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THE UNITED KINGDOM ATOMIC ENERGY AUTHORITY

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OF THE UNITED KINGDOM
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Contents

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

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Winfrith S.G.H.W.R. opening ceremony

The Winfrith Steam Generating Heavy Water Reactor was opened by H.R.H. The Prince Philip on 23rd February, 1968. Experts from the atomic energy and electricity industries of 26 countries travelled to Winfrith for the ceremony and to see the reactor at first hand. They also toured the site and saw a film and a permanent exhibition describing the reactor.

The S.G.H.W.R. was designed, developed, and built by the U.K.A.E.A.—on schedule and within the estimated cost.

Speech by H.R.H. The Prince Philip

At a luncheon following the opening ceremony, Prince Philip made the following speech.

The first four Chairmen of the Authority were all present on this occasion:—Lord Plowden, Lord Sherfield, Lord Penney and Dr. J. M. Hill (the present Chairman). Others attending included the Rt. Hon. Anthony Wedgwood Benn, M.P., Minister of Technology, Sir Stanley Brown, Chairman of the Central Electricity Generating Board and Lord Hilton of Bankside, a former Member of the Authority and former Chairman of C.E.G.B.

"I dare say that this occasion will rate a line or even a paragraph in the history books dealing with technical subjects. The record will state that the Atomic Energy Authority was responsible for designing, building and operating a Steam Generating Heavy Water Reactor and that it included considerable technical and commercial advantages. It will be looked upon and judged as an example or as a demonstration of the state of British technology of the day.

"But that is only a very superficial aspect of the story. For a start, it suggests that British technology is a thing in itself; that there is something inevitable about technological improvement; that the whole process is something similar to immaculate technological conception. Nothing, of course, could be further from the case.

"None of this particular reactor nor of the rest of the reactors at work in Britain could have been brought into existence without people. At every stage, from the

Prince Philip performing the opening ceremony in the control room of the S.G.H.W.R. From left to right:—Dr. J. M. Hill, Chairman of the Authority, Prince Philip, Mr. J. C. C. Stewart, Member for Reactors, U.K.A.E.A., and the Rt. Hon. Anthony Wedgwood Benn, M.P., Minister of Technology.

control and direction of the original research, through the selection of areas of applied research to the decisions to go ahead with design and construction, people have had to assess alternative courses of action and to decide the next step. The right decisions at the right time are vital to the success of any project. There are, unfortunately, only too many examples of the result of failures in decision-making. This is not one of them.

"Some people made decisions; others were concerned with the considerable programme of original and applied research. It is very easy to take this for granted but in fact it means that boys at school have shown the will and the capacity to study science and engineering; it means that they have had the persistence to go through long and demanding courses of advanced study and practice in universities and technical colleges, and at the end of it all that they have been able to combine this technical knowledge with their native ingenuity to produce this original design.

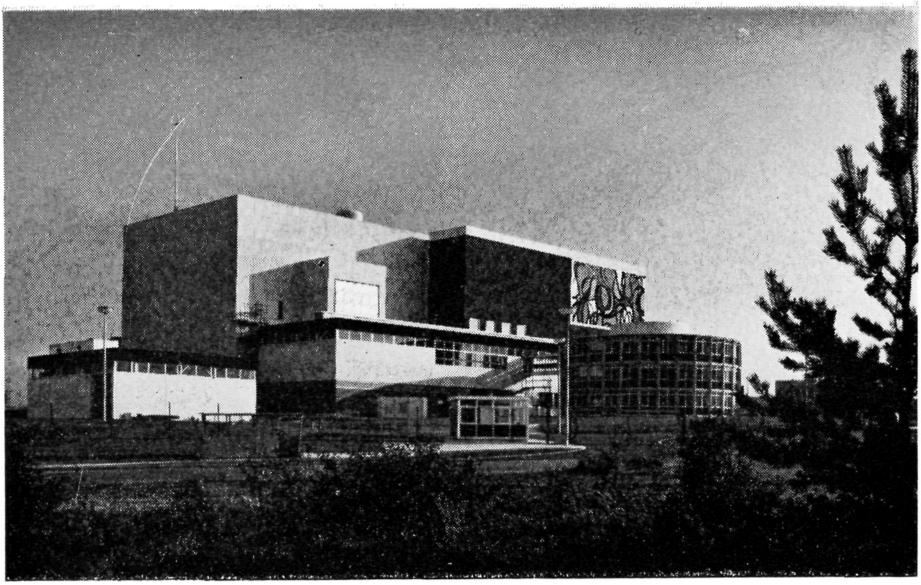
"People in many professions and industries have also been involved in the construction of this reactor. Their contribution is just as vital to the success of the whole project. This too is taken for granted and if it is questioned, the answer is that they are doing a job for which they are being well paid. That's much too simple. I defy anyone who was remotely concerned with the construction of this reactor to deny that it has been a fascinating and a satisfying experience. They are just as much rewarded by the success of the project as they would be disappointed by any failure.

"Technology cannot exist without people. This reactor was completed on time, to the contract price and with the required performance because people combined intelligently and willingly to plan, design and complete this job. There was nothing inevitable about it.

"Napoleon, who knew a thing or two about people and about war, put it this way: 'In war, morale is three quarters of the affair, the balance of forces is but one quarter'.

"We are not actually at war at the moment in the accepted sense of the term. There is no physical fighting, the casualties are not dead and wounded and territory or political domination are not the ultimate goals. In another sense, however, we are very much at war: we are in fact in a state of siege and if we are to fight our way out of this situation, Napoleon's dictum is just as true for us today. The balance of

The party on the top of DIMPLE reactor in the Reactor Physics Hall during the Prince's tour. From left to right:—Mr. J. C. C. Stewart, Member for Reactors, U.K.A.E.A., the Rt. Hon. Anthony Wedgwood Benn, M.P., Minister of Technology, Dr. J. M. Hill, Chairman of the Authority, Mr. D. W. Fry, Director, A.E.E. Winfrith, Prince Philip and Mr. I. Johnstone, Reactor Physicist in charge of DIMPLE reactor.



A general view of the reactor buildings showing the administration building on the right.

forces is not against us; we know the potential of our scientists, we know the sort of brilliant work which British engineers can achieve, and no-one has ever doubted the workmanship and the skill of technicians, craftsmen, and operatives. But that, according to Napoleon, is only one quarter of the business; morale accounts for the other three quarters.

"The opening of this reactor to-day represents an important tactical success in more ways than one. It provides con-

Mr. H. Murata, a Director of the Japanese Power Reactor and Nuclear Fuel Development Corportation, with Mr. E. de Rothschild of N. M. Rothschild & Sons, Merchant Bankers.

Assessing the S.G.H.W.R.—Mr. W. L. Cisler, President of Detroit Edison Co., U.S.A. (right).

clusive evidence that in this field of advanced engineering Britain is very much among the leaders of the relatively few nations capable of doing this kind of work. It has been achieved by good morale, backed up by scientific and technical competence of a very high order, and as such it should help to encourage and to stimulate morale in other sectors of the front.

"The next stage is to exploit this success to the full in the world markets. We know that this is a sensible and practical solution to the problem of producing electrical energy from relatively small reactors economically, but potential customers I think probably need a little more persuasion. With energy and enterprise we can turn this success into a major victory.

"In the meantime the struggle goes on; in the offices of the decision-makers, in the laboratories and in the workshops, people are exercising their talents for their own advantage as well as for the general prosperity of the nation. Their enthusiasm, their morale, is absolutely vital.

"As Shakespeare has Henry V say before Agincourt: 'That he which hath no stomach for this fight, let him depart, his passport shall be made and crowns for convoy put into his purse'".

Technical outlines of the S.G.H.W.R.

Parameters of the Winfrith S.G.H.W.R are listed below. This section briefly describes the evolution of the system and its main features.

Selection of the S.G.H.W.R. system

The first extensive study of pressure tube reactors in the United Kingdom was started in 1957. After an examination of several systems which use heavy water moderation, the Steam Generating Heavy Water Reactor was chosen for development because it was believed that it would be competitive with other thermal reactor systems. That belief has become more certain as development has proceeded.

The first concept studied was a gas-cooled heavy-water moderated reactor with an indirect steam cycle. It allowed full use to be made of the United Kingdom's growing knowledge of gas heat transfer data and matching fuel technology. This system showed too high an overall capital cost, largely because of the need for steam raising plant and an obvious step was to change the coolant to steam fed directly to the turbine. Lower capital costs were possible by this means, but steam cooling

Lord Carron with Mr. V. W. Avis, Chairman of the Staff Side of Winfrith Whitley Committee and Mr. F. T. W. Paget, of Reactor Group, U.K.A.E.A.

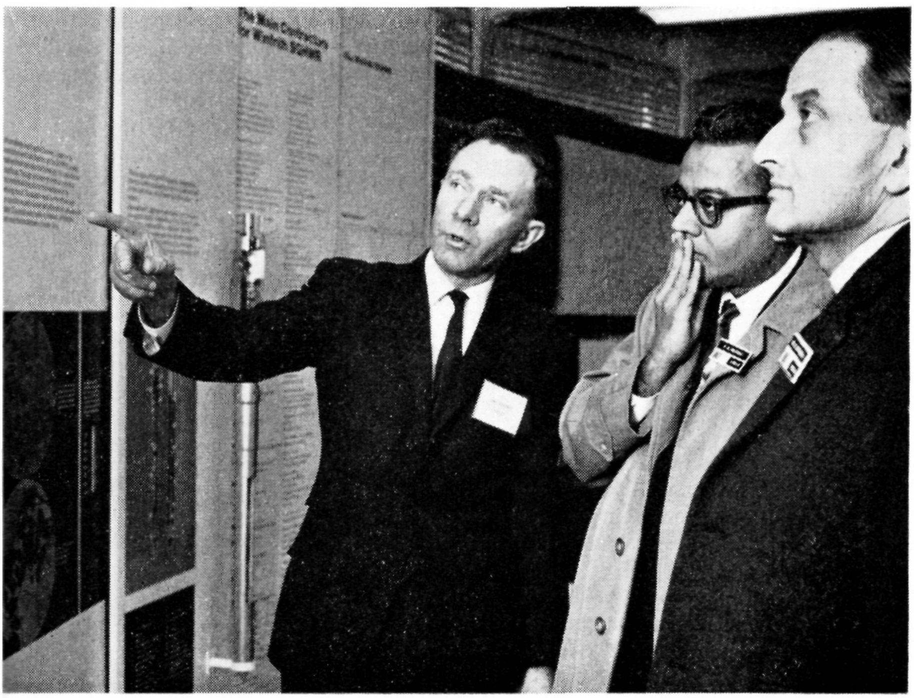
like CO_2 cooling required a steel cladding material for the fuel and to offset the resulting high neutron absorption in the core, fuel enrichments had to be higher than was considered acceptable. Both the gas-cooled and the steam-cooled reactors were examined in considerable detail by a design team before they were rejected. From steam cooling, it was a comparatively short step to water cooling with boiling taking place in pressure tubes within the core, that is the S.G.H.W.R. concept.

In fixing the size of the Winfrith S.G.H.W.R. a major consideration was to use a channel size which would also be suitable for future power reactors of this type. This enabled the maximum information to be obtained on manufacturing and construction problems for larger size power reactors. A further point was that a 100 MW(E) station would give appreciable revenue from the sale of electricity to be set against the costs of plant operation.

Core

The S.G.H.W.R. is a direct cycle system moderated mainly by heavy water and cooled by boiling light water. The core of the reactor consists of a bank of 112 zirconium alloy pressure tubes which pass through vertical channels in a 12 ft. (3660 mm) diameter 13 ft. (3965 mm) long aluminium alloy calandria or cylindrical tank containing the heavy water moderator. The moderator is maintained at a comparatively low temperature (below 80°C) and at atmospheric pressure. Each pressure tube contains one 12 ft. (3660 mm) long fuel element and the heat generated in the fuel is removed by light water coolant

Left to right: Mr. J. Lorne Gray, President of Atomic Energy of Canada Ltd., Mr. R. V. Moore, Managing Director of Reactor Group, U.K.A.E.A., Sir Stanley Brown, Chairman of the C.E.G.B., and a member of the A.E.A. staff.



Dr. Vibram Sarabhai, Chairman of the Indian Atomic Energy Commission (right) and Mr. V. N. Meckoni (centre) also of the Indian A.E.C., at the S.G.H.W.R. Exhibition at Winfrith.

Don Jose M. Otero, President of the Spanish Junta de Energia Nuclear (centre) and Mr. N. Bjorklund, Chairman of the Finnish Nuclear Industries Group (right), with Mr. Arthur Palmer, M.P., Chairman of the Select Committee of Science and Technology.

passing upwards through the tubes and partially turning to steam.

Coolant circuit

The mixture of steam and water is piped to two large drums where the water separates from the steam before passing to the main circulating pumps and so back to the core. The dried steam is led directly to the turbine and finally to the condenser, the condensate returning to the coolant circuit via the steam drums. Although the heavy water is the main moderator*, a useful contribution, about 30% of the moderation is provided by the light water coolant which thus serves a dual purpose.

Fuel

The fuel is uranium dioxide with the proportion of U-235 isotope in the uranium increased slightly above that which occurs naturally (i.e. enriched UO_2). The fuel is in the form of cylindrical pellets 0.57 in. (14.48 mm) in diameter contained in 12 ft. (3660 mm) long tubes of Zircaloy-2. A cluster of 36 such tubes or pins makes up one fuel element. In the centre of each cluster is a tube which acts as a structural member supporting the 36 pins and also serves to distribute auxiliary cooling water throughout the fuel element.

The Winfrith reactor is provided with an on-load refuelling machine. This is supported above the reactor core on two combined rotating shields which allow the machine to be positioned over any channel. The shields form part of the primary containment.

An important economic feature of the pressure tube design, however, is that refuelling may be carried out with the reactor either on-load or off-load. With off-load refuelling the cost of the refuelling machine is saved. Only two or three days are necessary to shut down, change a portion of the fuel and resume full power operation.

