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MONTHLY INFORMATION BULLETIN OF
THE UNITED KINGDOM ATOMIC ENERGY AUTHORITY

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OF THE UNITED KINGDOM
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ATOM
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Sir John Cockcroft

The following Address was given by Dr. Robert Spence, C.B., F.R.S., Director of Harwell, at a service of memorial and thanksgiving for Sir John Cockcroft, held at Westminster Abbey on 17th October.

WE have come this morning to this historic Abbey Church, to commemorate the life of John Cockcroft, scientist, creator and administrator of great projects, and technological statesman, whose career was so uniquely characteristic of our time.

He was born and raised in one of those deep cut valleys of the western Pennines which seem so grim and grey but which are so rich in human fellowship. Like millions of his contemporaries he went to France to participate in the tragic struggles of the First World War, sacrificing in so doing the normal life of a young man. But he had good fortune in three major respects. He survived the war unscathed, he had the opportunity of working with Lord Rutherford and the brilliant group at the Cavendish Laboratory and he married a girl who was to create the happy, devoted family life from which he drew so much strength in later years.

Great scientific success came to him whilst he was in Cambridge and he was afterwards awarded the Nobel Prize jointly with his friend and collaborator E. T. S. Walton. These fundamental researches were interrupted by the outbreak of the Second World War when rapidly increasing demands were made on his time and energy, demands which he met with apparent ease through the exercise of an extraordinary degree of self-discipline. Everything was done with the utmost economy of effort and never a word was wasted.

There was always about him a deep tranquillity, shared with Elizabeth and centred on home, within which his mind worked with unsurpassed speed and precision.

He became a leader in the war-time development of radar; then he was sent to Canada to direct the Anglo-Canadian Atomic Energy Laboratory in Montreal, where he laid the foundations of a successful Canadian programme and prepared the ground for developments over here.

In this country after the war, atomic energy came under the personal control of the Prime Minister, and one of Mr. Attlee's first acts was to appoint John Cockcroft as Director of the new Atomic Energy Research Establishment to be built at Harwell. These two men, each outstanding in his sphere, were notable for their courage, for their personal modesty and for their sense of brotherhood with others. They both acknowledged the necessity for an immediate military programme with all its sombre implications but they also looked beyond it to the solid benefits which would be gained for Britain and for the world through peaceful application of the giant forces of the atomic nucleus.

John and Elizabeth and the children left the town they founded at Deep River in Ontario and moved to Harwell in 1946. The task ahead was immense, the uncertainties great and the weight of responsibility heavy but John's cautious confidence and his optimistic spirit banished any thought of failure. Their house at the airfield became a centre from which flowed kindness, friendship and hospitality. Every industrial worker on the site knew Dr. Cockcroft, every scientist respected him. He had a wonderful memory for names and was always accessible to those who wished to see him.

When the government's production programme had been achieved and civil nuclear power became a reality further honours came to John Cockcroft, including the Order of Merit, conferred in 1957.

His membership of the Atomic Energy Authority, his many international commitments, his honours, all gave him real pleasure, as they came to him naturally and unsought.

His last years were spent in Cambridge as Master of the splendid new College named in honour of Winston Churchill; it flourished under his wise guidance from the beginning.

Foremost of the New Men, his life was conducted according to Christian principles which have been acclaimed here for centuries; dedication and service, love of family and home, love for others. He earned the devotion of his colleagues and the respect and affection of all who knew him; his memory will ever be fresh in our hearts.

Select Committee's Report

The Report of the Select Committee on Science and Technology, set up in December 1966, was published on 22nd November, 1967.

Below is a summary of the Committee's recommendations on the United Kingdom nuclear reactor programme:

1. (*a*) The consortium system of tendering for nuclear power stations should be phased out as present contracts are completed and the generating boards should regard themselves as free to place orders for nuclear stations in the same way as they now do for other types of power station.

(*b*) Any reorganisation of the nuclear industry in Britain should have as its aim the more effective integration of the Atomic Energy Authority's effort on research and development with competitive industrial activity than is now the case.

(*c*) In present circumstances the best interests of the country would be served by the combination in a single organisation or company of the skill and resources of those now separately engaged in the design and construction of nuclear boilers.

