ATOM

Number 149 / **March 1969**

MONTHLY INFORMATION BULLETIN OF

THE UNITED KINGDOM ATOMIC ENERGY AUTHORITY

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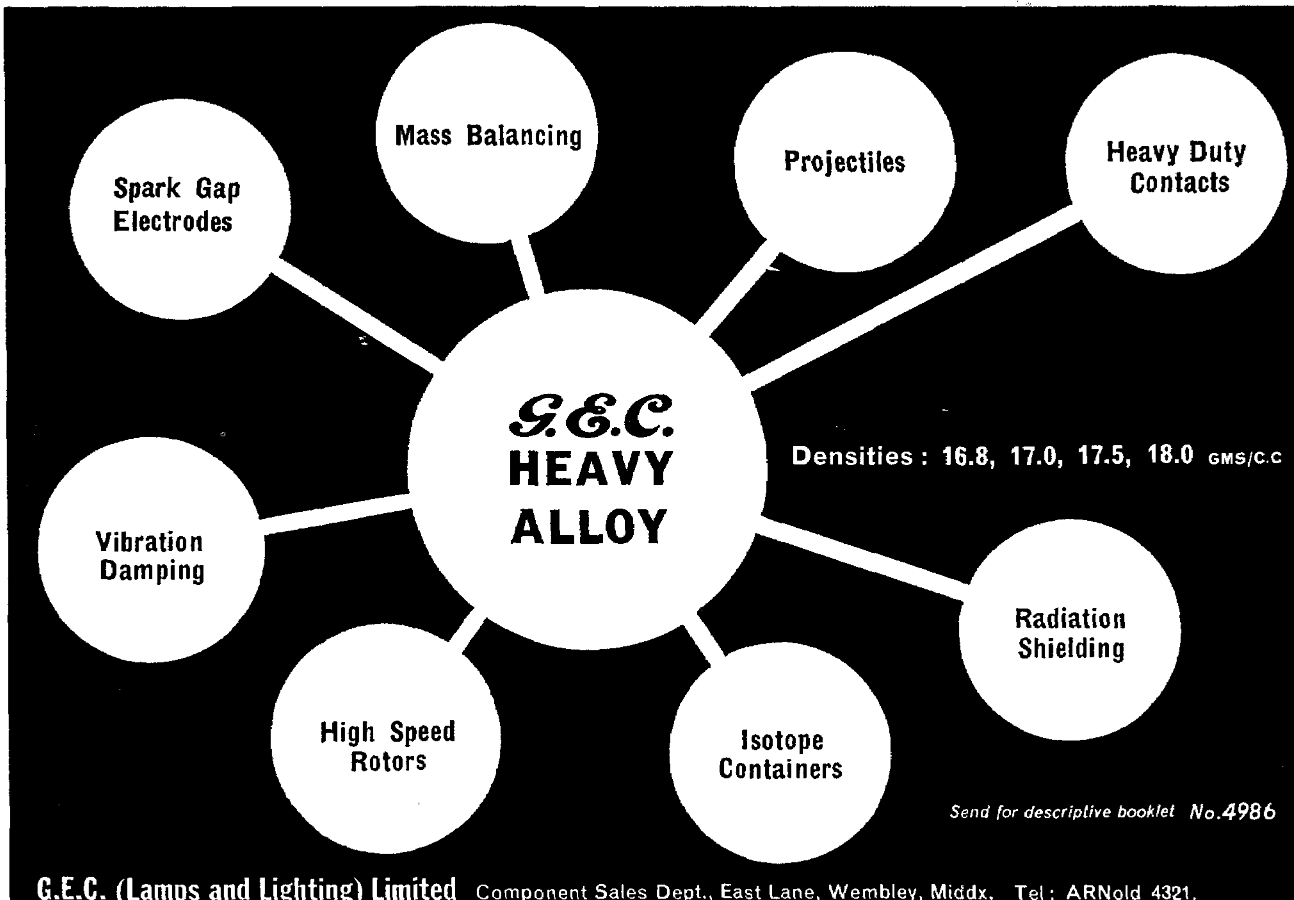
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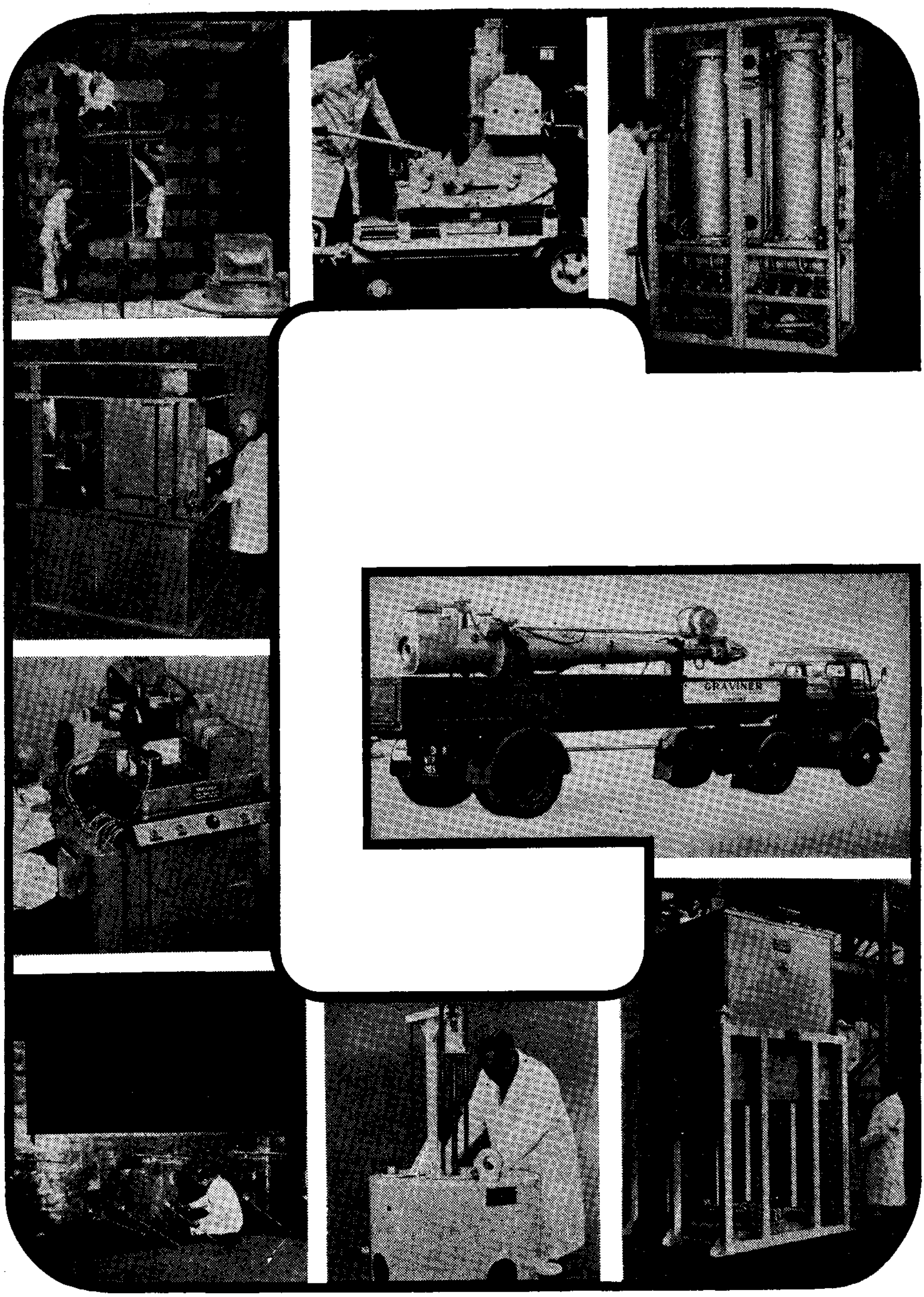
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ATOM

MONTHLY INFORMATION BULLETIN
OF THE UNITED KINGDOM
ATOMIC ENERGY AUTHORITY

NUMBER 149

March 1969

Contents

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

Enquiries concerning the contents and circulation of the bulletin should be addressed to

Public Relations Branch.
U.K.A.E.A.
11 Charles II Street
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Following the use of plutonium

The following press release was issued by the International Atomic Energy Agency on 5th February, 1969.

For the first time safeguards inspectors of the International Atomic Energy Agency (IAEA) have used special measuring devices to assist in following the use made of plutonium created in a nuclear power station under their control.

Two inspectors visited the Winfrith Heath reactor research centre of the U.K. Atomic Energy Authority (UKAEA) during January. Safeguarded plutonium is used here in ZEBRA (zero energy breeder reactor assembly) for physics experiments connected with fast reactors. Weighing 30 kg in the form of 20 gramme plates, the plutonium represents part of the production from the 300 megawatt (electrical) Bradwell power station. This station was voluntarily placed under IAEA control by the UK Government in 1966 for the purpose of verifying that material used and produced in it is for peaceful purposes only.

The inspectors used portable detection equipment modified by the UKAEA from instruments commercially available.

The ZEBRA fuel inspection was designed for statistical sampling. It was based on measurements of the characteristic gamma-ray and spontaneous fission neutrons from the plutonium isotopes. The gamma-ray measurements were carried out with the type NIS 292 portable gamma spectrometer originally developed by UKAEA (Aldermaston) and now commercially available. The neutron measurements were made using the prototype of a new version of this instrument, which incorporates a neutron counter and discriminating circuitry in addition to its gamma-spectrometric function. This modified type NIS 292 spectrometer shows promise as a versatile and portable instrument for materials accountancy.

AEA in Brazil

The UKAEA is to have a 3,000 sq. ft. display at the British Industrial Exhibition, Brazil from 5th - 16th March. It will include exhibits from Reactor, Production, Research & Weapons Groups.

Nuclear company re-named

Babcock English Electric Nuclear Limited has been re-named British Nuclear Design and Construction Limited. This is the nuclear company in which the United Kingdom Atomic Energy Authority and the Industrial Reorganisation Corporation have shareholdings of 20% and 26%, respectively, and which has taken over the activities at Whetstone, Leics., of Nuclear Design and Construction Limited.

The headquarters of the company will be in the existing offices of N.D.C. Ltd., at Whetstone.

APACE centre courses

APACE (Aldermaston Project for the Application of Computers to Engineering), sponsored by the Ministry of Technology, has for the past two and a half years been assisting British industry in the use of modern computer aids to engineering. Their range of training courses has been specially designed for engineers, and is staffed by engineers experienced in their particular areas. A consultancy and advisory service is available, and a bureau service in the engineering field, with professional support, is provided.

The following courses will be run at the APACE Centre:

Computer Appreciation Course for Engineers—4 days, fee: £48; April 22nd-25th; May 6th-9th; June 3rd-6th

Circuit Analysis Users' Course—3 days, fee £36; March 18th-20th; May 20th-22nd

Electronic Computer Aided Design Introductory course—4½ days, fee £54; March 24th-28th; June 9th-13th

APT Part I Course—4½ days, fee £54; April 14th-18th

Interactive Graphics Programming Course—4½ days, fee £60; April 28th-May 2nd

FORTRAN *Programmers' Course for Engineers*—5 days, fee £60; May 12th-16th.

Fees cover attendance and lunch daily. Overnight accommodation is arranged for course members on request.

Further information about the above may be obtained from The Secretary (Ref. A), APACE, UKAEA, Blacknest, Brimpton, near Reading, Berks. Telephone Tadley 4111, Ext. 5951/5873.

IN PARLIAMENT

A.E.A. staff

11th December, 1968

MR. BOOTH asked the Minister of Technology which regulations in his Department restrict employment to persons of particular birth, citizenship, descent or residence, in the United Kingdom Atomic Energy Authority.

Mr. Benn: None, though the United Kingdom Atomic Energy Authority do not recruit aliens as permanent members of their staff. British subjects, whether born in this country or not, are eligible for appointment provided that they satisfy the requirements as to residence in the United Kingdom.

Dungeness B delays

20th December, 1968

MR. MCGUIRE asked the Minister of Power what are the reasons for the delay in completing the Dungeness B power station; and what additions to the capital and generating costs will arise from this delay, and from the difficulties recently encountered.

Mr. Roy Mason: The details of the mechanical engineering difficulties at Dungeness B station are a matter for the Central Electricity Generating Board and I am asking the Chairman to write to my hon. Friend about them. As I indicated in my reply to his Question of 10th December—it is too early to make a reliable assessment of what effects these difficulties may have on completion date or cost.

