ATOM

Number 147 / **January 1969**

MONTHLY INFORMATION **BULLETIN OF**

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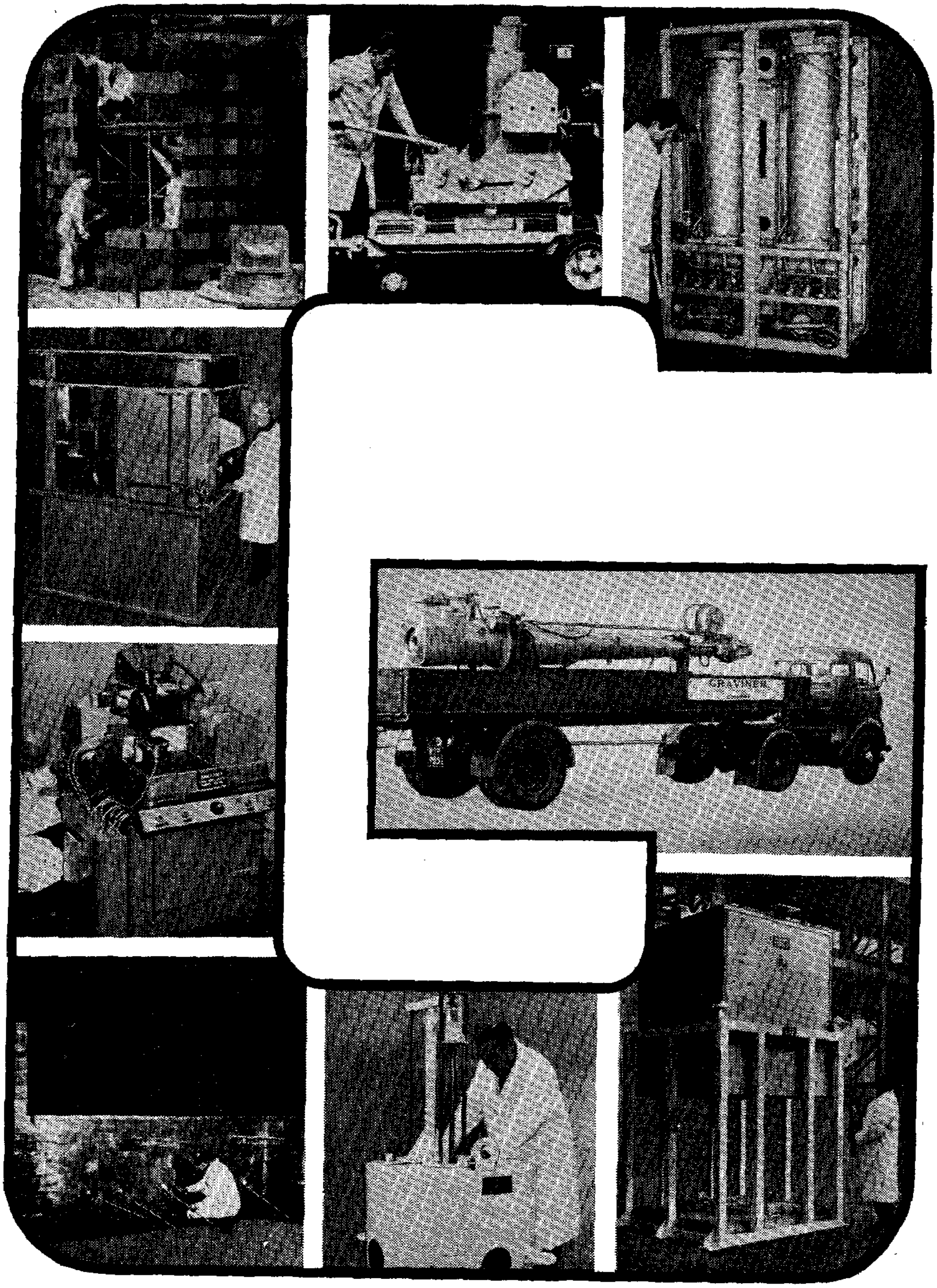
GRAVINER

ATOM

MONTHLY INFORMATION BULLETIN
OF THE UNITED KINGDOM
ATOMIC ENERGY AUTHORITY

NUMBER 147

January 1969

Contents

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

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

DRAGON to continue

The following was issued on behalf of the Board of Management of the O.E.C.D. High Temperature Reactor Project DRAGON. *A simultaneous release was made by the Organisation for Economic Co-operation and Development in Paris.*

Continuation of the O.E.C.D. DRAGON High Temperature Reactor Project at Winfrith, Dorset, to 31st March, 1970 was assured to-day (Tuesday, 26th November) in London when representatives of the United Kingdom, EURATOM, Austria, Denmark, Norway, Sweden and Switzerland signed a prolongation agreement increasing the overall budget of the project since its establishment in April 1959 to £31 million, and outlining a new programme.

Agreement in principle on the extension was in fact reached last July, and to-day's signature formalises this. To-day's agreement includes a provision that signatories will consult together regarding a further possible extension beyond 31st March, 1970. It is agreed that this question shall be determined not later than 30th September, 1969.

The DRAGON project's new programme will include evaluation of high temperature reactor behaviour, based in particular on experience obtained with the reactor experiment at Winfrith. The agreement also provides for consultancy services in the conceptual design of power reactors and components to be made available, on terms to be agreed, to signatories and organisations in their countries.

The DRAGON project was set up in April 1959 under an agreement concluded between the U.K. Atomic Energy Authority, the Austrian and Swiss governments, the national atomic energy authorities of Denmark, Norway and Sweden, and the EURATOM Commission (representing Belgium, France, Germany, Italy, Luxembourg and The Netherlands). Originally for five years, this agreement was extended in 1962 to eight years with an increase in the overall budget from £13.6 million to £25 million. In 1966 a further extension to the end of 1967 was agreed, coupled with a budget increase of £1.5 million, and negotiations were begun for a longer prolongation.

26th November, 1968

Mr. J. C. C. Stewart

Mr. J. C. C. Stewart, C.B.E., Member for Reactors, relinquished that office on 9th December, 1968 on accepting an appointment as Deputy Chairman and Chief Executive of Babcock English Electric Nuclear Limited.

Lead shielding

Lead Development Association, in co-operation with the United Kingdom Atomic Energy Authority, is organising a conference on Lead Shielding and Nuclear Safety from 25th to 27th March 1969, at the Hyde Park Hotel, Kensington, London.

The programme will include two full days of technical discussions at which expert authors, recognised as leading authorities in their various fields, will present papers reviewing all aspects of lead shielding, with special sessions devoted to transport of radioactive materials. On the third day there will be technical visits directly concerned with the subjects discussed.

The Conference should be of special interest not only to those involved in the manufacture and use of lead shields, but also to all those engaged in transport, public safety and insurance.

Programmes, with registration and hotel booking forms, may be obtained on request from the Lead Development Association, 34 Berkeley Square, London, W.1.

Radiation and Man

The International Radiation Protection Association has decided to hold its Second International Congress in Britain. The place selected is Brighton, the dates are 3rd-8th May, 1970, and the organising body is a Committee of the British Radiological Protection Association, an Association of seven scientific societies in the United Kingdom which are concerned with this subject. The first Congress was held in Rome in 1966.

The theme of the Congress will be "Radiation and Man" and will deal both with radiation protection and with the biological effects of radiation.

Further information can be obtained from Mr. Brian Godbold, Central Electricity Generating Board, Laud House, 20 Newgate Street, London, E.C.1. Tel.: City 1202, Ext. 3144.

IN PARLIAMENT

Seaton Carew costs

14th November, 1968

MR. SWAIN asked the Minister of Power (1) why the forecast estimated cost of coal in 1974 was not taken into consideration before the Seaton Carew decision was made;

(2) how the price of electricity which will be produced at Seaton Carew from nuclear energy compares with electricity produced from coal using the forecast estimate of coal as a raw material for 1974.

Mr. Mason: Account was taken of possible reductions in future coal costs, but the advantage of nuclear remained substantial.

Siting policy

14th November, 1968

MR. SWAIN asked the Minister of Power, what safety precautions are proposed to protect the population in the event of a serious accident at any nuclear power station.

Mr. Mason: I am considering publishing a White Paper on nuclear siting policy.

Costs of nuclear generation

14th November, 1968

MR. SWAIN asked the Minister of Power what is the forecast estimate of the cost of electricity produced from nuclear power in 1975.

Mr. Mason: A nuclear station to be commissioned in 1975 could be expected to have lower costs than the estimate for Hartlepool of 0.52d. a unit.

Mr. Swain asked the Minister of Power, what is the amount of public money involved in the production of nuclear energy.

Mr. Mason: The gross investment by the Central Electricity Generating Board in nuclear power stations at 31st March, 1968, was £640 million and initial fuel £69 million. The Atomic Energy Authority's investment is a matter for my right hon. Friend the Minister of Technology.

Talks with Brazil

18th November, 1968

MR. DALYELL asked the Minister of Technology if he will make a statement on his talks with the technological delegation from Brazil.

Mr. Benn: A Brazilian technical mission, headed by General Jose Costa Cavalcanti, Minister of Mines and Energy, visited this country as guests of Her Majesty's Government from 10th to 13th November, 1968. This visit was the culmination of a series of exchanges intended to acquaint the Brazilians with British technology at a stage when they are considering a nuclear power programme.

The Brazilian party was able to study the Steam Generating Heavy Water Reactor (SGHWR) at Winfrith, and the Advanced Gas-Cooled Reactor (AGR) at Dungeness. Both systems are well suited to meet Brazilian requirements, and our visitors had comprehensive discussions about these systems, and the British nuclear power programme generally, with officials from the UKAEA and the CEGB. They were able to talk with both my hon. Friends the Joint Parliamentary Secretaries, and officials from my Department.

I believe that the visit was of benefit to both sides. The Brazilians were able not only to see something of our technology, but also to note the stature of our nuclear power programme as well as the manner in which it is being administered. My Department is now arranging for the visit to be followed up with further information about the legislative and administrative arrangements necessary for the successful introduction of a nuclear power programme, with special emphasis on the means to be employed to reproduce Britain's outstanding safety record.

I believe that collaboration in the nuclear field between the two countries would be mutually advantageous and that the visit has contributed to this end. I shall, of course, do everything I can to promote it.

European collaboration

22nd November, 1968

MR. DAVID WATKINS asked the Minister of Technology what recent moves there have been concerning collaboration with European countries on nuclear energy matters.

Mr. Benn: The U.K.A.E.A. have been pursuing for some years a development programme on centrifuge technology for the enrichment of uranium.

Work on similar lines has taken place in the Netherlands and in the Federal Republic of Germany. The United Kingdom and these two countries have now agreed to issue the following statement:—

"A meeting will take place in The Hague on Monday, 25th November between Ministers of the Netherlands, the Federal Republic of Germany and the United Kingdom. It will be attended by the Rt. Hon. Anthony Wedgwood Benn, M.P., Minister of Technology and by the Rt. Hon. Frederick Mulley, M.P., Minister of State, Foreign and Commonwealth Office, on behalf of the United Kingdom; for the Netherlands by Mr. de Block, Minister of Economic Affairs and Mr. de Koster, State Secretary Ministry of Foreign Affairs, and for the Federal Republic of Germany by Dr. Stoltenberg, Minister of Scientific Research and Mr. Lahr, State Secretary, Ministry of Foreign Affairs. The purpose of the meeting will be to discuss the implications of recent developments in relation to the technology of the gas centrifuge method of uranium enrichment, a field in which the three countries have been particularly active; and to consider the possibility of establishing collaborative arrangements for the exploitation of this method of uranium enrichment".

Reorganisation

25th November, 1968

MR. MACLENNAN asked the Minister of Technology what plans he has for the reorganisation of the nuclear power industry in the light of the fact that the Industrial Reorganisation Corporation are unable to secure agreement as to the formation of a second nuclear boiler group.

Mr. Benn: Following the set-back to the negotiations to create the second design and construction company, the Industrial Reorganisation Corporation is receiving wide support in a renewed attempt to complete the reorganisation as soon as possible.

27th November, 1968

MR. W. T. WILLIAMS asked the Minister of Technology what are his proposals with regard to the reorganisation of the nuclear industry, in particular with regard to the future position of Atomic Energy Authority staff in relation to such reorganisation and if he will make a statement.

