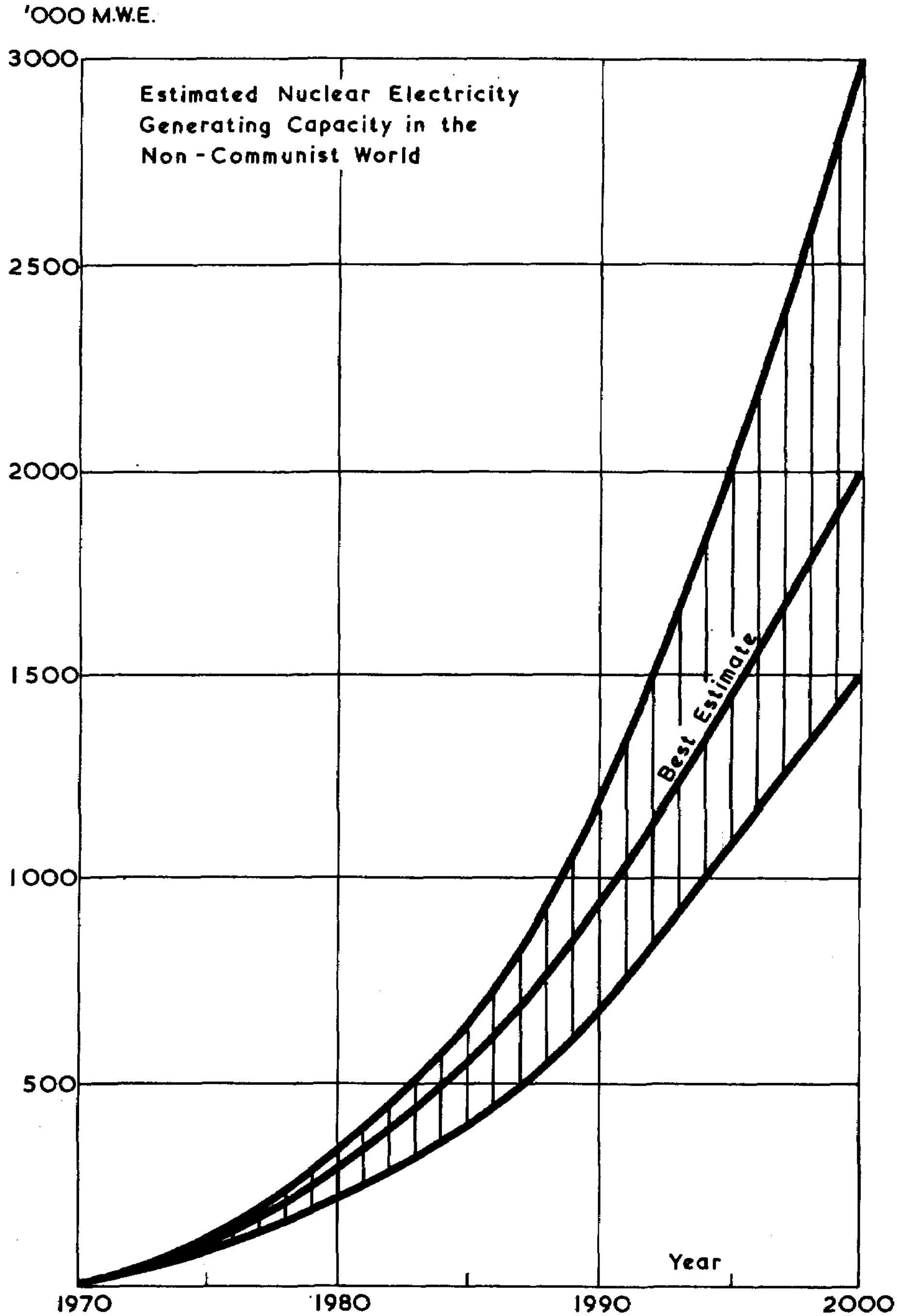


Figure 2.

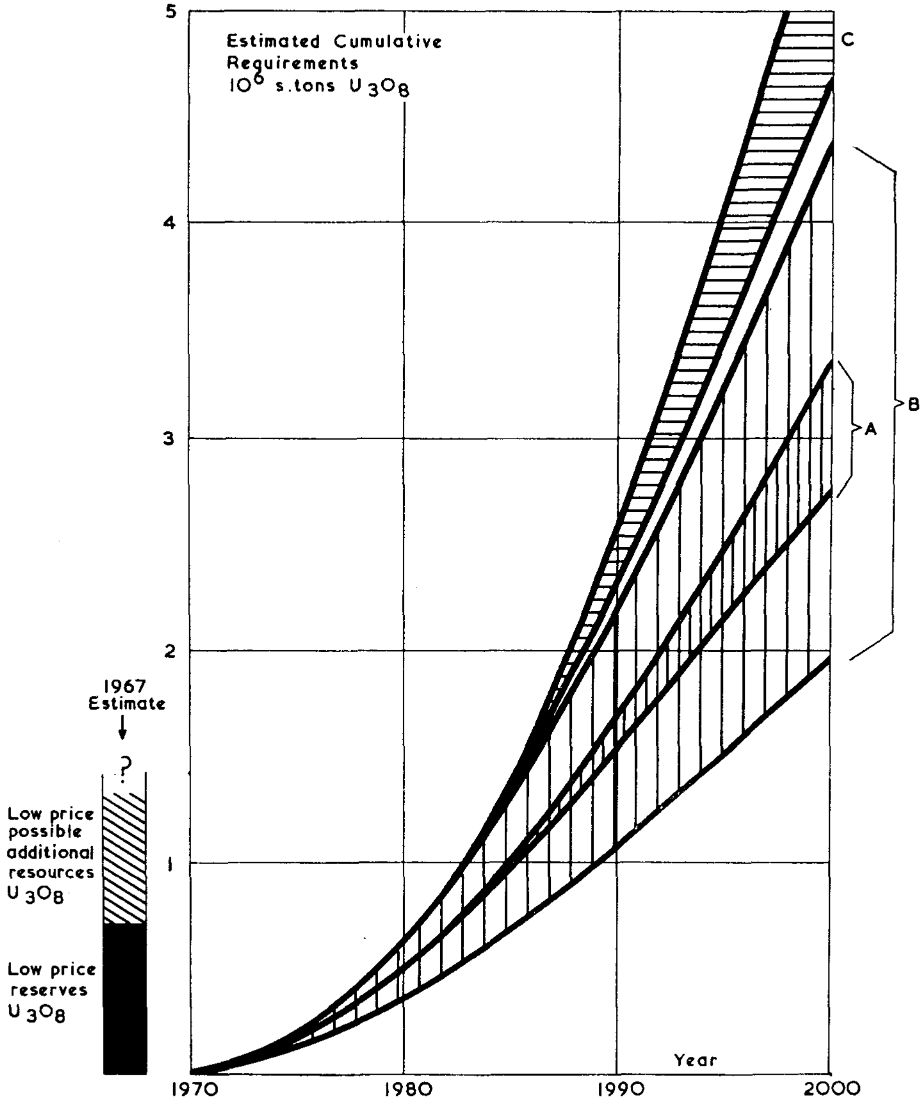


Figure 3.