Large commercial fast reactors

22nd January, 1969

MR. LUBBOCK asked the Minister of Technology whether assessment of the 1,000 MWE commercial fast reactor design has now been completed; and if he has yet decided whether to proceed with this design or to choose a smaller output as the basis of the first commercial fast reactor to be built in the United Kingdom.

Mr. J. P. W. Mallalieu: The United Kingdom Atomic Energy Authority is still assessing alternative designs for large commercial fast reactors with a view to producing, in co-operation with the United Kingdom nuclear industry, a specification acceptable to the Central Electricity Generating Board. This assessment will be available for consideration with C.E.G.B. in the third quarter of this year so that a decision can be taken on the details of the next stage of this work. The size ultimately chosen is a matter for decision by the C.E.G.B. and my right hon. Friend the Minister of Power.

Statutes on computer

22nd January, 1969

MR. STRATTON MILLS asked the Attorney-General if he will make a further statement on the progress of the studies relating to the computerisation of a statute book; what is the total amount which has been spent on this work to date, the number of people currently involved and the departments specifically operating the investigation.

The Attorney-General: The Stationery Office is at present investigating the possibility of putting the Statutes on to computer for type-setting purposes and with a view to its possible use eventually for the retrieval of legal information. In addition, the Atomic Energy Authority is conducting some preliminary research on the problems involved in computerising the Statutes relating to atomic energy. Proposals for the extension of this work are being considered. It is estimated that this research has cost about £7,000 to date. Four people are at present giving part of their time to this work.

Atomic co-operation

22nd January, 1969

MR. DALYELL asked the Minister of Technology what is his policy on the relationship between obligations under Anglo-American defence agreements about the exchange of nuclear weapons information and plans for European collaboration in developing the cheap gas-centrifuge route to high-grade nuclear fuel.

Mr. Benn: There is no direct relationship. The United Kingdom-American defence agreement on atomic co-operation is principally concerned with the exchange of weapons information which is quite a different matter from either the technology of centrifuges or plans for collaboration in the development of centrifuges.

Mr. Dalyell asked the Minister of Technology if he will make a statement on his negotiations with the United States Atomic Energy Commission in relation to the cheap gas-centrifuge route to high-grade nuclear fuel.

Mr. Benn: Informal consultations with the United States authorities on matters within the ambit of the bilateral Agreement for co-operation on the civil uses of atomic energy take place from time to time on a confidential basis.

Mr. Dalyell asked the Minister of Technology if he will make a statement on his negotiations with the Dutch and German Governments in relation to the cheap gas-centrifuge route to high-grade nuclear fuel.

Mr. Benn: These discussions are proceeding satisfactorily, but further work has to be done before any definite scheme can emerge for Ministerial consideration.

Capenhurst

22nd January, 1969

MR. DALYELL asked the Minister of Technology if he will make a statement on the future of Capenhurst in relation to the development of high-grade nuclear fuel.

Mr. Benn: The re-equipment of part of the Capenhurst diffusion plant for the production of slightly enriched uranium for the civil nuclear power programme is now virtually complete. Plans are now being made for the further expansion of enrichment capacity.

Scottish programme

22nd January, 1969

MR. EADIE asked the Secretary of State for Scotland what estimate he has made of the effects of the delay in the building of the present nuclear building programme in Scotland on Scotland's industrial prospects; and how far it is behind schedule.

Mr. Ross: The present nuclear building programme of the Scottish Electricity Boards consists of Hunterston B generating station, which has been under construction since October, 1967, and which is on schedule.

Chapelcross breakdown

29th January, 1969

MR. EADIE asked the Minister of Technology what is the cost to date of the breakdown of the Atomic Energy

Authority's reactor at Chapelcross; how long the reactor is expected to be out of action; and what estimate he has made of the total resulting loss of revenue from electricity sales.

Mr. J. P. W. Mallalieu: About £200,000. It is not yet possible to forecast how long the No. 2 reactor will be out of commission. The loss of electricity sales to date is put at £1,700,000, and this will increase by £90,000 per month while the reactor is out of action.

The other three reactors continue to operate at about 90 per cent. load factor.

Mr. Eadie: Everyone will be glad that these faults have been remedied in the interests of the men employed, if nothing else, but does not my hon. Friend agree that this incident is a classic example of the recommendation made by the Select Committee on Science and Technology that all forms of energy production in this country should be subjected to independent investigation on the question of cost?

Mr. Mallalieu: This incident, which is most unfortunate, is not typical of anything which is now known. This reactor is a very old design, and what happened there is most unlikely to happen with a modern design.

Mr. Monro: Does not the Minister agree that the staff have shown great skill and initiative in trying to overcome this exceptionally difficult breakdown? Can he confirm that there will be no redundancies because of it?

Mr. Mallalieu: I should like notice of that question, but I very much hope that no redundancies will arise. I agree with what the hon. Member says about the great work that the staff are doing in trying to put this right.

Reorganisation of the nuclear industry

29th January, 1969

MR. MACLENNAN asked the Minister of Technology what progress he has made in the reorganisation of the nuclear power industry.

Mr. Benn: Hon. Members will have seen the announcement on 15th January of the formation of the second of the two nuclear design and construction companies envisaged in my Statement of 17th July last year. The industry should now be better equipped to meet our needs at home and compete abroad. I am grateful to the Industrial Reorganisation Corporation for the work it has done. The two parent companies of Atomic Power Constructions—Fairey's and International Combustion—have, for the time being at least, not found a place in either of the two new companies.

Now that the industrial structure is settled, I shall be in a position to go forward with the other arrangements foreseen in my statement on 17th July last year.

Mr. Palmer: Apart from the recommendations of the Select Committee on Science and Technology, which my right hon. Friend has largely ignored, is he now satisfied that the structure which is emerging for the nuclear reactor industry is that which he set out to obtain? Has not my right hon. Friend been pushed by events rather than the other way round?

Mr. Benn: I think that any Minister who believes he will get everything he wants is very optimistic. What my hon. Friend calls " being pushed by events " I would call " taking account of the realities ", including the realities of international collaboration in this sphere. I think that the I.R.C. has done a good job on the remit that I gave. I believe that it will put this country in a better position to exploit the hundreds of millions of pounds which it has put into research in the peaceful development of nuclear energy.

Mr. Price: Does the Minister agree that the main cause of the delay was due to the desire of the Government and the I.R.C. to do the Tote double and produce two out of the three consortia at the same time as producing mergers amongst the boiler-making firms?

Secondly, what will happen to the Dungeness B contract, in view of the fact that A.P.C. so far has not been fitted into the new arrangements?

Mr. Benn: On the latter part of the question, I must ask the hon. Gentleman to put that matter to the Minister of Power, because I am not responsible for nuclear power stations being built for the C.E.G.B., even indirectly. But it has had industrial implications in the negotiations that have taken place, and I would add that to the factors which were mentioned as being the cause of such delay as there was. However, it was done very quickly and we should not grumble at the way that the I.R.C. carried out its duties.

Mr. Lubbock: Can the right hon. Gentleman say, first, which of the two new companies will be responsible for exploitation of the steam generating heavy water reactor and the high-temperature reactor, respectively? Secondly, can he say whether there have been any fresh implications concerning the arrangements that he has announced for international co-operation between our companies and those in Europe?

Mr. Benn: On the latter question, these would be industrial links in which I should be interested but for which I am not responsible. This work is going on. Both B.E.E.N. and T.N.P.G. are to be licensed to exploit the fast reactor and the S.G.H.W. One will go ahead almost certainly on an inside track. The H.T.R. must be the subject of further discussion, though availability of the technology will not be restricted to one or the other.

Sir H. Legge-Bourke: Would the right hon. Gentleman now be prepared to lay a White Paper giving his full comments on the report of the Select Committee on Science and Technology, which reported on the future of the nuclear reactor programme?

Mr. Benn: I did, in a sense, give the answer. It is part of the answer—which bore upon the structure of the industry—in the statements which I made in May and July on the industrial arrangements that have taken place. I wrote to the Chairman, dealing with all the other recommendations which bore on my responsibility, but not those which did not. The final duty remaining on me is to deal with outstanding issues involving the A.E.A., and this I shall do as quickly as I can.

A.E.A. staff and costs

4th February, 1969

MR. MARPLES asked the Minister of Technology if he will list the research establishments under the Atomic Energy Authority, including their location, the date they were originally established, the total staff, both qualified engineers and scientists and others, and the cost to public funds of each establishment in 1958 and during the current financial year.

Mr. J. P. W. Mallalieu: Information about Atomic Energy Authority research establishments is given in the following tables.

It would not be in the public interest to publish figures of the staff and expenditure of the Defence Research Establishments.

A. CIVIL RESEARCH ESTABLISHMENTS

Name	*Location*	*Year of Origin*	*Q.S.E.*	*Other Staff*	*Net Cost £ million 1958-59*	*Net Cost £ million 1968-69 (Estimated)*
Atomic Energy Research Establishment.	Harwell, Berks.	1946	900	4,580	10.0	13.4
Research Laboratory	Wantage, Berks.	1956				
Culham Laboratory	Culham, Berks,	1960	185	610	—	2.5
Atomic Energy Establishment	Winfrith, Dorset	1957	380	1,770	0.7	3.3
Experimental Reactor Establishment.	Dounreay, Caithness	1955	250	2,055	2.5	4.5
Reactor Fuel Element Laboratory.	Springfields, Lancs.	1946	140	475		
Reactor Engineering Laboratory	Risley, Lancs.	1961	90	345		
Reactor Materials Laboratory	Culcheth, Warrington, Lancs.	1951	95	190	3.4	6.1
Reactor Development Laboratory.	Windscale, Cumberland.	1947	140	305		

B. DEFENCE RESEARCH ESTABLISHMENTS

Name	*Location*	*Year of Origin*
Atomic Weapons Research Establishment	Aldermaston, Berks.	1951
Foulness Establishment	Foulness, Essex	1948
Orfordness Establishment	Orfordness, Suffolk	1959

The process of nuclear fission

This is a popular version of a paper presented by Dr. J. E. Lynn, of the Nuclear Physics Division, Harwell, to the Annual Meeting of the American Physical Society—American Association of Physics Teachers in New York, from 3rd-6th February, 1969.

Nuclear fission, or "atom-splitting", the great energy-producing phenomenon of modern times, has now been found to be a more complicated process than previously thought.

In the process of fission the atomic nucleus, the tiny dense core of the atom, has usually been visualised as an electrically charged liquid drop. The surface "skin" tends to keep the drop spherical, like an ordinary drop of water, but the electric charges, repelling each other, try to elongate the drop. In the stable nuclei the surface forces are the stronger, but if a very heavy nucleus is given an internal shock (e.g. by the absorption of a neutron, one of the elementary particles of nuclear matter) it can be deformed sufficiently far from the spherical shape for the surface skin to lose its effectiveness; the electric charges rapidly push it into a longer and longer shape, and it eventually splits into two smaller nuclei.

Third factor

In the last few years this picture has had to be greatly modified. A third factor has been added to the balance of forces—the preference of the individual protons and neutrons that make up the nucleus for certain distinct nuclear shapes above all others. These preferred shapes are not always spherical. Very heavy nuclei, like uranium, are slightly ellipsoidal (this has been known for a long time). It has now been discovered that these nuclei also have a preference for a rather longer shape, like a rugby ball. So the original shock may succeed only in flipping the nucleus into its rugby ball shape, and it may have to wait some time before it gets into the even longer unstable "dumb-bell" shape that leads to splitting.

There is considerable evidence for this new picture. The time that the nucleus has to wait in its intermediate rugby ball shape has been directly observed. It has also been found recently that neutrons in certain narrow ranges of speed are much more effective in causing the nucleus to fission than other neutrons at different speeds (this is called intermediate structure in neutron-induced fission*). This can only be explained by the new two-stage picture of fission. The nucleus can oscillate between its nearly spherical shape and its rugby ball shape, but to do this it has to be given the right amount of energy, just as a radio receiver has to be tuned in to get the programme of one's choice. Because the nucleus has to pass through the rugby ball shape before it can finally split into two parts, the incoming neutron has to bring in just this right amount of energy for oscillation in order to induce fission.

Practical consequences

This new phenomenon has important practical consequences. Nuclear reactor designers, for example, particularly of future fast breeder systems, must be careful that the neutrons in the heart of the reactor are arranged to have speeds in the ranges where they are most effective in inducing fission rather than at speeds at which they would be uselessly lost by a kind of nuclear absorption leading only to gamma-ray emission.

International collaboration

It is illuminating to examine the international nature of the contributions that have led to the new understanding. Spontaneous fission isomerism was first discovered by Russian scientists, and so also was the recognition of the role of the individual neutrons and protons of the nucleus in selecting preferred nuclear shapes. Further discoveries about spontaneously fissioning isomers were made by Danish and American scientists, while observations of intermediate structure in neutron-induced fission were made in laboratories of France, EURATOM, Britain and the U.S.A.