Mr. Benn: In implementing the proposals for the reorganisation of the nuclear industry, set out in my statement of 17th July, careful consideration is being given to the position of Atomic Energy Authority staff. Many consultations with staff and trade union representatives have taken place, and these will continue.

27th November, 1968

MR. DAVID PRICE asked the Minister of Technology when he will be introducing legislation to establish a new publicly-owned company to take over the Atomic Energy Authority's responsibilities for nuclear fuel.

Mr. Benn: I cannot anticipate when legislation will be introduced, but, as the hon. Members are aware, some aspects of the reorganisation which do not require legislation are already going ahead.

Mr. Palmer: Is my right hon. Friend aware that there is disappointment among members of the Select Committee on Science and Technology, who worked hard on this question, at the great delay in reorganising the nuclear reactor industry? Does he not recall that he himself told the Committee well over 12 months ago that the need for the reorganisation was urgent and that it should be carried through as quickly as possible?

Mr. Benn: I appreciate that, but we have one design construction company going. The negotiations on the second one have fallen through. The work, involving the Atomic Energy Authority and including legislation, has proved a very big job indeed. I assure my hon. Friend that we have not been slow in tackling this very complex problem, on which we most certainly received help from his Committee.

Mr. Price: I understand many of the right hon. Gentleman's problems, but why cannot progress be made with getting ahead with the publicly-owned nuclear fuel company? Does not he agree that continued delay is bad for the morale of the staff both of the A.E.A. and of the private nuclear engineering firms involved?

Mr. Benn: I appreciate that point, but if we are to have proper legislation it means dealing with the Authority's future, with the Atomic Energy Board and with a number of other things, and all this cannot be rushed. In the industry itself there is now a greater degree of certainty about the future than there was before we were able to announce our decision.

Mr. Gregory: Does not my right hon. Friend agree that, despite the difficulties we are experiencing in the regrouping and reorganisation of the boiler-making side of the industry, and also in the civil engineering, we should try to speed up the process in order to give a chance to this very important industry? The more delay there is the more difficult the problems become.

Mr. Benn: The delay on that side is not being caused by me but by the difficulty in getting the industrial mergers set up. I asked the I.R.C. to undertake this some time ago and I am not directly engaged in the negotiations.

Mr. Gregory: Is the Minister aware that the long delay in completing reorganisation is causing great anxiety to workers and management in the nuclear engineering industry in my constituency? The question that must be put is: what will be the future of those firms at present within the nuclear engineering industry which may be left out on the fringe of a second consortium structure?

Mr. Benn: The truth is that if we try to reorganise anything it is bound to affect those concerned in the work which was done before, and uncertainty is inseparable from this process. If my hon. Friend has any particular points in mind which he would like to bring to me I will see what I can do to ease unnecessary uncertainty.

Reactor programme report

27th November, 1968

MR. DAVID PRICE asked the Minister of Technology when he intends to present to the House his written observations on the Report of the Select Committee on Science and Technology on the subject of the United Kingdom Nuclear Reactor Programme, dated 25th October, 1967, House of Commons Paper No. 381-XVII.

Mr. Benn: I have written to the Chairman of the Select Committee about the Committee's recommendations which are of concern to me. My letter is being studied by the members of the Select Committee, who are considering its publication.

Superheated plasma containment

27th November, 1968

MR. PALMER asked the Minister of Technology if he will make a statement on the recent successful experiments conducted at the Culham Laboratory of the Atomic Energy Authority in the containment of superheated plasma in a magnetic field.

Mr. J. P. W. Mallalieu: Recent experiments reported in the Press demonstrated that the ideally-expected slow rate of escape of hot plasma across the confining magnetic field can be achieved under these particular experimental conditions. This is encouraging to the scientists whose work is directed ultimately to the development of a fusion reactor.

Sir H. Legge-Bourke: In view of the very much longer time scale on which most of the work at Culham operates compared with the rest of the work in the A.E A., will the hon. Gentleman consider the possibility that the S.R.C. might be the better auspice under which to put the Culham Laboratory?

Mr. Mallalieu: These things are being considered and I will look at that suggestion.

Fast reactor progress

27th November, 1968

MR. EADIE asked the Minister of Technology if he will make a statement about progress on fast breeder reactors.

Mr. J. P. W. Mallalieu: The Atomic Energy Authority's Dounreay Fast Reactor, which commenced operation in 1959, has provided information and operating experience needed to design a prototype reactor for full scale power production. This 250 MW(E) prototype reactor is now being built, and it could be the basis for designs of commercial fast reactors to be introduced by the mid-to late 1970s.

Mr. Maclennan: Will my hon. Friend confirm that before the mid-1970s power will be available to Scottish industry from the prototype fast reactor?

Mr. Mallalieu: Yes, certainly.

Uranium from Scotland

27th November, 1968

MR. ALEX EADIE asked the Minister of Technology if he will make a statement on the progress made in prospecting for uranium in Scotland.

Mr. J. P. W. Mallalieu: As part of the uranium reconnaissance programme carried out in the north of Scotland numerous samples of water and steam sediments have been collected. Much analytical work has still to be done but at least four areas appear to merit more detailed assessment.

Mr. Eadie: Is my hon. Friend aware that this has created a great deal of interest in the Press in Scotland? Can he tell the House whether any calculations have been made of the economic and financial advantages this would mean to the economy?

Mr. Mallalieu: I am sure that it is arousing interest in Scotland, as elsewhere. On the economic question, this is trying to prepare an insurance, a fallback position, in case there is any difficulty in getting supplies from elsewhere.

Nuclear ships

27th November, 1968

MR. WALL asked the Minister of Technology if he will make a statement on the development of a nuclear reactor for surface ships.

Mr. Fowler: I have nothing to add to the Answer my right hon. Friend made in reply to a Question by the hon. Member on 14th October.

Mr. Wall: Is the hon. Gentleman aware that the Italians are now building a nuclear-powered naval auxiliary ship? Is it not time that this country, the leading maritime nation, should begin to get some experience of this new type of propulsion afloat? Will the Government consider building some sort of naval vessel to give us that experience?

Mr. Fowler: The hon. Gentleman asked about naval vessels. If he wants an answer on that subject he must address his question to the Secretary of State for Defence. We have two shipbuilders in touch with us about possible Mintech support for a study of this and other projects, and we shall need to do some work on it. We are determined to go ahead with a prototype ship only if it can be justified in terms of the expected benefits to British industry, and if they are commensurate with the costs.

Mr. Small: Does my hon. Friend recognise that we are being leapfrogged in maritime reactor technology by Japan, West Germany, and Russia, and that active attention is urgently necessary?

Mr. Fowler: Much of the technology is quite familiar to us. My hon. Friend must accept from us that we are determined to do only what is commercial. We are

continued on page 25

A review of experience with gas-cooled reactors

The following paper by R. V. Moore, G.C., C.B.E., B.Sc.(Eng.), F.I.Mech.E., F.I.E.E., Managing Director, Reactor Group, U.K.A.E.A. was presented to the American Nuclear Society, Washington D.C. in November, 1968.

Introduction

Operating experience with nuclear power plants, compared with that of fossil-fuel plants, is still quite limited. Nevertheless, nuclear installation capacity in the world has started to rise quite rapidly over the last year or two. Because operating experience is limited at the present time, what there is is extremely valuable and the lessons learnt must be incorporated promptly and efficiently into plants still in the design phase.

There are, in fact, three distinct thermal reactor systems in commercial operation today. At present gas-cooled graphite moderated reactors have the largest installed capacity but this is rapidly being overhauled by the light-water reactors, either P.W.R. or B.W.R., of which a very large number are under construction in the United States. The smallest programme is for heavy-water moderated reactors.

The graph opposite shows the installation rate for these three classes of reactors. The steady rise in installation of the gas-cooled graphite moderated reactors contrasts with the rather rapid and recent increase in the case of the light-water reactors. At today's date, the most extensive operating experience is with the gas-cooled graphite moderated reactors; but even in this case, barely a decade of operating experience has been accumulated by the electrical utilities.

The subject of this paper is to review some of this practical operating experience, and to take a look at the trend of developments as it affects future operation of these plants. The paper first reviews the scale of the gas reactor programme, then reviews operating experience which has so far accumulated, and concludes with some observations on the future trends which can be foreseen.

The scale of the gas reactor programme

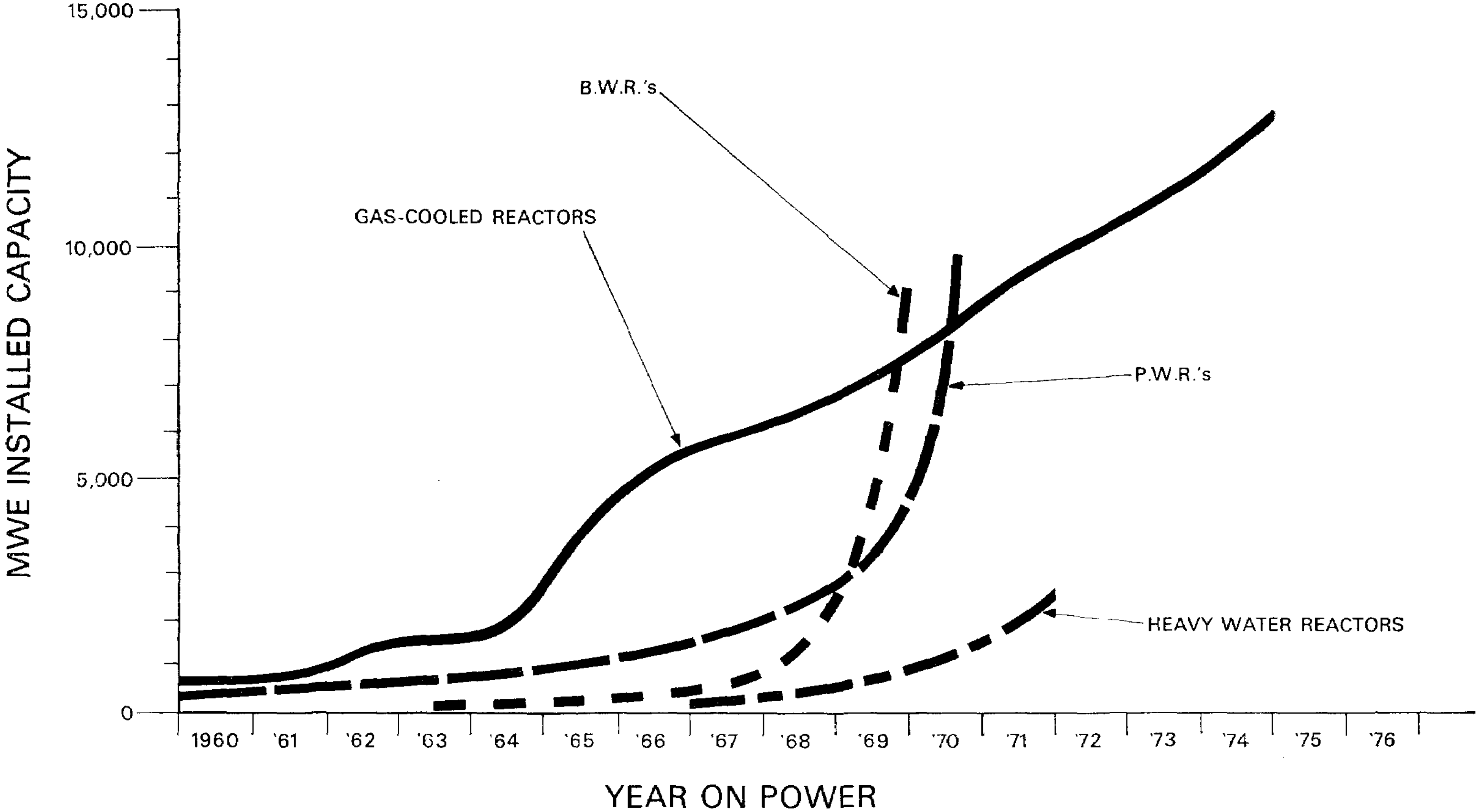
There are today well over 30 commercial gas/graphite reactors in service in the world (Table 1) with a total installed capacity between them of nearly 6000 MWE gross electrical output. Some 25 of these are in daily operation in the U.K. with a capacity of over 4500 MW gross. France has over 800 MWE and Italy over 200 MWE installed, while the Tokai Mura reactor now operating successfully in Japan has a gross capacity of over 160 MWE.