However, there are several problems associated with such a reactor. Notable among these is the difficult technology associated with the high heat rating of the fuel. This high rating is illustrated by Figure 4, where the size of the reactor core of a fast reactor is compared with that of the earlier Magnox and the later Advanced Gas-Cooled Reactor (A.G.R.) all possessing the same power of 600 MWE. In U.K. and in several other countries the excellent coolant characteristics of liquid sodium metal have led to its adoption as the preferred fluid to extract heat from the highly rated core. The use of this liquid sodium at temperatures up to 600°C involves a complete new technology.

The most interesting feature of all is, however, the potential of a fast reactor to breed more nuclear fuel than it consumes—hence the term "fast breeder reactor". Initially, the plutonium fuel for fast reactors will come from the reprocessing of thermal reactor fuel. The core of the fast reactor is then surrounded by a "blanket" of uranium in which the isotope U-238 predominates. Spare neutrons escaping

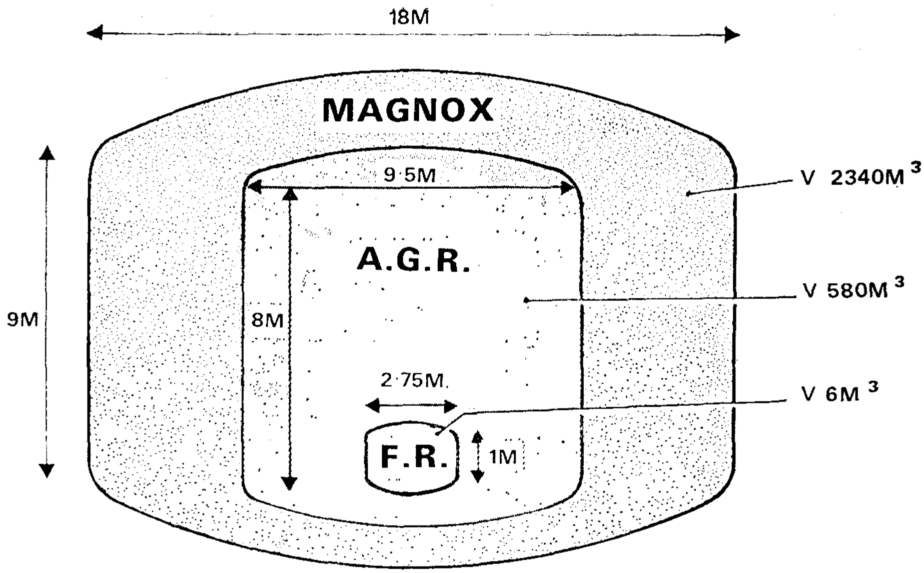


Figure 4. *Core dimensions of* 600 *MWE reactors.*

from the core are captured by this blanket to produce more plutonium. The "neutron-economics" are such that in a fast reactor a high proportion of the U-238—which cannot undergo fission in a thermal reactor—can be converted eventually to fissile plutonium, capable of fuelling more than one fast reactor.

The effect of this phenomenon is clearly of prime importance in the logistics of nuclear fuel; it enables us to envisage the use of a high proportion of the 99.3% of natural uranium which consists of U-238. It should be added that, similarly, the abundant element, thorium, can be converted to fissile uranium in the blanket of a fast breeder reactor.

Nevertheless, fast breeder reactors are not expected to come into widespread use before the 1980's; and their impact upon the annual demand for uranium will only begin to be appreciable towards the end of the century. Figure 5 illustrates this.

The matching of fast reactor installations to those of thermal reactors is clearly an important factor in minimising overall electricity costs and fuel requirements. In the U.K. some of my colleagues have devised a computer programme which can manipulate the many factors which affect the optimisation. We have found this method very valuable in clarifying issues which tend to be imponderable. As the U.K. has the firm intention of introducing fast reactors as rapidly as possible after the operation of our 250 MWE prototype, now constructing, the plutonium arising from our thermal reactors is mainly destined for fast reactor fuel inventories. Nevertheless, the computer programme referred to enables us to compute the price at which it would pay us to buy or sell plutonium for a particular range of assumptions.

Economics

It will be evident from the growth figures I have cited for nuclear power that, although the technology could hardly have advanced so quickly had it not had the initial impetus of military programmes, the adoption of nuclear power by many of the world's electricity utilities would not have occurred unless it was economically attractive.

Moreover, each State has its own particular circumstances, and it is for the most part quite misleading to suppose that costs cited for one territory have any precise significance for another. Each case must be considered on its own merits. Rather than attempt any generalised economic presentation, I will illustrate the subject with data on nuclear power costs in the U.K.

The first U.K. nuclear power programme consisted of 5,000 MWE. The last twin-reactor station of this programme is due on power this year. Figure 8 shows actual and estimated construction costs and illustrates how these improve progressively with later stations. It should be noted that the increase in size of individual reactors is an important factor in this economy. Table 3 indicates current nuclear generating costs. To put these figures in perspective, it may be noted that the *average* cost of generation of electricity in U.K. is presently 1.07d./kWhr (10.7 mills/kWhr); and the cost from a new fossil fuelled station generating at the same load factor as a nuclear station about 0.6d. The cost to the electricity consumer is of course much higher (1½d.-2d./kWhr or more).

The implementation of the second U.K.