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* This is on a much larger scale than the resonance fine-structure that has been well-known to nuclear physicists for a long time.

Fast breeder reactor power stations

This paper, by R. V. Moore, G.C., C.B.E., Managing Director, Reactor Group, UKAEA, was presented to a meeting of Société Royale Belge des Ingénieurs et des Industriels, in Brussels, in January.

The present position

In recent years, Western Europe and the United States particularly have both embarked on large programmes for the construction and operation of commercial nuclear power stations. The anticipated growths for nuclear power in the West European countries including the UK are illustrated in Fig. 1. At present, only a few per cent of the 200,000 MWE of installed generating capacity in this region is nuclear but, by 1985, between one fifth and one third of the capacity in several countries will be nuclear.

At the present time, three reactor systems predominate—all three are thermal reactors, which can be distinguished by the choice of moderator, either graphite moderated, light water moderated or heavy water moderated.

The graphite moderated reactors are cooled by gas, most of them by CO_2. The earlier reactors use uranium metal fuel, are unenriched, the metal rods being clad in a can of magnesium alloy called magnox. The French and the British are among the main protagonists for this class of reactor. The magnox fuel element has been superseded in later reactors (the AGRs) by enriched uranium dioxide fuel elements clad in thin stainless steel. This change permits much higher temperatures and higher ratings than were possible with the earlier type of fuel element.

In the light water moderated reactors, developed mainly by the United States, the light water also serves as the coolant. Two versions have reached commercial use. In one, boiling is suppressed, the so-called Pressurised Water Reactor or PWR. In the other, boiling is allowed to take place in the core of the reactor, steam, after separation from water, being fed direct to a saturated-steam turbine. This reactor is, of course, called the Boiling Water Reactor (BWR).

Several forms of heavy water moderated reactor exist, but the type of commercial significance is the Canadian CANDU-reactor, which is designed to operate with unenriched uranium dioxide fuel elements, the reactor being cooled also by heavy water. The heavy water coolant and the heavy water moderator are, however, separated by pressure tubes forming the fuel channels. Recently a different version of this class of reactor using natural fuel has appeared in which the reactor core is enclosed in a pressure vessel (as opposed to the individual pressure tubes of the Canadian reactors) and this is being marketed by West Germany.

It may come as a surprise to many that gas-cooled, graphite moderated reactors have, as of today, the largest installed capacity (Fig. 2) in the world. This position, however, is rapidly being overhauled by light water reactors, either PWR or BWR, of which a large number are under construction in the United States. The steady rise in installation rate of gas-cooled graphite moderated reactors contrasts with the rather rapid and recent increase of the light water reactors. The smallest programme of the three is for heavy water moderated reactors.

At today's date, the most extensive operating experience is with gas-cooled, graphite moderated reactors, but even in this case it is salutary to note that only six or seven years' operating experience has yet been accumulated by utilities.

It has been accumulated during a period when each successive plant built has incorporated new technical developments. Replication and rationalisation of plant already developed has not so far been prominent. This must mean, I suppose, that the economic benefits from improved design, based on rapidly advancing technology, have been considered to exceed the benefits which would accrue from repeating designs already under construction or in operation.

Since in this lecture I shall be talking mainly about a reactor system 5 to 10 years away from commercial operation, it is worthwhile digressing for a moment

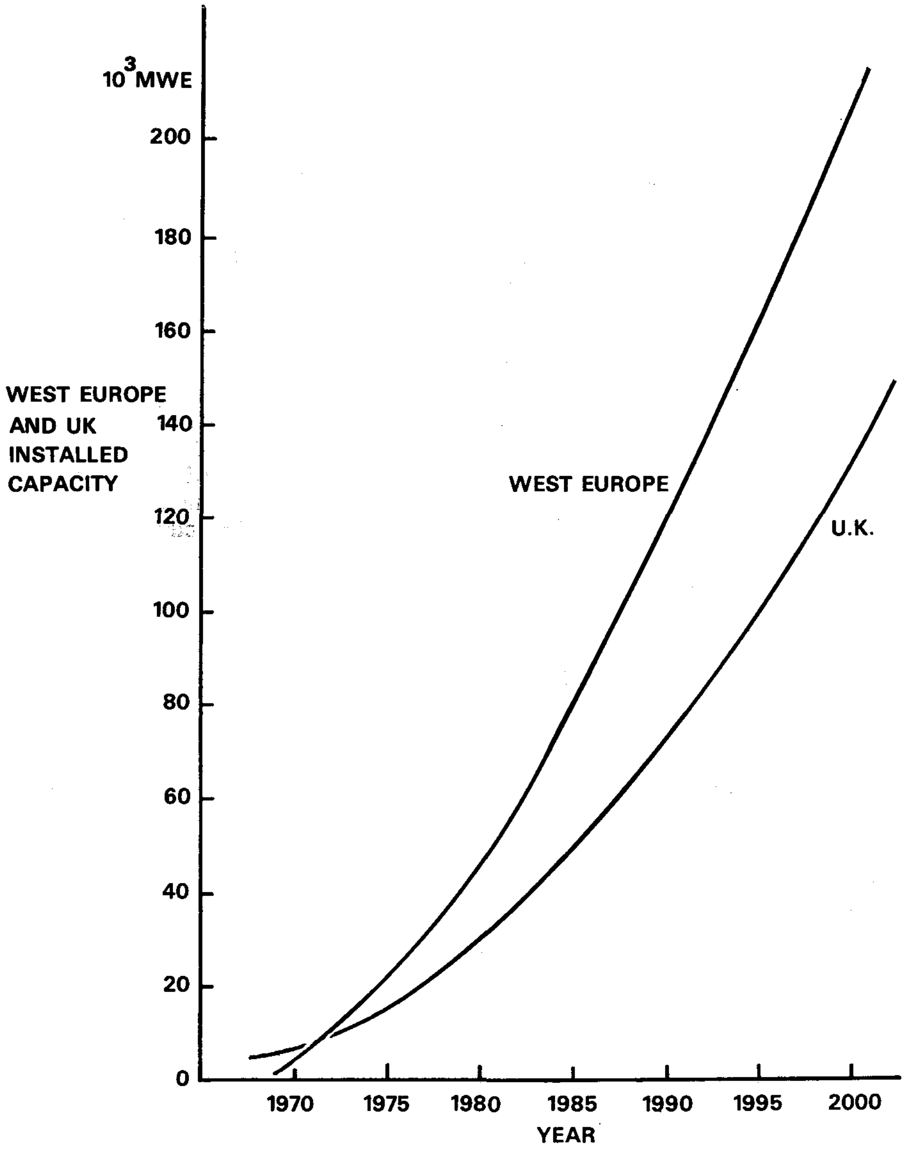


Fig. 1. *Installed nuclear generating capacity—West Europe and U.K.*

to form some idea of the rate of progress of the more established reactor systems in recent years.

We can do this with the help of Fig. 3 which shows two diagrammatic sections, to the same scale, of a magnox gas-cooled graphite reactor—Bradwell—on-power in 1962, and Hunterston 'B' AGR which is now under construction and is due on power in 1972. It can be seen that the smaller plant—Hunterston 'B'—has over four times the output of Bradwell, a simple but striking indication of design advances over a decade.

The figure also shows one of the main engineering advances: the concrete irradiation shield of the Bradwell reactor has become in the Hunterston 'B' design a pre-stressed concrete pressure vessel, enclosing the steam raising boilers which in the earlier reactor were individual units separate from the main structure.

The other main difference between these two plants I have already men-

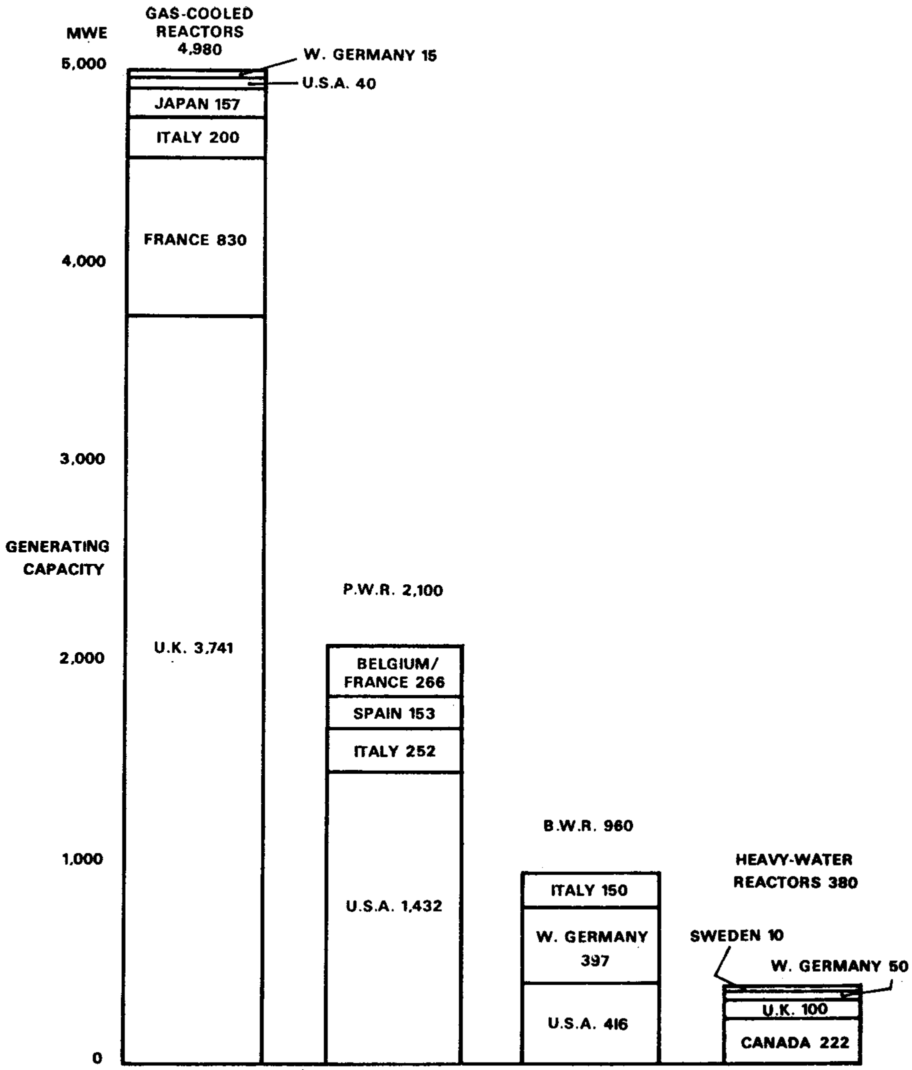


Fig. 2. *Nuclear generating capacity by reactor type.*

tioned: it is that the natural uranium metal fuel elements of Bradwell have been replaced in Hunterston 'B' by uranium oxide fuel elements clad in stainless steel.

It is worth noting that, in addition to reducing capital costs, the enveloping prestressed concrete pressure vessel in place of the separate steel pressure vessels for reactor and boilers has much improved the general safety of the plant.