There are eight further gas/graphite reactors at present being constructed in the U.K. together with two more where construction is due to start. They represent a further 6000 MWE of installed capacity and will bring the percentage of total installed capacity filled by gas-cooled nuclear plant in the early 1970's from the present 10 to nearer 15%. The forward French programme will see an addition to their network of some 3000 MWE of gas-cooled plant by 1975 and by that time the total Anglo-French gas-cooled capacity on load will exceed 15000 MWE.

The present large installed capacity of utility-operated gas-cooled reactor stations and the further building programme underway emphasises the confidence in this system which experience in operation has given.

The main chronological details in the build up to the present position since 1946 in the U.K. and in France are shown in Table 2. Following the operation of reactors built solely for plutonium production the U.K. were satisfied in 1953 that the gas-cooled system could be used in an economic nuclear power station and by 1956 the Calder Hall gas-cooled reactors, which, while producing power were not optimised for this purpose, were generating electricity to the U.K. grid. This station and its duplicate Chapelcross have operated up to date with cumulative load factors of over 85%.

The Central Electricity Generating Board who had followed the Calder experience closely were sufficiently convinced to put



INSTALLED CAPACITY-REACTOR TYPES

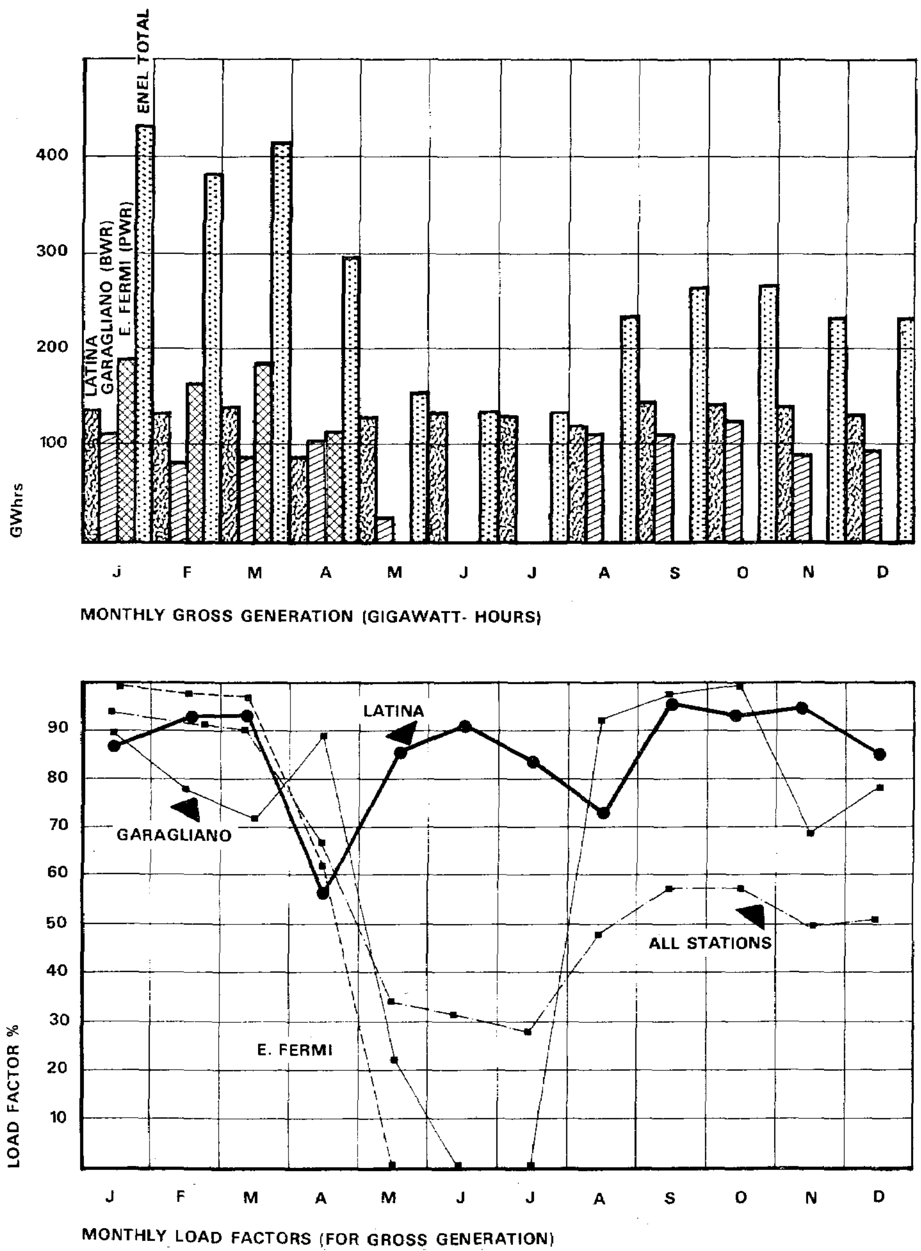


Fig. 1—*ENEL stations performance* 1967

on order in 1956 their first two gas-cooled nuclear stations, Berkeley and Bradwell, with a combined gross output of over 700 MWE. A year later the South of Scotland Electricity Board ordered the Hunterston A Station of 360 MWE gross to be followed by the Italian organisation ENI ordering a station of over 200 MWE for the Latina site, south of Rome.

In 1962 Berkeley and Bradwell were generating power followed a year later by Latina and by 1966 (only 10 years after Calder) the total installed capacity in the U.K. alone had risen from less than 500 MWE to nearly 4000 MWE gross. Gas-cooled stations began generation with almost monotonous regularity, Bradwell, Berkeley, Hunterston A, Latina, Hinkley A, Trawsfynydd, Dungeness A, and Sizewell, followed by Tokai Mura in Japan,

Table 1—*World list of major gas-cooled reactors in service*

Station	Gross capacity MWE	Number of reactors	Year of start-up	Total electricity produced up to January 1968—MWhrs (rounded figures)
United Kingdom				
Calder Hall†	220	4	1956	29,000,000 (Calder Hall and Chapelcross)
Chapelcross†	220	4	1958	
Berkeley	334	2	1962	11,000,000
Bradwell	374	2	1962	13,000,000
Hunterston A*	360	2	1964	9,000,000
Hinkley Point A	664	2	1965	11,500,000
Trawsfynydd	585	2	1965	6,750,000
Dungeness A	577	2	1965	8,000,000
Sizewell	652	2	1966	4,750,000
Oldbury	626	2	1967	100,000
A.G.R. Windscale†	40	1	1963	1,200,000
Sub-total	4,652	25		94,300,000
France				
G1 Marcoule	3	1	1956	3,750,000 (G1, G2 and G3 Marcoule)
G2 Marcoule	40	1	1959	
G3 Marcoule	40	1	1960	
EDF1 Chinon	70	1	1963	1,100,000
EDF2 Chinon	200	1	1965	2,500,000
EDF3 Chinon	480	1	1966	270,000
Sub-total	833	6		7,620,000
Italy				
Latina	210	1	1963	6,600,000
Japan				
Tokai Mura	166	1	1966	1,200,000
U.S.				
Peach Bottom	40	1	1967	180,000
Grand total	5,901	34		102,900,000

†—U.K.A.E.A. Stations
*—South of Scotland Electricity Board Station

all came into operation over this period. A year later in 1967 the first station using the concrete pressure vessel concept, Oldbury, joined the U.K. grid.

Concurrently the French had brought their Marcoule reactors and EDF 1, 2, and 3 on power with an installed capacity of near 850 MWE.

The gas-cooled system has all along been backed by research and development facilities on a considerable scale covering all aspects of reactor technology and including irradiation facilities, fuel and metallurgical research laboratories, engineering development installations and an extensive computer network. It has been found of incalculable value that future developments to the gas-cooled system have been based on a strong R & D effort coupled with a large volume of day by day experience coming from power stations operating under commercial conditions.

The progress made in total installed capacity and units of electricity generated has been complemented by a steady logical progress in design and design parameters. (Tables 3 and 4.) In 1958 a comprehensive investigation had shown that considerable savings in capital cost could be achieved in adopting slightly enriched ceramic fuel in place of the natural metallic fuel used up to that time and this became the basis of the Advanced Gas-Cooled Reactor (AGR). The prototype for this reactor development came into operation in 1963 and from the highly encouraging experience coming from it the first utility-ordered AGR (Dungeness B 1320 MWE gross), due to join the network in 1970, was ordered by the C.E.G.B. Their choice followed a detailed study of other reactor systems.

An illustration of how the AGR development has reduced the size (and by inference the capital cost) of the gas-cooled reactor

Table 2
Main chronological steps in U.K. gas reactor evolution

1946—Design Offices start on design of British Experimental Pile built at Harwell (BEPO).
1947—Start design Windscale Air-Cooled Piles.
1951—Calder feasibility studies.
1953—Design work started on 1st commercial nuclear station—Calder Hall.
1956—1st commercial nuclear station—Calder Hall—on power.
1958—Chapelcross station on power.
1962—First 2 C.E.G.B. commercial nuclear stations (Bradwell and Berkeley) on power.
1963—Advanced Gas-Cooled Reactor, Windscale—on power.
1963—Latina station on power (ENEL).
1964—Hunterston A station on power (South of Scotland Electricity Board).
1965—Dungeness A station on power.
1965—Hinkley Point A station on power.
1965—Trawsfynydd station on power.
1965—Contract let for Advanced Gas-Cooled (AGR) Reactor at Dungeness B (1320 MW gross).
1965—Tokai Mura, Japan, on power.
1966—Sizewell station on power.
1967—Oldbury station on power (pre-stressed concrete vessel).
1967—Contract let for AGR at Hinkley B (1320 MW gross).
1967—Contract let for AGR at Hunterston B (1320 MW gross).
1968—Contract for AGR at Hartlepool under negotiation (1320 MW gross).

Main chronological steps in French gas reactor evolution

1959—G2 Marcoule on power.
1960—G3 Marcoule on power.
1963—EDF 1 Chinon on power.
1965—EDF 2 Chinon on power.
1966—EDF 3 Chinon on power.

Forward programme

1969—St. Laurent 1 (480 MW) on power.
1971—St. Laurent 2 (515 MW) on power.
1972—Bugey 1 (540 MW) on power.
1973/74—Fessenheim 1 (750 MW) on power.
1974/75—Fessenheim 2 (750 MW) on power.

can be gauged from a study of Fig. 2 which shows to the same scale a Bradwell reactor (150 MWE) commissioned in 1962 and one of the latest AGRs to be ordered (Hunterston B) which will generate by 1972/73.

Parameters have consistently moved forward. From a 34.5 MWE reactor at Calder in 1956, we have moved to a 625 MWE reactor (1250 MWE station) size in the present Advanced Gas-Cooled Reactors under construction. From relatively low grade steam conditions at Calder, we have moved to 2300 p.s.i. (162 kg cm^2) 1050°F (565°C) steam in our latest stations thus producing steam conditions right in line with the requirements of modern, high efficiency turbo generator sets. From an overall thermal efficiency of around 20%, we have moved to around 42%. From large thick walled steel pressure vessels and external heat exchangers, we have progressed, as our confidence grew with experience, to pre-stressed-concrete pressure vessels with an integral design of core, heat exchangers, and blowers and in the process have given ourselves freedom to site the latest stations near to large urban centres.

The scale of the gas reactor programme to date has been considerable. I shall now deal with the operating experience which lies behind it.