2. (*a*) So much of the Authority's facilities as is presently devoted to research and development of a commercial nature should become part of the new single nuclear boiler organisation or company.

(*b*) The Government should undertake a full review of the Authority's present function and staffing with the object of securing

(*i*) that the Authority concentrate their effort on their primary task of pure research and development in the most effective way, and (*ii*) that any of the Authority's activities not inextricably linked with their primary task are passed over to other more appropriate organisations.

3. A new British fuel supply and manufacturing company should be established (consisting jointly of the A.E.A. and others).

4. (*a*) A technical assessment unit should be established, capable of advising the Government on the merits and prospects of particular projects proposed to be undertaken by the Authority.

(*b*) A study should be made of the possibility of the establishment, within the framework of the British system of government, of a body similar to the U.S. Joint Congressional Committee to deal with all aspects of energy policy, and provided with expert staff for the purpose.

5. In addition to discussion between the Government and the nationalised fuel industries, full consultations should also be held with the oil industry and an examination by an independent outside agency of the purely financial aspects of costing of all methods of energy supply should be put in hand and the report published.

6. The British Nuclear Export Executive should be wound up, and an intensive survey of potential overseas nuclear needs and opportunities should be put in hand at once by the Board of Trade in close consultation with the engineering manufacturers and the A.E.A.

7. High Temperature Reactor development should be intensified, with as much industrial collaboration as is possible, and if the E.N.E.A. find themselves unable to continue their support of the DRAGON project, the United Kingdom should take it over and complete it, with appropriate financial safeguards in relation to commercial development.

8. The Authority and industry should be encouraged and enabled to speed up development of the Steam Generating Heavy Water Reactor and other water reactors showing promising commercial possibilities.

9. Development of the fast reactor from now on should be with a view not only to its commercial use at home but also to its being offered abroad to meet whatever may be the market requirements overseas.

10. A Departmental committee should be convened to examine the possibilities of nuclear marine propulsion in the light of the experimental work being carried out in other industrial countries.

11. The Ministry of Technology should review the whole field of fusion research to ensure that Britain can take advantage of any technological advance.

The Report from the Select Committee on Science and Technology, Session 1966-67 is available from H.M.S.O. price £2 19s. 0d.

Heavy water reactors conference

This will be the subject of a three-day conference which the British Nuclear Energy Society is organising, from 14th-16th May, 1968. It will be held at the Institution of Civil Engineers, Great George Street, Westminster, London, S.W.1.

The outline programme is as follows:

Tuesday 14th May, 1968

Session I SGHWR General Design

Three papers will be presented covering the outline of the concept, the evolution of the reference design for the prototype, supporting R and D programme, prototype construction programme, the mechanical components of the system, the development of a commercial design, fuel element design and metallurgical considerations.

Wednesday, 15th May, 1968

Session II SGHWR Performance

Four papers will be presented considering nuclear, thermal and hydraulic design aspects influencing the choice of main parameters, the interaction between the experimental programme and the development of calculation methods, the philosophy of the control and shut-down systems of the prototype and experience of their operation, variations for other applications, fault analysis, general requirements of fuel management in prototype and commercial reactors.

Session III Materials and Operation

Two papers will be given on considerations and experience determining the selection of reactor materials, the chemistry of the coolant and moderator circuits. One paper will be presented on accident analysis and hazard evaluation including a description of the broadly-based supporting development work and one paper summarising experience during the commissioning and early operation of the prototype with a review of commissioning measurements including comparison with design predictions.

Further information can be obtained from: The Secretary, The British Nuclear Energy Society, 1-7 Great George Street, London, S.W.1.

IN PARLIAMENT

D.M.T.R.

24th October, 1967

MR. HECTOR HUGHES asked the Minister of Technology if he will make a statement on the cause of the escape of chemical which caused the closing for a time of Dounreay Experimental Station at the end of July, indicating the extent and nature of the escape and its effect on the work of the station.

DR. BRAY: The Dounreay Materials Testing Reactor was shut down for a short period at the end of July because of the failure of a capsule containing specimens of materials under irradiation. This resulted in a small local release of short-lived airborne radioactivity confined entirely to the reactor containment building. There was no significant interruption to the work of the reactor and none at all to the rest of the establishment.