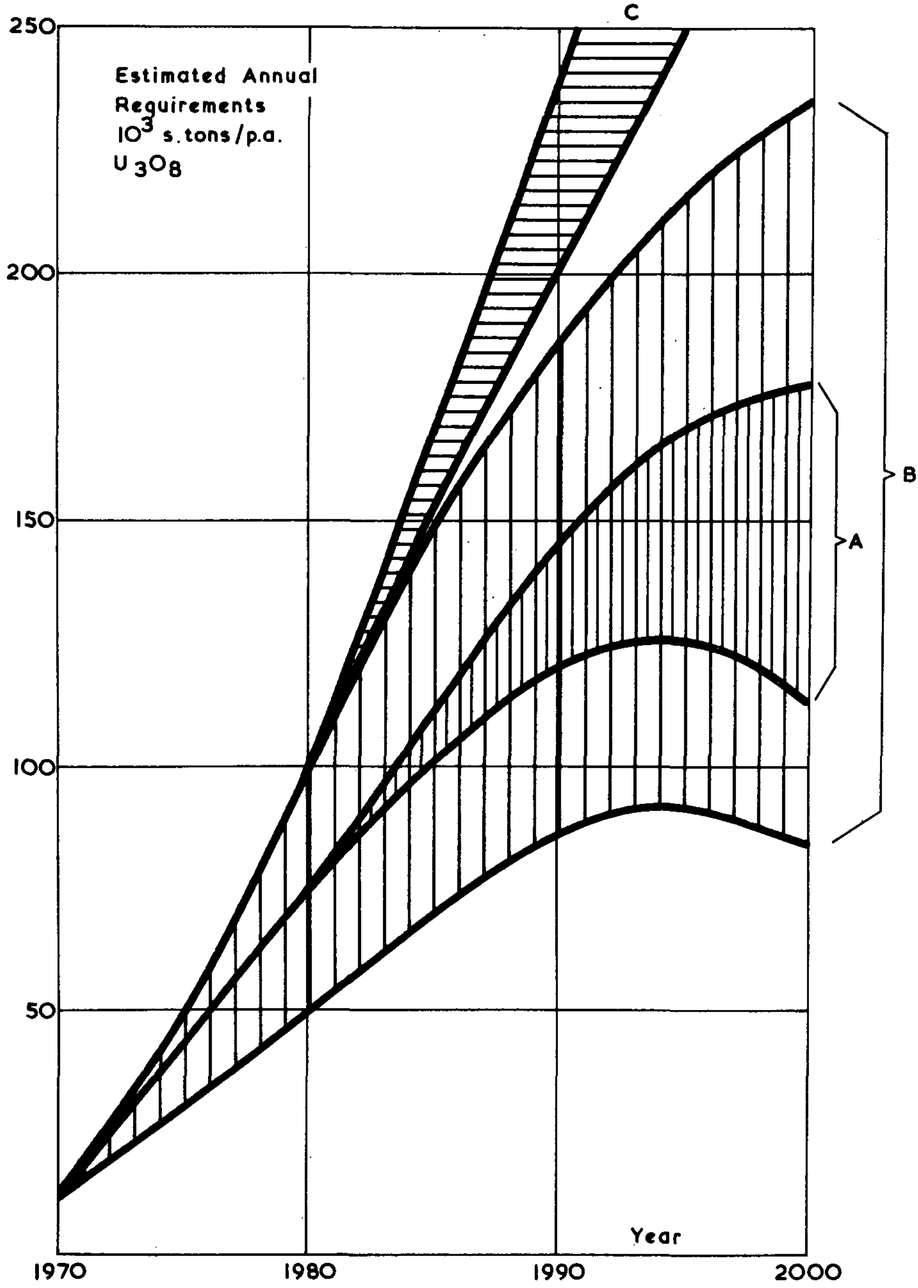


Figure 5.

Table 3: *Nuclear Generating Costs in U.K. (with some comparative conventional generating costs)*

	Capacity (MW s.o.)	Year of Commissioning	Type	Generating Cost (d/kWh s.o.)
Berkeley	276	1962	Magnox	1.25
Bradwell	300	1962	Magnox	1.14
Hunterston A	320	1964	Magnox	
Hinkley A	500	1965	Magnox	1.07
Trawsfynydd	500	1965	Magnox	0.96
Dungeness A	550	1965	Magnox	0.78
Sizewell	580	1966	Magnox	0.74
Ferrybridge C	2,000	1966	Coal	0.55
Oldbury	600	1967	Magnox	0.74
Tilbury B	1,420	1968	Coal	0.73
Wylfa	1,180	1969	Magnox	0.70
Pembroke	2,000	1970	Oil	0.59
Drax I	1,980	1971	Coal	0.64
Dungeness B	1,200	1972	A.G.R.	0.56
Hinkley B	1,250	1972	A.G.R.	0.52
Hunterston B	1,250	1972	A.G.R.	
Hartlepool	1,250	1974	A.G.R.	0.52
Drax I and II combined..	3,960		Coal	0.61

nuclear power programme of some 8,000 MWE started with the 1965 tender for the 1,200 MWE Dungeness B station (2 × 600 MWE) and Figure 6 shows the result of the comparison between estimated costs for the nuclear station and those for the most modern coal fired station, issued at the time by the Central Electricity Generating Board. On the ground rules employed, the clear advantage of the nuclear station is apparent. In addition, the figure illustrates the important characteristic of a nuclear station: that the capital cost component is high, but the fuel cost is low. The reverse applies to a fossil-fuelled station. This means that having built a nuclear station, it pays to operate it continuously, i.e. on base load.

It is perhaps instructive to remark here that not only are fuelling costs of a nuclear station low, but also that the amount of fuel required annually is small in comparison with a fossil-fuelled station. For each 100 MWE, about 20 tonnes of uranium is required annually instead of 300,000 tonnes of coal. This can be an important factor if fossil fuels have to be imported or transported over large distances and are liable to fluctuation in supply.

As for future economics of nuclear power stations in U.K., Figure 7 illustrates the kind of picture we have. The tendency is to install progressively larger units, both in fossil and in nuclear stations, to secure economies of scale. This is, of course, possible with us because we have a large, integrated electricity transmission network. Apart from the marked downward trend in nuclear generating costs due to size and technical improvements, it is also apparent that further significant economies are anticipated from the introduction of more advanced reactor systems: advanced thermal reactors (of the Mark III gas-cooled and the steam generating heavy water types) and fast breeder reactors. It is this benefit nationally in reduced electricity costs which makes it worth incurring the massive expenditure involved in developing a new reactor system.

The nuclear fuel cycle

Although, as we have seen, nuclear fuelling costs are only about a third of the total cost of power, there are several stages in fuel processing and use which it is desirable to appreciate so that maximum economy and convenience may be secured.

Apart from the earlier Mark I gas-cooled or Magnox type of reactor and certain variants of heavy water reactors, the remaining types of thermal reactor employ uranium which is slightly enriched in the fissile U-235 isotope from 0.7% in natural uranium to between 1% and about 3%. For illustrative purposes, I shall include "enrichment" as part of the fuel cycle. Subsequently, I will discuss the effect of omitting it from the fuel cycle of a natural uranium fuelled reactor. Enrichment has hitherto been a high investment, technologically-complex process in which separation of the isotopes has been obtained by repeated passage of the gaseous compound, uranium hexafluoride ("hex") through diffusion barriers. Such diffusion plants have only been constructed by the nuclear weapon States. Recently, the centrifuge process has been studied by several countries and it has been announced that the British, Dutch and West Germans plan to collaborate in setting up plants based on this process. These, and other plant extensions planned by the existing producers will ensure a plurality of enriched uranium suppliers in the future.

The fuel cycle of a thermal reactor may be considered as a multi-stage process, which for convenience in Table 4 I have group into seven activities to which are attributed percentage components of fuel cycle costs. No costs have been assigned to stage 5, Reactor use, as these costs are considered as part of a nuclear station's operating expenses. Stages 2 and 6, Enrichment and Reprocessing, are those with rather complex technologies and where economies of scale are most marked. The value of end-products of the cycles: plutonium and unused uranium, usually amply justify the cost of the reprocessing operation. These products may be recycled to the appropriate part of one's own fuel cycle or, quite often, sold to others when a cash credit is preferable to holding stocks of such materials for re-use. My remarks on the attractiveness of employing plutonium to fuel fast reactors will be recalled.