Operating experience with gas-cooled reactor power stations

This experience can, perhaps, best be considered firstly in terms of the overall experience with complete stations and secondly with specific experience of components within them. When dealing with

Table 3—*Gas-cooled reactors—design evolution*

	1946 Harwell/ Windscale	1956 Calder Hall	Commercial natural uranium stations	1970 AGR
Moderator	Graphite	Graphite	Graphite	Graphite
Coolant	Air	CO_2	CO_2	CO_2
Fuel	Natural uranium	Natural uranium	Natural uranium	Enriched UO_2
Fuel cladding	Aluminium	Magnox	Magnox	Stainless steel
Refuelling	Off-load	Off-load	On-load	On-load
Pressure vessel	Atmospheric (No pressure vessel)	Steel	Steel, then prestressed concrete	Prestressed concrete

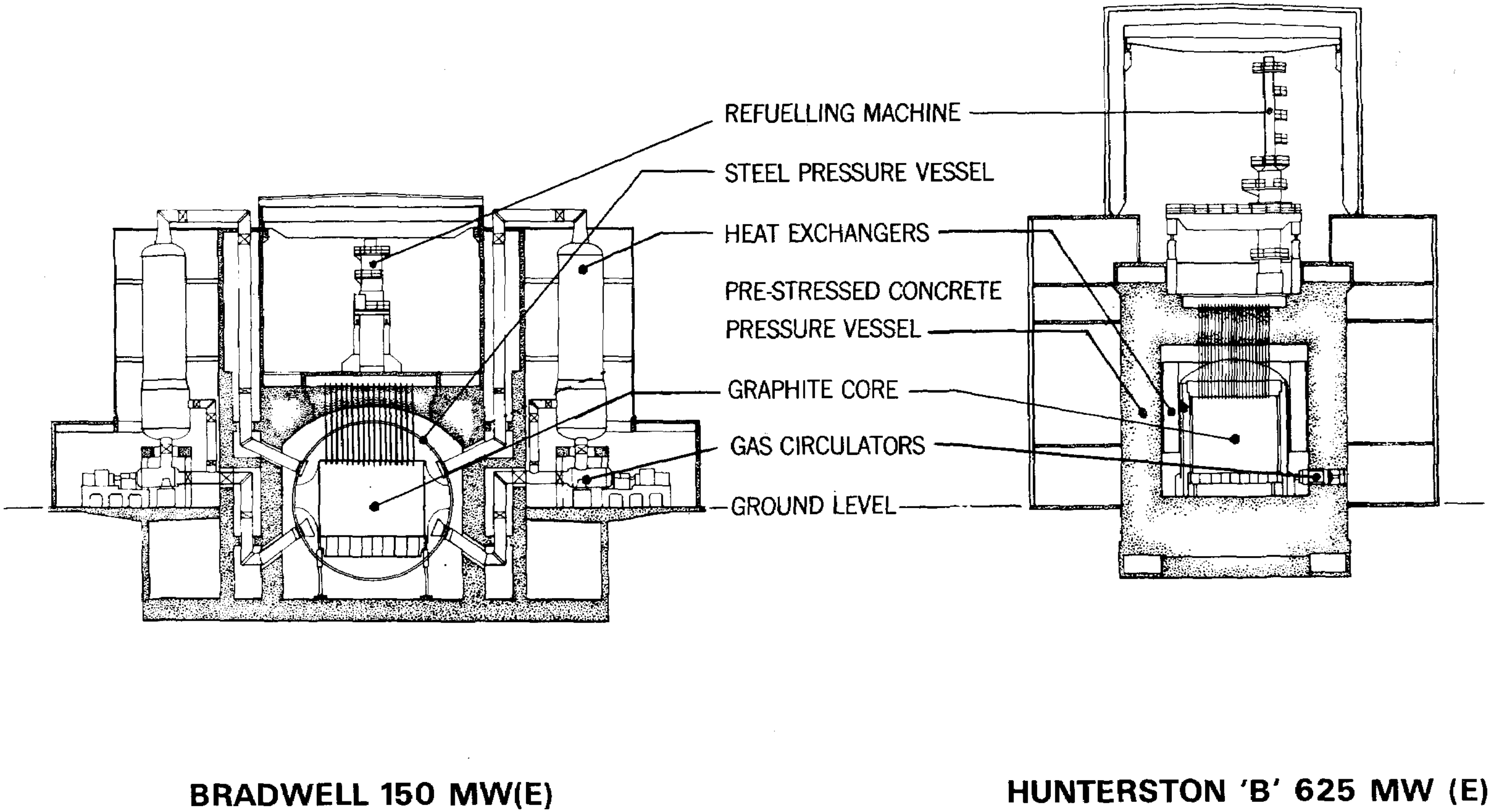


Fig. 2—*Bradwell and Hunterston B*

Table 4—*Progress of main reactor parameters—typical gas-cooled reactors*

Reactor and date on power	MWe nett per reactor	Thermal efficiency	Mean fuel rating MWE/TeU	Gas outlet temperature °C	Coolant pressure p.s.i.a.
1956—Calder* ..	34.5	19.2	0.27	336	115
1962—Bradwell ..	150	28.2	2.22	390	196.5
1965—Dungeness A ..	275	32.8	2.76	410	350
1971—Dungeness B ..	600	41.5	4.0	675	450
1972—Hinkley B ..	625	41.7	5.1	665	600

*Parameters at outset

Table 5—*Cumulative load factors—gas-cooled stations*

U.K. commercial stations

Station	Cumulative load factors %
Calder	87.0
Chapelcross	87.5
Berkeley	71.8
Bradwell	80.7
Hinkley Point A ..	78.9
Trawsfynydd	46.6
Dungeness A	73.6
Sizewell	47.1
Hunterston	81.7

French gas-cooled stations

Station	Cumulative load factors %*
G2/G3 Marcoule ..	84.5
EDF 1 Chinon	30.5
EDF 2 Chinon	63.2

Italian gas-cooled stations

Station	Cumulative load factor %
Latina	83.3

*French stations are quoted on basis of gross electrical power.

component experience it may be most helpful to concentrate on those parts of the design where significant concern on subsequent performance was felt in the early design stages and on unexpected happenings which arose in operation. Naturally, because I am most familiar with them, this survey will relate to U.K. built reactors although some French data is included in the accompanying Tables for purposes of comparison.

Overall experience

It is of paramount importance to the utility that their power plants have high availability. In this respect gas reactors have performed admirably. From Table 5 it will be seen that of the nine fully operative commercial gas-cooled stations (22 reactors) in the U.K., starting from Calder Hall in 1956, five stations (14 reactors) have already achieved cumulative load factors of well over the 75% target originally set and two stations have cumulative load factors of over 70%. The relatively low early load factors of the remaining two are due in the main to difficulties encountered with conventional plant in their first years of operation. There is no doubt

Table 6—*Progress of Bradwell and Latina load factors*

Station	Station design output MWe nett	Maximum achieved MWe nett	Annual load factor %*					
			1962/63	1963/64	1964/65	1965/66	1966/67	1967**
Bradwell (2 Reactors)	300	322.8	72	72	79	87	82.5	90.3
Latina .. (1 Reactor)	200	216		84	82.6	78.6	86.2	

**Year ending March 1967 *Calendar Year

that these, too, will, in due course, comfortably pass the 75% figure.

As with any other new venture it was expected that the first year or so of operation would show up various teething troubles. As these were cleared the availability of the stations showed a progressive improvement. The experience with one of the first two utility-ordered stations, Bradwell, illustrates this general trend. Table 6 shows how its yearly load factor has increased from 72% in 1962/63 to over 90% in 1967/68. Its load factor during the winter months has been over 90% for the last four years.

The Central Electricity Generating Board has carried out a provisional analysis of the causes of outage on their nuclear stations. This is summarised in Sheets 1 & 2 of Table 7. It can be seen that in the early years of operation, faults on plant, other than the reactor, predominate. After this early period, annual load factors (including outages for planned overhaul) are regularly between 80 and 90%, when unplanned outages become relatively insignificant. The distribution of faults causing unplanned outages on the station after the early years is fairly random. As a typical example of reactor trips, involving shut-down and depressurisations, the record for the nuclear power stations at Bradwell and Berkeley during 1967 is shown on Table 8.

Although the stations built and operated to date (the "Magnox" stations) are all of the CO_2 cooled, graphite moderated type, there are some significant differences in the manner in which different designers have tackled the engineering problems. For example, one station (Hunterston A) has the fuel charge and discharge operation carried out from the bottom of the reactor vessel while the others carry out the operations from above. Again, two stations (Dungeness A and Oldbury) have gas blowers driven directly from back pressure turbines while others employ either a D.C. motor or some form of induction motor with frequency variation.

These engineering design variations have meant that in a number of cases specific plant experience gained on one station was not necessarily directly applicable to the others. The latest gas-cooled reactors under construction have limited the engineering differences between more or less concurrent stations. This has been possible because the optimum arrangement and design of plant has become clearer from the experience of operation we now have.

An impressive example of how experience carried directly from one station to the next can pay a handsome dividend may be illustrated by consideration of the Bradwell and Latina stations. The Latina reactor in Italy followed some 18 months behind Bradwell. They were both built by the same company to the same basic engineering design.

Table 6 and Fig. 1 show the load factors, and illustrate the dependability of the Latina reactor. They are, by any reckoning, remarkable. Only once in its five years of operation has the yearly load factor been below 80% (then it was 78%), while the cumulative load factor is about 84%. There are some differences in the Latina design compared with Bradwell. Latina, for example, is a single reactor station with a reactor output 50 MW above Bradwell. It also has a control system designed to meet an electrical distribution system from the station which differs from Bradwell. Nevertheless the plant design is essentially the same, in consequence a considerable amount of experience arising in Bradwell was applicable to the Latina station. The interpretation and use of this experience by the Italo/U.K. team involved was a large contributory factor in the station's success.

Substantial reductions have been made in commissioning right from initial fuelling which has risen from 700 elements a day at Bradwell to 2900 per day at Oldbury through physics measurements (whereas experience has allowed considerable streamlining of tests) to the eventual running up to power. As a typical example, Table 9 shows the times taken to adjust channel coolant flow gag settings at the base of each fuel channel. In this, as in many other cases, the reductions in commissioning time have been due both to improved organisation and to a better understanding of the accuracies required. The relaxation in requirements, as in so many other fields, has been a big pay off from the U.K. investment in acquiring experience.

Maintenance of plant became easier as confidence grew with experience. It has been found possible for example to enter a

Table 7: ***Provisional allocation of outage between reactors, other plant and overhaul*** Sheet 1

	Bradwell								Berkeley							
	Reactor 1 Unit				Reactor 2 Unit				Reactor 1 Unit				Reactor 2 Unit			
	1964/65	1965/66	1966/67	1967/68	1964/65	1965/66	1966/67	1967/68	1964/65	1965/66	1966/67	1967/68	1964/65	1965/66	1966/67	1967/68
% Outage due to reactor faults .. (1)	0.55	0.36	0.64	0	0.83	0.27	0.29	1.52	2.82	0.33	0.64	6.11	3.30	0	5.13	0.15
% Outage due to reactor limitations (2)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
% Miscellaneous reactor outage .. (3)	1.14	1.39	0	1.17	0.27	0.28	0	0	0.16	2.04	0.57	0.16	0	0.33	1.46	0.37
% Total reactor outage (1)+(2)+(3)	1.69	1.75	0.64	1.17	1.10	0.55	0.29	1.52	2.98	2.37	1.21	6.27	3.30	0.33	6.59	0.52
% Outage due to plant other than reactor..	1.68	0	10.44	0	2.07	0	2.94	0.33	2.27	0.06	0	2.90	0	0	0	0
% Overhaul	10.17	19.33	0	9.87	10.52	0	11.78	0	32.34*	0	15.99	0	15.47*	13.84	0	9.94
% Availability of reactor plus associated generating plant ..	86.46	78.92	88.92	88.96	86.31	99.45	84.99	98.15	62.41	97.57	82.80	90.83	81.23	85.83	93.41	89.54

Notes:—1. The reactor unit comprises the core, fuelling machinery, gas circulators and control instrumentation equipment.

2. The boilers are included under other plant.

3. Periods shown refer to 1st April in one year to 31st March in the following year except for 1967/68 which is for the 11 months 1st April 1967 to 29th February 1968.

4. Miscellaneous reactor outages include S/D imposed by fuelling machinery.

*Includes major plant modifications to control circuits, fuelling equipment and gas circulators.