Uranium imports

24th October, 1967

MR. DAVID GRIFFITHS asked the Minister of Technology how much foreign currency is spent on the uranium imported for use in the existing nuclear power stations; what is the total annual cost in foreign currency of supplying the stations now operating; and what will be the total annual cost when the first series of nuclear stations is complete.

MR. BENN: It has not been the practice, for defence and commercial reasons, to reveal details of the imports of uranium by U.K.A.E.A. In broad terms, however, the annual cost in foreign currency of supplying the uranium for the nuclear stations now operating is about £8 million; this will rise to about £10 million in 1969-70 when the first series of nuclear stations is complete.

Hunterston B

25th October, 1967

MR. EADIE asked the Secretary of State for Scotland how many jobs will be involved as a result of his decision to authorise the construction of Hunterston B nuclear generating station.

DR. DICKSON MABON: The number of men employed on site construction is expected to reach a maximum of 2,000 in about three years' time. About 300 men will be permanently employed in running the completed station.

Fast reactor hazards

27th October, 1967

MR. BROOKS asked the Minister of Technology whether he has studied the evidence of Dr. Edward Teller that fast breeder reactors are potentially dangerous, owing to the amount of plutonium required to operate them, details of which have been sent to him; and if he will make a statement.

DR. BRAY: Dr. Teller's recent statement raises no new issues. The safety of fast reactors has been a major consideration in their development over the past 15 years. The design of the prototype fast reactor at Dounreay is of the highest standards of safety. I am confident that commercial fast reactors based on this design will maintain the excellent safety record already established by the British nuclear power industry.

A.E.A. royalties

6th November, 1967

MR. MCGUIRE asked the Minister of Power whether, in view of the report of the Comptroller and Auditor-General on the accounts of the Atomic Energy Authority, he will in future, when quoting costs per unit sent out from Magnox nuclear power stations, adjust them to allow for the £24 million royalties to the Atomic Energy Authority which have been waived.

MR. FREESON: No. It would be impracticable and misleading to include additional costs which the operator is not in fact having to incur. For the Second Nuclear Power Programme, however, it is our present practice to include the agreed royalty of 0·014d./kWh in quoting estimates of A.G.R. costs.

7th November, 1967

MR. MCGUIRE asked the Minister for Technology whether, in view of the report of the Comptroller and Auditor-General that the advanced gas cooled reactor nuclear stations will produce power at costs below those for conventional stations, he will take steps to arrange for the electricity undertaking to pay to the Atomic Energy Authority the full amount of the royalties needed to meet the costs of the work done by the Atomic Energy Authority for these stations.

MR. BENN: As the report of the Comptroller and Auditor-General shows, the royalty to be paid on those advanced gas-cooled reactor stations to be brought into operation in the U.K. by 1975 should bring in, over their assumed life, a cash return equivalent to a very substantial part of the Atomic Energy Authority's expenditure on the development of the advanced gas-cooled reactor system.

I consider this to be a fair settlement for this first batch of advanced gas-cooled reactor stations.

Power stations

7th November, 1967

SIR C. OSBORNE asked the Minister of Power why nuclear power stations have been built at a cost of £500 million more than comparable coal-fired power stations would have cost; and what reply he has sent to the representations made to him by the Chairman of the National Coal Board on this matter.

MR. MARSH: I am aware that the Chairman of the National Coal Board has quoted a figure of £500 million as the extra cost of the first nuclear power programme compared with a similar capacity of conventional stations, but this figure does not take into account the considerable savings in running costs once the stations have been built.

MR. EDWIN WAINWRIGHT: In so far as the first phasing of nuclear power proved very expensive, and since building five nuclear power stations of the A.G.R. type might be expensive, has my right hon. Friend considered building three instead of five stations so that we can obtain sufficient knowhow on nuclear power?

MR. MARSH: There is a great deal of discussion going on into the question of the load forecast in order to work out exactly how many stations we should build and when. But I do not think that there can be any argument that, with the future nuclear power stations, the costs of generation will be low compared with other fuels.

Radioactive waste disposal

7th November, 1967

MR. DALYELL asked the Minister of Technology what study he is making of pollutants in the form of radioactive waste from nuclear reactors.