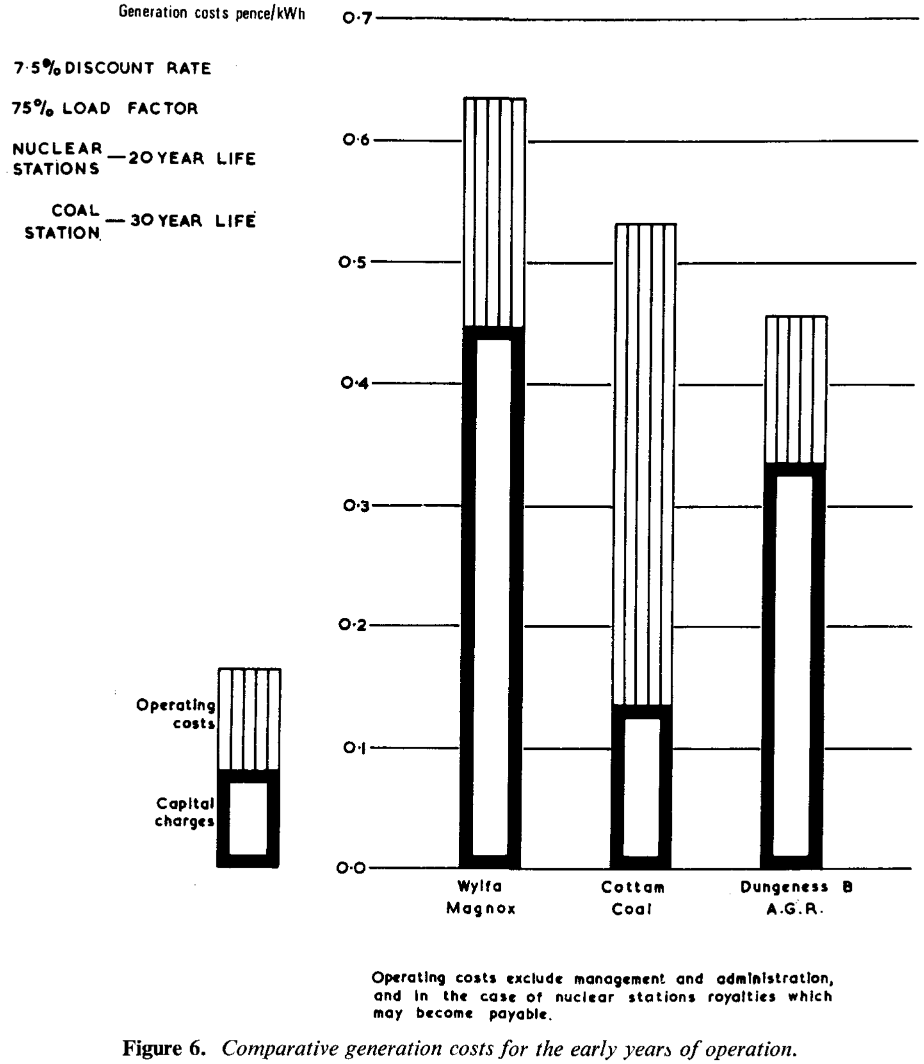


Figure 6. *Comparative generation costs for the early years of operation.*

The fuel cycle of a natural uranium fuelled reactor omits stage 2—Hex conversion and enrichment, and in the past it has been claimed that stage 6—reprocessing may also be omitted or, at least, deferred. But for reactors coming on power in the mid-seventies, it is likely that the plutonium credit will be too attractive to postpone