Table 7: *Provisional allocation of outage between reactors other plant and overhaul* Sheet 2

	Hinkley Point A						Trawsfynydd						Dungeness A						Sizewell				
	R1 Unit			R2 Unit			R1 Unit			R2 Unit			R1 Unit			R2 Unit			R1 Unit			R2 Unit	
	1965/66	1966/67	1967/68	1965/66	1966/67	1967/68	1965/66	1966/67	1967/68	1965/66	1966/67	1967/68	1965/66	1966/67	1967/68	1965/66	1966/67	1967/68	1965/66	1966/67	1967/68	1966/67	1967/68
% Outage due to reactor faults (1)	0.96	0.52	4.57	4.87	0.16	2.05	0.75	30.16	4.61	2.58	3.48	16.71	10.15	6.13	0.07	4.01	0.77	0.26	0	5.18	7.82	3.09	0.26
% Outage due to reactor limitations (2)	1.26	4.09	5.36	0.74	4.43	3.43	0	0.25	0	0	0	0	0	0	2.55	0	0	2.58	12.25	3.70	0.86	3.01	0
% Miscellaneous reactor outage (3)	0.48	0.90	0	0.27	0.55	0	16.44	1.20	0.79	12.97	6.67	1.15	2.12	0.32	0.10	0	0.04	1.29	4.59	0.52	0	1.05	1.04
% Total reactor outage (1)+(2)+(3)	2.70	6.51	9.3	5.88	5.14	5.48	17.19	31.61	5.40	15.55	10.15	17.86	12.27	6.45	2.72	4.01	0.81	4.13	16.84	9.40	8.68	7.15	1.30
% Outage due to plant other than reactor ..	14.02	11.92	7.70	21.51	6.80	5.66	28.09	34.98	10.92	18.32	25.30	6.87	13.04	8.17	10.76	6.42	6.61	8.57	4.38	30.29	7.34	21.70	17.63
% Overhaul ..	8.35	0	10.62	0	5.49	0	6.04	0	13.25	0	3.01	13.34*	0	9.19	6.68	0	11.19	0	0	15.98	15.46	0	16.56
% Availability of reactor plus associated generating plant ..	74.93	82.55	71.75	72.61	82.57	88.86	48.68	33.41	70.43	6.13	61.54	55.93	74.69	76.19	79.84	89.57	81.39	87.30	78.78	44.33	68.52	71.15	64.51

Notes:—1. The reactor unit comprises the core, fuelling machinery, gas circulators and control instrumentation equipment.
2. The boilers are included under other plant.
3. Periods shown refer to 1st April in one year to 31st March in the following year except for 1967/68 which is for the 11 months 1st April 1967 to 29th February 1968.
4. Miscellaneous reactor outages include S/D imposed by fuelling machinery.

*Includes major plant modifications.

Table 8—*Record of reactor trips, shut-downs and depressurisation—Bradwell/Berkeley* 1967.

Berkeley

	Trip		Shutdown		De-pressurise		Cause
	R1	R2	R1	R2	R1	R2	
January			1		1		To release handling mechanism from reactor
February				1			To recommission circuit 16 after bellows repairs
March				1		1	To recover fuel element lower bridge piece and 2 struts
May	1						High temperature margin trip
		1					During thermocouple response test
June				1			Caused by increase in circuit gas humidity
August		1					Caused by inadvertent disconnection of thermocouple from axial temperature trip unit
September		1					By temperature protection trip during duct valve test
						1	Depressurised after trip to reposition incorrectly-loaded flux-scanning guide tube
Totals	1	3	1	3	1	2	

Bradwell

	Trip		Shutdown		De-pressurise		Cause
	R1	R2	R1	R2	R1	R2	
April			1		1		Shutdown for statutory inspection and overhaul
May		1					Trip caused by complete loss of station supplies following fault in 132 kV grid sub-station
June	1						Trip during routine handling of SDA with trailing lead t/c fuel element
July	1						Trip following earth fault trip of Rayleigh feeder during severe storm
August		1					Trip initiated by loss of supplies to SDA during maintenance
September	1						Trip initiated by SDA during sector rod withdrawal
Totals	3	2	1		1		

reactor after operation and this has been done both at Calder and Oldbury.

Summarising, we can say that commercial gas-cooled reactor stations have been surprisingly easy to operate and to maintain at high availability. It would be quite wrong, however, to suggest that this satisfactory position has been reached without considerable effort and this paper now goes on to examine some specific difficulties which have had to be overcome.

Specific component experience

The operation of plant and components over prolonged periods and under industrial conditions is the only sure way to prove design decisions. From this experience we have built up a sound appreciation of what can and cannot be done with the gas-cooled nuclear power station.

The main features of this system are the graphite moderator and reflector; the fuel; the fuel handling facilities; the pressure vessel; the gas circulators; the boilers; and the control and instrumentation. An examination of the experience with each of these follows:

Table 9—*Coolant gag setting times during commissioning C.E.G.B. stations*

Station		Time taken to set channel gags, days		Total number of fuel channels
		Planned	Actual	
Bradwell	R1 R2	21 21	52 62	2,624 2,624
Berkeley	R1 R2	8 16	31 34	3,265 3,265
Hinkley Point	R1 R2	24 24	56 9	4,500 4,500
Trawsfynydd	R1 R2	28 9	17 8	3,740 3,740
Dungeness	R1 R2	12 12	10 5	3,932 3,932
Sizewell	R1 R2	16 13	14* 22	3,738 3,738
Oldbury	R1 R2	12 12	9 14†	3,308 3,308

*The design prevents simultaneous measurement and adjustment of channel mass flows, with a consequent increase in the time required for the gag-setting operations.

†Delays due to gas circulator trouble and lack of cooling water.

Graphite

The major considerations governing the early design of the graphite core were dimensional changes likely under operating conditions, understanding the mechanism of stored energy accumulation during irradiation, and, as parameters became more advanced, dealing with any CO_2/graphite chemical reaction and subsequent erosion, which might lead to unacceptable weight loss of the moderator.

The general approach to the dimensional change problem was to evolve a design which was not totally reliant on the physical properties of graphite for its successful operation. An example of this is in the keying of the structure to its steel supports and restraints so that its bulk movement is as steel rather than graphite. Where reliance on specific graphite properties within this bulk movement was required for successful operation, a large irradiation specimen programme and considerable out-of-reactor development has produced satisfactory design methods so that no problem has been experienced with any reactor core in commercial operation.

There has been now for some time, a complete understanding of the stored energy mechanism and there is no operational difficulty on this score. Re-entrant cores, where the graphite is kept at an acceptable temperature by a by-passed coolant flow, ensure that on the advanced gas-cooled reactors stored energy is no limiting factor in operation.

In the early years some doubts were felt on reactivity margins and this led to graphite specifications on purity, density, surface defects and machining tolerances which subsequent experience has shown to be unnecessary. Relaxations which have been made have seen the utilisation of raw material rise from 50 to well over 70%.

The Windscale Advanced Gas-Cooled Reactor which has been in operation since 1963 with continuous load factors in the 80 to 90% region has provided a wealth of experience on CO_2/graphite chemical reaction and the techniques of methane injection to limit weight loss to completely acceptable limits have been perfected on that reactor.

The graphite core problems which were treated with great reserve in the early stages now have proved to be amenable to good design and in practice have given no trouble in commercial operation.

Fuel

The performance of the fuel has been

Table 10—*Fuel failures in C.E.G.B. stations* during operation to 28th March, 1968*

		Berkeley	Bradwell	Hinkley Point	Traws-Fynydd	Dungeness A	Sizewell	Total
Slow failures	Suspect	8	16	9		1	1	35
	Estab.	91*	25	8	21	260**	418**	823
Rapid failures ..		15	6	10	6	10	1	48
Fast failures ..		3	5	—	2	—	1	11
Totals		117	52	27	29	271	421	917
Total fuel element charged ..		183,154	83,219	91,376	78,660	72,093	61,128	569,624

*The majority of these slow failures occurred during 1965 and are attributed to a batch of about 10,000 elements with inclusions in the canning material.

**These failures occurred in certain isolated batches of fuel.

Failures listed as Slow (suspect) were withdrawn following high or slowly rising activity signals but were not subsequently established as failures during examination. Nevertheless they are included in the total failures during operation.

The following figures from French reactors are attached for comparison.

	EDF 1-Chinon	EDF 2-Chinon	EDF 3-Chinon
Slow failures	8	2	4
Rapid failures	0	1	1
Fast failures	0	0	1
Total fuel elements charged (approx.)	25,000	40,000	45,000

exceptionally good. Out of about 600,000 fuel elements loaded into CEGB commercial reactors up-to-date only 60 had failures of a type which could conceivably have caused operational difficulties; of these only 11 had faults which necessitated immediate reactor shut-down. All the failures have been successfully discharged without leaving any permanent contamination in the reactors concerned. Table 10 shows the details and gives some French figures for comparison.

One unsuspected feature of fuel behaviour revealed by experience and affecting a very small number of fuel elements, was the rapid burst phenomenon. Here an incipient failure is masked until a late stage, at which time it gives a rapidly (hours) rising signal to the burst cartridge detection gear, requiring a discharge of the affected element.

A successful technique was evolved for identifying these failures at an early stage by making a number of step changes to CO_2 gas pressure, on going to power. Incipient failures can be readily recognised by this technique. It is unusual to find more than one such potential failure in a reactor charge of about 40,000 elements.

Other unforeseen difficulties dealt with in the very early stages concerned the bowing of stacked fuel elements and the rattling of some fuel element types under particular flow conditions. Both conditions were cured by simple mechanical means: the bowing by fitting braces and the rattling by fitting spring loaded arms to steady the fuel against the channel wall.

Following the post irradiation examination of fuel discharged from the reactors, it was decided to raise the target irradiation from 2500 MWD/Te to 3000 MWD/Te in 1963 and again to 3600 MWD/Te in 1965. Preliminary results from long-term irradiation experiments are encouraging enough to make the possibility of both running the fuel to its reactivity limit and increasing its mean burn-up a real one.

The burst fuel detection gear mentioned earlier was the object of intensive development. It has operated successfully, and for the latest advanced gas-cooled reactor has been considerably simplified as a result of experience.

Fuel handling

The successful development of on-load refuelling has been a major achievement. It would be idle to pretend however that, in the past, "on-load" fuel handling has not given considerable trouble on certain of the stations. These difficulties have centred around mechanical and electrical engineering problems which were exaggerated in some cases by inadequate space for access and maintenance.

Operations within the reactor, e.g., the recovery of single fuel elements, have given trouble, as have the articulated fuel charge/discharge chutes necessary because one pressure vessel standpipe served several fuel channels. Considerable effort by the Generating Boards and industry has gone into solving these difficulties and the position now is that no loss of output through insufficient refuelling is anticipated. At Berkeley and Bradwell, for example, there has been no refuelling backlog for over two years and the refuelling programme for a month is now usually accomplished in half that period. Recently at Hinkley Point some 1840 elements were refuelled in one month on load. Latina has had virtually trouble free fuel handling from the outset and some 24000 elements have been charged and discharged on load at that station.

The handling difficulties described do not arise on the Advanced Gas-Cooled Reactors now under construction. In these the fuel is placed in the graphite channel as one stringer, is handled at the pile cap, not in the reactor, and each channel has its own standpipe in the main reactor vessel. The Windscale A.G.R. has been in operation for five years now and has had virtually trouble free on-load fuelling throughout that period.

Pressure vessels

Probably the most sensitive area of concern during the design stage of the early gas reactors centred around the pressure circuit in general and the steel pressure vessels in particular. A massive programme was mounted covering design, manufacture, inspection, testing, site welding and subsequent irradiation examination. It is perhaps not surprising that matters which receive the greatest attention should give the least difficulty; in practice the steel vessels have given no cause for significant concern.

They do, however, represent a considerable limitation in the freedom of siting of a station, and a most significant advance was made when prestressed concrete vessels were introduced for Oldbury and subsequent reactors. Oldbury went on power in 1967. The most troublesome difficulties during the testing stage of the Oldbury vessels concerned the insulation of the vessel and not the vessel itself. This was corrected and the form of insulation used on the latest vessels has been modified to take account of that experience.

Gas circulators

Faults on gas circulators have fallen largely into two categories, shaft seal oil leakage, and the fatigue failure of components. The problem of vibration of components in the gas stream has indeed been one of the troublesome problems which has arisen and is very hard to anticipate.

Table 11 gives the cumulative availability of gas circulators on the first six CEGB nuclear stations. It can be seen that at Berkeley and Sizewell, faults on the gas circulators have caused a significant loss of availability. The effect with other stations has been extremely low.

At both Berkeley and Sizewell the lower cumulative availabilities can be traced back to one major fault early in the life of the station. At Berkeley the fault concerned the inleakage of oil into the reactor. This oil leakage occurred in varying degrees on most stations, but it was only at Berkeley

Table 11—*Cumulative gas circulator availabilities—C.E.G.B. stations to 30th April, 1967.*

Station	% Availability
Bradwell	97.5
Berkeley	89.9
Hinkley Point	97.2
Trawsfynydd	98.3
Dungeness	97.4
Sizewell	85.3

The availabilities given are for complete gas circulator units including ancillary equipment.

that the necessary modifications entailed a prolonged outage. It was found that any carbonaceous deposits resulting from this ingress were most effectively removed by injecting oxygen into the reactors and that carbon deposition was reduced by controlling the amount of carbon monoxide in the coolant.