Control

Reactivity and hence reactor power level is controlled by varying the moderator height. This facilitates power level changing and is one of the advantages conferred by a liquid moderator. For shut-down, a boric acid solution is injected

*Moderator: The material used to reduce the energy, and hence speed, of fast neutrons.

Dr. Karl Wirtz, Chairman of the Scientific Council, Karlsruhe Nuclear Research Centre, W. Germany, (left) with Dr. C. G. Campbell, of Reactor Group, U.K.A.E.A., at the S.G.H.W.R. Exhibition, Winfrith, after the opening of the reactor.

rapidly into small tubes inside the core; in addition, the moderator is dumped to drain tanks below the core level. As the shut-down system consists of pipes and valves, it allows greater flexibility in design layout than would a solid rod control system with its associated rod drives, and it does not interfere with access to the channels for fuel loading.

Shielding

The calandria is enclosed and supported by neutron shields which serve a dual purpose. They limit the activation of the primary circuit components and other reactor parts outside the core when the reactor is in operation and they provide shielding against gamma activity from the core when the reactor is shut down, thus permitting access to the primary circuit area for maintenance.

Containment

The Winfrith reactor is provided with a vented form of containment. In the unlikely event of primary circuit rupture, the pressure build-up in the primary containment is vented by a system of ducts through a pond to the turbine hall which forms a secondary containment. The ducts reseal before significant quantities of fission products can be released to the secondary containment, and the primary containment is then held at slightly below atmospheric pressure.

Commercial S.G.H.W.R.

Research and Development

For the past two years, in addition to irradiation studies of typical S.G.H.W.R. fuel pins, very extensive heat transfer and pressure drop experiments have been carried out on S.G.H.W.R-type fuel clusters in out-of-pile loops. The major equipment for this work has been the 6 MW rig at Winfrith in which tests with water coolant have taken place on full size electrically heated clusters which physically resemble very closely the fuel assemblies of the actual reactor. The effects of design variations have also been studied. This work has shown that the present design of fuel element may be considerably up-rated whilst maintaining adequate channel power margins. The 6 MW rig has been provided with additional electrical power and is now capable of carrying out tests with up to 9 MW of heat applied to the test section.

A number of channels in the Winfrith S.G.H.W.R. have been connected to an additional pump which will boost their coolant flow and allow experimental fuel elements to be irradiated at higher ratings than the standard fuel.

Commercial plant

It has already been mentioned that the core length and diameter of pressure tube for the Winfrith S.G.H.W.R. were chosen as the result of early optimisation studies of different reactor outputs in the expectation that this size of channel could be standard for a wide range of reactor size. This choice was made some years ago but current work shows no reason to make a change. Hence the design of larger commercial power stations can be based on reactor cores using similar channel tubes to those at Winfrith. This gives scope for some standardisation in core components and means that fuel elements for commercial plants can be loaded into the Winfrith reactor for proving.

It is easy to over-rate the advantages of standardisation and, carried to the limit, it could result in premature fixation of design and inhibit attainment of development potential. Moreover, the channel tube assemblies are a key item in the engineering design of the S.G.H.W.R. and undoubtedly with this type of component, required in several hundreds, the best engineering results are obtained by progressive evolution, based on experience of design, manufacture and erection, detailed cost studies and value analysis. In the main, however, it can be said that the design of this essential component is already established and largely developed.

The design of commercial stations has received considerable attention. An important consideration in increasing the output of the reactor has been whether the concept of manufacturing core components off site, with correspondingly simple site erection, could be maintained. This has obviously worked well for the Winfrith S.G.H.W.R. and studies have shown that these techniques can be applied equally well to larger commercial units.

The largest single reactor component is the calandria and limits could be set by transportation difficulties or regulations on the size of component that could be moved as a single unit to site. Attention has therefore been directed to the design of calandrias which can be transported to site as sub-units which require only bolting together and perhaps seal welding on site.

There is now no doubt that this is a perfectly satisfactory method of construction and in fact assembly of a calandria in two halves makes works fabrication simpler as there is considerably better access for internal welding.

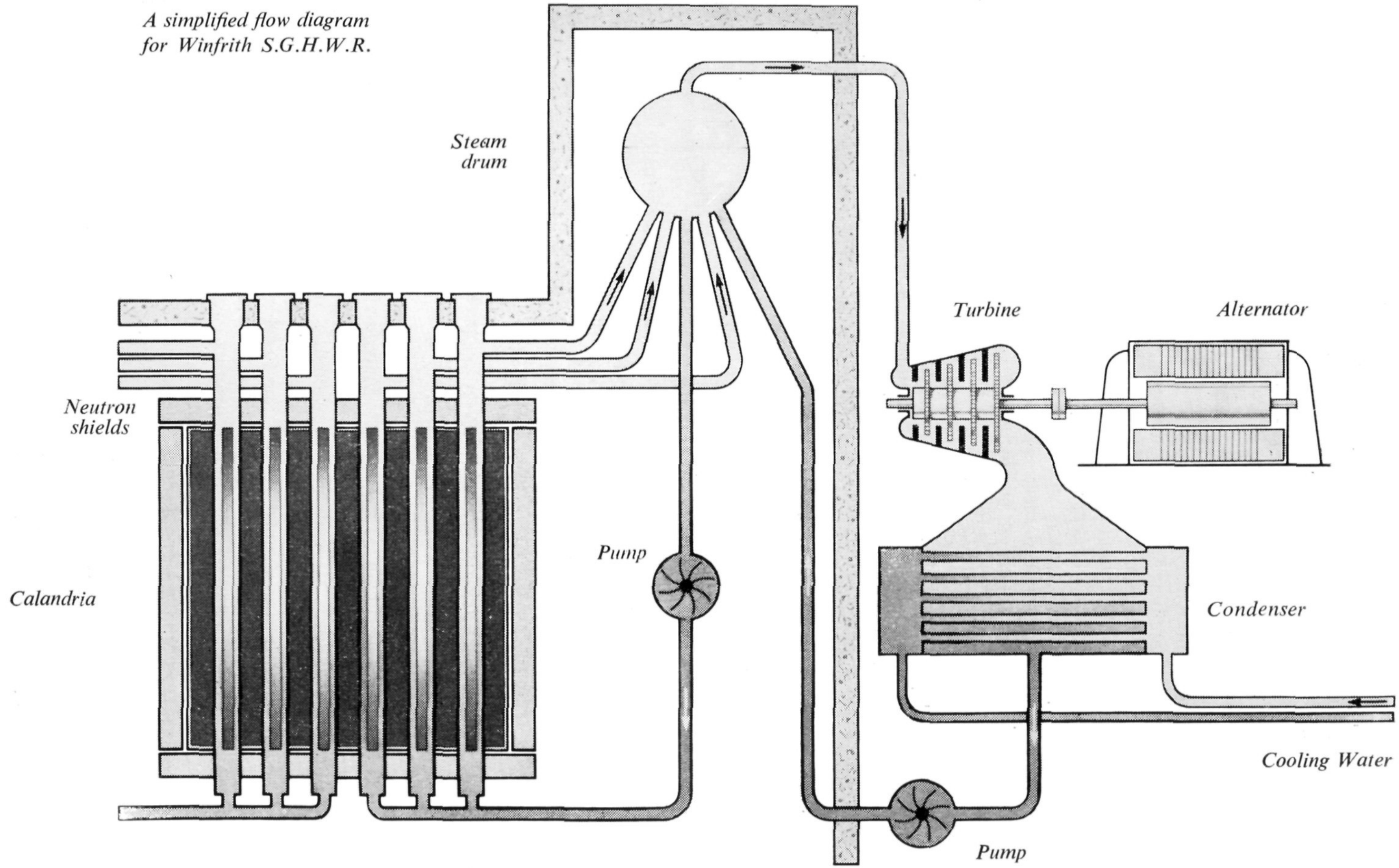
A simplification in core erection can be achieved by welding the channel assemblies to headers in groups of six or twelve, and shipping these to site as units instead of sending each channel assembly singly. Though the necessity of lowering the assemblies through the calandria means that the assemblies can only be headed at the upper end, this can substantially reduce the number of welds to be made on the primary circuit at site. In a typical layout the number of pipe welds on a commercial station could actually be less than those on the Winfrith plant.

As stated before, an important advantage of a pressure tube reactor is the relatively easy access to individual channels and hence to individual fuel elements. This makes either on-load or off-load refuelling possible. Although on-load refuelling has been provided at Winfrith the current designs for commercial stations have concentrated on off-load refuelling.

A simple off-load refuelling scheme incorporating a pond above the core enables fuel to be moved within a few hours of the plant being shut down. The required proportion of fuel in, say a 500 MW(E) station could be replaced in a weekend. In these circumstances the off-load system is unlikely to carry a significant availability penalty and it is a simpler and cheaper arrangement with fewer routine demands on operations and maintenance personnel.

The particular form of containment used at Winfrith is not an implicit feature of the S.G.H.W.R. as such. The reactor can be housed in any form of containment, for example pressure containment with a separate turbine hall. Indeed, in some countries such an arrangement may be preferred as it may have already been used

A simplified flow diagram for Winfrith S.G.H.W.R.



and accepted for other water reactor systems, or it may fit more easily into a split contractual arrangement in which a "nuclear island" only is supplied.

Although key parts of the reactor can be made only by specialist manufacturers, the S.G.H.W.R. does not make demands for skills or capital facilities over and above those which such manufacturers usually possess as a result of their experience with conventional plant or in the chemical plant industry. The steam drums and pipework are within the capabilities of most good quality boiler makers and indeed there is scope for adapting the design of steam drums to a manufacturer's fabrication facilities.

Experience in the manufacture of the Winfrith calandria showed that with careful planning the fabrication of this vessel to close tolerances on a tight schedule was no problem to a contractor experienced in aluminium work. Also no difficulty was experienced with the upper and lower steel neutron shields which had to be bored to match the calandria tubes but were made separately in a boiler maker's works. The manufacture of the channel tube assemblies was carried out by a contractor accustomed to doing large scale engineering work to accurate dimensions. Apart from the special expanding tool for making the zirconium to steel joints which had been proved in a separate development programme, the techniques required of the contractor were only the ones used in his normal class of work.

Summary

The S.G.H.W.R. is an advanced reactor system and its engineering is firmly based on conventional techniques. It lends itself to the building of reactors of different outputs using standard size channel tube assemblies and fuel elements, thus enabling full advantage to be gained from repetition in production methods for these key reactor components, and from Winfrith operational experience.

For any new thermal system to succeed, it must at some stage of its development be capable of satisfying, in competition with other systems both nuclear and conventional, the exacting demands of electricity supply companies. These companies have their own responsibilities to meet, not only in terms of generating costs but also in terms of station reliability and availability. It is considered that the experience gained in the development, design and construction of the Winfrith S.G.H.W.R. has already fully established the engineering of this advanced reactor system.

The construction record

Outline

Sanction for the construction of the Winfrith S.G.H.W.R. was given in February, 1963 and site work started in May of that year. No noteworthy problems were encountered in the civil engineering work or in the construction of the reactor.

Construction was ahead of schedule until February, 1967, when mercury contamination was discovered in the calandria. The damage was put right by replacing the affected metal and chemically cleaning the system. This unscheduled event did, in some measure, confirm the ability of this form of reactor construction to accommodate maintenance and remedial work on specialised reactor components and it will be noted that the original target of power by the winter of 1967-8 was retained.

Construction was virtually complete by the spring of 1967. Commissioning tests were carried out, the fuel was loaded and the reactor brought to criticality by 14th September, 1967. Electricity was first exported to the grid on 24th December, 1967, and the reactor was brought to full power operation (100 MW(E)) on 25th January, 1968.

Points of interest

Manufacture of the calandria was a critical activity in the overall construction schedule. It was one of the first reactor components required on site and therefore time for design and fabrication was short. In addition, a high standard of dimensional accuracy was required to ensure that the gas gap of 0.75 in. (19 mm) between calandria and pressure tubes would be maintained when the core was assembled with the channel tube assemblies supported from the upper neutron shields. Modelling techniques were employed to ensure the fabrication of this component on time.

Though the core is only 12 ft. (3660 mm) high a complete channel tube assembly with its upper standpipe and lower tailpipe is approximately 35 ft. (10,700 mm) long. A production line was set up to

Parameters for 100 MW(E) Winfrith S.G.H.W.R. and a typical 500 MW(E) commercial design

		Winfrith S.G.H.W.R. 100MW(E)	Typical commercial design 500MW(E)
Plant performance			
Alternator output	MW(E)	100	377
Station net electrical output	MW(E)	92	500
Station net thermal efficiency	%	30.3	31.0
Reactor thermal output	MW(th)	292	1600
Reactor description			
Core diameter	in. (mm)	123 (3,120)	246 (6,250)
Core height	in. (mm)	144 (3,660)	144 (3,660)
Lattice pitch (square)	in. (mm)	$10\frac{1}{4}$ (260)	$10\frac{1}{4}$ (260)
Calandria diameter	in. (mm)	146 (3,700)	276 (7,000)
Calandria height	in. (mm)	156 (3,960)	156 (3,960)
Pressure tube internal diameter/ thickness	in. (mm)	5.14 (130 /0.2 /5.0)	5.14 (130 /0.2 /5.0)
Calandria tube outside diameter/ thickness	in. (mm)	7.25 (184 /0.13 /3.3)	7.0 (178 /0.10 /2.5)
Number of circulating pumps		4	6
Fuel			
Fuel Material	in. (mm)	UO_2	UO_2
Pellet diameter	in. (mm)	0.57 (14.5)	0.57 (14.5)
Can material		Zircaloy-2	Zircaloy-2
Can thickness (nominal)	in. (mm)	0.028 (0.71)	0.027 (0.70)
Number of elements in cluster		36	36
Fuel length	in. (mm)	144 (3,660)	144 (3,660)
Weight of U per channel	TeU	0.198	0.198
Fuel average rating	MW(th)/TeU	14.3	—
Coolant		H_2O	H_2O
Coolant pressure at core inlet	lb./sq. in. (kg/cm^2)	970 (68.0)	850 (60.0)
Coolant inlet temperature	°F (°C)	527 (275)	506 (263)
Coolant outlet temperature	°F (°C)	538 (281)	522 (272)
Heat to coolant (maximum channel)	MW(th)	3.8	5.0
Coolant mass velocity (maximum channel)	lb/ft^{2}hr	2.18×10^6	—
	(kg/cm^{2}sec)	(0.296)	—
Steam exit quality (maximum channel)	%	11.3	—
Steam pressure-turbine stop valve	lb/sq. in. (kg/cm^2)	890 (62.0)	750 (53.0)
Steam temperature-turbine stop valve	°F (°C)	534 (278)	512 (266)
Steam flow rate to turbine	lb/hr (kg/sec)	1.20×10^6 (150)	6.0×10^6 (755)
Final feed water temperature	°F (°C)	390 (199)	392 (200)

Moderator		Heavy Water, D_2O
Total weight	tonnes	32.8
Maximum temperature	°C (°F)	80 (176)

Control	
Load following	Moderator height adjustment
Long-term changes in reactivity	Boron removed from moderator
Shut-down	Boric acid solution injected into tubes in the core, accompanied by moderator dumping.