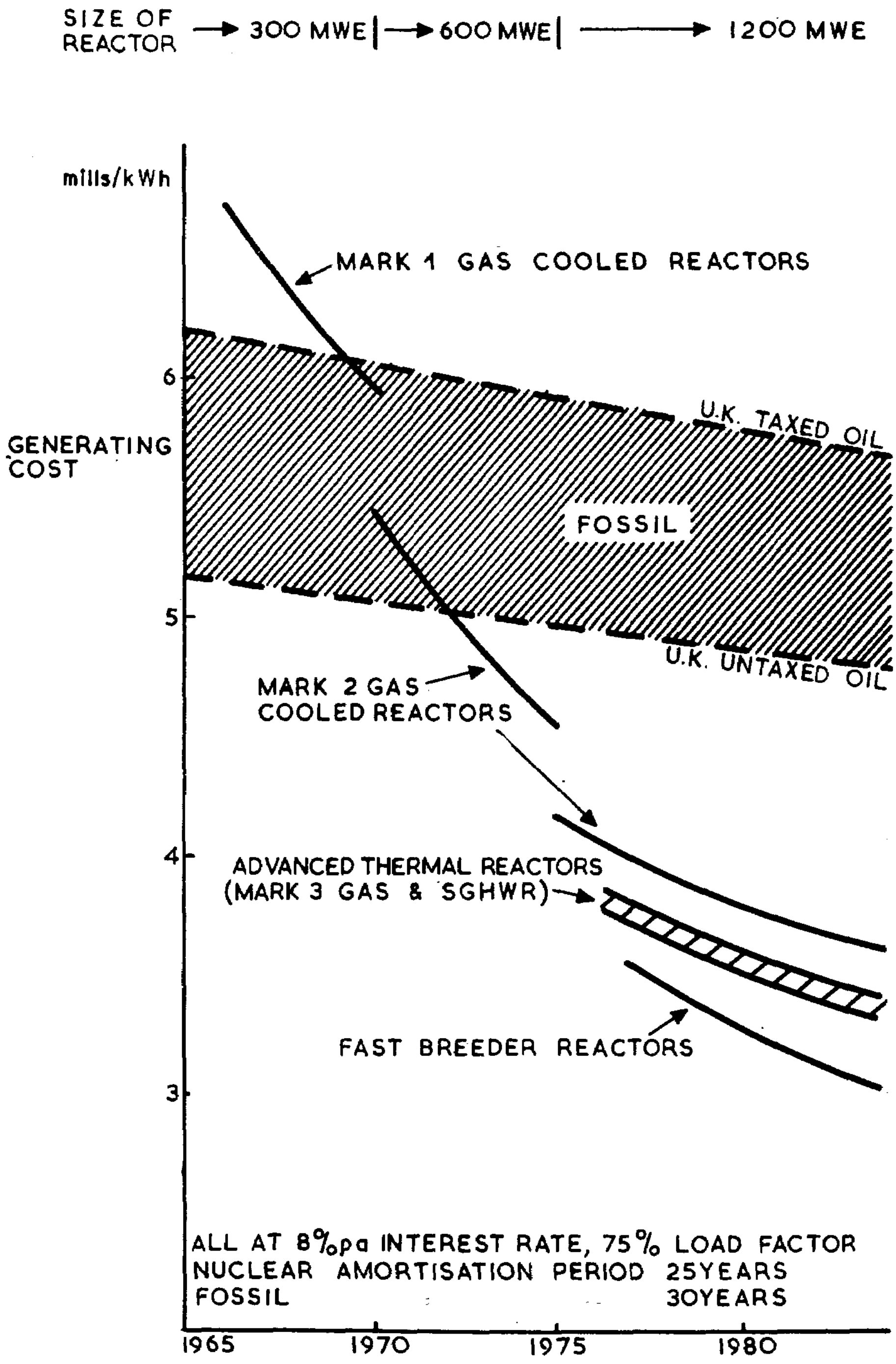


Figure 7. *Trend of nuclear generating costs in U.K.*

Table 4: *Cost Components of Enriched Thermal Reactor Fuel Cycle*

Stage	Cost Component %
1. Mining and milling	+32
2. Hex conversion and enrichment	+41
3. Oxide conversion*	+ 3
4. Fuel element fabrication	+36
5. Reactor use	0
6. Transportation and reprocessing of irradiated fuel	+ 4
7. Credit attributable to plutonium and unused uranium	−16
Total ..	100

*Most thermal reactors will employ fuel in the form of the oxide UO2

the reprocessing of spent natural uranium fuel. Thus, for a natural uranium fuelled reactor, Table 5 illustrates the relative size of the fuel cycle cost components. The net cost of this fuel cycle will clearly be less than that of the enriched fuel cycle, but this will not always be a compelling advantage in favour of natural uranium.

Choice of reactor

The selection of a reactor type upon which to base a nuclear power programme is a difficult matter. The wise purchaser, if he had not already got staff of his own who are familiar with the task, will engage the services of well-experienced engineering consultants, who will help him to take account of all the relevant factors leading to a decision. Such consultants can also do much to narrow the choice: too many alternatives can be confusing and lead to much delay in decision. The circumstances of each purchaser are quite different, and so generalised comparative economics of reactors can be misleading and caution has to be exercised in drawing conclusions from what may appear to be analogies. It is also worth remembering that each reactor type has its own technology; to adopt more than one type correspondingly makes greater demands.

Broadly, thermal reactors of all four types shown in Figure 1 include versions which can be said to be economically competitive, at size of 300 MWE and above. The attractiveness of a given type to a particular purchaser depends on many factors. Sometimes a supplier who is attempting to enter the market can offer his particular version at an appealing low price. But the prudent purchaser will inquire to what extent the reactor variant he is being offered is proved; if no reactor operating experience is available, the purchaser may take the risk of having to endure modifications or corrections being undertaken. This may be tolerable, provided that there is clear responsibility for the supplier to supply an operational plant and to compensate for delays.

Among the factors which the purchaser will have to take account of are:

(a) capital cost (and optimum size of installation)
(b) fuelling cost
(c) operational expenses
(d) the extent to which local production of capital plant and fuel is possible
(e) safety
(f) guarantees
(g) the weight of advantage to be attributed to independence in fuel supply in comparison to the advantages of scale and experience which a fuel service supplier can offer
(h) the advantages of training and consultancy services which reactor and fuel service suppliers can offer.

Table 5: *Cost Components for Fuel Cycle of a Natural Uranium Thermal Reactor*

Stage	Cost Component %
1. Mining and milling	+55
2. Hex conversion and enrichment	0
3. Oxide conversion	+ 4
4. Fuel element fabrication	+92
5. Reactor use	0
6. Transportation and reprocessing of irradiated fuel	+13
7. Credit attributable to plutonium and unused uranium	−66
Total ..	100

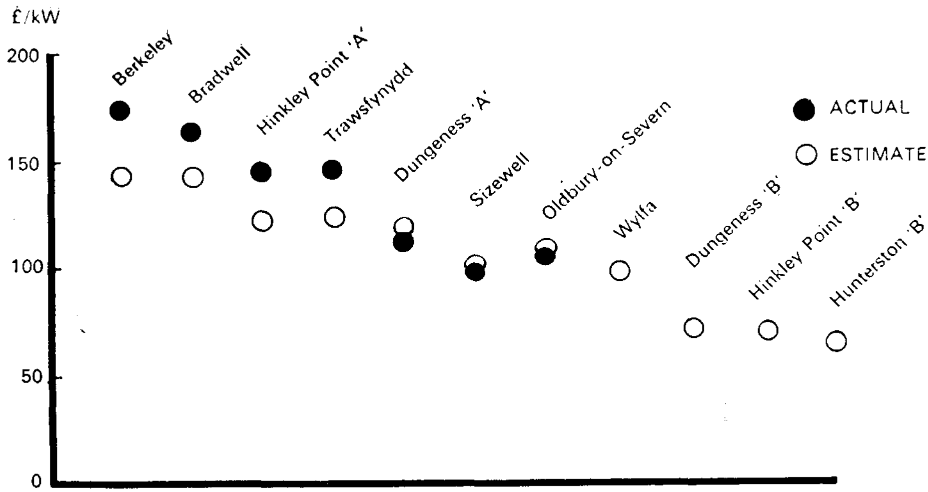


Figure 8. *Nuclear construction costs in U.K.*

In making an economic appraisal a number of assumptions have to be made and these include:

(i) amortisation period
(ii) interest rate
(iii) interest during construction
(iv) load factor
(v) availability and future cost of uranium
(iv) plutonium credit

By way of illustration, consider the interplay of these factors and assumptions in the case of a natural uranium fuelled reactor. For the future, economic factors and the attraction of modest fuel usage may appear to favour a heavy water moderated reactor such as CANDU or the natural uranium version of the British SGHW reactor. Yet if uranium turns out to be reasonably plentiful, a given utility is unlikely to be influenced much by whether whether 10te, 15te or even 20te has to be provided for each 100 MWE year of nuclear capacity generation. Again, a natural uranium fuelled reactor appears attractive to countries possessing an indigenous supply of uranium and aspirations of undertaking domestic fabrication of fuel elements. Yet, although the enrichment stage can be avoided, the reprocessing stage probably cannot be omitted and, as I have mentioned before, reprocessing is most economically done in large plants serving altogether several thousands of MWE of reactors. Rather similar considerations apply to the supply of heavy water. Moreover, even in fuel fabrication, which seems to be a relatively simple process conducive to domestic added value, it has to be remembered that most non-uranium components (such as zirconium alloy tubing) have to be imported from a large scale producer who possesses the necessary technology. I have earlier referred to the high capital cost characteristic of nuclear generating systems. Unfortunately, an insistence on natural uranium fuelling brings as a common consequence a higher reactor capital cost than for the corresponding version employing slightly enriched uranium. Of course, it is for each reactor purchaser to select the most advantageous combination of features. But I hope that my remarks will suggest that, desirable though independence and self-sufficiency in fuel supply may appear, it is often difficult to achieve completely in a manner consistent with maximum economy, and is indeed rarely thought necessary in other fields, so long as more than one overseas source of supply is available.