At Sizewell the gas circulator outage was due to a fault on the circulator motor cooler which resulted in the failure of the motor. At Bradwell fatigue failure at circulator blade roots resulted from excessive vibration after 12 months' service. Subsequently in 1966, after four years' operation, diffuser cone modifications were required also stemming from fatigue. Failure also occurred at Hinkley Point A during preliminary running and large delays occurred while modifications were carried out. Subsequently there has been no operational recurrence of this problem.

Boilers

The boilers which may be considered as a conventional piece of engineering have encountered tube leaks during operation due in the main to weld defects and this has caused outage on all stations while the position of the leaks was being located.

Trawsfynydd is the only station where boilers have been a major cause of outage: on-load corrosion was discovered in 1965/66 and contributed significantly to outages in that and the subsequent year. Following modification to the boiler water treatment no further boiler corrosion has been observed.

At Dungeness A vibration of boiler tubes was detected during commissioning. Baffles were introduced to break up the boiler volume and subsequently no difficulties have been discovered with the boiler in service.

The vibration problem was also encountered during the commissioning of the Latina station where, in the commissioning stages, some boiler tubes fractured completely under gas loading. The vibration problem was cured at Latina and in the process both there and in the U.K. a much more complete understanding of this phenomenon was gained. This experience was built into subsequent reactors and into the reactors now under construction.

Control and instrumentation

The last item of interest pertaining to reactor experience is the control and instrumentation. A considerable amount of detailed experience on specific instruments has been obtained. Some difficulty, for example, was experienced in measuring fuel element temperatures within the reactor due to the falling resistance of thermocouples. Experience showed that the solidly connected thermocouple (as opposed to a contact device) was the most suitable and these are now used successfully.

There has been some spurious tripping of reactors but malfunctioning of the reactor control and instrumentation system generally has not been a significant cause of loss of availability.

Possible developments

The U.K. operational experience with gas-cooled reactors has shown that they are much more repairable than was initially thought to be possible. Furthermore the experience has been gained largely with reactors which initially were not well designed to facilitate repair and maintenance, particularly in the radioactive parts of the plant.

With present gas-cooled graphite reactors the boilers are part of the reactor unit (Fig. 2). In earlier stations provision was made to detect and to eliminate boiler tube leakage by blanking off the faulty tubes: major repairs were more difficult owing to limited access.

Babcock and Wilcox (U.K.) and Taylor Woodrow have now developed a replaceable boiler unit and the associated prestressed concrete pressure vessel within the walls of which the boilers are accommodated (Fig. 3). Not only does this enable a large measure of fabrication and testing to be completed at the manufacturers' works, with the advantages of sounder manufacture and inspection and speedier site construction but in the event of serious trouble the complete boiler unit can be withdrawn from the reactor and either repaired or even replaced by another unit.

Early designs of gas-cooled graphite reactors used uranium metal fuel clad in a magnesium alloy fuel can. This has been superseded by the ceramic form of uranium-UO_2-clad in a thin stainless steel fuel can. It seems likely that this fuel will be superseded in turn by coated particle fuels in which small pellets of UO_2 (about 200-300

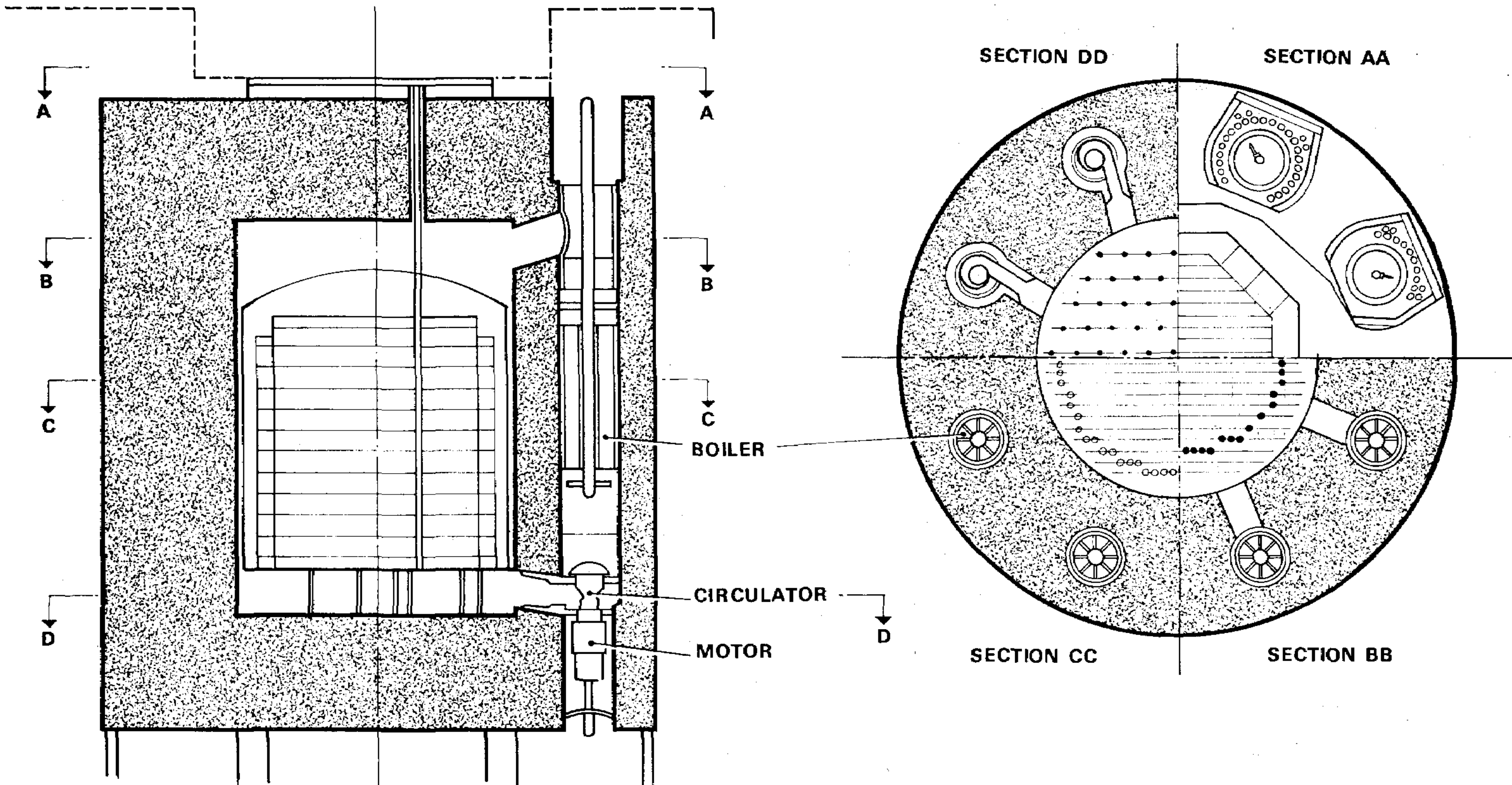


Fig. 3—*Diagram of pod boiler arrangement*

microns diameter) are individually coated with layers of pyrolitic carbon and silicon carbide which retain the fission products.

One advantage of this new type of fuel is that it can be more uniformly spread throughout the graphite moderator. This improves the neutron flux distribution and cooling so that higher core ratings can be achieved. Another important advantage is that the graphite moderator "becomes part of the fuel" and can be designed to be replaceable. The long burn-ups with coated particle fuels add to the economic viability of the principle.

Not only will these new design features facilitate repair and maintenance bringing improved plant availability but also, as more and more of the plant becomes replaceable station lifetimes of upwards of 30 years can be contemplated. Extending the useful life of these large power output, capital intensive plants could be of considerable economic significance to utilities in the future, still further reducing the costs of nuclear power.

Conclusions

The 100 million megawatt hours of operating experience with gas-cooled graphite reactors has, on the whole, been very satisfactory. High load factors were achieved soon after start up, the plants are easy to control, and the utilities are well pleased with their performance.

Where poor plant availabilities have been met it has been mainly attributable to poor engineering, the shortcomings predominantly occurring with conventional plant items. The nuclear part of the plant has been, in general, carefully designed and thoroughly developed attracting the best engineering skills.

Operating experience has shown that nuclear reactors are much more maintainable than was at first thought and up-to-date designs facilitate and extend the scope for maintenance and repair. This will improve further the availability of nuclear plants and extend their useful life.

Acknowledgements

The author wishes to thank particularly the U.K. Central Electricity Generating Board, the Nuclear Power Group of Knutsford and the Nuclear Design and Construction Company of Whetstone for their help in supplying information.

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. The fees shown are exclusive of accommodation.

Pulse Techniques in Nuclear Particle Counting

27th to 31st January, 1969

Subjects covered by this course are requirements for nuclear pulse counting systems; linear and non-linear pulse-shaping circuits; transistors; the use of transistors as circuit elements; linear pulse amplifiers for nuclear particle counting; low-noise head amplifiers; pulse discriminator circuits—pulse shaping prior to scaling; scaling circuits and counting-rate circuits; fast timing circuits; multi-channel pulse data analysis; logic circuits; automatic recording for counting systems; practical design aspects of electronic equipment; reliability of electronic equipment. Fee: £40.

Radioisotope Methods in Chemistry

27th January to 14th February, 1969

This course is arranged in three one-weekly parts, each consisting of lectures and practical work.

Part I—Introduction to radioisotope work.

Part II—Radioisotope methods in analytical chemistry.

Part III—Specialised and advanced applications to chemistry.

Students may take any or all of the three parts of the course.

Fee: £120 or £40 for each part.

Radiological Protection

24th to 28th February, 1969

9th to 13th June, 1969

This short course aims to give users of radioactive substances and radiations in industry, research or teaching a broad introduction to the principles and practice of radiological protection, with a strong emphasis on practical considerations. Fee: £40.

Nondestructive Testing Appreciation

3rd to 7th March, 1969

The purpose of this course is to give a broad view of nondestructive testing in Great Britain and to show how the Nondestructive Testing Centre at Harwell fits into this picture. It has been designed to give management, design engineers and senior inspectors an appreciation of the nondestructive testing facilities available to them and to show how the Harwell Non-destructive Testing Centre supplements existing facilities by providing a research, development, information and advisory service. Fee: £40.

Basic Radiological Protection
3rd to 28th March 1968
This course is intended to meet the initial health physics training requirements of new graduate entrants who will be concerned with operational radiological protection. It will consist of lectures on the basic science of health physics, operational radiological protection and public health aspects of the subject. There will be appropriate practical work.
To reinforce the lecture programme there will be visits, film, discussions and practical work. Fee: £160.

Process Instrumentation
10th to 21st March, 1969
This course is intended for graduates who are working on the instrumentation of process plant, nuclear reactors and scientific apparatus or who have a direct interest in the subject. A visit will be arranged to a process plant or a power station where modern control techniques are being applied. Most lectures will be by specialists from U.K.A.E.A. establishments. Fee: £80.

Science and Mathematics Teachers and use of Radioisotopes in Schools
24th to 28th March, 1969
This course for science and mathematics teachers, which may also be of interest to teachers in Colleges and Departments of Education, is intended to give a background knowledge of current developments in some of the subjects investigated at Harwell. There will also be an alternative section giving an introduction to the use of radioisotopes in schools in the physics, chemistry and biology syllabus. It will include visits to laboratories and nuclear reactors and short experimental sessions as well as an extensive lecture programme. The aim is to provoke interest in recent applications rather than to provide material directly applicable to a school syllabus. Fee: £5.

Introduction to Production Control by Computer
31st March and 1st April, 1969
A new system of production control (WASP) which ensures better loading of machine tools has been devised at Harwell. The course will show how "WASP" may be used on its own, or in conjunction with other computer control systems. Fee: £25.

Advanced Reactor Technology
14th April to 9th May, 1969
Intended for experienced physicists and engineers. The main emphasis of this course will be on reactor systems for industrial exploitation, including the advanced gas-cooled reactor, the high temperature gas-cooled reactor, the various water reactor systems and the fast reactor. For each reactor type there will be lectures on the special features of the system and on reactor physics, materials, heat transfer, engineering design and, where appropriate, operational experience. Lectures on recent advances in nuclear fuel and materials and their utilisation, fuel cycles, reactor physics, heat transfer, pressure vessels, safety and shielding and economic and legal aspects will also be featured. Fee: £160.

High-Voltage Technology
23rd April to 2nd May, 1969
This course is intended for graduate engineers and scientists who are new to high-voltage technology, or whose experience of this subject has been limited to a specialised aspect.