Turbine Hall		
Length	ft. (m)	270 (82.3)
Breadth	ft. (m)	90 (27.4)
Height	ft. (m)	100 (30.5)

Cooling Towers	
Type	Forced draught
Number	Two banks of seven sections each
Temperature drop achieved in the condenser cooling water °F (°C)	15 (6.3)
Cooling water flow gals/min. (l/min.)	80,000 (300,000)

Project history	
Sanction to build	February, 1963
Construction commenced	May, 1963
Construction completed	May, 1967
Reactor critical	September, 1967
Power exported to grid	December, 1967
Full power generated	January, 1968

produce more than 100 channel tube assemblies to the required accuracy at a rate of 30 per month.

Rolled joints attach the upper and lower steel extensions of each assembly to the zirconium alloy pressure tube, and a programme of development and testing was carried out to prove the technique.

The lower end of each pressure tube was tapered down and the steel hub into which it was rolled was slightly smaller in diameter than the bore of the calandria tubes. This allowed each assembly to be threaded through the upper neutron shield, the calandria tube and the lower neutron shield after these items had been erected. Subsequent steam and water pipework connections were made to the assemblies in situ by normal welding techniques.

By such attention to design and manufacturing details, it was possible to do the precision fabrication at contractors' premises and keep work on site to straightforward erection procedures. The remaining ancillary parts of the reactor system such as the heavy water cooling circuit and the ion-exchange beds for control of boron in the moderator are chemical plant circuits. Though at Winfrith these were assembled on site, some of them could be made up as pre-assembled units before delivery and this might well be done on future commercial reactors.

APACE centre courses

The following training courses will be held at the APACE Centre, Aldermaston Project for the Application of Computers to Engineering.

April

23rd–26th APT Users No. 8.

May

6th–10th FORTRAN Programming (for Engineers) No. 6.

21st–24th Computer Appreciation (for Engineers) No. 13.

June

10th–14th 2 CL Users No. 3.

18th–21st Computer Appreciation (for Engineers) No. 14.

Overnight accommodation is arranged on request.

Further information can be obtained from the Secretary, APACE Centre, UKAEA, Blacknest, Brimpton, Nr. Reading, Berks. Telephone: Tadley, 4111, Ext. 5951/5873.

U.K.A.E.A. PRESS RELEASE

S.G.H.W.R. agreement with Japan

An Agreement has been signed between the United Kingdom Atomic Energy Authority and the Power Reactor and Nuclear Fuel Development Corporation of Japan (P.N.C.) for the purchase by the Corporation of certain information concerned with the steam generating heavy water reactor system (S.G.H.W.R.) and associated experimental facilities. P.N.C. is to develop an advanced thermal convertor and the Agreement will enable the Corporation to make use of this research information which includes computer codes, derived during the development of the Winfrith S.G.H.W.R.

The Agreement, which is subject to the approval of the Japanese Government, was signed by Dr. J. M. Hill, Chairman of the U.K. Atomic Energy Authority, and Mr. H. Murata, the Director of Project Management of the Power Reactor and Nuclear Fuel Development Corporation.

The Winfrith S.G.H.W.R., which is being officially opened by H.R.H. Prince Philip, the Duke of Edinburgh, on Friday, 23rd February, 1968, was brought to full power operation of 100 megawatts of electricity on Thursday, 25th January, 1968. The reactor, which has been designed, developed and constructed by the U.K. A.E.A., first produced electricity for the National Grid on 24th December, 1967.

Background note

The Power Reactor and Nuclear Fuel Development Corporation was set up in October, 1967, by the Japanese Atomic Energy Commission to take over responsibility for the development of advanced nuclear reactors and nuclear fuel. The President of the Corporation is Mr. G. Inouye. The advanced thermal convertor to be developed by the Corporation will be a heavy water moderated boiling light water cooled reactor. In addition, P.N.C. propose to develop a fast breeder reactor. The programme for the convertor reactor anticipates the construction of a prototype reactor (200 MW(E)) to start about 1970, with larger stations following in the late 1970s.

The Winfrith S.G.H.W.R. is a direct cycle system, moderated by heavy water and cooled by boiling light water. The core of the reactor consists of a bank of pressure tubes which pass through vertical tubes in a calandria or tank containing the heavy water moderator. Each pressure tube contains a single fuel element and the heat generated is removed by light water passing up the tube and being partially turned into steam. After separation in a steam drum the steam passes directly to a turbine.

22nd February, 1968

Inventions and designs licensed to industry

A NEW edition of the booklet *Inventions and designs licensed to industry* is now available from Public Relations Branch U.K.A.E.A., 11, Charles II Street, London, S.W.1. This booklet lists the many inventions and designs made by the U.K.A.E.A. and the companies which have been licensed to use them by the U.K.A.E.A. Patents Licensing Department.

In the Lords

Fuel policy

The following extracts are from the debate on fuel policy which took place in the House of Lords on 14th February, 1968.

LORD STONHAM: With nuclear power we believe that the stage has now been reached when it can be regarded not only as fully competitive in price but as a potentially major source of energy.

On December 12 I gave your Lordships an outline of the primary fuel pattern we expect in 1975. Of our enlarged total requirement for energy seven years hence, coal may be supplying rather more than one-third and oil two-fifths. Nuclear energy, providing about 10 per cent, and natural gas, with about 15 per cent, are likely to supply the remaining 25 per cent of the total. These figures not only demonstrate the growing proportions likely to be taken up by the newer fuels, and

Risley Nuclear Engineering Society Dinner

Lord Hinton of Bankside was the principal speaker at the 21st Annual Dinner of the Risley Nuclear Engineering Society, held on 16th February. The founder President of the Society, Lord Hinton was presented with a silver gilt medallion in commemoration of his long association with the society. With Lord Hinton are, on his right, Dr. R. Spence, Director of Harwell and, on his left, Dr. J. M. Hill, Chairman, U.K.A.E.A., and Mr. H. V. Disney, President of the Society. 350 people attended the dinner.

the continuing decline in demand for coal, but also show the virtual stabilisation of oil's proportion at around the present level of 40 per cent.

In the longer term, this pattern holds out the prospect of advantages which we cannot afford to reject, and the experience of the Middle East war has emphasised the importance of the newer fuels on grounds both of security and cheapness.

There is no doubt that nuclear power will make a significant contribution to our future energy requirements on its own economic merits. We have undertaken very careful studies into the prospects for nuclear power. There are, of course, uncertainties. But, acknowledging these, we are satisfied that there are ample grounds for confidence that the trend of reducing costs and improving nuclear technology will continue, and that the vast potential of nuclear energy will be fulfilled.

Lord Sherfield: My Lords, I rise to speak on one aspect of this Motion. It is the place which nuclear energy takes in the plans for primary fuel use in the next few years. The noble Lord, Lord Stonham, has said that we must get nuclear power and gas in perspective in relation to the prospective needs for coal. I should rather like to put coal in perspective in relation to the economic advantages and the promise of nuclear power and natural gas.

Unlike coal, nuclear power has no lobby. It is capital intensive, not labour intensive. In fact it employs very few people. It puts no burden on the transport system and, at least until recently, the nuclear industry has not been strenuously interested in exports. It has suffered in the past through guilt by association with nuclear weapons and also by the extent to which nuclear energy was over-sold to the public in the early years. It is, therefore, quite easy to revive prejudice against it, as spokesmen for the coal industry sometimes appear to try to do, a pastime in which, according to the evening Press, the Russians have recently joined.

There are indeed only a limited number of people who speak up for nuclear power, besides the Atomic Energy Authority and the Central Electricity Generating Board, whose Chairman has been notably resolute in proclaiming his confidence in it. I advance the proposition that publications and statements of the Government are inclined to soft-pedal the achievements and prospects of nuclear power, and sometimes seem to have, I think probably sub-consciously, a built-in bias against nuclear power in relation to coal. In saying this, I do not intend any captious or partisan criticism of the spokesmen in your Lordships' House of the Minister of Power, who has the difficult job of trying to hold the balance between powerful and sometimes embattled State monopolies. It is almost inevitable in these circumstances that the White Paper which we are discussing should reflect this balancing act. It is full of " on the one hand " and " on the other hand ". As the late Lord Somervell used to say, " How I hate those bloody hands!"

Take, for example, the treatment of nuclear costs in Appendix III of the White Paper. We are given the ground rules on the basis of which these costs are calculated—a 20-year life, as opposed to 30 years for conventional stations; a 75 per cent load factor and a 7½ per cent interest rate. We are told that the generating cost of Dungeness " B " is expected to increase by .05d. per kWh. over the 1965 estimates. This is a result of including further items in the construction cost. It is not due, except for inflation, to the increased cost of the nuclear plant. The estimated cost of the Drax coal-fired station has been increased by .04d. per kWh. as a result of increased coal costs and higher capital costs. We are then told that a new method of calculating load factor has been chosen and that this method minimises the disadvantage in fuel costs of conventional plant as compared with nuclear plant.

Next, it is said that the interest rates on the construction of nuclear stations has been increased to 8 per cent, as against the 5½ per cent used by the C.E.G.B. Elsewhere it has been stated that the interest rate over the life of the station has also been increased to 8 per cent—incidentally, a modification since the White Paper was published. And, in the end, there is an admission that these ground rules might be thought pessimistic in two respects: first,

" a longer amortisation period "—

than 20 years—

" might be justified ";

and, second,

" a higher availability or greater system savings might be attainable. . .".

Indeed, I believe all components of nuclear stations are in fact designed to have a life of 30 years at 85 per cent load factor.

" Both these changes ",

it is said,

" if reflected in the ground rules, would favour nuclear power. . . . Nevertheless ",

proclaims the White Paper,

" it has been felt proper, for the time being at least, to retain the use of the more severe ground rules ".

My Lords, I can understand that it may be inconvenient, or undesirable or impolitic, to do full justice to the facts about nuclear power, but I find it difficult to see why it should be improper. Could it be that the more favourable figures might bring a blush to the cheeks of the noble Lord, Lord Blyton? One is left with the impression that every conceivable charge has been loaded on to nuclear costs, which, of course, also include a royalty payable on the advanced gas-cooled reactor stations, but that, rather annoyingly, the nuclear station comes out on top. However, the result is —and quite rightly—that the atomic energy programme from now onwards will pay for itself. Will the coal industry do the same? The prospects do not seem to be very bright on the basis of the write-off and loan provisions which are referred to in the White Paper.

It is sometimes felt, I think, that predictions about nuclear power have been too optimistic in the past. So let us turn from predictions to performance. The early Magnox stations, condemned sometimes as " white elephants ", have, as the White Paper recognises, been extremely successful. By May, 1967, Bradwell, the first to start operation, had already achieved a cumulative load factor of 78 per cent, whereas Hinkley Point, in a shorter period, had achieved a cumulative load factor of 80 per cent. With the exception of Trawsfynydd, which has had a lot of trouble with the conventional side of its plant, almost all the Magnox stations have exceeded their design capacity, and have progressively improved their thermal efficiency. The nuclear fuel has performed some 20 per cent better than its target, and this has enabled the refuelling cycle to be advantageously extended. So, after all the gloomy predictions, and in spite of the unforeseen changes in the economic factors since the original estimates were made in 1955, the later stations in the Magnox programme will be, as the White Paper says, competitive with contemporary coal-fired stations for the supply of base load electricity.

One must, of course, recognise, as the White Paper points out, the social factors involved in fuel policy, particularly the problems which are inescapably involved in the rundown of a great industry. But nuclear power brings with it important positive social advantages, which can indeed be picked out from various parts of the White Paper—small demand for labour, virtually no burden of transport, perfectly clean air (no sulphur dioxide, no " smog ", no coal tips); no danger to life or health. And, in addition, as the White Paper says:

" much may be expected of the expansion of nuclear power as a spur to the wide range of engineering industries involved in research, development and construction of nuclear plant and equipment for the home and export markets ".

I accept, of course, the extreme difficulty of getting the balance between the various fuels right. The Government claim that, in framing their measures, they have been at pains to avoid distortion of the desirable long-term pattern of development in the energy sector, even though this is heavily qualified by the words, " to the maximum extent possible ". But the implication is that they have not avoided it in the short term. In other words, industry will not get power as cheaply as it could get it in the next few years, solely because of the extent to which the coal industry is being protected. This is a drag on our economic performance. The prime question is whether it is an acceptable drag.

But even if, as the Government maintain—and as the noble Lord, Lord Stonham, with some support from the Opposition Benches, has emphatically reasserted to-day—the coal industry must have *this* heavy *protection* against *oil*, against imports, and so on, I still think it is a mistake to muffle the achievements and the prospects of nuclear energy in the United Kingdom. For one reason, it has a thoroughly bad effect on the export prospects of our nuclear industry. There has been increased criticism of our failure in this respect in recent years.