Self-sufficiency in nuclear energy

Self-sufficiency is a strong motivation which is much encouraged by sentiments of national pride and independence. Since the war we have seen many attempts at collaboration and interdependence among States. There has been remarkable progress, but many difficulties remain.

Bearing in mind the intense secrecy attending the initial development of atomic energy, it is commendable that, beginning with the 1955 Geneva Conference, so much dissemination of information and collaboration has indeed taken place. But the much publicised problems of EURATOM within the European Community and the duplicative development programmes among several of the Member States reveal underlying political problems emphasising considerations of self-sufficiency.

Assuming that economic nuclear generation of electricity is the prime objective, self-sufficiency starts with research and development into many aspects of nuclear science: nuclear physics data has to be accumulated, personnel trained, new materials must be investigated, chemical processes and nuclear reactions studied, radiations measured and radioactive materials manipulated. Out of this come costly zero energy reactors, materials testing reactors, experimental reactors, test loops and post-irradiation examination facilities. Then a reactor system is selected and a prototype must be built and operated. As an adjunct to all this, much work has to be done to prepare, enrich, process, manipulate and reprocess the fuel; there are also many engineering problems to be overcome and new technologies introduced. Then there is the exploitation of the by-products: the radioactive isotopes, the specialised instruments, and so on. This scale of activity can, in the space of a few years, readily incur expenditures totalling £100m.-£200m. (T.L. 2,500m. to 5,000m.) with considerable continuing commitments. Naturally, there is much technological fallout and, if the programme is successful, an economic reactor system.

About seven or eight countries have embarked on their own comprehensive nuclear energy programmes; and most of these have been operating for many years. Consequently, any other country entering the field now would have much ground to catch up, unless a wide-ranging license were taken from those already experienced.

Benefits of nuclear energy at least cost

Clearly competing requirements for scarce financial and technical resources constitute a powerful incentive to many States to avoid the massive investment which a self-sufficient nuclear development programme demands. Nevertheless, since economic development is so closely associated with the development of cheap and plentiful electric power, the attractions of low electricity generating cost from nuclear power are enticing. Can these potential advantages be realised without incurring the paraphernalia and vast cost of one's own nuclear energy research and development programme? I believe that it can, but it is not as simple as, for example, introducing one's first fossil fuelled station after a series of hydroelectric stations.

So begin with, it must be recalled that in most countries there is a traditional mistrust of nuclear matters, because of association with the atom bomb. It cannot be over-emphasised how important it is to promote public understanding and trust well before introducing nuclear power. To establish the necessary public confidence calls for a deliberate public relations exercise sustained over a period of years. The need for, and choice of, new generating capacity is usually the responsibility of an electricity utility which may not have been answerable—in the public relations sense—for anything so potentially alarming to the uninformed as nuclear energy.

The first task, however, of the utility is to equip itself to handle the assessment and introduction of a nuclear power station project. As I have remarked earlier, it is prudent for such a utility to retain the services of a well experienced firm of consulting engineers. These two parties should then work together as closely as possible to specify requirements. It is also wise for the utility to acquire a nucleus of engineers of its own who either have experience of nuclear power or can be trained to acquire such experience. A training programme clearly has to be phased so that staff with appropriate disciplines covering aspects of engineering, safety, reactor physics, operation and nuclear fuel management are available when needed. Suitable training of technicians and industrial workers must also be undertaken.

Having regard to requirements for specialised training and for the continuing need for scientific advice and investigation, it can be very valuable if either a government-sponsored laboratory or a university, or both, can be identified to fulfil such a supporting role. Taken along with other scientific work, this need not make too large a demand on resources. Moreover, such a support centre can play an important part in assisting with the introduction of other aspects of nuclear energy, such as the use of radioactive isotopes for irradiation in agriculture, industry and medicine.

Government, too, has a leading role in the introduction of nuclear energy. Often, this starts with questions of finance and investment and matters of national policy involving, for example, the use of imported or domestically produced fuels. Additionally, government can, through its relationships with various national and international bodies, seek advice and help in nuclear matters. Next, there are various legal and regulatory responsibilities which government must fulfil.

It is soon apparent that to discharge these functions, government need the services of a specialised department or agency to assist them. Many of the staff who are technically qualified for these tasks are also the type of staff required by the electricity utility. Where such staff are in short supply, it is obviously preferable to avoid duplication between the government body and the utility, so far as possible. However, some of the governmental responsibilities cannot properly be delegated to the utility. For example, the function of licensing the utility to build and operate a nuclear power station in a particular locality should be exercised by a body which is quite independent of the utility. The underlying reason for this dichotomy is that the prime function of the utility is to generate electricity as economically as possible; and that is not necessarily completely consistent with public considerations. Thus, a commercial risk of failure of equipment may seem justified to take from the economic point of view; but such a risk—if it should include possible harm to the public—may not be acceptable for political or national considerations. Thus I believe that it is essential to have a governmental body which has a number of responsibilities, some of which will be statutory but in other ways will provide government with expert advice in all aspects of the nuclear field.

If it is desired to develop a domestic nuclear fuel industry, consideration has to be given to the nature of the entity best suited to national needs. It is worth giving careful reflection to the timescale of instituting such a fuel industry. It does not necessarily have to be established in time to provide the first fuel for the first power reactor installed. Indeed, it is not only often uneconomic to do so, but can impose a strain by introducing new technologies at a rate which make them hard to assimilate.

The extent to which local industry is able to participate in the construction of a nuclear plant is also an important factor in minimising foreign exchange expenditure. To begin with, the civil engineering aspects of a nuclear station are usually the most rational area to seek local participation, though even these contain appreciable technology of a novel character.

Nevertheless, the possibility of being able to acquire new technology to promote greater self-sufficiency is an option which is worth having; the option can be taken or not, depending upon circumstances at the time. This then is a factor to be borne in mind when selecting suppliers: do they have experience to impart in the necessary technologies; and under what conditions are they willing to do so? It is a considerable assurance if suppliers can offer access to operating experience of identical or very similar plant to that one projected, with opportunities for consultation, training and the like.

Conclusion

To conclude, I will summarise the main points of the paper. Nuclear power is now well established and appears already to be economically attractive in many parts of the world for stations of 300 MWE size or more, on base load operation. Uranium reserves are likely to be adequate to satisfy demands until the early eighties but it is important that more should be discovered to cover needs until requirements are reduced by the progressive introduction of fast breeder reactors. Further economies in nuclear generating costs are in prospect. To benefit from these developments does not require the immense investment which self-sufficiency demands. A relatively small organisation of specially trained staff, together with the help of expert consulting engineers and experienced suppliers can handle the introduction of nuclear power, but there are points to watch both for government and electricity utility in public relations, choice of suppliers and in determining the rate and programme of introducing the new technologies.