The Hunterston 'B' type of reactor will generate power in Great Britain at a cost below that possible using conventional fuels. But already a third generation of gas-graphite reactors is on the drawing board. In these reactors the UO_2 fuel of the second generation reactors will be replaced by fuel composed of small UO_2 particles covered in coatings of silicon carbide and carbon, which will contain the products of fission within the particle. These fuels are being developed in Europe mainly by the DRAGON project. With them, higher ratings and higher temperatures will become possible, reducing reactor costs, while higher temperatures could lead to direct-cycle gas turbine prime movers with the promise of still further reduced capital costs and lower

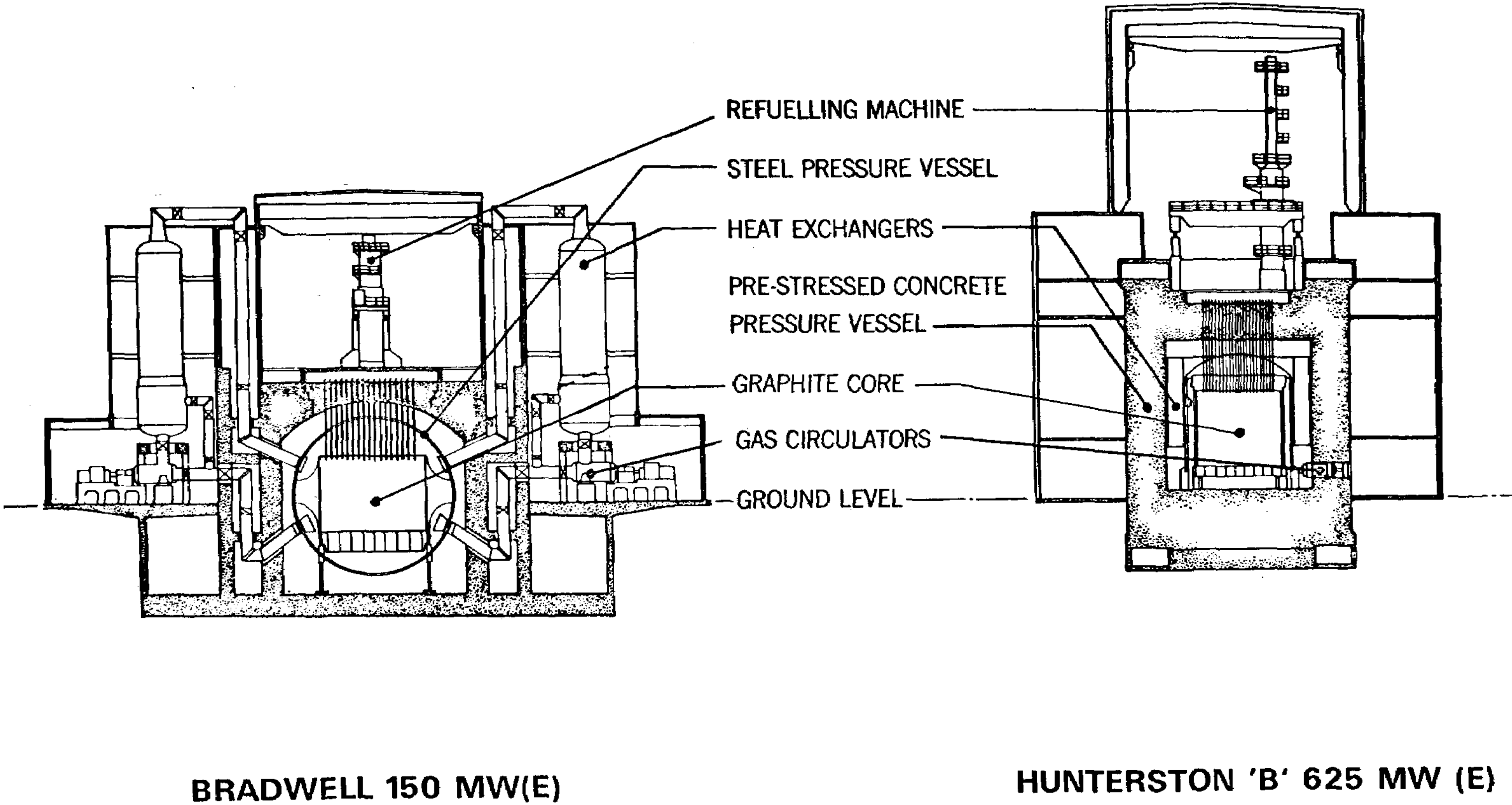


Fig. 3. *Bradwell 150 MWE and Hunterston "B" 625 MWE.*

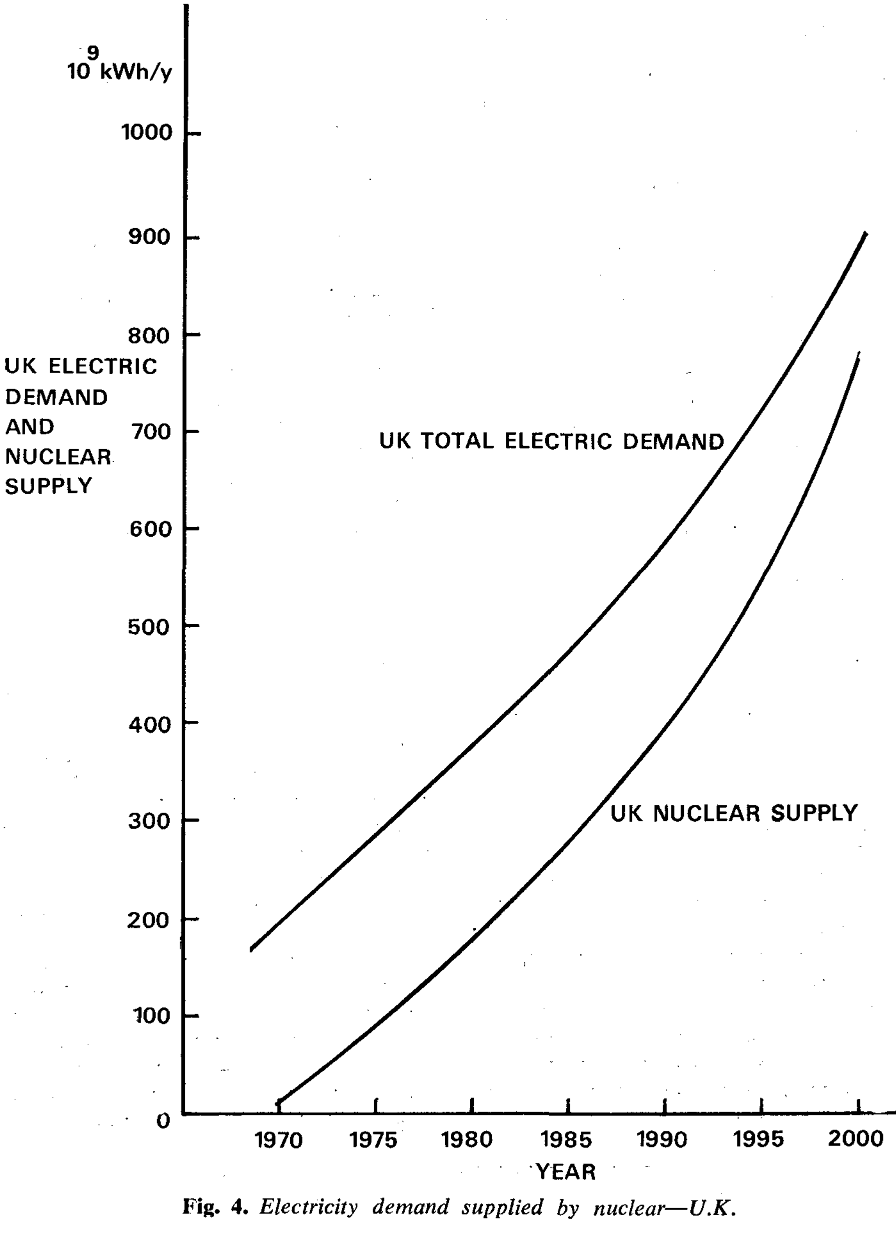


Fig. 4. *Electricity demand supplied by nuclear—U.K.*

electricity costs. I shall mention this third generation of reactors later in the lecture in another context.

In the next few years it will be interesting to observe the healthy competition from these new reactors striving for a place in the nuclear power programmes of different countries. The utilities and their advisers will be weighing the promise of lower capital and electricity costs against arguments of known reliability achieved by reactors of more established design.

By way of illustration Figure 4 shows how the demand for electricity in the UK can be expected to rise each year so that by the end of the century the generating system will have an installed capacity around five times the present amount. Recent assessment of the UK position indicates that, unless there is a sharp downward trend in the cost of fossil fuels, it will be economically worth while to install at least 70% of all new generating capacity plant with nuclear boilers. The rate of nuclear installation for the UK can be expected to be around 3,000 MW per year in the early 1980's and approaching 10,000 MW per year by the end of the century.

With such enormous installation programmes pending (equivalent installation rates will be achieved in most other parts of the industrialised world) it is quite clear that it is going to be of paramount importance to utilise the uranium (and indeed the thorium) resources available in the world much more efficiently than we are doing at present. The reactors discussed so far all suffer from the limitation that less than 1% of the heavy metal elements is converted into useful power. How we are to achieve better utilisation is the main theme of this lecture. The key is the fast-breeder reactor.

Uranium, thorium and plutonium availability and utilisation

The fuel logistics for 1,000 MWE reactors of the type we have discussed so far are shown in Table 1. It can be seen that the fuel requirement is around 200 tonnes of U_3O_8 concentrate for each 1,000 MWE year of electricity generated. There is not a lot to choose between the different types of thermal reactors. Re-cycling plutonium in thermal reactors would only marginally improve the situation.

On this basis the programmes outlined earlier for Western Europe and the UK would require upwards of 600,000 tonnes in the next 30 years and would be consuming U_3O_8 at the rate of about 50,000 tonnes/year at the end of the century.

On a world scale, the demand could be near 50,000 tonnes/year in the mid 1970's and 100,000 tonnes/year a decade later. In his lecture last April to this Society, Commissioner Johnson put the assured reserves of uranium ore recoverable with the price of $10/lb at between 200,000 to 500,000 tonnes U_3O_8.

Thus if thermal reactors only were used to satisfy the demand for nuclear power, prices of U_3O_8 would seem bound to rise into the $15 to $30/lb range to recover the lower grade uranium deposits.

This order of price rise would increase nuclear power costs from thermal reactors by upwards of 10%, so that unless fossil fuel prices were also to rise much of the present advantage of nuclear power stations would have been lost.

Consideration has been given through the years to developing nuclear power reactors to make use of thorium reserves, as these would add about half as much again to the amount of available uranium. Thorium utilisation in gas-cooled graphite moderated reactors has been explored in the DRAGON project for high temperature helium cooled reactors operated on a U-235/thorium fuel cycle. Reactors designed on this basis would not be (as at one time thought) self-sustaining in their fissile materials requirements and, apart from thorium, they require quite large amounts of uranium at a high level of enrichment; they also pose quite difficult fuel processing problems and would require a new range of process plants.

To improve the fuel logistic properties towards a self-sustaining cycle the fused salt reactor has been considered, in which reprocessing is done continuously to extract the fission products and any surplus

Table 1. Fuel logistics—1,000 MWE reactors

		Magnox	AGR	BWR	CANDU	Typical Fast Breeder
Peak fuel rating	MWH/T	3	14	27	22	260
Station efficiency	%	33	42	33	30	42
Initial enrichment	U-235%	0·71	1·4	2·2	0·71	20% Pu
Core inventory U_3O_8	T	1,200	640	640	250	40*
Feed enrichment	U-235%	0·71	2·3	3·0	0·71	—
Fuel feed U_3O_8	T/y	370	200	240	170	1
Uranium utilisation	%	0·2	0·4	0·4	0·8	70 approx.
Burn-up	MWD/T	3,500	20,000	33,000	8,600	10% h.a.
Reject enrichment	%	0·4	0·6	0·5	0·2	—
Plutonium yield	T/y	0·63	0·22	0·29	0.63	0·26 nett.

*Including breeder regions.

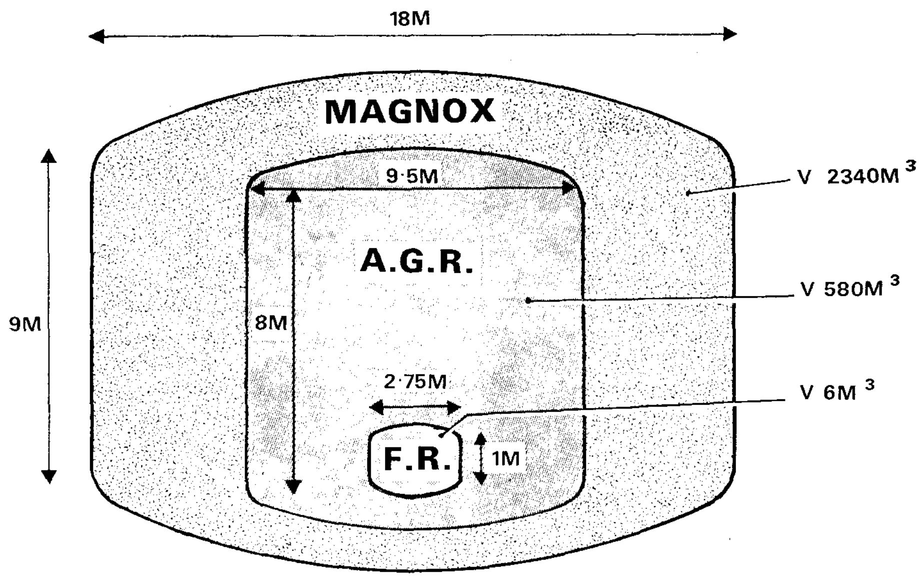


Fig. 5. *Core dimensions of 600 MWE reactors.*

of fissile material. There is thus more chance of achieving a self-sustaining cycle with this proposal.