The course will consist of two parts. The first, lasting four days, will cover electrical breakdown mechanisms in gaseous, liquid and solid dielectrics.

The second, lasing three days, will be concerned with the application of basic knowledge to the design of high-voltage equipment, and there will be lectures on bushings, cables, capacitors, circuit breakers and transformers. Fee: £64.

Introduction to Radioisotopes
28th April to 9th May, 1969
The course is aimed at those with preliminary training in a scientific discipline who need an introduction to the techniques of handling and measuring radioactive materials, mainly at the tracer level. It is also a useful preliminary to a more specialised course. Fee: £80.

A.E.A. Reports available

THE titles below are a selection from the December, 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 2065
Evaluation of the ^{239}Pu *Fission Cross-section in the Energy Range* 1 *KeV to* 100 *KeV.* By G. D. James and B. H. Patrick. October, 1968. 11 pp. H.M.S.O. 1s. 9d.

AERE-R 5629
A Fortran Programme for the Numerical Solution of Parabolic Partial Differential Equations. By J. T. Klaschka. October, 1968. 18 pp. H.M.S.O. 3s.

AERE-R 5927
An Improved Potentiometric Titrator. By A. J. Wood, R. Causer and G. W. C. Milner. October, 1968. 13 pp. H.M.S.O. 2s. 6d.

AERE-R 5937
A Comparison of Methods for the Determination of Nitrogen in Titanium Carbide. By A. Parker, C. Healey and E. H. Henderson. October, 1968. 14 pp. H.M.S.O. 2s. 6d.

AHSB(RP) R85
Personnel Dose Assessments Following Accidental Non-uniform Irradiation of the Body. By W. A. Langmead, N. Adams, B. Holliday, G. Tyler and J. Brown. September, 1968. 33 pp. H.M.S.O. 7s.

AHSB(RP) R87
Dose-rate Distributions from Spherical and Spherical-shell Radiation Sources, with Special Reference to Fish-eggs in Radio-active Media. By N. Adams. October, 1968. 19 pp. H.M.S.O. 3s. 6d.

AWRE O-60/68
The Cross Section for the $^{16}O(n, \alpha)\,^{13}C$ *Reaction for Neutron Energies in the Range* 7-12 *MeV.* By D. Dandy, J. L. Wankling and C. J. Parnell. October, 1968. 14 pp. H.M.S.O. 2s. 6d.

AWRE O-65/68
The Development of a Commercially Available Explosive Donor for the A.W.R.E. Small Scale Gap Test. By M. Chick. October, 1968. 20 pp. H.M.S.O. 3s.

CLM-R 82
Plasmascope Observations of Plasma in a Magnetic Field. By D. W. Atkinson and J. A. Phillips. March, 1968. 19 pp. H.M.S.O. 6s.

CLM-R 95
The Properties of Linear Filamentary Multipole Magnetic Fields. By G. D. Hobbs and J. B. Taylor. April, 1968. 18 pp. H.M.S.O. 3s.

TRG Report 1269(R)
Friction and Wear Behaviour of Sliding Bearing Materials in Sodium Environments at Temperatures up to 600°C. By W. H. Roberts. 1966. 42 pp. H.M.S.O. 7s.

Health physics summer school

The tenth annual Summer School in Health Physics (Radiation Protection) will be held at Imperial College from 30th June to 11th July, 1969.

Topics covered will include basic physics, biology, radio-biology and genetics; an assessment of the hazards to the worker and the population; derivation of safe working levels; medical supervision of radiation workers; legal and administrative aspects; monitoring and monitoring services; principles of radiation and contamination hazard control; application of radiological protection in large and small establishments, nuclear power stations, factories and hospitals; transport of radioactive materials; disposal of radicactive wastes; and a survey of accident and emergency conditions.

A visit will be arranged to laboratories in which radioactive materials are handled and an opportunity will be given for using a range of portable monitoring equipment.

The lecturers, most of whom are international authorities in their subjects, are drawn from the senior staffs of Government departments, hospitals, universities and the United Kingdom Atomic Energy Authority.

The fee for the course, which is non-residential, is £35, inclusive of lunch and light refreshments.

A brochure giving details of the programme, lecturers and timetable, will be available in March 1969. Initial enquiries should be addressed to the organizer, Dr. H. D. Evans, Nuclear Technology Laboratories, Department of Chemical Engineering and Chemical Technology, Imperial College, London, S.W.7.

continued from page 5

not going to commit ourselves to a prestige project which is not commercial.

Sir H. Legge-Bourke: Is not the hon. Member aware that his reluctance to add to his statement of 14th October is a little odd in the light of the news which has since come to hand that Germany now proposes to build a second ship after the "Otto Hahn"? Should not we examine carefully the economics which led Germany to that conclusion?

Mr. Fowler: The hon. Member is aware that in terms of nuclear power technology we have a considerable lead over the Germans. It may be necessary for the Germans to do more research in this field than it would be necessary for us to do. I repeat that we shall go ahead with the project when it shows commercial viability.

2nd December, 1968

MR. EDWARD M. TAYLOR asked the Minister of Technology what proposals, he has now received from British shipbuilding firms regarding the construction of a nuclear-propelled merchant ship; whether any of these proposals were from Scottish shipbuilding firms; and if he will make a statement.

Mr. Fowler: The Department has received a request from one shipbuilding company for a substantial grant to finance a study by them and a shipping company of the market requirements for a nuclear container ship and the production of a specification for such a vessel. Another shipbuilding company has submitted a paper giving an estimate of the economic benefit of nuclear propulsion for this type of ship. Both will be discussed with the companies. Neither communication was from a Scottish shipbuilder.

M.H.D. and fusion

3rd December, 1968

MR. BRIAN PARKYN asked the Minister of Technology whether magneto-hydro-dynamic power production was taken into consideration when assessing the long-term implications of the work on plasma physics at the Culham laboratories of the United Kingdom Atomic Energy Authority.

Mr. J. P. W. Mallalieu: No. It is not expected that magneto-hydro-dynamic power production will be practical with any fusion reactor that may be developed.

Dounreay

4th December, 1968

MR. HECTOR HUGHES asked the Minister of Technology if he will give details of the contribution which Dounreay Experimental Station makes to productive and export industry; and if he will reorganise the work carried on there in such a way as to make that work more useful for productive industry and exports in order to help Great Britain's balance of payments problems.

Mr. J. P. W. Mallalieu: Electricity generated by the Dounreay Experimental Fast Reactor is supplied to the North of Scotland Hydro Electricity Board and thus to industry in the area.

Contracts from overseas organisations for irradiation experiments are currently worth some £2 million. The Establishment also manufactures and reprocesses enriched fuels for materials testing and research reactors for overseas customers.

APACE Centre courses for engineers

The following courses are due to be held at the APACE Centre.

Computer Appreciation Course for Engineers—4 days, fee £48.
January 28th-31st
February 25th-28th
April 22nd-25th

FORTRAN *Programmers' Course for Engineers*—5 days, fee £60.
January 20th-24th

2CL Users' Course—4½ days, fee £54.
February 10th-14th

Post Processor Course—2 days, fee £24.
February 19th-20th

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

Electronic Computer-Aided Design Introductory Course—4½ days, fee £54.
February 3rd-7th
March 24th-28th

Circuit Analysis Users' Course—3 days, fee£36.
February 12th-14th
March 18th-20th

Fees cover attendance and lunch daily. Overnight accommodation is arranged for course members on request. Further information from The Secretary, APACE, UKAEA, Blacknest, Brimpton, near Reading, Berks. Telephone Tadley 4111, ext. 5951/5873.

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

Fast reactors reduce uranium demand

A six-fold reduction in Britain's uranium requirements can be achieved by using fast reactors to burn plutonium.

Dr. Hans Kronberger, F.R.S., Scientist-in-Chief, Reactor Group, U.K.A.E.A., stated this in his opening remarks at a panel discussion on plutonium utilisation at the International Conference on the Constructive Uses of Atomic Energy, in Washington, D.C.

Plutonium is produced as a by-product in nuclear reactors like those already operating in Britain; 11.3 tons of it will have been produced in this way by 1975, and production will increase steadily from then on. The plutonium can be either stockpiled for use in fast reactors or burnt in thermal reactors (e.g. AGRs or SGHWRs).

Either way, plutonium will help to reduce uranium imports but whereas burning it in thermal reactors cuts the uranium bill by only 15%, its use in fast reactors reduces the bill by a factor of six at the end of the century.

This is because of the breeding characteristics of the fast reactor. The only requirement of plutonium in a fast reactor is in the initial fuel charge and processing plant inventory. Once this is provided, the fuel cycle is maintained with a small feed of uranium (e.g., depleted uranium from the isotope separation plant waste) and the plutonium bred by the reactor is sufficient to produce enough plutonium for a further identical fast reactor in about 15 years.

The paper estimated that ore usage after the year 2000 (installed nuclear capacity exceeding 163,000 MW) will be only 4,000 tonnes p.a. if fast reactors are introduced in 1976, with supporting programmes of AGRs. If only AGRs are installed, and no plutonium burnt, the total would be 25,000 tonnes p.a.

The strategy of reactor installation is not, however, decided on uranium ore requirements alone. A full economic assessment of the various alternatives must be made which allows for the reactor types available and their associated capital and operating costs, the logistics of plutonium, the likely timescales and costs of achieving development objectives, the capital investments in fuel fabrication, reprocessing and enrichment plants, the likely levels of uranium price in the future together with the needs of the future U.K. electrical programme.

Such an assessment, using a computerised discounting technique, shows that the U.K. should plan to store its plutonium for use in the fast reactors due to come on power in the late 1970's. This strategy gives the lowest overall system costs and at the same time substantially reduces the uranium ore usage when compared with the all-thermal reactoı cases.

A case for departure from this policy might arise only if the introduction of further fast reactor power stations beyond PFR was delayed. *11th November*, 1968

S.G.H.W.R.'s first year

The performance of the SGHWR—its availability so far has been 64%—was described to a large international conference in Washington D.C.

At a panel discussion on the performance of power reactors at the International Conference on the Constructive Uses of Atomic Energy, in Washington D.C., Dr. J. E. R. Holmes of the A.E.E. Winfrith, U.K.A.E.A., described the operation of the reactor as follows:—

"Summarising the position, commissioning reached the stage where heavy water and fuel were loaded in September 1967. Criticality was first achieved on the 14th September of that year and electricity was initially supplied to the national grid on 24th December. Sustained full power operation at 100 MW(e) was achieved on 25th January, only a few weeks later than the target originally set when construction work was started in February 1963. From January to October of this year, the load factor has been 52% associated with a station availability of 64%, a performance which we believe to be very creditable for any new plant and particularly so for the first of a new system.

"The operating characteristics, including physics and hydrodynamics, have been found to be very close to prediction and no unexpected features in operation have been encountered. Control of the reactor and plant as a whole is very straightforward. Whilst the plant normally operates on automatic control, manual control can be used if required.

"The loss of operating time has arisen from an accumulation of a number of faults, individually of a minor nature. A large proportion can be described as faulty 'conventional' plant items such as valves and steam leaks from glands, though, in most cases, the nuclear system application calls for no more rigorous duty than the item meets in conventional turbine/boiler units.

"Of the 104 fuel elements in the core, more than 30 are of an experimental nature. Some of these experimental elements have developed minor defects in the cladding. We have, however, been able to remove them easily because the pressure tube construction allows ready access to individual elements. Early removal of a defect means that we can carry out examination of the fuel in the active caves before the evidence has become confused as a result of continued operation. Other items which led to loss of operation have included difficulties with slipping belts on the exciter drive of the motor alternator set feeding a supplementary primary circuit pump, maloperation of the drum level indicators and inadequate performance, in the early stages, of the condensate clean-up plant.

"The use of heavy water as a moderator presents no issues which are not well understood. In a reactor system where the heavy water is used only as the moderator, such as the SGHWR, then the heavy water circuit need not be under pressure. Consequently, the design and operation of a low-loss heavy water system is readily attainable and there is a large amount of relevant experience, in many places, to draw on. For example, the DIDO class of materials testing reactors of UK manufacture provide more than sixty reactor years of experience in this respect."

11th November, 1968

Desalination R & D

"It is our policy to implement advances in technology into commercial plants in the shortest possible time so that the customer receives the earliest benefits in the form of more reliable plant, and of cheaper water."