But it is not just the fault of the nuclear industry. The Central Electricity Generating Board hesitated for two years, in 1963 and 1964, before placing an order for an advanced gas-cooled reactor. This was the period when they were toying with the idea of ordering American reactors. This was also the period in which the American and Canadian nuclear industries broke through into the world market, and when official endorsement of the advanced gas-cooled reactor might have had a significant effect. We in this country have been " faint but pursuing " ever since. A much stronger official endorsement than we have had of the merits and performance of our system in this country is now required if an impression is to be made on the foreign purchaser. The Select Committee on Science and Technology in another place drew attention in this respect to the economic advantage to this country of an increase in the size of the present nuclear programme. There is no reflection of this recommendation in the Fuel Policy statement.

My Lords, in 1967, United States public utility companies ordered 30 reactors, with a total capacity of some 24,000 megawatts. At the end of last year, the reactors built, building and projected in the United States totalled 60,000 megawatts. Yet, the new Consolidated Edison power station near New York, using a boiling water reactor, will generate electricity for 0.49d. per unit, while the new Hunterston station will generate it for 0.46d. per unit—that is markedly lower—and two American water reactors built in Italy and Belgium are now both in trouble. Against the background of this massive expression of American confidence in nuclear power, and against the powerful efforts of American salesmanship, the muted tones of our own official statements are far from effective.

It is certainly stated clearly in the White Paper that the costs of the advanced gas-cooled reactor stations now ordered are expected to be lower than the estimated costs both for the Drax coal-fired and for the Pembroke oil-fired stations which are being built, and that further reductions in nuclear costs are confidently expected from further developments of the system. But, in other parts of the White Paper, the prospects of the A.G.R. are rather qualified in one way or another. We need the same emphatic confidence in our system, which is abundantly justified by our achievements, as the Americans have in theirs. In this respect, the choice of power plant for the proposed aluminium smelter is of special significance. There is, of course, the further question of whether our nuclear industry is properly organised, but this is not, I think, germane to this debate, and I will leave my comments on it to a later occasion.

In conclusion, my Lords, it is scarcely necessary to stress the importance of cheap power to the growth of our economy in the next few years. Yet we shall not be getting power as cheaply as we could, solely because of the extent to which it has been decided to protect the coal industry. We are repeatedly told that one of the principal aims of the Government is to improve the technological performance of this country, yet one sometimes has the impression that while the majority of people in a position to influence our technological progress are striving manfully to bring this country into the last quarter of the twentieth century, a substantial minority are trying to drag it back into the last quarter of the nineteenth century. The treatment of nuclear energy, in the present context of fuel policy, bears many traces of the struggle between these two conflicting forces. I most earnestly hope that the forces on the side of technological advance will prevail.

Lord Jackson of Burnley: Notwithstanding my sympathy with the coal industry, and contrary, I am afraid, to the views expressed by the noble Lord, Lord Blyton, I strongly support the Minister of Power's decision to put his faith in the future in nuclear power for the generating of electricity. I hope that, having made a declaration to this effect, the

Minister may now be able to give early consent to the proposed new nuclear power stations at Hartlepool and Heysham, with which there have already been longish delays. I think that the power industry and the heavy engineering manufacturing industry are likely to be considerably embarrassed unless steps of this kind are taken. As the noble Lord, Lord Sherfield, said—and I endorse all that he said—the electricity utilities in the United States are ordering nuclear power plant at a rapid rate, notwithstanding their access to coal at less than half the price of its availability in this country. There is a grave danger that we shall lose what lead we have earned in this field—if, indeed, we have not lost it already.

The Parliamentary Secretary, Ministry of Public Building and Works (Lord Winterbottom): The noble Lord, Lord Sherfield, raised the question of the exporting of British nuclear plant, particularly the advanced gas-cooled reactor. I am in great sympathy with the noble Lord, Lord Sherfield. As I said at the beginning of my speech, this is a field in which we are travelling hopefully, and we may even arrive. I think we have perhaps been wrong, because of the pressures on Government, in not saying clearly enough the progress that we are making in this country in the field of nuclear power. I hope that the trumpet call sounded by the noble Lord this evening will be heard outside the walls of this Chamber. The present "state of play" is that recently there was a British tender for a Franco-Belgian scheme, on which we lost out, but meanwhile tenders have gone out to the Argentine and Belgium and will shortly be offered in the Netherlands and Italy. A licensing agreement giving a Federal German firm the right to sell advanced gas-cooled reactors in that country has also been negotiated, and discussions, including in some cases prices, have been held with a number of other countries. So I think that the attack on the nuclear market has been mounted. Late, I agree, but better late than never.

It is true to say that the noble Lord, Lord Hawke, in his note to me, asked about the comparability of the boiling water reactor system and the advanced gas-cooled reactor system. Unfortunately, this is a field in which technical argument can prove almost anything, but fortunately this is also something where strong salesmanship can convince the customer. But the one hard fact in this argument is that when a British firm, offering an advanced gas-cooled reactor to the Central Electricity Generating Board, and a British firm offering a boiling water reactor, quoting on exactly level terms, put their offers before (I believe) an impartial authority, that authority chose the advanced gas-cooled reactor.

In the Commons

Research and development

12th February, 1968

MR. DAVID PRICE asked the Minister of Technology if he will state the nature of the cuts of £3½ million in 1968-69 and £6 million in 1969-70 in the research and development programme of the Atomic Energy Authority; and if he will give a detailed break-down of these cuts to the nearest £100,000.

Dr. Bray: The Authority aim to achieve the cut in the cost of their civil research and development programme in 1968-69 mainly by some reduction in capital expenditure and by some run down of manpower. The balance of the cut will be met by limiting extramural research and development contracts. The effect of the cuts in 1969-70 is still being studied by the Authority.

Specialised power requirements

12th February, 1968

MR. J. H. OSBORN asked the Minister of Technology what negotiations the Atomic Energy Authority has had with prospective aluminium smelting companies with a view to building and operating a power station to supply the needs of the Atomic Energy Authority, Capenhurst, as well as the proposed aluminium smelting industry.

Dr. Bray: A proposal from Rio Tinto Zinc and the A.E.A. for a jointly-owned nuclear power station was examined by the Government, in consultation with C.E.G.B. This led to consideration of the provision of power for aluminium smelters as a separate issue, and the Government are at present examining proposals.

Mr. Osborn: Is there any reason why the A.E.A. should not generate its own power for any purposes in conjunction with Rio Tinto Zinc, and are the Government and the Ministry of Technology opposing the project as undesirable or supporting it?

Dr. Bray: On the contrary the proposal opened the way to the development of the aluminium smelter industry in this country, which introduced the principle of special tariffs for loads of this characteristic. The Government have said that these loads are in principle available for similar projects, and when proposals are put up for the expansion of Capenhurst the case can be made.

Mr. Dalyell: Can my hon. Friend say when the examination to which he has referred is likely to be completed?

Dr. Bray: In accordance with the time scale for the completion of Capenhurst, which is not yet firm.

Siting policy decisions

20th February, 1968

MR. EADIE asked the Minister of Power if he will list in the OFFICIAL REPORT the authorities he consulted before deciding upon a change of policy in the future siting of nuclear power stations.

Mr. Marsh: In addition to other Government Departments and my own professional advisers, I consulted the Nuclear Safety Advisory Committee. The members of this independent committee are highly qualified and experienced men representing both sides of industry, insurance, Government research establishments and inspectorates, the academic world, and interests in the field of nuclear design, construction and operation.

Effluent monitoring procedure

21st February, 1968

MR. MCGUIRE asked the Minister of Housing and Local Government what estimate he has made of the amount of radioactive effluent which is discharged yearly by the nuclear power stations at present operating; and what is the system of checking that the disposal of such radioactive effluent is not causing contamination in the area where it is dumped.

Mr. Greenwood: I am sending my hon. Friend the latest environmental monitoring reports for each nuclear power station. The reports give details of the radioactive effluents discharged and of the measurements made to check the effect on the environment. The Central Electricity Generating Board measure the gamma radiation at and around each station and the effect of liquid effluent near the point of discharge. They analyse fish caught near the point of discharge and milk from farms near the stations, and independent analyses are made by the Ministry of Agriculture, Fisheries and Food.

Nuclear station breakdowns

21st February, 1968

MR. EADIE asked the Minister of Power what nuclear power stations have been involved in having to discontinue generating either partly or fully because of technical difficulty during the last 10 years; and if he will list the stations and the estimated cost that was involved.

Mr. Marsh: There have been no technical breakdowns at nuclear generating stations of a kind which cast doubt on the reliability of nuclear stations as compared with conventional. Breakdowns at particular power stations are matters of day-to-day management and if my hon. Friend requires further details he should write to the C.E.G.B.

Didcot power station

21st February, 1968

MR. GREGORY asked the Minister of Power what is the anticipated cost of generation from the coal-fired station under construction at Didcot; what is the date at which it is expected to be in full operation; and how this compares with the expected cost of generation at the nuclear power stations under construction at Dungeness B, Hinkley Point B and Hunterston B.

Mr. Marsh: The C.E.G.B.'s estimate of the base load generation cost of Didcot is 0·61d./kWh and of Dungeness B and Hinkley Point B 0·57d. and 0·52d./kWh respectively. The cost of Hunterston B is a matter for my right hon. Friend the Secretary of State for Scotland.

The first generating unit at Didcot is expected to be commissioned in 1969, and the station should be in full operation by 1972.

Nuclear Safety Advisory Committee

22nd February, 1968

MR. McGUIRE asked the Minister of Power if he will publish in the OFFICIAL REPORT the names and the professional and business qualifications of the Nuclear Safety Advisory Committee.

Mr. Marsh: This information is set out below:

NUCLEAR SAFETY ADVISORY COMMITTEE
Membership

Chairman:

Sir Owen Saunders, F.R.S., M.A., D.Sc., Professor of Mechanical Engineering, Imperial College of Science and Technology; Vice-Chancellor, University of London.

Members:

Mr. C. A. Adams, B.Sc., F.Inst.P., Chief Nuclear Health and Safety Officer, Central Electricity Generating Board.

Dr. T. E. Allibone, C.B.E., F.R.S., D.Sc., Ph.D. (Cantab.), Ph.D. (Sheffield), M.I.E.E., F.Inst.P., Chief Scientist, Central Electricity Generating Board.

Professor A. L. L. Baker, D.Sc., Hon. A.C.G.I., M.I.C.E., M.I. Struct.E., Professor of Concrete Structures and Technology, University of London.

Mr. G. F. Bullock, M.A., General Manager, Vulcan Boiler and General Insurance Co. Ltd., Manchester.

Mr. H. Cartwright, M.B.E., M.A., Director of Water Reactors, Reactor Group, United Kingdom Atomic Energy Authority, Risley.

Mr. W. J. C. Plumbe, H.M. Chief Inspector of Factories.

Mr. Patrick Conner, O.B.E., Scottish Regional Officer (retired), Amalgamated Engineering Union.

Professor P. I. Dee, C.B.E., F.R.S., M.A. (Cantab.), Professor of Natural Philosophy, University of Glasgow.

Professor J. Diamond, M.Sc., M.I.Mech.E., B.Sc., Professor of Mechanical Engineering, University of Manchester.

Mr. P. T. Fletcher, C.B.E., B.Sc., M.I.C.E., M.I.Mech.E., M.I.E.E., Managing Director, G.E.C. (Process Engineering), Limited.

Mr. Trevor Griffiths, B.Sc., M.I.E.E., Chief Inspector of Nuclear Installations.

Mr. F. Hayday, C.B.E., National Industrial Officer to the National Union of General and Municipal Workers, Vice-President of the T.U.C., and Vice-Chairman of its General Council, 1963-64.

Dr. J. M. Kay, M.A., Ph.D., M.I.Mech.E., M.I.Chem.E., Chief Engineer, Richard Thomas and Baldwins, Limited.

Dr. John F. Loutit, C.B.E., F.R.S., M.A., D.M., F.R.C.P., Director, Radiobiological Research Unit, Medical Research Council, Harwell.

Dr. A. S. McLean, M.B.. Ch.B., D.I.H., Director, Health and Safety Branch, United Kingdom Atomic Energy Authority.

Colonel G. W. Raby, C.B.E., M.I.Mech.E., M.I.E.E., Chairman and Managing Director, Atomic Power Constructions, Limited.

Dr. R. Scott Russell, M.A., Ph.D., D.Sc., Director, Radiobiological Laboratory, Agricultural Research Council, Wantage.

Mr. R. F. Jackson, M.A. (Cantab.), M.I.Mech.E., A.M.I.E.E., Director of Reactor Technology, Reactor Group, United Kingdom Atomic Energy Authority, Risley.

Secretaries:

Mr. W. R. Loader and Mr. W. S. Gronow.

Replacements are currently being invited to fill the seats of the following members, recently deceased or retired:

Sir John Cockcroft (deceased), O.M., K.C.B., C.B.E., F.R.S., M.A., Ph.D., M.Sc. (Tech.), lately Master of the Churchill College, Cambridge.

Dr. S. C. Curran, F.R.S., F.R.S.E., D.Sc., M.A., B.Sc., Ph.D., Principal, University of Strathclyde.

Mr. H. N. Pemberton (deceased), M.I.Mech.E., lately Chief Engineer Surveyor to Lloyd's Register.

Euratom membership policy

22nd February, 1968

DR. DAVID OWEN asked the Prime Minister whether it is now the policy of the Government that, as an initial step, Great Britain should seek to become a full member of EURATOM.

The Prime Minister: As the House knows, we have applied for membership of all three European Communities and these applications stand. Any suggestion from the Council of Ministers that we might join one Community in advance of the others would of course be considered on its merits.

Dr. Owen: Following the suggestion of Herr Brandt—and I understand the difficulties over the fusion of the treaties —does my right hon. Friend accept that the EURATOM Treaty, with its article about common enterprises, offers the opportunity for forming European firms in this vital industry?