Some exploratory work has been carried out in Russia and Belgium to see whether thorium could be utilised in fast-breeder reactors using the spare neutrons to convert thorium into U-233—a fissile material which could then be used in fast reactors or passed on to thermal reactors.

The most likely fuel to be used in the fast breeder reactor will, however, be plutonium, produced in increasingly large quantities in thermal reactors. The magnox gas-cooled reactors already installed in the first British nuclear power programme are good yielders of plutonium which will mean that Great Britain will be particularly well placed, not only to make an early start with a programme of fast breeder reactors, but also possibly to supplement temporarily the resources of other countries enabling them to make an earlier transition towards fast reactor installations than would otherwise be feasible.

Once fast breeders become commercial propositions the cumulative world uranium requirements during the years ahead can be reduced to around one sixth, and the rate of uranium feed eventually to the order of one hundredth, of those with thermal reactors alone, so relieving the pressure of world demand on the uranium resources.

Fast reactor benefits and characteristics

Taking Britain as an example, with a phased programme of commercial fast breeder reactor power stations starting in the late 1970s, the possibility arises in that country of increasing the benefit to the nation from nuclear power compared with power supplied by fossil stations by the order of £2,000M, several times the development costs which will have been incurred through the years and many times the cost of the development work which remains to be completed. A prompt start on the fast breeder reactor programme can potentially increase this national benefit by up to £50M for each year gained with the major installations.

The problems facing the designer seem worth reviewing at this stage. As most of you are already aware, in a fast neutron reactor there is no moderation; in fact every effort is made to keep the energy level of the neutrons as high as possible. Typically the average energy of the neutrons is 2 MeV (equivalent to a velocity of 150,000 x 10^6 m/sec) compared with 3,000m/sec of the more pedestrian thermal neutron reactor.

The fuel is highly enriched and so the heat rating must be maximised to limit the capital investment in the first fuel charge. The absence of moderator and the high rating lead to a very compact core, around which the fertile material, U-238 or perhaps in due course thorium, is tightly packed to mop up usefully the spare fast neutrons. Figure 5 shows a rough comparison between the core sizes of FR, AGR and magnox reactors producing 600 MWE.

Whereas, too, in a thermal reactor it is not possible to fission many of the 240 and 242 isotopes of plutonium, the higher energy neutrons present in fast reactors do cause their fission. This opens up the possibility of using profitably the plutonium from thermal reactors without having to restrict the burn-up of fuel in the latter to get a product rich in Pu-239.

The high heat rating required of the fuel in a fast reactor core, over ten times that of thermal reactors, gives rise to severe cooling problems. The choice of coolant is conditioned by the fact that it is undesirable to introduce neutron-moderating materials into the core, which generally eliminates, or places low on the selection list, water or hydrogeneous materials. Gases, if used, must be at very high pressure and high flow rates to achieve the heat ratings desired. Liquid metals, and particularly the alkali metals, have seemed most suitable until now; of these sodium potassium alloys and later sodium have become pre-eminent.

It is of interest to note the properties of sodium which have led to its choice for fast reactors in most countries:—

1. Good resistance to irradiation damage.
2. High boiling point, permitting high operating temperatures and high steam cycle efficiency.
3. Low vapour pressure at working temperatures, consequently low coolant circuit pressures determined primarily by coolant flow pressure drops.
4. High emergency temperature allowances without vapour burn-out.
5. High thermal conductivity and fairly high specific heat transport rates without high flow rates or high temperature changes across the core.
6. Low cost and ready availability in large quantities.

Sodium has limitations for which the designer must make provision; for example, its freezing point is at 98° above ambient temperature (for which reason a sodium potassium alloy was first used); it becomes temporarily gamma active during operation; it requires austenitic steels cladding the circuit and the fuel to limit corrosion; it reacts strongly with water, leading to expensive design precautions in the steam raising plant.

Although the sodium-cooled fast reactor is emerging as universally the first choice for concentrated development work, the alternatives, with gas-cooling, steam-cooling and a lead-cooled molten salt core, have been given serious study. The possibility of gas in particular is still considered to be a suitable long term alternative and is currently being studied in various countries and collaboratively in Europe under the auspices of the ENEA.

The gas-cooled reactor offers the possibility of good breeding ratio due to a low neutron loss associated with the coolant. For it to have a small fuel inventory comparable with liquid metal cooled reactors, a fairly high fuel rating is required, which in turn depends on good heat transfer arranged between the fuel and coolant. A high coolant pressure and large heat transfer surface, and preferably a low pressure drop through the fuel, are needed to minimise pumping power. These requirements seem to become more attainable with the use of the new particulate fuels if direct cooling of the fuel particles becomes a reality.

Here, in the not-too-distant future, the technology of the gas-cooled thermal and fast reactors could merge. A gaseous He coolant operating at upwards of 70 kg/cm^2 and 700°C could be used with core, blower and boiler in a compact arrangement integrated in a concrete pressure vessel. As already mentioned, the substitution of gas turbines in a direct cycle for the power boiler/steam turbine plant is a potentially interesting possibility on this sort of timescale.

Steam-cooled fast reactors until recently have also retained a fair amount of interest, particularly perhaps in West Germany and the USA. Steam-cooling at high pressure might be coupled with the latest developments both in the direct steam cycle nuclear boiler and power station turbine fields. The potential savings in capital cost would have to be sufficient to compensate for the much poorer breeding properties than expected with sodium-cooled reactors, due to hydrogen softening of the neutron spectrum. The introduction of emergency water coolant in depressurising accident conditions, or otherwise nullifying the consequences, seems to give rise to difficult design problems. Refuelling with frequent access, or alternatively providing neutron wasting absorber for reactivity control after full core replacement, seems to be more difficult than with the sodium and gas-cooled reactors.

Fast reactors based on molten salt, eliminating fuel fabrication costs and permitting continuous reprocessing for the removal of fission products and excess fissile material, have for a decade attracted attention. To avoid the large out-of-core fuel inventories that would be involved if the fuel flowed through heat exchangers, direct contact between a liquid metal, lead, and the fuel-bearing salt in the core has been studied as a mechanism for heat removal. Heat transfer between the lead and the molten salt fuel is a main area for study; another is corrosion of the core vessel by the salt and corrosion of core and heat exchanger vessels by molten lead.

It is likely that these alternative fast breeder reactor systems will continue to be of interest during the 1970's, but none of them seems likely to come to fruition as a viable installation on a commercial scale before the mid 1980's. Good progress along the gas-cooled development line could perhaps by then best offer interesting competition for the sodium fast breeder reactor, which at the present time appears to lead the field by several years.

Experimental plants including the Dounreay Fast Reactor (DFR)

Serious development of fast breeder reactors using the technology of sodium-cooling started in Britain as long ago as the early 1950's with feasibility studies and outline reactor designs. By the end of the 1950's there were two zero energy facilities and an experimental fast reactor in operation (Figure 6).

To establish the physics characteristics of fast reactor cores and show that, while

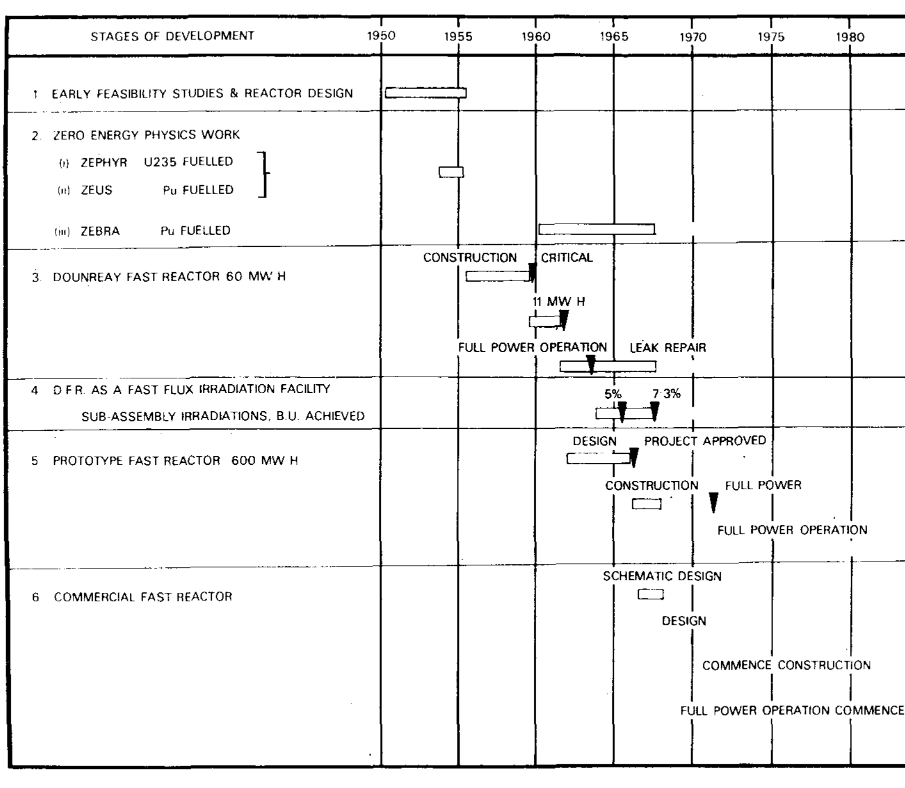


Fig. 6. *Progress of U.K. fast reactor development.*

generating power, the breeding of a surplus of fissile material would be a practical proposition, the ZEPHYR (plutonium fuelled) and ZEUS (uranium fuelled) zero energy facilities were commissioned at Harwell in 1954.

To solve the engineering problems associated with the design of high-power density, fast reactor cores required the construction of an experimental reactor. The resulting sodium-cooled Dounreay Fast Reactor (DFR) is now of almost historical interest. Many lessons were learned from its design, construction and subsequent operation. So much so that it was possible to start construction of a power station prototype producing 250 MWE in 1966 (the PFR) also at Dounreay.

Design progress between the two plants is striking. The DFR has 24 coolant circuits with pumps to drive the primary core coolant flow, mainly to alleviate concern over the possibility of pump or circuit failure; now far fewer (a minimum of say three) are sufficient even for much larger output reactors. Metallic uranium fuel was used in PFR, clad in niobium, as this was thought to be the best way to limit swelling due to fission products at high burn-up, but now ceramic oxide and carbide fuels clad in austenitic stainless steel are considered a better proposition. Individual fuel elements were designed for the DFR whereas now sub-assemblies with multiple fuel pins are the preferred concept.

The major problems encountered during the first years of operation of the DFR concerned gas entrainment and the precipitation of impurities in the liquid metal coolant. Cleaning processes for the blanket gas and for the liquid metal have now reduced these problems to manageable proportions.

Following prolonged full power demonstration runs during 1963 and 1964, the centre part of the core was modified to accept experimental sub-assemblies more closely simulating the oxide, multiple pin fuel designs for larger output reactors and the first of these sub-assemblies

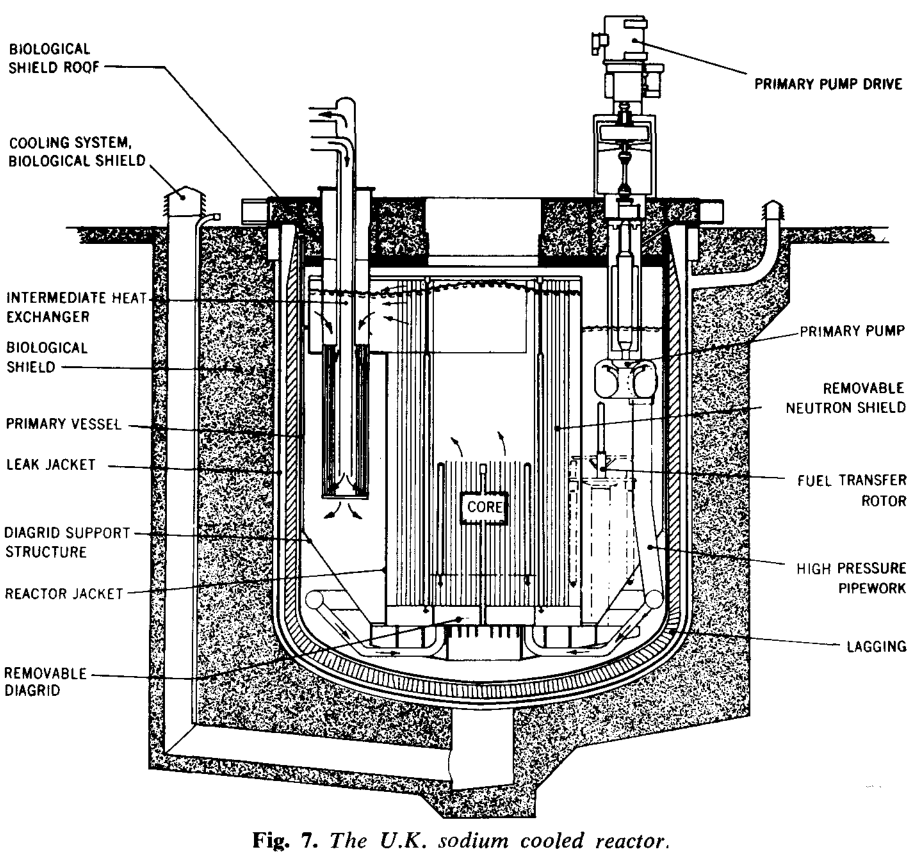


Fig. 7. *The U.K. sodium cooled reactor.*

reached its design burn-up of 5% during early 1965; many later assemblies have been taken to burn-ups exceeding 7½%. Operation of the plant was interrupted for nearly a year during 1967 and 1968, for repair of a defective weld in a sodium branch pipe. The reactor is now continuing in operation as an irradiation facility for developing improved types of fuel. The thorough inspection made during the prolonged shut-down revealed that after nine years of service there was no general deterioration of the plant.