DR. BRAY: In England the Ministers of Agriculture and Housing are responsible for authorising the disposal of radioactive waste. In Scotland and Wales these responsibilities are exercised by the respective Secretaries of State. Studies are undertaken by the Departments concerned and by the Atomic Energy Authority, the Agricultural Research Council, the Medical Research Council and various university laboratories. The disposal of radioactive waste is also the subject of continuous international study in which the U.K. plays an active part.

7th November, 1967

MR. BROOKS asked the Minister of Power what is the present forecast of the amount of radioactive waste anticipated annually from the nuclear power stations likely to be in operation in Great Britain in 10, 20, and 30 years' time from now; and how is the gaseous component of that waste to be disposed of.

THE PARLIAMENTARY SECRETARY TO THE MINISTRY OF POWER (MR. REGINALD FREESON): There is no simple basis on which to give such long term forecasts. Future radioactive waste arisings will depend, for example, not only on the number and design of nuclear stations, but also on fuel element design. Low activity solid waste is accumulated safely on all station sites. High activity waste is trapped within the fuel elements which are returned to atomic energy establishments. Day to day gaseous waste, the chief radioactive constituent of which is argon 41 with a half-life of less than two hours, is discharged into the atmosphere under stringent control which ensures that it presents no hazard to health.

MR. BROOKS: I thank my hon. Friend for his detailed reply. However, is he not aware that the likely expansion in the output of highly dangerous radioactive material —dangerous to life for up to 600 years— will present very serious difficulties in years ahead, particularly as it is unlikely that the disposal of the gaseous component can be achieved by the same methods in future?

MR. FREESON: As I understand the position, if the present facilities for waste storage were taken up, further provision could be made available by extending the present facilities on site. There is site space available. However, there are complicated factors in this kind of subject, as was indicated in my Answer. If my hon. Friend would like to write to us about the matter, we will pursue it in detail with him.

Troon Research Centre

THE £300,000 Weir Westgarth Desalination Research Establishment was opened at Troon in Ayrshire, Scotland, on Wednesday, 11th October, 1967. It is believed to be the most advanced centre of its kind in the world and was scheduled to be opened by Mr. Anthony Wedgwood Benn, Minister of Technology, but, due to urgent Government business, the ceremony was conducted by his Joint Parliamentary Secretary, Mr. Gerald Fowler, M.P.

Built by Weir Westgarth, the centre will be operated in conjunction with the Atomic Energy Authority in accordance with the terms of their joint research and development agreement under the first phase of the £1·3 million desalination programme.

The initial research programme at the centre covers:

(1) Economic methods of controlling or eliminating scale formation.

(2) Flash chamber geometry.

(3) General plant efficiency—using rigs where temperature, pressure, flow rate, flash chamber size, etc., can be varied.

(4) Measuring and controlling the corrosive effects of hot sea water, and its dissolved gases, on the materials from which distillers are, or could be, built. One part of this rig provides "standard" sea water at carefully controlled concentration, gas content, temperature, etc.: the other part contains the test pieces, wafers or sometimes tubes, to be exposed.

The centre will study units in sizes from 250,000 gallons to 10,000,000 gallons a day both for single and dual purpose plants. It will also be used for desalination studies of systems other than multi-stage flash distillation.

Sea water is available in the test bay from two main circulating pumps which give an output of 2,000,000 lbs. per hour. Smaller pumps are available for the operation of small scale test equipment when the large flows are not required. Three package boilers deliver steam to the station with a total load of 46,000 lbs. per hour of dry saturated steam at 215 lb./sq. in. Ring mains are provided round the test bays carrying sea water, fresh water from the town mains and from evaporators and boiler feed water; compressed air and electricity are also available on the ring main principle with two supplies of compressed air—one a dry supply for instruments and the other normal shop air for operating hand tools.

There is also a small machine shop, a workshop and an instrument repair and maintenance workshop. An analytical line for the solutions of deposits within the evaporators has been provided and there is an auto-analyser for the chemical analysis of large numbers of samples of sea water and evaporator brines simultaneously.

Oldbury nuclear power station

ELECTRICITY was generated for the first time from the No. 1 reactor of the 600 MW(e) Oldbury nuclear power station on 7th November, 1967. No. 2 reactor is fully loaded with fuel (natural uranium) and the complete station is expected to be fully operational by the end of the year.