The Prime Minister: I have noted that this suggestion has been put forward, but there has certainly been no proposal by the Council of Ministers collectively that this should be proposed to us. We have expressed the view in the past in relation to our application for membership of all three Communities that we would have a very great deal to contribute to the successful working of EURATOM or the nuclear component within the merged Communities.

Sir H. Legge-Bourke: Before the Prime Minister considers joining with EURATOM would he make sure that the EURATOM countries first have some agreement on how they should budget for that organisation?

The Prime Minister: There are a number of problems. I think that I have expressed not only that point but also the fact that EURATOM seems to have been something of a disappointment to some of its members and that we would have a great deal to contribute to make it more effective.

Mr. Heath: While Britain remains outside the Community, does not the right hon. Gentleman agree that probably the most profitable opening is in the servicing of nuclear reactors both in Europe and outside? On Tuesday, the right hon. Gentleman said that he was prepared to have a co-operative arrangement with Europe. Does that extend to the knowledge of the processing of enrichment at Capenhurst or is that excluded?

The Prime Minister: Perhaps the right hon. Gentleman has in mind possible exclusions by us in connection with our arrangements with the United States. Nothing is excluded in this matter. We put forward a proposal in Paris, and elsewhere. It has not been followed up, so obviously it has not been discussed in detail with the other Governments. All aspects of peaceful nuclear research were in our minds, including the joint production which I mentioned on Tuesday, and also the joint production of reactors, on which considerable progress is being made, even now, between ourselves and certain of our European partners.

Comparative generating costs

23rd February, 1968

MR. WOOF asked the Minister of Power which nuclear power station he expects to be producing electricity at 0·54d., or less, per unit sent out in 1970.

Mr. Marsh: None. The lowest cost nuclear station expected to be in operation by 1970 will be Dungeness B with an estimated base-load generating cost of 0·57d./kWh. Allowing for different dates of construction and cost levels, this will be comparable with the generating costs of the best coal-fired stations, e.g., Ratcliffe (0·54) and Cottam (0·56) which are due to be commissioned in 1968. Drax is expected to be commissioned in 1971 with a generating cost of 0·60d.

Fast reactor sites

28th February, 1968

MR. SWAIN asked the Minister of Power whether the new relaxations in the safety regulations on siting of nuclear power stations will apply to any commercial stations based on the fast breeder type of reactor.

Mr. Marsh: It is too soon to take decisions on the siting of commercial fast breeder reactors, but the Government will be asking the Nuclear Safety Advisory Committee to give consideration to the problem in due course.

Chapelcross breakdown

29th February, 1968

MR. SWAIN asked the Minister of Technology how long he estimates it will be before the nuclear reactor at Chapelcross power station, shut down since an accident in May, 1967, is in operation again; and what has been the cost of the breakdown in loss of sales.

Mr. Wedgwood Benn: Remedial work is making good progress but at this stage the Atomic Energy Authority is unable to forecast how long it will take. It is likely to be some months.

The loss of sales up to the end of February, 1968, will be about £0·8 million.

Dounreay

29th February, 1968

MR. SWAIN asked the Minister of Technology if he will make a statement about the progress at Dounreay of the work on the fast breeder reactor; how many shutdowns there have been; what are the reasons for them; and in what year he expects this type of reactor to be in commercial production.

Mr. Wedgwood Benn: A small experimental fast breeder reactor has been in operation at Dounreay since 1959. This reactor has been used since 1963 as a test bed for advanced fuels and materials. There have been frequent scheduled shutdowns because of the experimental nature of the programme.

In May last year, a small leak was discovered in the primary sodium circuit of the reactor. Since then, work has been directed towards locating and repairing the leak and it is anticipated that remedial work will be completed in the next few months.

As a result of the experience obtained with the experimental reactor, a 250 MW(E) fast reactor is now being constructed at Dounreay to be producing power by 1971. Construction has not been affected by the sodium leak in the experimental reactor and is proceeding to programme. It is anticipated that further commercial reactors of this type will be introduced by the mid to late 1970's.

Uranium supply

29th February, 1968

MR. SWAIN asked the Minister of Technology what is his Department's estimate of the supply and price prospects of natural uranium, in view of the incipient world shortage; and what effect this is expected to have on cost estimates for nuclear stations in this country.

Mr. Wedgwood Benn: The growing volume of current exploration work in various parts of the world should result in sufficient uranium being forthcoming at reasonable prices for the U.K. and other nuclear power programmes. The effect of a rise in price of uranium on nuclear power costs is comparatively small; for example, a price variation of 10 per cent. would mean a change of about $1\frac{1}{4}$ per cent. in generating costs for a typical advanced gas-cooled reactor station.

Safety record

4th March, 1968

MR. MCGUIRE asked the Minister of Power what accidents and breakdowns there have been at nuclear power stations operated by the Central Electricity Generating Board; which of these incidents resulted in escape of radioactive materials; and what was the cost.

Mr. Freeson: There have been no accidents or breakdowns involving an escape of radioactive materials from the site of any nuclear power station operated by the Central Electricity Generating Board. Breakdowns of a conventional nature are matters of day to day management. If my hon. Friend requires further details, he should write to the Board.

Ministerial responsibility

5th March, 1968

MR. EADIE asked the Prime Minister if he will make a statement on the division of responsibility between the Ministry of Power and the Ministry of Technology in all matters concerning nuclear power and for fuel derivatives.

The Prime Minister: My right hon. Friend the Minister of Power is responsible for the co-ordinated development of fuel and power; for the coal, gas and electricity supply industries and for settling with them their general programmes of research; for the inspection and licensing of nuclear installations; and for the oil industry.

My right hon. Friend the Minister of Technology is responsible for the United Kingdom Atomic Energy Authority and has sponsorship responsibilities for manufacturing industries supplying equipment to the industries mentioned above.

Packaging radioactive materials

A new British Standard specifies methods which may be used to test the suitability of packaging for the transport of radioactive materials, in particular of fissile materials and large radioactive sources.

BS 3895—*Methods for the assessment of packaging for the transport of radioactive materials: Part 2 Fissile materials and large sources: (Metric units)*—takes into account International Atomic Energy Agency Regulations for the safe transport of radioactive materials (IAEA Safety Series No. 6 1967 edition). It provides a basis for United Kingdom authorities concerned to approve designs of packaging for fissile materials and large sources.

A number of appendices are provided to assist the designers of packaging, giving advice on the mechanical and thermal protection required for the packaging under accident conditions, guidance on calculative assessment, and other general information relating to the test requirements.

Copies of BS 3895: Part 2: 1968 may be obtained from the BSI Sales Office, 101/113, Pentonville Road, London, N1. Price 20/- each (postage 1/- extra to non-subscribers).

Fast reactor development in the United Kingdom

This paper, by Dr. Hans Kronberger, F.R.S., Scientist-in-Chief, U.K.A.E.A., was presented to the Institute of Atomic Studies, Bucharest, in December 1967.

Future historians will attach very special significance to the present decade as being a turning point in mankind's utilisation of the energy resources of this planet. In this present decade nuclear power in many countries has become economically competitive with the fossil fuels—coal and oil. The development even for modern conditions has been extremely rapid. It is only just over ten years since practical amounts of electric power have been generated from nuclear reactors; 5 MW in the U.S.S.R. in 1954, 35 MW at Calder Hall in the U.K. in 1956, and 60 MW in the U.S.A. in 1957 although the latter was preceded three years earlier by a marine propulsion unit of this type of reactor. Since then enormous strides have been made not only in the above mentioned three countries, but in many other places of the world in the establishment of nuclear power. Within ten years or so it has moved from a spectacular *tour de force* and historic event into a well established method to produce electricity more cheaply than by any other means. In my previous lecture I outlined the nuclear power development in the United Kingdom. In our country at the moment one-ninth of all electricity produced comes from nuclear power from 3,500 MW of power stations, 23 reactors in all. By next year we shall have 8,000 MW(E), more are under construction or firmly planned; our latest reactors have generating costs at least 15% below those achievable with the best contemporary coal-fired power stations.

Even in the United States with its large fossil fuel reserves, nuclear power has become cheaper than conventional power and huge orders for nuclear power stations have been placed in the United States during the past year. Many countries all over the world now have large programmes for the installation of nuclear power.

These developments have all been based on reactors in which fissions take place primarily in uranium 235 by neutrons which have been slowed down in a moderator. We call these reactors thermal neutron reactors or in short, thermal reactors. For fission to take place in U-235 the neutrons have to be slowed down in a moderator which can be heavy water, light water or graphite. A great number of varieties of reactors have been developed on this principle, but they have a number of basic features in common.

Perhaps you will permit me to put down a few simple significant figures. I must apologise if these figures are familiar to a number of nuclear experts amongst you, but I like to use them in order to demonstrate the great advance achieved by the future fast fission reactors.

The first fact which is significant is the amount of uranium required to install a thermal nuclear power station. Now we start with the uranium ore dug out of the ground. This is concentrated and coninverted to natural U_3O_8. Thermal reactors use metallic uranium, uranium oxide, or carbide. The uranium can be natural or enriched in a diffusion plant, but you will find that for all thermal reactors whether they be natural or enriched, gas-cooled or water-cooled, high or low thermal efficiency, the initial uranium requirement (expressed as tons of *natural* U_3O_8) is of the order of 1 ton per MW(E) installed. This, of course, is an approximate figure. For instance, we hope that some of the more recent developments in gas-cooled reactors might halve the uranium requirement per installed MW(E).

The natural uranium requirement to keep thermal reactors in operation is also very similar for various thermal reactor types, about 0·2-0·3 tons of natural U_3O_8 per MW(E)-year production. Incidentally, the 0·2 tons of uranium oxide per MW(E)-year should be compared with 3,000 tons of coal to produce the same amount of electricity.

Although these figures look very favourable, particularly as compared to fossil fuel, one must remember that thermal reactors make very poor use of uranium. The primary fuel for thermal reactors is the U-235 isotope which is only contained in a concentration of 0·7% in natural uranium. In addition, some plutonium is formed in thermal reactors during irradiation and burned together with the 235, but even so, only around 1% of the uranium dug out of the ground is utilised in thermal reactors. The other 99% is wasted. Fast reactors on the other hand should use 75-80% of the uranium.

Cost of uranium

While supplies of low cost uranium ore are plentiful and comparatively cheap the poor utilisation of uranium presents no problem, but this situation is not likely to persist if one considers the number of thermal reactors which will be installed all over the world during the next two decades and the world supply of uranium. The electric generating cost from thermal reactors depends on the price of uranium ore: about 10% of the cost of the kW-hour are due to the costs of the natural uranium. An increase of the cost of uranium would not rule out nuclear power, but it certainly would affect the pattern of development. To put this into perspective: electricity from an Advanced Gas-cooled Reactor in Britain costs about 0·45 pence per kW/hour; 0·06 pence of this is due to the cost of uranium at $8/lb. of U_3O_8. An increase of uranium ore price by 50% to $12/lb. would thus increase the cost of electricity by 0·03 pence per kW/hour. In other words, a 50% increase of uranium ore price will increase the electricity cost by 7%.

Fig. 1 is an estimate of the total *annual* world demand for uranium oxide; Fig. 2 shows the cumulative demand—in other words the integral of Fig. 1. I must stress that it is very difficult to predict the number of nuclear power stations to be installed. If anything my curves are too low. Now you will notice around the year 1980 the uranium demand branches into two lines. The lower line is due to the reduced uranium demand if one assumes that fast reactors will become widely installed.

Now let me talk about fast reactors. These utilise most uranium, say 80%. When we mapped out the nuclear power programme for the United Kingdom about 15 years ago, long before we started the