For further physics experiments into the characteristics of large plutonium-uranium cores, the ZEBRA facility was completed at Winfrith in 1962. This facility is providing vital design data for the 250 MWE Prototype Fast Reactor and subsequent commercial plants of even larger output now beginning to take shape.

Prototype Fast Reactor (PFR) power station design and progress

The work on the PFR power station under construction at Dounreay has been going ahead broadly according to a programme, which will ensure completion of the construction work on the power station during 1971 and the generation of electricity during 1971/72. It is designed so that the fuel elements and many of the components used will be suitable for the larger 600-1, 200 MWE commercial designs to follow.

The reactor (Figure 7) is enclosed in a single stainless steel tank, 13m in diameter and 15m deep, which contains the whole primary circuit comprising reactor core, breeder blanket, shielding, six intermediate heat exchangers and three primary pumps for circulating the sodium coolant. By suspending the tank from its perimeter and making all the external connections through the roof, penetrations of the tank itself, which is below ground level, are eliminated, giving the highest possible integrity against loss of coolant.

A summary of the main parameters is given in Table 2.

Each fuel sub-assembly contains 325 pins, 2.7m long and 0.585cm outside diameter. The stainless steel of the can is 0.038cm thick and contains a 91.5cm length of ceramic plutonium-uranium oxide fuel with a 22.8cm length breeder of uranium oxide above and below, with a plenum at the lowest point in which fission products can accumulate during irradiation. The fuel element (Figure 8) which will initially be mixed oxides of plutonium (20%) and uranium, clad in stainless steel and made up of clusters of thin pins through which the sodium flows upwards, will operate at a peak rating of 260 MW/tonne to between 5% and 7½% peak burn-up.

Table 2. Main parameters—Prototype 250 MWE Fast Reactor power station

Thermal output	MW	600
Generator capacity (installed)	MW	305
Coolant temperature (core inlet)	°C	400-420
Coolant temperature (core outlet)	°C	560-585
Fuel pins per sub-assembly		325
Fuelled length	cm	91.5
Fuel can outside diameter	cm	0.585
Fuel can thickness	cm	0.038
Primary vessel diameter	cm	1,270
Steam temperature (at TSV)	°C	513-538
Steam pressure (at TSV)	kg/cm²	163

The reactor components are supported from a diagrid which can accommodate 271 hexagonal units 14.2cm across the flats in a honeycomb pattern. The fuel sub-assemblies forming the core occupy 78 of the central spaces and these are surrounded by reflector and breeder sub-assemblies of the same size. Replacement of these assemblies will be done off-load through a rotatable top shield. Absorber rods for control and shut-down are of the same hexagonal cross-section.

To complete the power station (Figure 9) there are three independent secondary loops containing sodium, each connecting a pair of intermediate heat exchangers to a boiler in which steam is raised for delivery to a turbine with standard (513-538°C, 163 kg/cm²) steam conditions, giving an electrical output of 260-270 MW from the alternator.

The present construction position is that the main vault is complete within the building framework. Fabrication of the stainless steel reactor vessel is proceeding and the leak jacket which will surround it has been completed, including stress relief. Tests of the fuel and the sodium circuit technology have been completed, either in the DFR or out-of-pile rigs, so that production of the fuel can start soon. Fabrication of the main sodium circuit components, including the heat

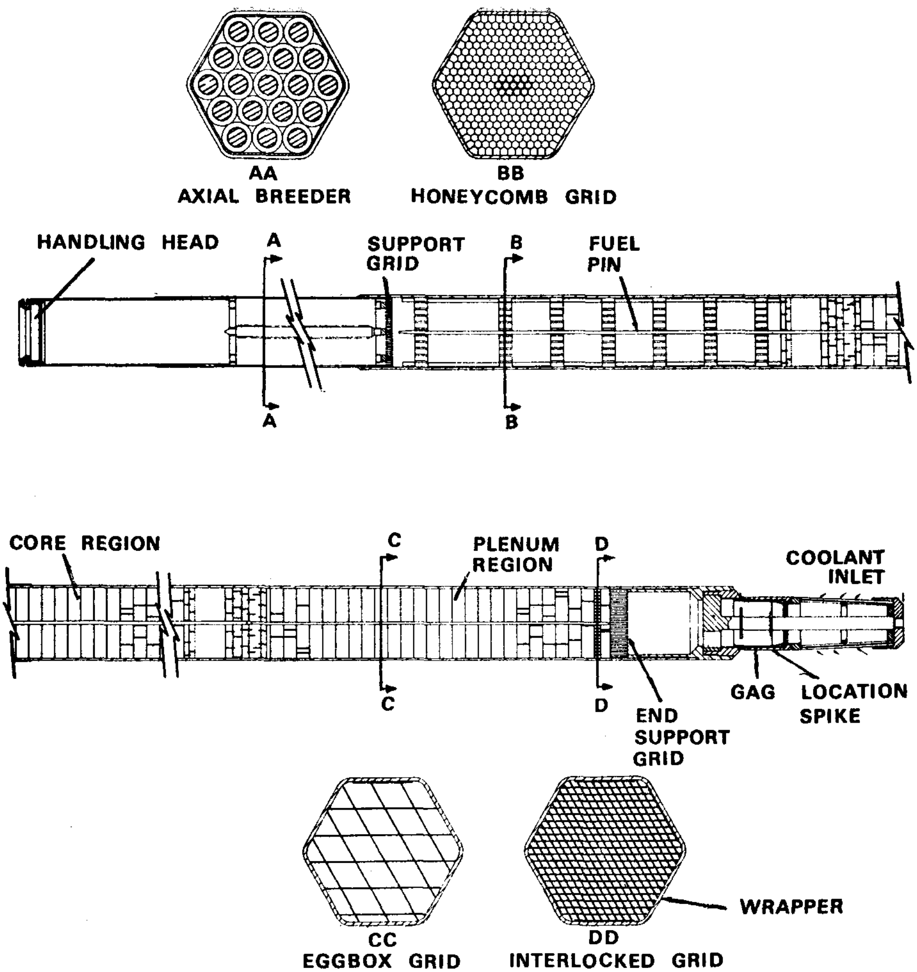


Fig. 8. *Fast reactor power station fuel.*

exchangers, is going ahead. Sodium deliveries to site have been made and purification to the required standard is in progress.

On the basis of completion of the PFR during the early 1970's, work is now going ahead on designs for commercial fast breeder reactor power stations for upwards of 600 MWE to go into operation in the years soon after 1975.

Commercial fast reactor (CFR) power stations

The general characteristics of an early fast reactor to be on power in the later 1970's will follow closely those of the PFR power station, particularly in respect of the plutonium-uranium oxide fuel elements.

Emphasis will be placed on minimising both the capital and generation cost of the first CFR power stations, but still basing their design on reasonably well proved technology. This is necessary to get a competitive station compared with contemporary thermal nuclear power stations, and also to ensure a high degree of reliability for a large generating unit.

A great deal of flexibility is, however, available in core design without greatly affecting capital or overall generating costs. In the early years, to minimise the hold-up of plutonium in the reactor and fuel plants, the optimisation will tend towards fuel ratings, fuel burn-ups and fuel doubling times, away from those which are economic when plutonium is plentiful.

The optimisation probably will later be changed to suit the fuel position in the

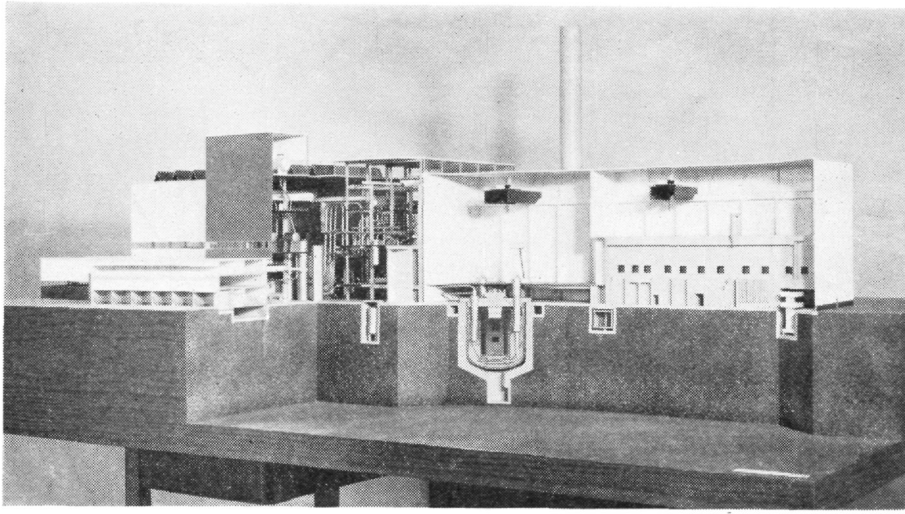


Fig. 9. *Model of the Dounreay PFR nuclear power station.*

1990's, and this will depend on a number of factors, including the plutonium producing characteristics of the thermal reactors, the size of the nuclear programme and possibly the availability and prices of both highly enriched uranium and plutonium.

Fuel logistic and cost improvements are to be expected from a continuous review of the materials and parameters specified, based on experimental evidence. As fuel fabrication is a major component in the fuel cycle cost there are strong incentives to raise fuel burn-up and the scale of fuel production as soon as these are practical. Fuel with a geometry reducing the ratio of core structural material to fuel may be used to reduce cladding costs and increase burn-up.

The use of carbide fuel with its potentialities of higher ratings and better breeding ratio, is also a line of development yet to be fully explored. Work is in progress for improvements in refuelling schemes, to optimise planned outage time, primary and secondary circuit arrangements and boiler design. In the longer term there will be cost reductions with reactor and turbine units of larger size and arising from engineering improvements.

Assuming a UK fast reactor programme subject only to plutonium availability after about 1980, upwards of 20,000 MWE is likely to be installed by the mid-1980's (Figure 10). Supporting manufacturing and processing plants will be required for about 400 T of fuel per annum. The technical problems of these fuel process plants and the more important cost items within the overall fuel cycle costs are already being considered.

Plant throughputs are small, relative to thermal reactor requirements by the same date. To achieve the low fuel cycle costs for which the fast breeder reactor seems capable (one-half of that of thermal reactor designs and less than one-sixth of that of fossil fuel designs), efficient fuel services outside as well as inside the power station are essential. Fully economic fuel fabrication and reprocessing plants with short cycle times and low plutonium hold up and process losses are vital.

Trend of nuclear generating costs

How do we see the trend in generating costs of nuclear power stations built between now and the end of the century? I have attempted to measure this in Figure 11.

The trend is strongly down towards lower generating costs; it would seem that the fossil fuels will find it increasingly more difficult to compete with the large energy concentration available from nuclear fuels.