Oldbury is located on the east bank of the River Severn some 10 miles north of Bristol and is owned and operated by the Central Electricity Generating Board. The station was designed and constructed for the C.E.G.B. by The Nuclear Power Group.

At Oldbury, for the first time in the world, a prestressed concrete pressure vessel with integral boilers and gas circulators was used to enclose each of the two reactor cores. This method of reactor containment is known as the "integral" design and has been used in all subsequent British commercial nuclear power stations. Site work started at Oldbury in 1962.

European Communities Delegation

THE address of Mr. D. H. Hill, First Secretary (Atomic Energy) to the United Kingdom Delegation to the European Communities in Brussels has changed.

His new address is 52, Avenue des Arts, Brussels 4, Belgium. The new telephone number is (02) 12.78.10 although it will still be possible to use the existing number (02) 19.11.65 with the possibility of some delay.

The telex service will continue to be provided by Britannia House, Prodrome, Brussels.

Electricity from the atom—Britain's second decade

By E. S. Booth, M.Eng., C.Eng., F.R.S., M.I.Mech.E., F.I.E.E., M.Inst.F., Board Member for Engineering, C.E.G.B., Part-time Member, U.K.A.E.A.

The following paper was presented to the Société Royale Belge des Ingénieurs et des Industriels, Brussels, 2*nd October,* 1967.

The paper surveys the development and operation of British nuclear power stations from 1956 *to* 1967 *and emphasises that reliable and safe operation of reactors has been successfully achieved. Evidence of Britain's operational experience in nuclear generation during the past decade, and her skills in the design, development and operation of second and third generation reactors, is the base for confidence in the reliability, safety and economy of nuclear plant in the* 1970*s.*

Introduction

ELEVEN years ago this month the pattern of energy supply in Britain was irreversibly changed when, for the first time anywhere, electricity from a nuclear power station began to flow in commercial quantities into the high-voltage transmission network of the Central Electricity Generating Board. Since then British scientists, technologists and nuclear plant operators have proved that nuclear power stations are not expensive luxuries—not scientific experiments with only a prestige value—but are an integral part of the power generation system of every country whose future growth is linked to its ability to provide an adequate and economic electricity supply.

It is my purpose this afternoon to survey Britain's achievements in the first decade of producing electricity from the atom, and state why we in Britain believe that, with the advent of the second generation commercial reactor (the Advanced Gas-cooled Reactor) in the early 1970s, nuclear power stations will, on technical and economic merit alone, justify their inclusion in the power plant programme. It will be for you to judge whether such confidence is well-founded.

The first decade

In 1953, construction of the first two reactors at Calder Hall began. The primary object was to manufacture plutonium for defence needs and the secondary object was to generate electricity. Thus, the world's first nuclear power station, with an output from each reactor of 35 MW(e), was opened by Queen Elizabeth on 17th October, 1956. At that time there was no doubt that heat produced by the fission of natural uranium could be harnessed to raise steam for turbo-alternators and so feed electricity into the high-voltage transmission system. However, this knowledge was insufficient to establish nuclear generation as an economic technology. The Generating Board needed in the first decade to satisfy themselves that the following essential conditions could be achieved:

(1) *Nuclear reactors must be able to operate reliably day in and day out*

There are two reasons for this: one is that the operation of the power system requires a high degree of probability that plant will be available when wanted; the other is that the capital cost of nuclear stations is very high and idle capital results in heavy financial burdens.

(2) *The structural integrity and safe operation of nuclear reactors must be demonstrated* because the Generating Board have a dual responsibility to provide a safe working environment for employees, and to ensure that the general public are protected against any hazard, no matter how remote the possibility, which might result from the operation of their nuclear plant.

(3) *The long-term economic construction and operation of nuclear power stations* must be foreseeable and then demonstrated.