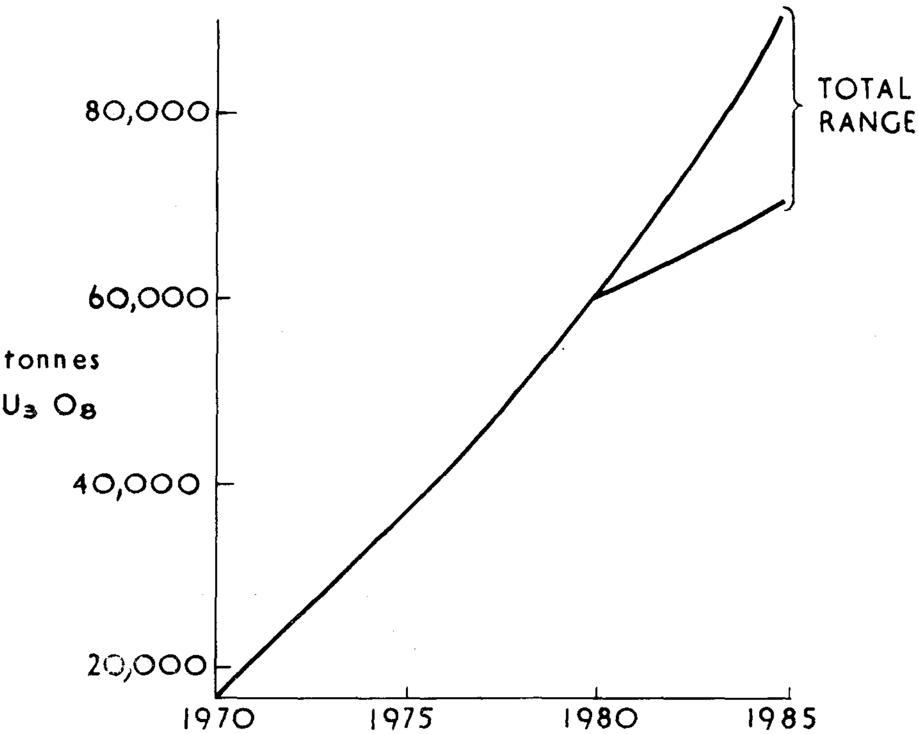


Fig. 1. *Estimated uranium demand—annual.*

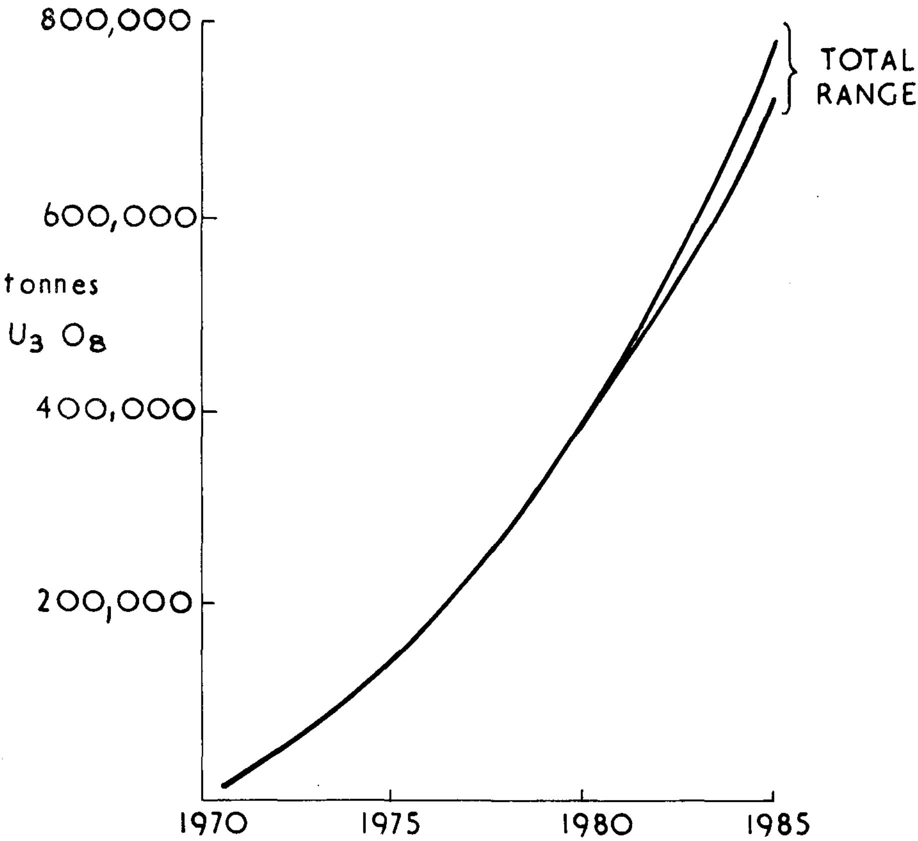


Fig. 2. *Estimated uranium demand—cumulative.*

Calder Hall power station, we appreciated that our thermal reactor programme would give rise to large quantities of plutonium. It was then supposed (but not known with certainty) that this plutonium could be a fuel of high intrinsic value. It appeared to us that it would be best utilised in fast fission reactors, although at the time we knew very little about such reactors.

Accordingly we started an experimental programme on the feasibility of fast reactors; in particular, we started a fast reactor physics programme as far back as 1951. In 1954 our first zero energy fast assembly (ZEPHYR) went critical; followed in 1955 by ZEUS which simulated the core of the 60 MW(H) Dounreay Fast Reactor, on which construction had been started in the same year.

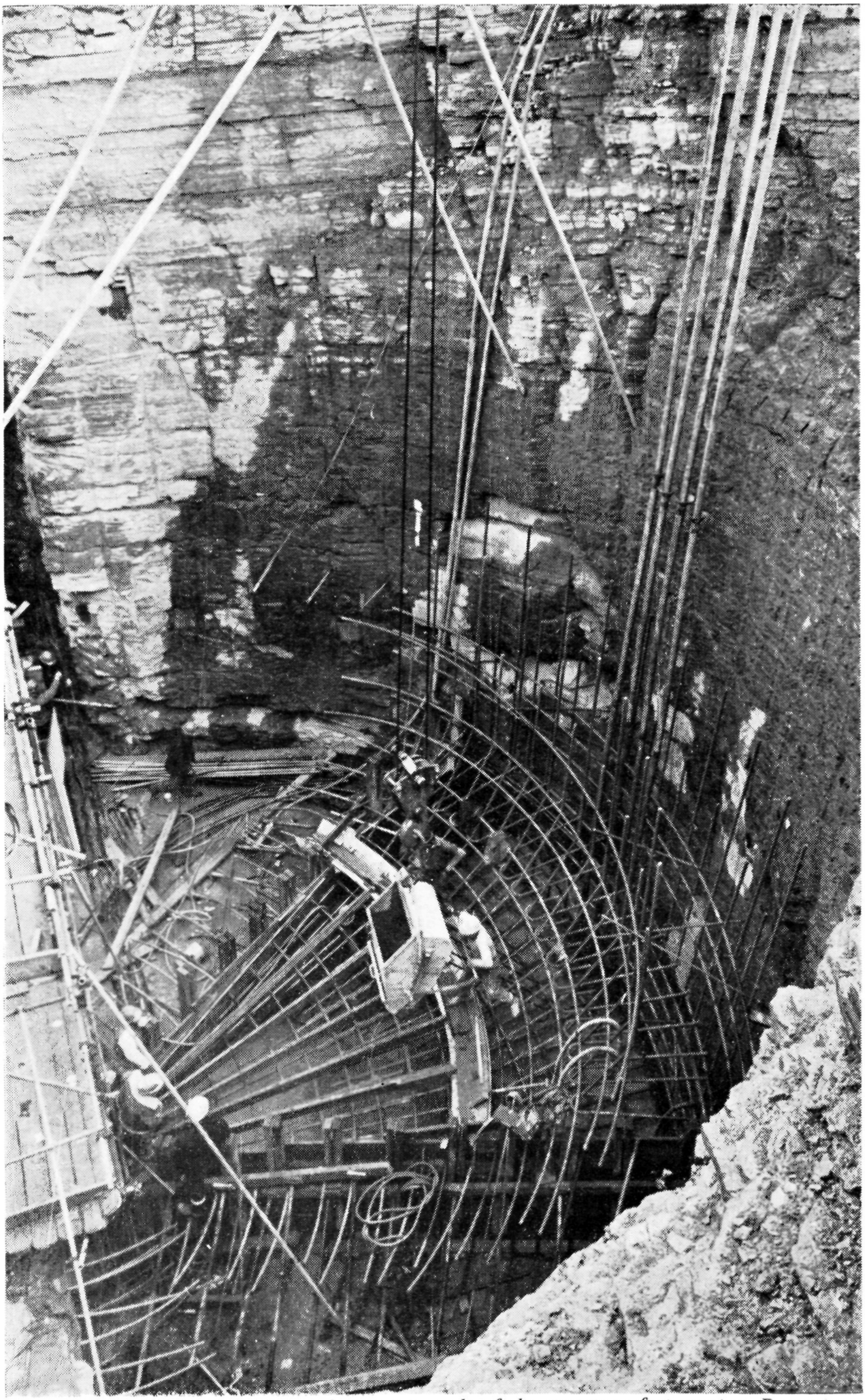
Now to come back to the plutonium production from our thermal reactors; the United Kingdom nuclear power programme in its present state will give rise to very large quantities of plutonium. The Phase I programme—the magnox reactors—which is now almost complete, will yield about 3 tonnes of plutonium per year. The second phase programme—the 8,000 MW AGRs will give a similar additional amount of plutonium. It became clear from our physics work that the best way of burning plutonium was in fast reactors. I am sure there must be a number amongst you who know a good deal about fast reactor physics and I again apologise to them if I say things which are quite well known to you. In fast reactors the object is to keep the neutron energy as high as possible. Although the neutrons are not deliberately slowed down by the use of a moderator, their energy will be decreased somewhat by collisions with fuel and structural materials. Nevertheless, it is possible to keep the average neutron energy reasonably high. At these high energies, not only are plutonium 239 and plutonium 241 fissioned (these materials will also readily fission in a thermal neutron flux) but also plutonium 240 and plutonium 242 and also uranium 238; the

	U-235		Pu-239	
	Fast	Thermal	Fast	Thermal
γ	2.45	2.44	2.94	2.90
σ_f	1.5	580	1.9	750
σ_c	0.51	110	0.41	280
N-1	0.92	1.05	1.41	1.11

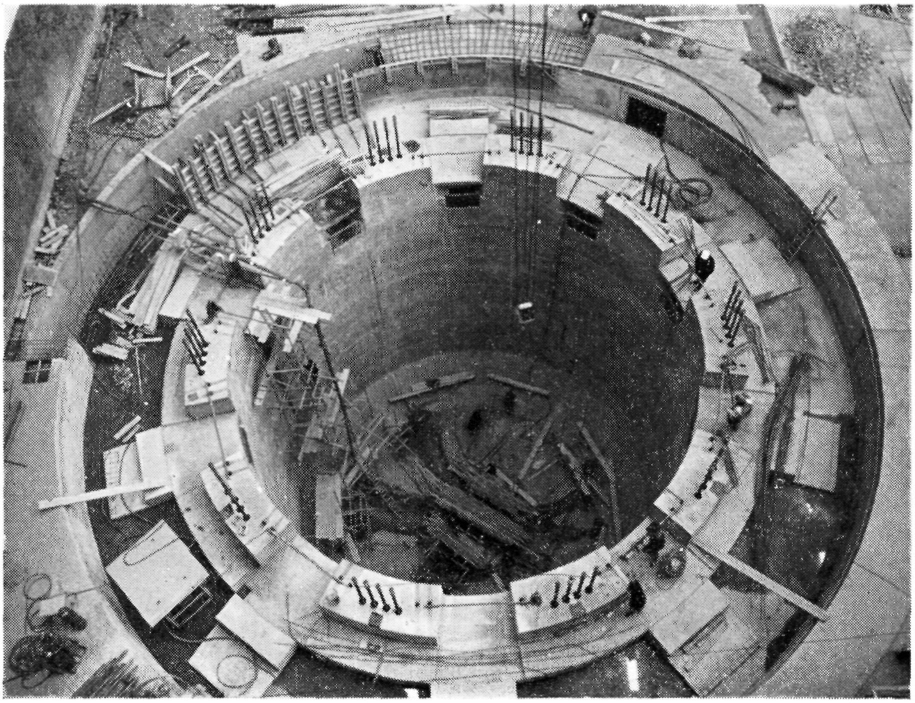
Fig. 3.

latter three materials are not fissioned in a thermal neutron flux. Plutonium is a better fast reactor fuel than uranium 235, the number of spare neutrons available being very much larger. As a result of this a good deal of the uranium 238 captures neutrons and is converted into plutonium 239, and it can be arranged that more 239 is produced by this process than consumed —this is the principle of the breeder reactor. This state of affairs is illustrated in figure 3. Some recent physics information has somewhat modified the numbers, but for the purpose of my lecture they are good enough to give an idea of what is involved. The figure indicates the superiority of plutonium 239 in supplying spare neutrons and the fact that N-1 is significantly greater than 1 for plutonium 239 shows the potentiality for breeding more plutonium 239 than is consumed, i.e., by absorbing neutrons in uranium 238. You will see from the figure that the fission cross sections in a fast flux are very much smaller than in a thermal flux (by a factor 4-500). This means that a high concentration of fissile material as compared to thermal reactors is required to make the reactor critical. The high price of the fissile material (plutonium 239) or the limitations in its availability demands a very high power rating per kg of fuel in order to keep the initial cost of fuel investment low. In order to keep the leakage of neutrons low we must make the core as small as possible: this means that we must achieve a high power density in fast reactors. In the 250 MW(E) prototype fast reactor which we are now constructing at Dounreay the average power density is 150 MW heat per tonne (with a maximum in the core centre of 240 MW heat per tonne). This compares with 13 MW per tonne average rating for AGR and about 25 MW per tonne for SGHW and boiling water reactors. The extremely high rating coupled with the small cores of fast reactors leads to problems of heat removal. In the United Kingdom we decided right from the beginning of the fast reactor project to concentrate on liquid metals as fast reactor coolants. Liquid sodium-potassium alloy was chosen as the most suitable coolant at that time, but it must be appreciated that at the beginning of our project very little was known of handling huge quantities of this material in a safe manner. Over the last 14 years we have collected an enormous amount of knowledge of alkali metal technology. Let me at this stage summarise: the British nuclear power programme consisting of 5,000 MW of Phase I magnox reactors and 8,000 MW of Phase II AGRs gives rise to very substantial quantities of plutonium. The plutonium will build up to about 6 tonnes per year. Plutonium is best utilised in fast fission reactors because not only is the yield of neutrons high, but all the plutonium isotopes are fissile and the spare neutrons enable more plutonium to be bred from uranium 238. The low fission cross-section of Pu in a fast flux (as compared to a thermal flux) requires a high concentration of fissile material and (in order to keep the fissile investment small) a high rating per tonne of fuel. The need to avoid neutron leakage leads to a small core, and hence to a high power density. The rating of the fast reactor under construction at the moment is around 150 MW per tonne—one order of magnitude higher than in the Advanced Gas-cooled Reactor. Perhaps the most spectacular way of illustrating this is to quote the power density. We have run the Dounreay Fast Reactor during the last four years at a power density of about 500 kW/litre. This is considerably higher than the power density in a combustion chamber of a jet engine. But most important of all—these reactors use 80% of the uranium.

Having given you a rough picture of the concept of fast reactors and the reasons for starting development in the U.K., let me now tell you something about the history of our fast reactor development.