Dr. Hans Kronberger, F.R.S., Scientist-in-Chief, Reactor Group, UKAEA, stated this in a paper on the U.K. desalination research and development programme, presented to an I.A.E.A. symposium on desalination, at Madrid (18th-22nd November).

"To do this we have identified for each process one experienced industrial partner who has a measure of exclusivity for the commercial exploitation of our respective joint development programmes. This arrangement also ensures that the desalination teams of the UKAEA have full access to their partner's know-how. Joint Management Committees were established, responsible for direction of the R. & D. programme on each particular process.

"The UKAEA desalination programme is administered by Reactor Group H.Q. at Risley, and draws on the resources of Harwell, Winfrith Heath and the Engineering Group at Risley. We have sited work within the UKAEA where there are existing skills and facilities which have made an immediate impact in terms of plant improvement.

"Since it is our aim that any new ideas should find their way quickly into the design of commercial plants, the large scale experimental work of the joint programme is carried out in the laboratories of our industrial partners."

Citing a 40% (8s. in the £) reduction in electrodialysis stack costs, achieved after tests in a plant built by William Boby Ltd. and operated by a local water authority, as an example of what was being achieved, Dr. Kronberger outlined the main points of the U.K.'s current three-year £4m. programme of research and development.

Multi-stage flash distillation (MSF)

Work on flash chamber geometry is first carried out on small rigs at Harwell and Winfrith, and then transferred to much larger rigs at Weir Westgarth's Troon (Ayrshire) test station. For scale control, a short list of possible additives was produced at Harwell for testing under more typical MSF conditions at Troon. Possible constructional materials are also tested at Troon. Harwell has a programme on aluminium alloys and larger scale tests are planned at Troon in a materials test plant consisting of three typical MSF stages.

Electrodialysis

As well as reducing stack costs, the aims here are to improve their operational reliability while at the same time increasing the utilisation of membrane area.

Freezing

A 10,000 gal./day plant is being constructed at the Simon Engineering Laboratories, near Stockport. This will allow the performance of each plant section to be studied independently, or as part of an integrated plant. Previous work at Harwell concentrated on nucleation and growth of ice crystals.

Reverse osmosis

Collaboration started recently with Portal Engineering, and studies have concentrated on the search for cheap porous support substrates for membranes.

20th November, 1968

Nuclear-powered desalting plants

Nuclear-powered dual purpose desalination plants should be operated primarily as water producers rather than power units, for full advantage to be taken of the high availability of British reactors.

This would lead to cheaper water.

Dr. Hans Kronberger, F.R.S., Scientist-in-Chief, Reactor Group, explained this in a paper on nuclear reactors for dual purpose desalination plants at an I.A.E.A. symposium in Madrid (18th-22nd November).

Earlier he had described the performance of British reactors used as single purpose power plants—many of those in operation have had availabilities exceeding 90%. However, the actual usage of the plant was affected by other considerations.

"In calculating the cost of electricity from a nuclear power station as part of a grid network, one makes the assumption that a nuclear power station will attract the base load at the beginning of its operation; however, as power stations of better performance and, in particular, lower fuel cost come into operation, so they will compete with the older power stations which thereby will move down on the order of merit scale. For instance, a nuclear power station with an amortisation period of 25 years could be considered as operating on 90% load factor for the first half of its life, reducing gradually to 33% by the end of 25 years, with a mean load factor of 60% in the second half and an overall mean load factor over 25 years of 75%.

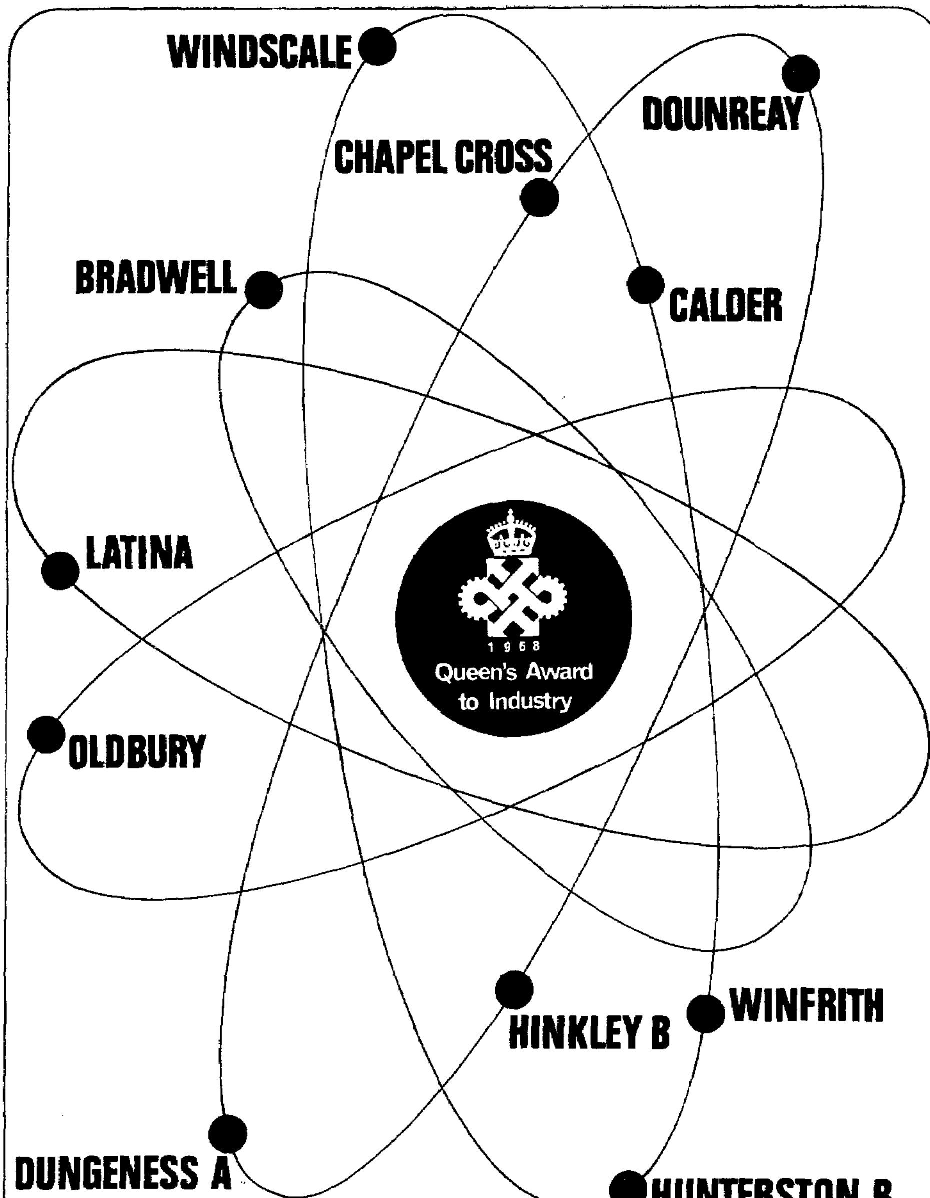
"The situation which is imposed by the electrical utilities is dramatically changed if dual purpose operation is contemplated. This comes about through the fact that there will be a demand for all the water produced by desalination plants during their life of operation, on the reasonable supposition that no competitive low cost source of water will become available.

"The following example will make this clear. We examined a dual purpose plant (SGHWR) producing 200 MW of electricity for sale and 120 MGD (US) of water. The interest on capital is 10% and the amortisation period 25 years; an average load factor of 75% has been assumed over the period of 25 years. Under these assumptions, the cost of water production is 55.4 cents per thousand gallons (US) with an electricity credit of 6.6 mils per kW/hr.

"On the basis that such a plant could have an availability of 90%, we considered continuing operation of a dual purpose plant at 90% load factor even when the electricity part of the plant had been relegated to a lower position on the merit scale and would normally be shut down.

"The extreme case considered is that of dumping the high pressure steam, but keeping the desalination plant in operation. By doing this the water production is increased by 20% over the 75% load factor operation with a total operating cost increase of only 5%. Thus the water cost per thousand gallons drops from the 55.4 cents per thousand gallons of the standard case to 48.6. This represents the extreme case of dumping steam when the electricity is not required.

"This paradoxical situation, namely that the cost of water production is reduced by keeping the dual purpose plant in operation and dumping steam if the electricity is not required, demonstrates that different planning assumptions for the long term utilisation of dual purpose stations must be made from those of 'electricity only' producers—not an unreasonable suggestion, bearing in mind the value of the water produced compared with that of the electricity. It is not generally realised that the daily income from the sale of water is about twice that from the sale of electricity (on the assumption that the electricity is charged at the same price as that produced from a single purpose electricity producer of the same electrical output)." *21st November*, 1968.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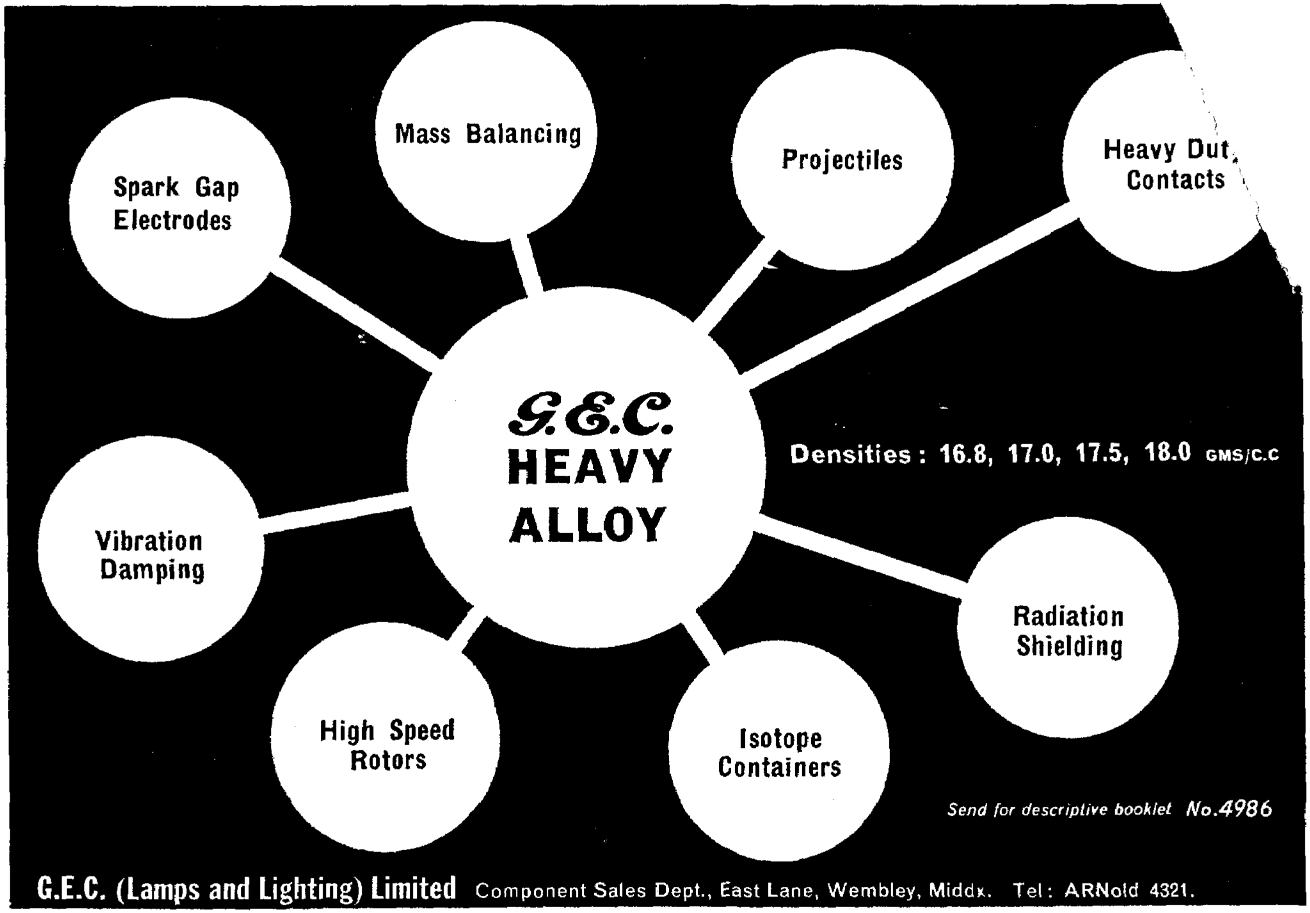
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