Ref. 1 Uranium Resources (1968); also Uranium Production & Short Term Demand (1969) Joint Reports of ENEA/IAEA.

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

Harwell Ceramics Centre

A brochure describing the Harwell Ceramics Centre has been published by the U.K.A.E.A.

The Centre serves ceramic manufacturers and users by developing new or improved materials or processes that are commercially viable.

Already there are about 40 scientists attached to the Centre who now spend a major proportion of their time working on industrial problems. About two-thirds of the work of the Centre is now covered by agreements of one form or another with industrial firms.

Materials under development include oxide refractories, special ceramics, carbon, graphite, and fibre-reinforced glass and ceramics. The commercial work is backed up by underlying research aimed at a deeper understanding of materials. For example, there is work on the strength and fracture of brittle materials, including ceramics, plastics, glass, graphite and composite materials. Many of the characteristics responsible for controlling mechanical properties are now understood and the Centre has already introduced changes to some of its clients' production lines, leading to improved materials.

Processes in use include standard methods of fabrication such as pressing and sintering, slip casting and sintering, hot pressing—and developments of these for special products. Under development are new processes in the fields of electron and ion beam technology for machining ceramics, sol-gel methods for the preparation of fine oxide powders, electrohydraulic crushing of brittle solids, and the preparation of structures from ceramic sheet.

The brochure describes the equipment available and processes under development at the Centre. It also details the arrangements by which the Centre is already doing business with industrial firms.

The Centre is allowed flexibility in its dealings with industry and schemes of collaboration are usually tailored to suit individual cases.

Copies of the brochure are available from The Harwell Ceramics Centre, Harwell, Didcot, Berks. Telephone, Abingdon 4141, Ext. 4392/4891.

16th May, 1969

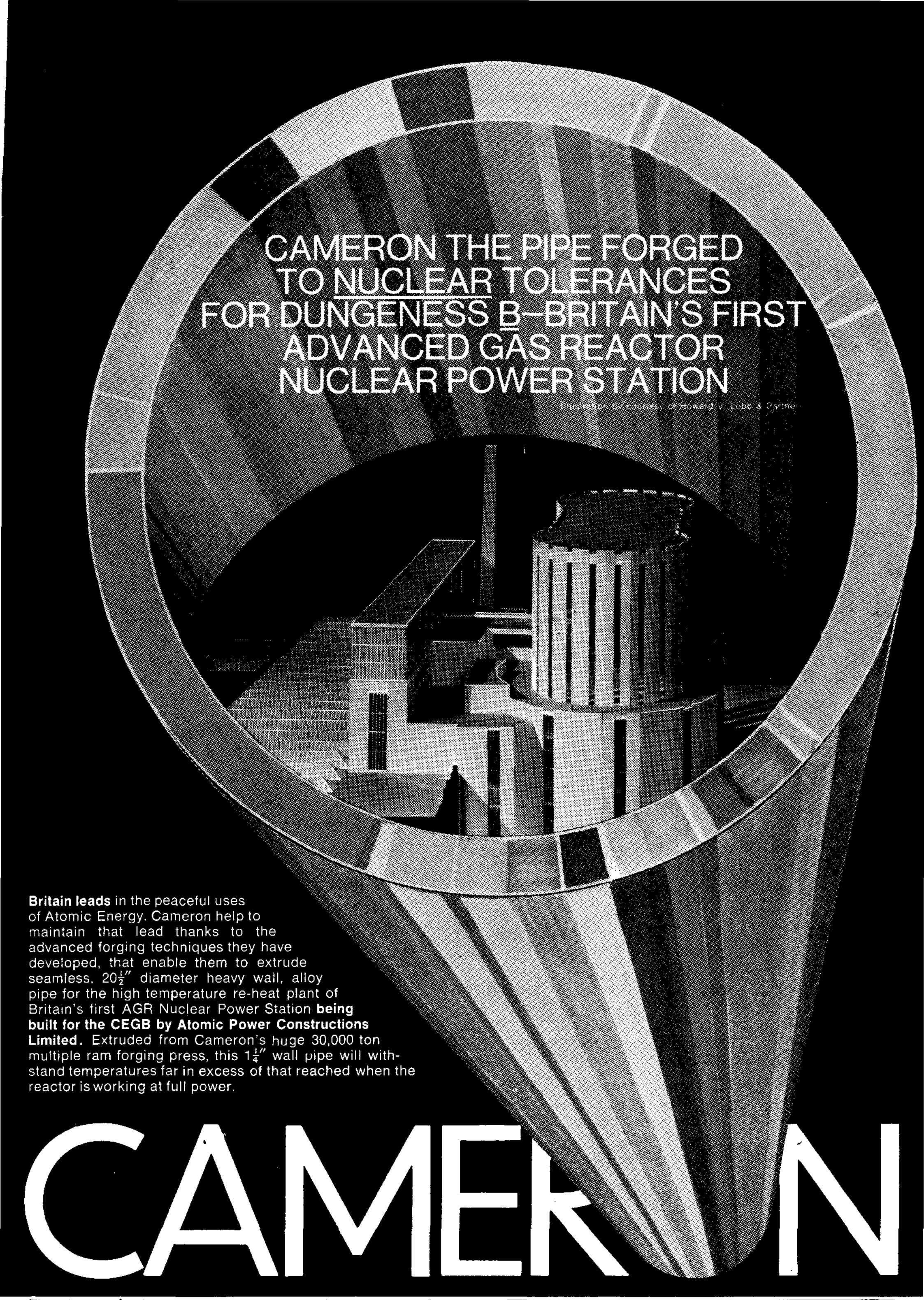
Ultrasonic probes

Of the many aids to quality control used by British industry, some of the most common are based on the use of ultrasonic testing instruments. Associated with each instrument is one or more ultrasonic probes. These probes form an essential part of the inspection system, and many different types exist adapted to particular test requirements.

The variety of probe types available today has resulted from the development of individual probes to suit individual test needs. The resulting probes have, in general, fulfilled their intended purpose quite satisfactorily. However, when probes developed for one purpose are used for another, or when reproducibility of results between equipment from different manufacturers is required, it is sometimes found that results are inconsistent due to ill-understood characteristics of the probes. Since the functioning of ultrasonic probes is a complex matter it has been found difficult, on the basis of knowledge currently available, to define the probe characteristics which are important or which may be relevant to any specific application.

In an attempt to resolve this problem, the Nondestructive Testing Centre at Harwell has been asked to undertake a programme to define important probe characteristics and, where possible, to develop methods of measuring them. The two classes of probe characteristics which will be investigated initially are those concerned with the shapes of beams emitted by the probes and with the frequency spectra which the probes are capable of producing. These two factors are interrelated, since the frequency characteristics in part determine beam shapes.