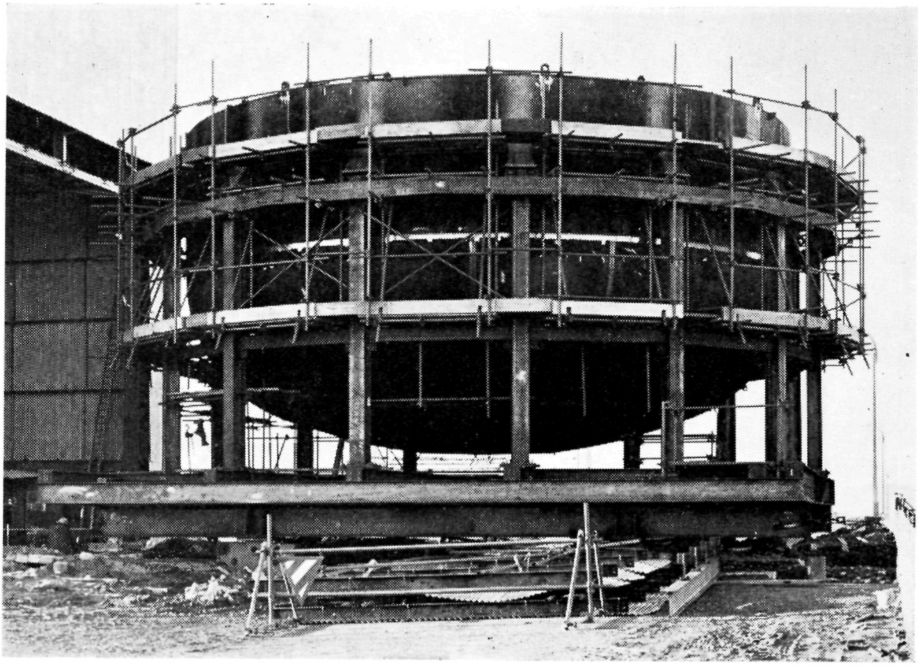


Construction work in progress on the reactor vault of the prototype fast reactor, Dounreay March, 1967.



Progress on the P.F.R.—the reactor vault on 11*th January*, 1968.

As I have already said, we started our fast reactor development programme as far back as 1951 with experimental physics work on small critical assemblies initially with uranium 235 and later with plutonium to get an approximate idea of the physics of such systems. We started the construction of a 60 MW heat fast reactor at Dounreay in 1955. May I remind you that at that time even thermal reactors had hardly commenced operation. I think the decision to build a fast reactor which even even than had a power density of ½ MW/litre was a supreme act of courage. Very little was known about NaK technology at the time and although we thought we had taken every possible step to ensure the safety of the reactor, it was decided to place this reactor a reasonable distance away from centres of population. We need not have gone quite as far as Dounreay, which is 1,100 kilometres from London, but because of the lack of industry in this remote corner of Scotland it was decided to put this reactor there to act as an impetus for further social development of that area. By present day standards the design of the Dounreay Fast Reactor is unnecessarily complicated. But again, one must remember that the biggest liquid metal pump at the time had an output of about 2,000 litres per minute and it was therefore necessary to have 24 such pumps in parallel to drive the coolant through the reactor. By comparison present day pumps (to be used in the 250 MW(E) PFR) have an output of 40 times this amount. At the time the fuel for the Dounreay Fast Reactor was uranium metal highly enriched in uranium 235 (46%) and containing 10% molybdenum to prevent dimensional changes of uranium under irradiation. We had thought that this uranium/molybdenum metal fuel would be capable of a burn-up of 0·2%. Further development of this fuel has enabled us to reach a burn-up of 3·6% in the cooler regions of the reactor and 2·2% in the hot zone (maximum fuel temperature of 543°C). With the enriched uranium metal core the Dounreay Fast Reactor came to power in November, 1959. We had initially a good deal of trouble with gas entrainment in the sodium/potassium alloy and with impurities dissolved in the liquid metal which affected fuel elements and control rod mechanisms. By 1963 we had overcome these problems and took



Part of the P.F.R. primary vessel.

the reactor up to its design output of 60 MW heat. Our real development aim, however, was to develop plutonium bearing fuel for eventual use in a large prototype fast reactor. For this purpose it was decided to modify the Dounreay Fast Reactor core to test sub-assemblies of uranium/plutonium oxide ceramic fuel in the centre of the core and to provide facilities in the reactor for a great number of irradiation experiments in such fuel. In order to do this we retained the enriched uranium metal fuel as a driver charge but stepped up the enrichment from 46% to 75% U-235; we also increased the molybdenum content of this fuel. In this form the Dounreay Fast Reactor became the most powerful test facility in the world. The loading pattern at the beginning of this year might illustrate this: at that time the reactor contained three ceramic plutonium oxide sub-assemblies of 77 pins each operating at a peak rating of 240 MW/t. It contained a further 50 experiments not only on various forms of ceramic fast reactor fuel, but also on cladding materials and fuel for advanced gas-cooled reactors and S.G.H.W.s; in addition another 50 similar experiments were placed in the blanket of the fast reactor. The Dounreay Fast Reactor thus became an invaluable irradiation facility not only for fast reactor experiments but also for experiments relating to thermal reactors for which we tried to obtain accelerated irradiation information. As you know our thermal reactors are guaranteed for 30 years' life and the Dounreay Fast Reactor provided the only possible way to obtain the high irradiation flux required to simulate 30 thermal reactor years in, say, two years. Thus we have tested the behaviour of graphite for A.G.R. and the behaviour of zirconium alloy pressure tubes for S.G.H.W. at dosages which could not be achieved in so short a time in any other reactors. Incidentally, D.F.R. has been providing also, electricity for the county of Caithness in the North of Scotland, including its two towns of Thurso and Wick.

Post-irradiation facilities

It goes without saying that coupled with irradiation tests in the Dounreay Fast Reactor we required extensive post-irradiation examination facilities at Dounreay. The handling of plutonium and the high activities poses very special problems. For instance we have taken an irradiated 77-pin sub-assembly out of the fast reactor, examined it in a cave, and put it back into

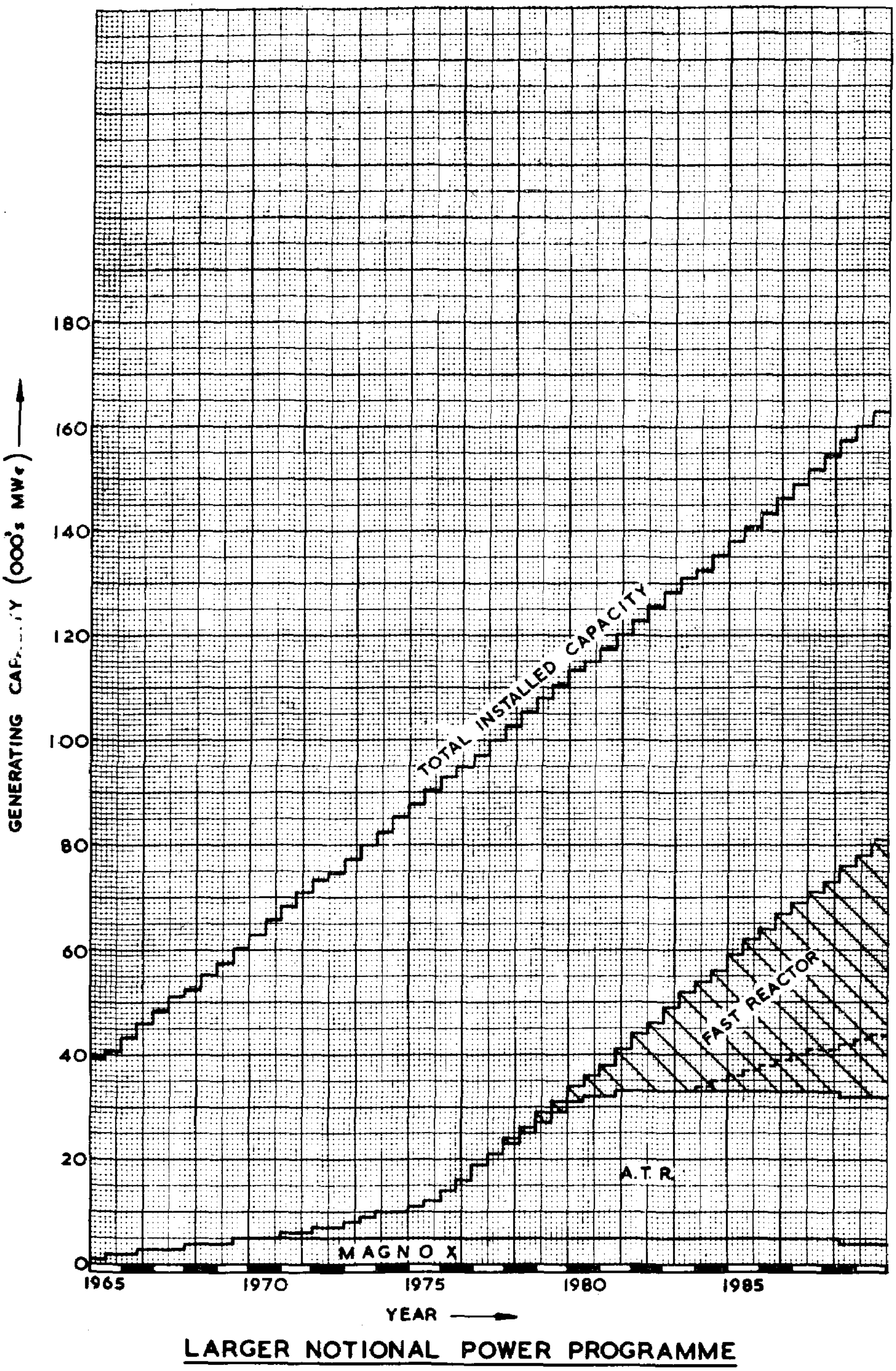


Fig. 4 The proposed installation programme of thermal and fast reactors in the United Kingdom.

the reactor for further irradiation. This involved the handling of 10,000 curies of activity!

Prototype fast reactor

The irradiation of uranium/plutonium oxide fuel together with an enormous amount of development on fast reactor fuel and fast reactor physics has given us enough confidence to go ahead with the construction of a 250 MW(E) prototype fast reactor. We started construction of this reactor in the autumn of 1966. We intend this reactor to be on full power in 1971.

The steam conditions of the prototype fast reactor correspond to standard steam conditions of modern British power stations giving a net thermal efficiency of about 42%. The design is radically different from the original Dounreay Fast Reactor. The sodium is contained in a large tank which has no inlet or exit ports. All the components are hung into the tank from the top. This ensures maximum integrity of the tank and enables one to give an absolute guarantee for retaining the coolant under all circumstances. All the components can be readily removed for maintenance. The 250 MW reactor has only three coolant circuits. There are three primary sodium pumps each giving a total flow of almost 90 tons of sodium per minute.

You will appreciate that the construction of the prototype fast reactor has been backed up by an enormous amount of development work on the physics, the fuel and the engineering components of this reactor. For instance, we have plutonium fuel development in progress not only at Dounreay, but also at a number of other laboratories in the Authority. The physics work has been mainly carried out at Winfrith where we have a large zero energy facility capable of taking a complete prototype fast reactor core. The facility is known as ZEBRA. Engineering component development has been carried out at the Reactor Engineering Laboratories at Risley where we have tested pumps, control mechanisms, and other components. We are now confident that we have plutonium/uranium oxide fuel capable of reaching an economic burn-up so far endorsed to 7·5% burn-up, but probably capable of going higher. We are confident of the physics of these reactors and our ability to control such reactors and we have gained over the last few years a good deal of experience in handling ton quantities of sodium. However, the final proof will be the operation of the 250 MW reactor as a power station.

With the prototype fast reactor in operation by 1971 we plan to install a series of commercial fast reactor power stations of about 1,000 MW(E) output each commencing in 1976. By that time the amount of plutonium available from our thermal reactor programme will enable us to construct about 15,000 MW of fast reactors between 1976 and 1986. At this stage it is difficult to give accurate figures on the generating cost of these fully developed commercial fast reactors, but we are reasonably confident that they should generate electricity at about $\frac{1}{3}$ pence/kWh as compared more or less to 0·45 pence per kWh for the best thermal reactors at that time. Fig. 4 shows the proposed installation programme of thermal and fast reactors in the United Kingdom.

We have embarked in the U.K. over the last 16 years on a considerable programme of fast reactor development, concentrating on the use of plutonium fuels. The main development is centred at Dounreay and the D.F.R. has played a major role in demonstrating the reliability and development potential of liquid-metal cooled systems; it has also demonstrated the feasibility of the safe use of a fast neutron system to produce electricity on a commercial basis. We believe the major problems of the sodium-cooled fast reactor system have been overcome and the prototype fast reactor will confirm our confidence in all aspects of fast reactor technology.

Radiation warning symbol

WITH the increasing use of ionizing radiation in medical and industrial radiography, and in the generation of such radiation, during nuclear research, in nuclear power stations, and by radioactive substances, a need arose for a distinctive symbol to indicate the presence of ionizing radiation.

The first edition of a British Standard for this purppse was published in 1962 and now a 1968 edition—BS 3510: *Specification for a basic symbol to denote the actual or potential presence of ionizing radiation*—brings the Standard closely into line with ISO Recommendation R 361: Basic Ionizing Radiation Symbol.

Copies of BS 3510 may be obtained from the BSI Sales Office, 101/113 Pentonville Road, London, N.1. Price 4/- each (postage 6d. extra to non-subscribers).

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

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

Measurement of Radioactivity

22nd April to 10th May, 1968

Intended for those having elementary knowledge of radioactivity who need to have theoretical and practical knowledge of a wide variety of counting methods with special reference to their interrelation, scope and limitations. Fee: £78 15s. exclusive of accommodation.

Magnet Design

29th April to 3rd May, 1968

Intended for design engineers and scientists with or without experience in the field. Covers basic theory, materials, Fabry factors for coils forces on coils, digital and analogue computation and computer calculations, field-measurement techniques, technology of low temperature and cryogenic magnets, practical winding design and construction techniques, superconducting and pulsed magnets. Fee: £26 5s. exclusive of accommodation.

Radioisotopes in Industrial Measurement and Control

20th to 24th May, 1968

Intended for professional engineers and others who need to keep up-to-date with modern methods of examination and control. Among the subjects included are: industrial tracing, mixing and bulk flow, wear measurement, radioactivation analysis, γ-radiography, thickness and density measurement and X-ray spectrometry. Fee: £26 5s. exclusive of accommodation.

Introduction to Reactor Instrumentation and Control

23rd to 31st May, 1968

Held at Durley Hall, Bournemouth, and intended primarily for graduates who are new to the nuclear reactor field and who need a broad knowledge of these subjects. Participants should have some basic knowledge of nuclear reactors, electronics, the measurement of physical quantities and automatic feedback control. Fee: £36 15s. exclusive of accommodation.