Conclusions

The breeding of fissile material is essential, if the world's abundant resources of the fertile elements uranium-238 and thorium-232 are to be fully and

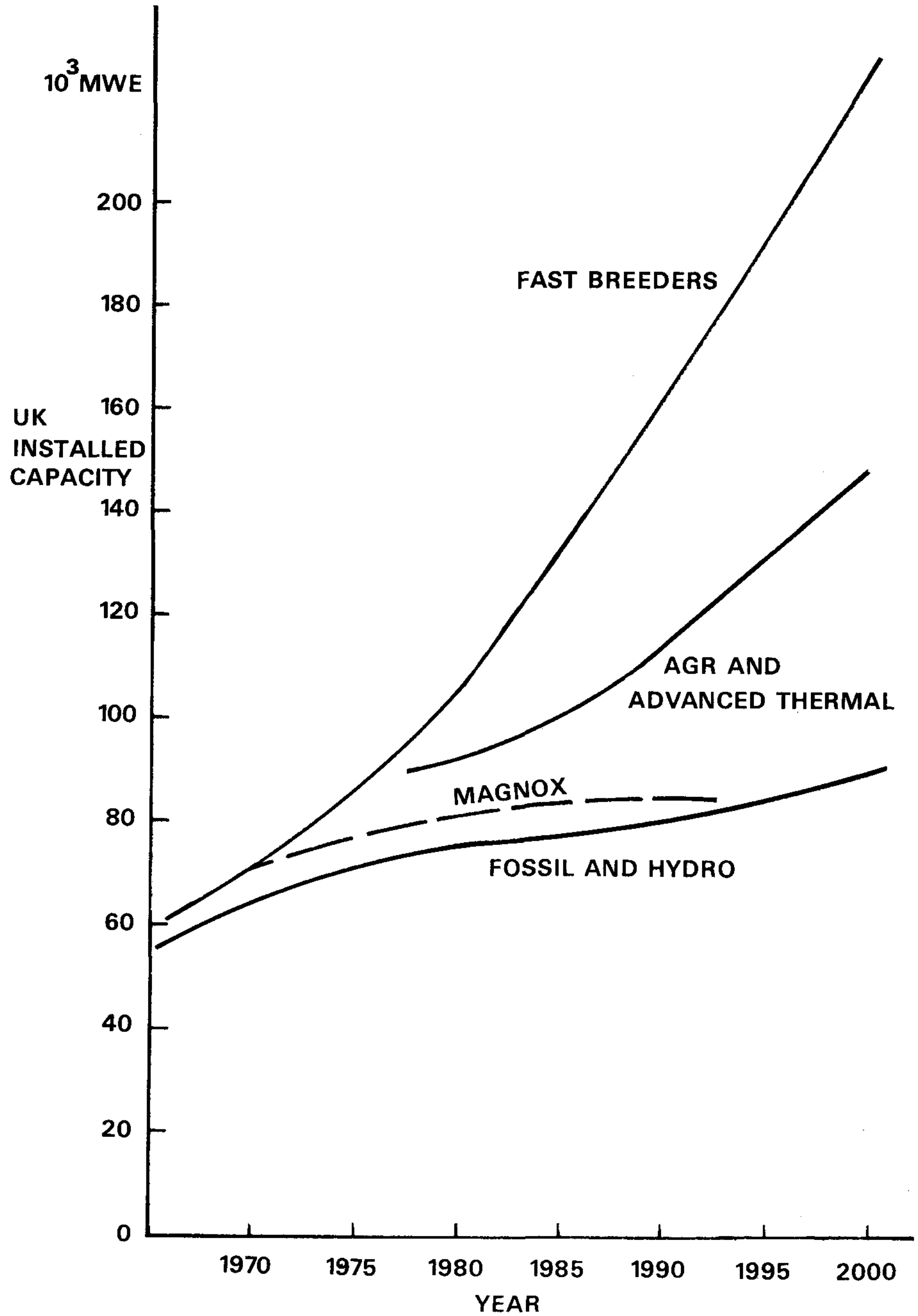


Fig. 10. *Typical U.K. thermal and fast reactor programme forecasts.*

economically utilised. By this means, improvement can be made from the fissioning of some 0·5% of the heavy atoms fed into current designs of thermal reactor to approaching 70% utilisation. With this utilisation, higher prices could be paid for uranium ore, and nuclear power would still be competitive with fossil fuels. This opens up the recovery of the lower grade ores and introduces the possibility of economic recovery from sea-water. Thus the fast breeder reactor is the key to abundant nuclear power.

Breeding in fast reactors is now clearly

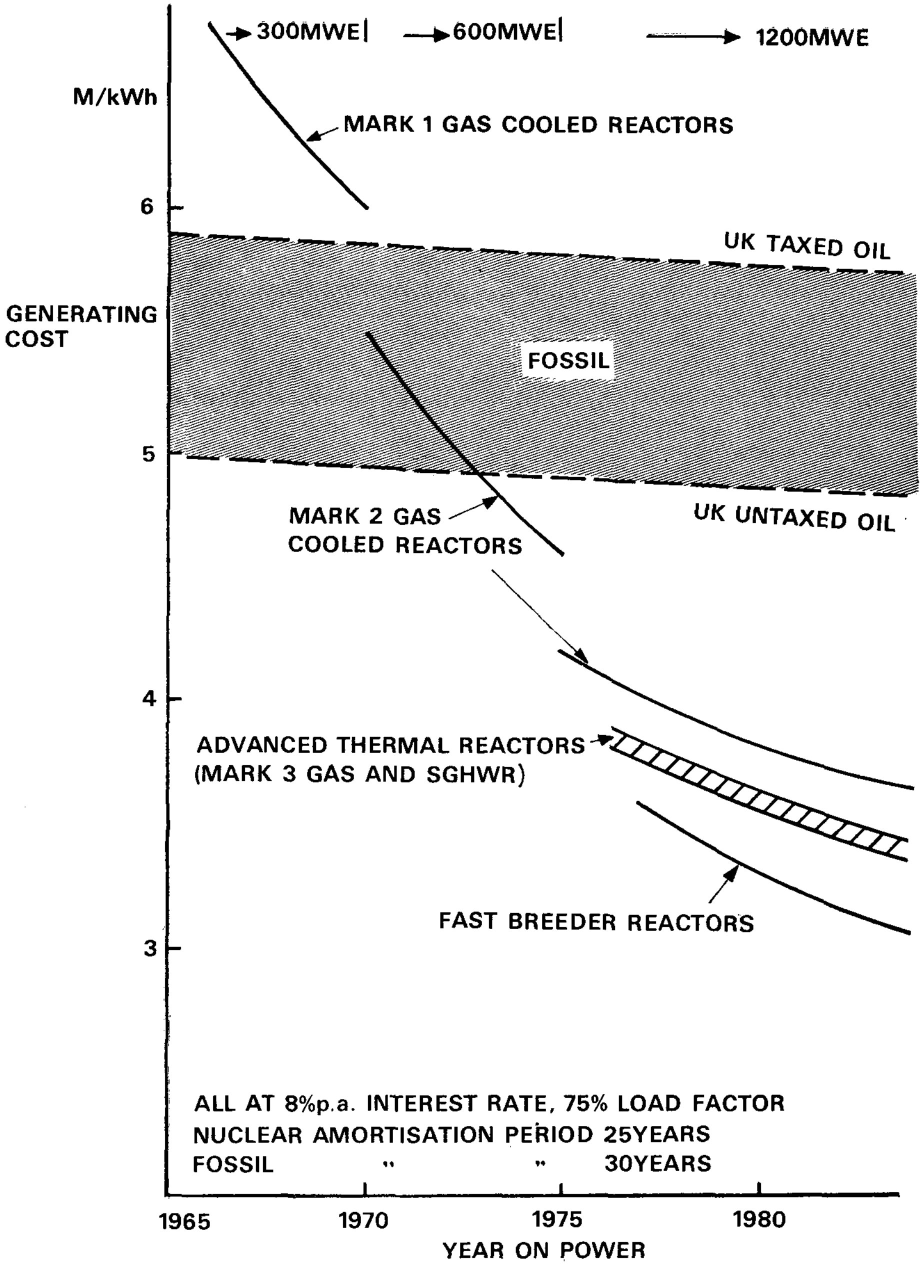


Fig. 11. *Trend of nuclear generating costs.*

feasible, whereas from the operation of thermal reactors there is not a nett surplus of fissile material produced. The present thermal reactors will, however, provide the valuable first plutonium inventories for the fast reactors, so achieving a higher value for their by-product than would apply if the plutonium had to be burned less efficiently in thermal reactors.

During the next decade the main designs of fast breeder reactor will use ceramic plutonium-uranium fuels with sodium as the now well-established coolant. Economic ratings and burn-ups have already been demonstrated in the Dounreay Fast Reactor experiments and elsewhere in the world. Further confirmation will be obtained with full-sized fuel elements in the Prototype Fast Reactor power station well ahead of their commercial application.

Fast reactors are likely to be the dominant type of power station reactor towards the end of this century and well into the next century. It would, therefore, seem wise in our longer-term work, to look towards other forms of fast reactor. This inevitably means other coolants and other fuels. In the UK, of the alternatives, we are most interested at present in the concept of the helium-cooled fast reactor with direct cooling of coated particle fuels—the reactor being integrated into a gas-turbine power production cycle.

Programmes on reactor development, which require major outlays in money, manpower and other resources, have until recently been largely national. It is to be hoped that in future they may be more the subject of international collaboration. Certainly in the United Kingdom, for developments beyond the present range of reactors, we shall be looking for international partners.

Concrete pressure vessels

A symposium on Model Techniques for Prestressed Concrete Pressure Vessels is being organised by BNES from 10th-11th July.

For very large and expensive structures models may provide the only practical means of measuring their behaviour under load to the point of collapse, and in the investigation the designer seeks also to check the computed values of strain and deflection at working loads.

The use of such models in the development of concrete pressure vessels was briefly discussed in one session of the conference, held in London in March, 1967, and the interest shown then, together with later developments, suggest that a meeting devoted solely to the subject would assist many people concerned with pre-stressed concrete vessels.

Those wishing to attend this symposium should apply as soon as possible for registration forms to: The Secretary, British Nuclear Energy Society, 1-7 Great George Street, London, SW1.

A.E.A. Reports available

THE titles below are a selection from the February, 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 788
A Measurement of the Axial Variation in Sensitivity of ¼-inch diameter Fission Chambers. By G. D. Burholt. October, 1967. 10 pp. H.M.S.O. 4s.

AEEW-R 622
A User's Guide to GENEX, SDR and Related Computer Codes. By R. J. Brissenden and C. Durston. August, 1968, 177 pp. H.M.S.O. 23s.

AERE-Bib 163
List of Unclassified Documents, Lectures, etc. by the Staff of the Chemistry Division and the Applied Chemistry Division, A.E.R.E., Harwell, 1968. Compiled by M. J. Dawes. January, 1969. 16 pp. H.M.S.O. 3s.

AERE-R 5837
The Estimation of the Compositional and Volume Changes in Noble and Refractory Metal Alloys due to Neutron Irradiation. By C. B. T. Braunton, D. N. Hall and C. M. Ryall. September, 1968. 106 pp. H.M.S.O. 14s.

AERE-R 5846
The Beam Transport System of the Harwell Variable Energy Cyclotron. By R. W. Barnfield. September, 1968. 41 pp. H.M.S.O. 7s.

AERE-R 5891
Structure in Sub-Threshold Fission Modes. By J. E. Lynn. September, 1968. 66 pp. H.M.S.O. 8s.

AERE-R 5900
Radioactive Waste Control at the United Kingdom Atomic Energy Research Establishment, Harwell. By R. H. Burns, G. W. Clare and J. H. Clarke. September, 1968. 15 pp. H.M.S.O. 12s.

AERE-R 5903
Post-Transition Corrosion of Zircaloy-2, Low-Nickel Zircaloy-2 and Zircaloy-4 by Steam at 300°C and 340°C. Deuterium Absorption and the Influence of Heat Treatment. By J. R. Findlay, C. F. Knights and R. Perkins. November, 1968. 17 pp. H.M.S.O. 3s.

Soil moisture probe

The neutron scattering technique for soil moisture measurement has become increasingly accepted over the last decade, particularly as it offers far greater precision for measuring moisture differences than the standard gravimetric method. It is a non-destructive method enabling an identical body of soil to be " read " *in situ* on every occasion.

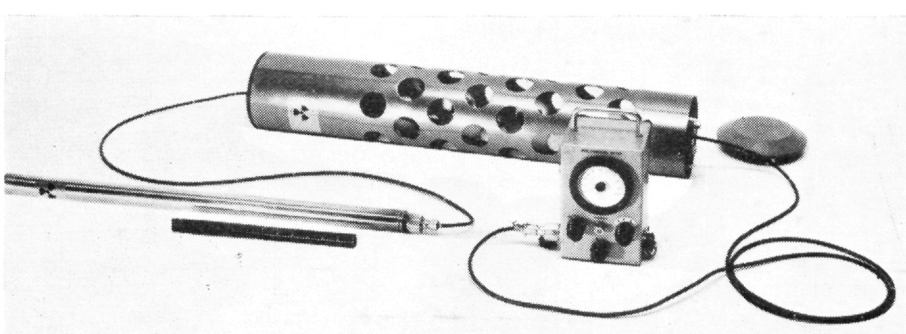
The probe is lowered to successive depths in an access tube in the soil, and fast neutrons emitted from the radioactive source in the probe are slowed down by elastic collisions with hydrogen nuclei of soil water molecules. This results in the formation of a cloud of slow neutrons, the density of which is a function of soil moisture content. Thus, the count rate, measured by a suitable slow neutron detection system mounted in the probe adjacent to the source, is displayed by a scaler or ratemeter, and the moisture content of the soil is obtained from a calibration graph.