The programme has been set up with the approval of the N.D.T. Centre Advisory Committee and after consultation with industrial users of ultrasonic probes, representatives of interested Research Associations and the British Standards Institution. Further user experience and practical suggestions regarding the problems of probe characterisation and the definition and measurement of characteristics will be welcomed. Please write to A. D. McEacherm, The Nondestructive Testing Centre, A.E.R.E., Harwell, Didcot, Berkshire. *2nd June, 1969*



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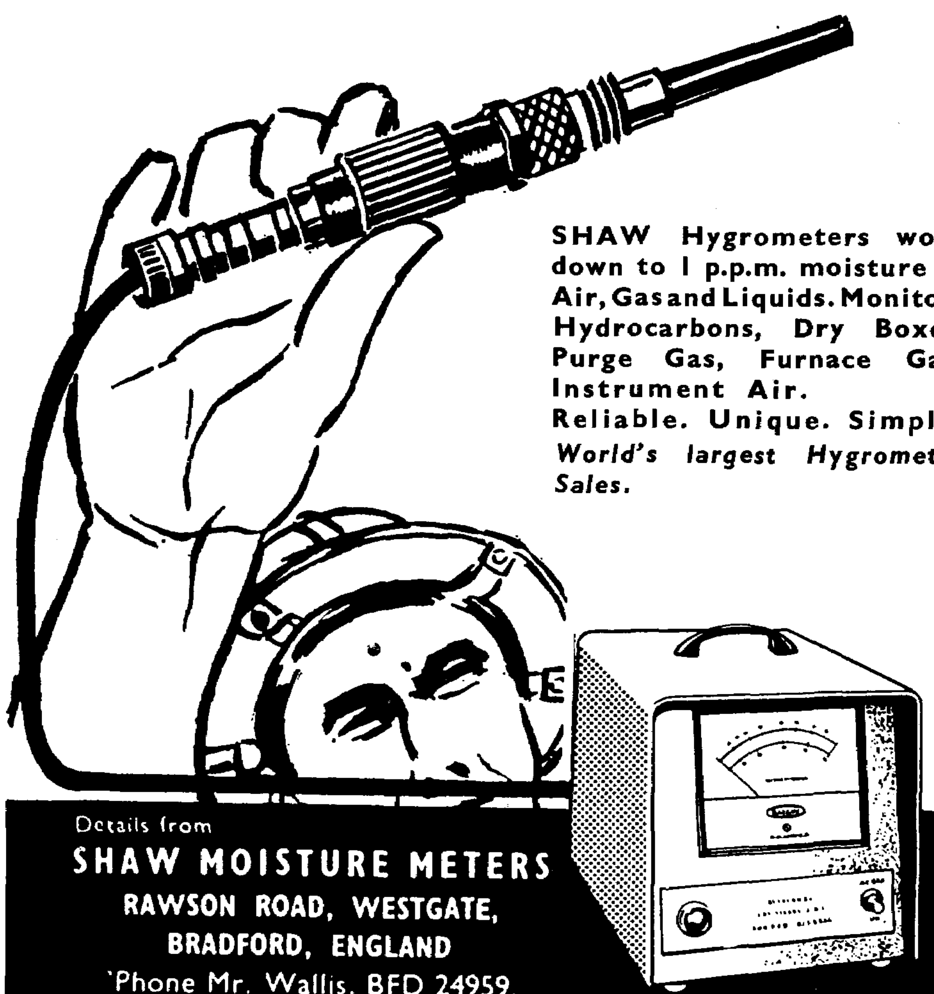

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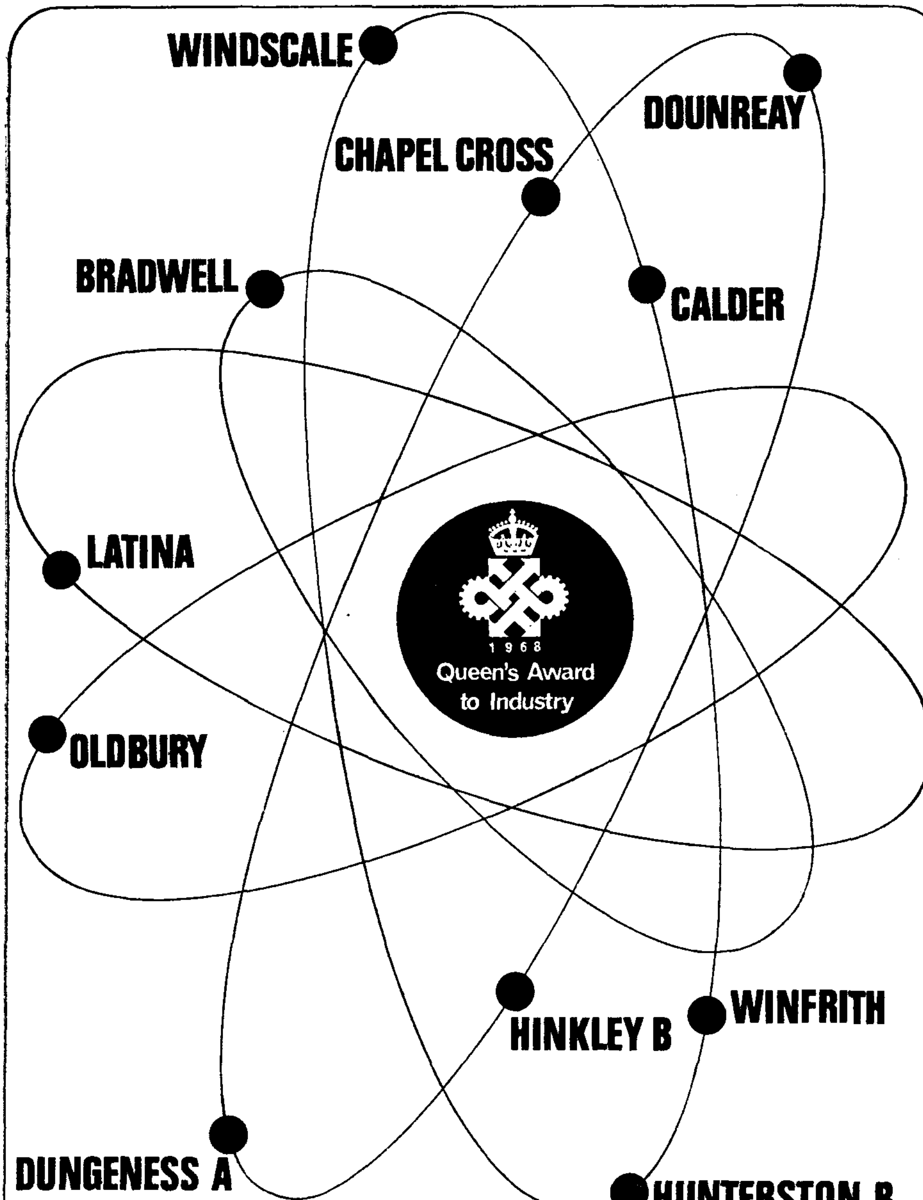
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