Two-Phase Heat Transfer

10th to 14th June, 1968

Held at Durley Hall, Bournemouth. Of particular value to engineers and scientists working in the field but may also appeal to those requiring an introduction to two-phase heat transfer. Fee: £26 5s. exclusive of accommodation.

General Isotope Course with special reference to Biochemistry

17th June to 12th July, 1968

Designed to enable qualified biochemists to use radioisotope methods in their work. Includes basic lectures on nuclear physics, radiochemistry, detection and radiological protection and practical exercises associated with them. Fee: £105 exclusive of accommodation.

Summer School on Neutron Diffraction

1st to 5th July, 1968

There will be about 15 invited lectures on elastic neutron scattering given by leading workers in the field. The main topic will be the accurate determination of neutron intensities and structure factors; this will include nuclear and magnetic scattering from both single crystals and powders. Fee: £8 exclusive of accommodation.

Lecturers on Radioisotope Work in Schools

22nd July to 2nd August, 1968

The course is intended to help those planning to conduct courses satisfying the training requirements outlined in AM1/65 of the Department of Education and Science, or others with similar needs.

There will be lectures to give background information on nuclear physics, radiochemistry, the detection of radiation and radiological protection but the emphasis throughout will be on the practical introduction of radioisotope methods into the chemistry, physics and biology syllabus. During the two weeks about 30 hours will be devoted to practical work mainly using radioactive sources and electronic apparatus appropriate to work in schools. Fee: £40 exclusive of accommodation.

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

Nondestructive testing at Physics Exhibition

New developments in ultrasonics which have particular value in nondestructive testing were part of the Harwell contribution to the Atomic Energy Authority stand at the Physics Exhibition this year. Exhibits showed advanced ultrasonic methods of measuring the wall thickness of tubes, grain size of metals and the potential increase in resolution offered by using frequencies in the region of 100 MHz.

Ultrasonic thickness micrometers

Two automatic instruments were shown, developed by the Electronic and Applied Physics Division at Harwell. They use a well established technique for measuring the wall thickness of a metal tube. A beam of ultrasound is focused on the wall and the frequency varied until the energy of reflection is a minimum; this occurs when the half wavelength is equal to the wall thickness.

One of the instruments employs a single probe which both produces the ultrasound and receives the reflected energy. As the transmitter frequency is swept over the range of interest the resonance absorption peak is detected and the transmitter frequency at this instant measured by digital counting methods.

The second instrument uses separate probes which provide continuous transmission and reception. The system locks the mean transmitter frequency to a position near the resonance and the tube can be quickly scanned; the output can be used to give a pictorial record of the thickness variation over the tubing.

Grain size measurement

The average size of metallic grains in a metal tube can be determined by directing a focused beam of ultrasound on to the tube wall. Some incident energy is reflected from the tube surface and some enters the tube wall. The part entering the wall is scattered by the grains of the tube and acquires characteristics of their size and shape.

NDT using ultrasonic frequencies in the region of 100 *MHz*

The range of frequencies used in nondestructive testing is normally limited to less than 25 MHz (25 megahertz or 25 million cycles per second) by the fragility of the ceramic transducers. At this limit the resolution obtainable is about $\frac{1}{4}$ mm. which, for many applications, is too coarse. A demonstration at the exhibition evaluated the potential of frequencies in the region of 100 MHz.

These exhibits showed some of the work of the Electronics and Applied Physics Division at A.E.R.E., Harwell, on whose experience the Nondestructive Testing Centre draws.

The Nondestructive Testing Centre offers a service to British industry which includes information and advice on all aspects of nondestructive testing, development work to overcome specific inspection problems, use of specialised facilities not available elsewhere and long term research.

Enquiries on this service should be addressed to: The N.D.T. Centre, Atomic Energy Research Establishment, Harwell, Didcot, Berks. Telephone: Abingdon 4141, Ext. 2112 or 2791.

A set of 27 data sheets describing exhibits shown by the various establishments of the Atomic Energy Authority is available on request from the Public Relations Branch, U.K. Atomic Energy Authority, 11 Charles II Street, London, S.W.1.

Proton scattering microscope

An instrument which uses a beam of protons to produce detailed information on crystal structure has been developed at Harwell.

Known as the proton scattering microscope, it is being further developed in the Central Research Laboratory of Edwards High Vacuum International Ltd.

In use, the new instrument directs a beam of protons at a single crystal specimen, at an acute angle to the specimen's surface; the protons scattered from the specimen produce a magnified image on a fluorescent glass screen corresponding to the crystal lattice structure and its orientation.

The specimen is mounted on a specially designed manipulator in a container maintained at a pressure of 10^{-5} torr.

The projection of the crystal structure on the fluorescent screen results simply from the fact that protons travelling close to the densely packed rows or planes of atoms have their trajectories blocked so that a reduction of intensity occurs in the direction of the rows or planes.

Proton scattering microscopy is complementary to electron and X-ray diffraction for the study of crystal structures. It can be used to study surface layers of only a few tens to hundreds of atoms thick. It offers a quick and simple method of orientating single crystals, and it can be used to study the positions of impurity atoms in a single crystalline lattice.

Further information can be obtained from the Scientific Liaison Officer of Edwards High Vacuum International Ltd., Manor Royal, Crawley, Sussex. The company will also exhibit a prototype at the Physics Exhibition, Alexandra Palace, London, 11th-14th March, 1968, and at the 4th International Vacuum Congress, Renold Building, University of Manchester, 17th-20th April, 1968.

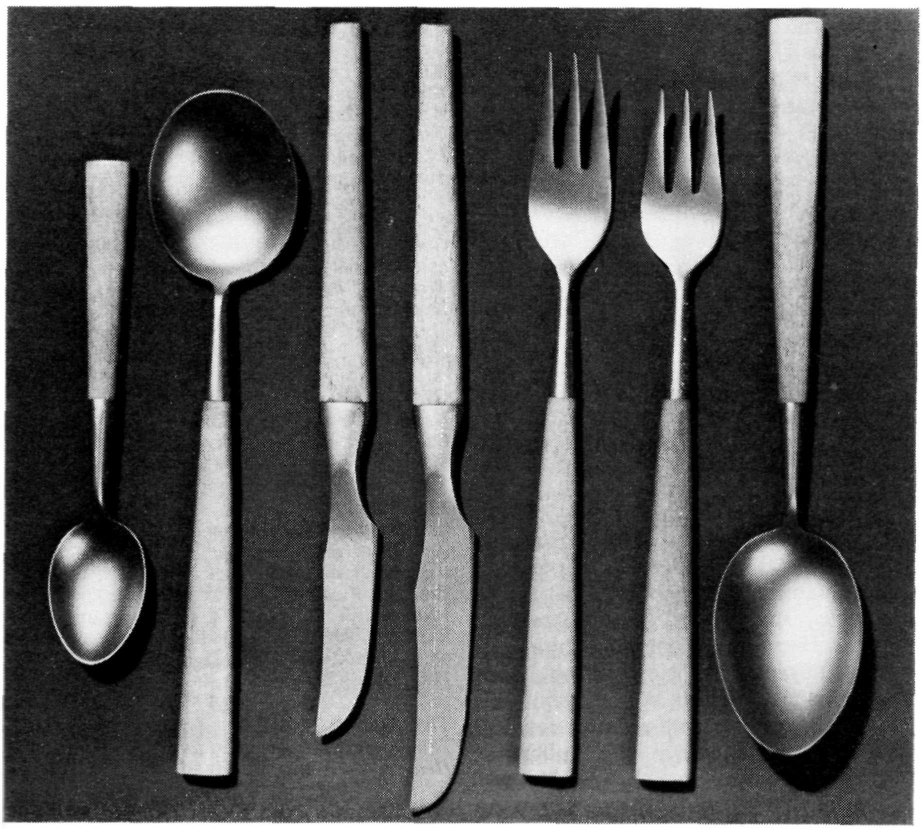
13th February, 1968

Wood plastic composites

Wood impregnated with plastic which is subsequently hardened by radiation offers many of the attractions of natural wood, but greater strength and resistance to absorption of liquids, cracking, swelling and warping.

A production batch of impregnated sycamore has recently been treated in the irradiation plant of Wantage Research Laboratory of the U.K. Atomic Energy Authority and will be used by Joseph Rodgers & Sons Ltd., for the production of handles for a new range of table cutlery. These handles are particularly hygienic in that they do not absorb liquids and can be repeatedly washed in

Samples from a new range of cutlery using handles made from sycamore wood impregnated with plastic by the Wantage Research Laboratory's irradiation plant.



hot water and even domestic dish washing machines without deterioration.

Natural wood is an attractive manufacturing material but has a tendency to absorb moisture and has limited resistance to abrasion. It also tends to shrink and expand with changing atmospheric conditions during manufacture and use, and may split when exposed to heat. Such properties make it difficult to retain a good surface finish in some applications.

These disadvantages are overcome in wood-plastic composites where the natural pore structure of the wood is filled with an inert plastic consisting of a liquid monomer. This is then hardened by radiation. The new material has great strength and dimensional stability, and withstands moist and dry heat without cracking. Its surface can be machine finished to a durable high polish which enhances the figuring of the wood grain.

The production batch of sycamore was treated in the Authority's 300,000 curie Package Irradiation Plant and is sufficient for the manufacture of 24,000 handles.

Treatment of wood in this fashion is an extension of the service already provided by the Wantage Research Laboratory of the U.K.A.E.A. for the radiation treatment of production batches of manufactured materials.

Enquiries concerning radiation facilities should be addressed to: Radiation Chemistry Section, Wantage Research Laboratory, Wantage, Berks.

Enquiries concerning Joseph Rodgers & Sons should be addressed to Mr. Frith, Alan Chadwick & Partners Ltd., 116, Brompton Road, London, S.W.3. (Tel. KNI 9334).

19th February, 1968

A.E.A. Reports available

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

AERE-M 1929
The Installed Tritium Monitoring System in the Dido and Pluto Reactor Halls. By B. T. James. December, 1967. 6pp. H.M.S.O. 3s. 6d.

AERE-M 1977
Swelling Measurements of Irradiated Fuel Spheres by Microradiography. By R. H. Keep. November, 1967. 13 pp. H.M.S.O. 4s.

AERE-M 2016
A Synchronous Drum Store for Neutron Time-of-Flight Data Recording. By M. C. B. Russell. January, 1968. 5 pp. H.M.S.O. 1s. 2d.

AERE-R 5145
The Harwell High Pressure Transfer Loop. By A. W. Bennett and R. K. F. Keeys. December, 1967. 46 pp. H.M.S.O. 8s.

AERE-R 5342
Gamma-Ray Branching Ratio in the Decay of Zr^{95}. By J. E. Hiscott. January, 1968. 9 pp. H.M.S.O. 2s. 6d.

AERE-R 5679
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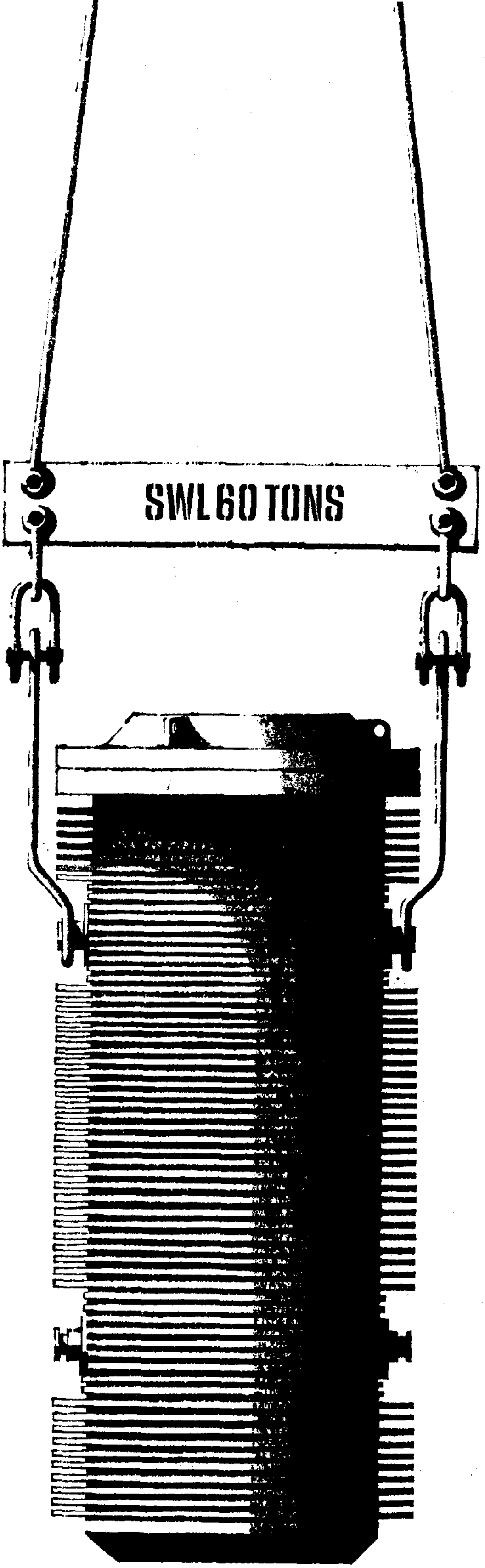

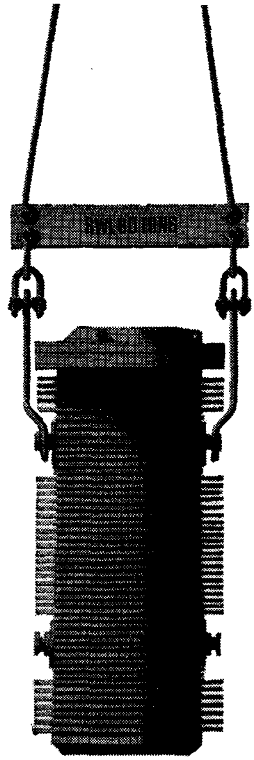

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