Many commercial neutron moisture meters are available, but they are heavy and bulky and their use is therefore restricted to areas easily accessible to vehicles. They have in many instances proved to be insufficiently robust and are thermally and electronically unstable. Frequent failures have led to serious loss of continuity in long term moisture records, and this has tended to bring the method into some disrepute.

The Atomic Weapons Research Establishment, Aldermaston, was commissioned by the Institute of Hydrology, Wallingford, to develop a probe assembly to overcome these disadvantages. The prototype they have produced has been subjected to a year of extensive field and laboratory trials by the Institute, with very satisfactory results.

The probe is housed in a stainless steel tube, 38 mm in diameter and 74 cm long, and weighs 1.8 kg. The principle design feature is that the probe contains not only the source (50 millicuries of americium/beryllium) and slow neutron detector but, unlike any previous equipment, also contains the EHT generation, pulse shaping, discrimination and primary voltage stabilisation circuits. The input to the probe is simply a 10 to 16 volt battery, internal or external to the scaler or ratemeter, and the current consumed is approximately 85 mA. One advantage of this arrangement is that the cable from the scaler to the probe is not required to carry high voltages and is therefore much less vulnerable in the field. The output pulses can be fed without complication into a wide variety of commercial ratemeters or scalers.

The typical count rate in a standard aluminium alloy access tube (44.5 mm o.d. x 16 s.w.g.) immersed in water is about 850 counts per second, and in air about 5 c.p.s. The source/detector system is mounted in the bottom section of the probe and the annular source surrounds the BF_3 proportional slow neutron counter tube at the centre of its sensitive length, giving maximum sensitivity while preserving axial symmetry. The effect of temperature variation on the prototype probe between -10 and $+40°C$ is insignificant, being less than ± 2 c.p.s. This is an important advantage when seasonal moisture changes are being followed. The prototype has shown no "warm-up" effect



The " Wallingford " soil moisture probe after switch-on and no discernable drift throughout the working day. This means that no time or accuracy is lost by switching off the equipment while walking between access tubes for instance, and battery life is therefore conserved.

Another important design feature is that the electronics and BF_3 counter can be withdrawn very easily as a unit from the top end of the probe after the removal of two screws, leaving the source in its normal position in the shielded probe; personnel are, therefore, never exposed to the unshielded source when servicing the equipment.

Accessories available for use with the probe are, a miniature field ratemeter, a transport shield, and a cable assembly.

The field ratemeter gives an analogue display on a 270° meter. The three time constants are 2, 4 and 8 seconds. Rechargeable DEAC cells power the probe and ratemeter for at least 8 hours continuous use. A negative voltage analogue output of 0 to 5 volts corresponding linearly to 0-1000 c.p.s. is provided for use with a logger or chart recorder. The ratemeter is approximately 13 x 11 x 10 cm in size and weighs about 2 kg.

The Institute of Hydrology is developing a miniature field scaler for use with the probe for use in circumstances requiring higher precision than is obtainable with a ratemeter. Count rate will be displayed directly in digital form after a preset 16 second counting period. This scaler will be about the same size and weight as the ratemeter.

The equipment is being built under licence and marketed as the 'Wallingford' Probe by: D. A. Pitman Ltd., Mill Works, Jessamy Road, Weybridge, Surrey. Telephone 01-97 46327.

20th January, 1969

Radioisotopes catalogue

Over 2,000 items are listed in the new edition of the Radiochemical Centre's catalogue " Radioactive Products."

They constitute the most comprehensive range of radioactive materials available from a single supplier.

There are over 140 new products and services and many improvements in product specification and delivery. The catalogue itself has been produced to a new format for easier reference by the user.

Over 120 new labelled compounds have been added, principally amino-acids, carbohydrates and nucleics, and the range of radiochemicals now available to chemists and biochemists exceeds 1,300 items.

Further improvements have been made in the specific activity of tritium and carbon-14 labelled compounds and many of the latter are now available at levels approaching the theoretical maximum.

The rapid growth in the demand for radioactive pharmaceuticals has prompted the introduction of standardized pack sizes with fixed activities on specific dates. This new system will facilitate pre-dispensing and stockholding and permit even higher standards of quality control, quicker delivery and, on average, larger decay allowances.

The newly introduced curium-242 alpha and neutron sources are shown in the list of industrial and laboratory radiation sources, which also features considerable extensions to the ranges of Mössbauer sources, beta sources, positron sources, low-energy gamma sources and targets for neutron generators.

Several improvements have been made in the design and construction of a number of radiation sources, for example, thulium-170 and antimony-124 sources.

Additions to clinical radiation sources include sphere-type cobalt-60 ophthalmic applicators for the treatment of retinoblastoma and extensions to the range of caesium-137 tubes for intracavitary radiotherapy and for after-loading.

Copies of this catalogue are available free on request from The Radiochemical Centre, Amersham, Bucks. (The Centre's new telephone number is 0240-4 4444.)

4th February, 1969

Radiochemistry course

A one-week course in radiochemistry is being organised by Liverpool Regional College of Technology, from 19th to 23rd May. The first half of the course will be devoted to practical work. A half-day visit will then be paid to the Joint Universities Research Reactor at Risley. The course will conclude with a two-day symposium, entitled " Radioisotopes in Analysis ". Further information is available from The College of Technology, Byrom Street, Liverpool, 3.

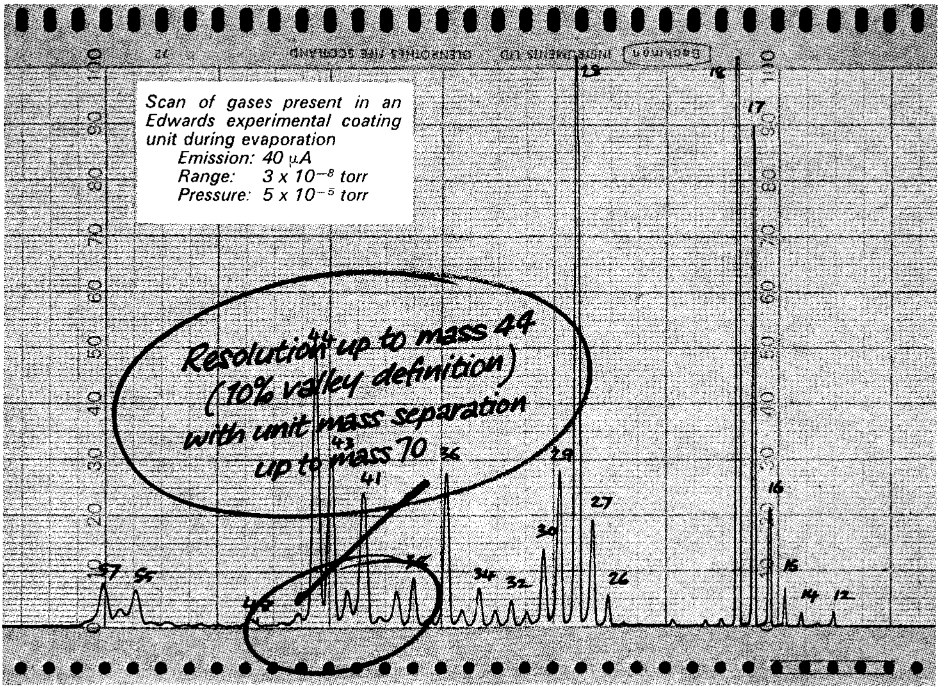
Edwards new E180

high resolution partial pressure gauge

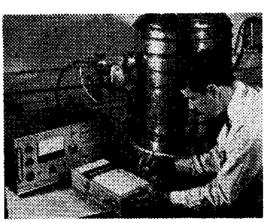
with

1. **Partial pressure measurement**
2. **Total pressure measurement**
3. **Leak detection**
4. **System monitoring**

— all in one inexpensive instrument



Compare these features with those of any other similar mass spectrometer partial pressure gauge



- Mass range 1 to 105. Push-button selection of masses 1, 2, 3 and 4.
- Direct reading, linear mass scale.
- Unit mass separation to mass 70.
- Partial pressure measurement to 10^{-10} torr.
- Total pressure measurement to 10^{-11} torr.
- Fast and slow scanning speeds.
- Suppression facility for monitoring single peaks in detail.
- Minimum detectable leak rate for helium 10^{-10} torr litre/sec (system with 1 litre/sec helium pumping speed).
- Magnet and head bakable in situ.
- Automatically protected, long-life rhenium filaments.

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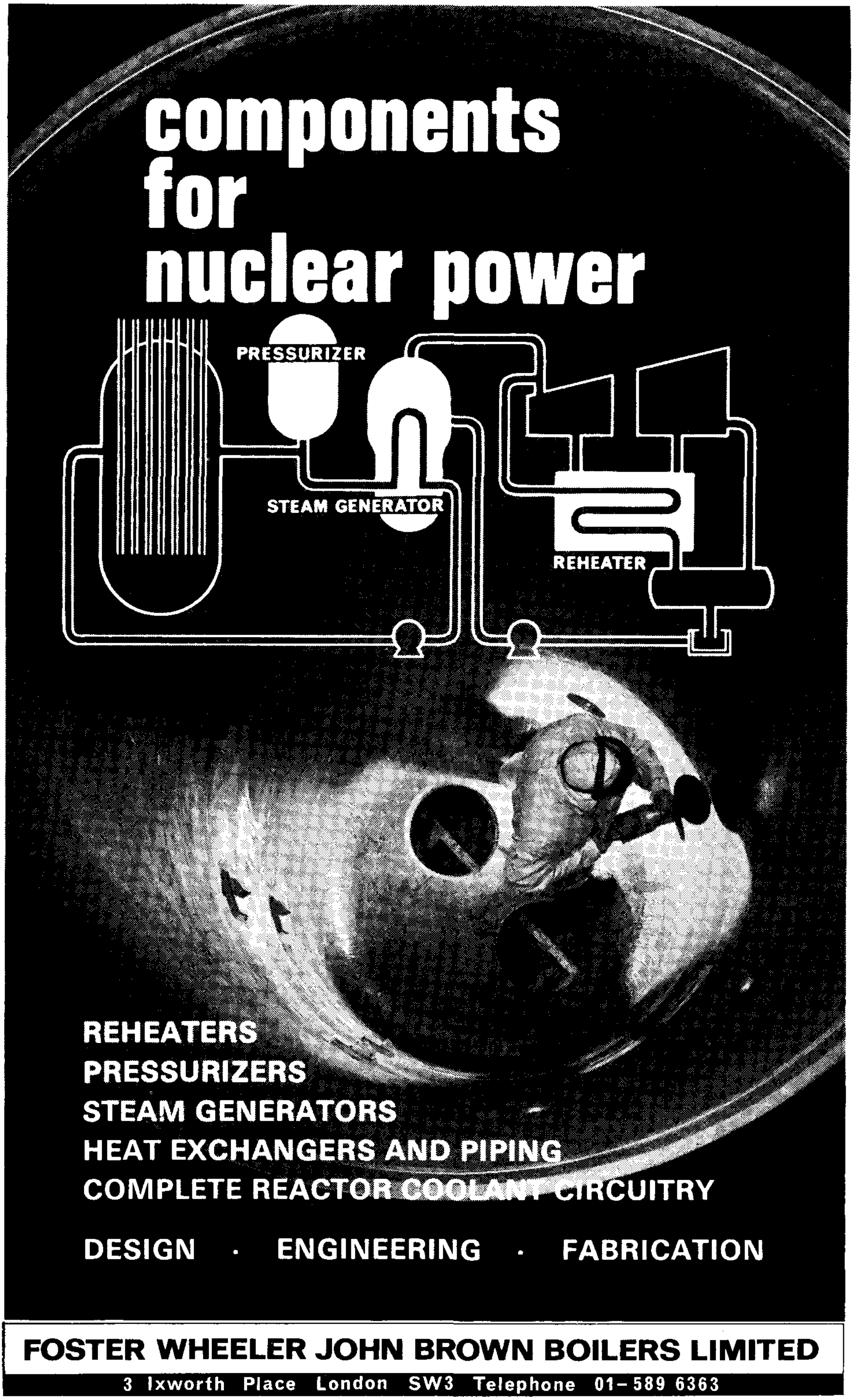
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