Progress since 1956

The advent of commercial nuclear power in 1956 was rightly hailed as a major technological achievement, but because publicity was focused on the reactors it was easy for those not closely concerned with nuclear power developments to overlook the fact that the nuclear reactor—heat exchanger—turbine system is still a heat engine subject to the second law of thermodynamics. The steam conditions at Calder Hall, i.e. 14·5 kg/cm² at 324°C, were primitive compared with those of the most advanced coal or oil-fired stations at that time, viz. 106 kg/cm² at 566°C, which also had reheat, a facility not available until late 1965 on the first generation of nuclear stations; that is the Magnox stations which are graphite-moderated, gas-cooled by pressurised carbon dioxide, and fuelled with natural uranium within a magnesium aluminium alloy (Magnox) can. Furthermore, the turbo-alternators at Calder had a capacity of little more than 30 MW; the standard size of set which was being installed in Britain some 10 years earlier.

The path to more efficient operation and lower capital costs for nuclear power stations was clear—steam temperatures and pressures must rise, rates of heat release and heat transfer from the uranium fuel elements must increase, and capital economies resulting from large-scale plant would have to be achieved; all without detriment to the safety of plant, personnel and the general public.

Heat transfer from fuel elements

The physical characteristics of natural uranium and Magnox fuel cans set a limit of about 450°C to the maximum gas temperature of Magnox reactors. To maximise thermal efficiency it was therefore essential to operate as near to this limit as possible, and to design fuel elements and cans so that heat transfer rates could be maximised. Considerable improvements have been made in the design of Magnox fuel cans and the latest herringbone design has much improved heat transfer characteristics compared with the early Calder Hall type. Figure 1 illustrates the fin designs at three stages of development:

Figure 2 shows the advance made in the heat transfer characteristics of the same types of can.

To improve heat transfer rates from fuel elements to the carbon dioxide coolant presented major design and engineering problems for another reason. Gas pressures needed to rise and, in fact, have risen in reactors contained within steel pressure vessels from 7·06 kg/cm² at Calder Hall to 19·0 kg/cm² at Dungeness A, and will be 27·2 kg/cm² at Wylfa where the reactors are contained in prestressed concrete pressure vessels, about which I shall say

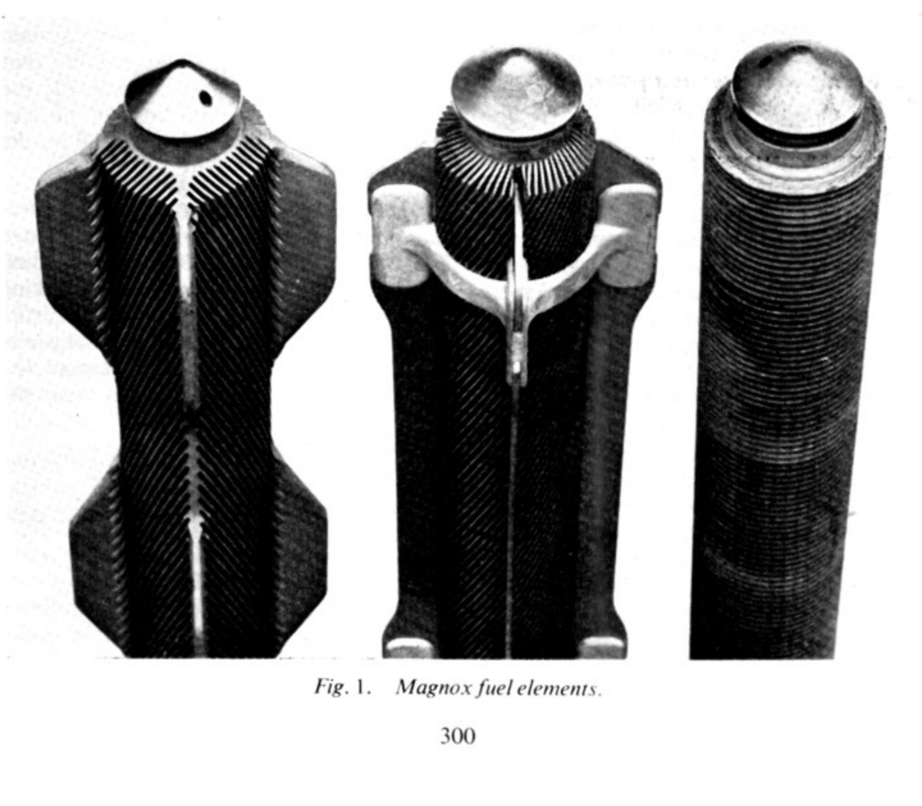

Fig. 1. Magnox fuel elements.

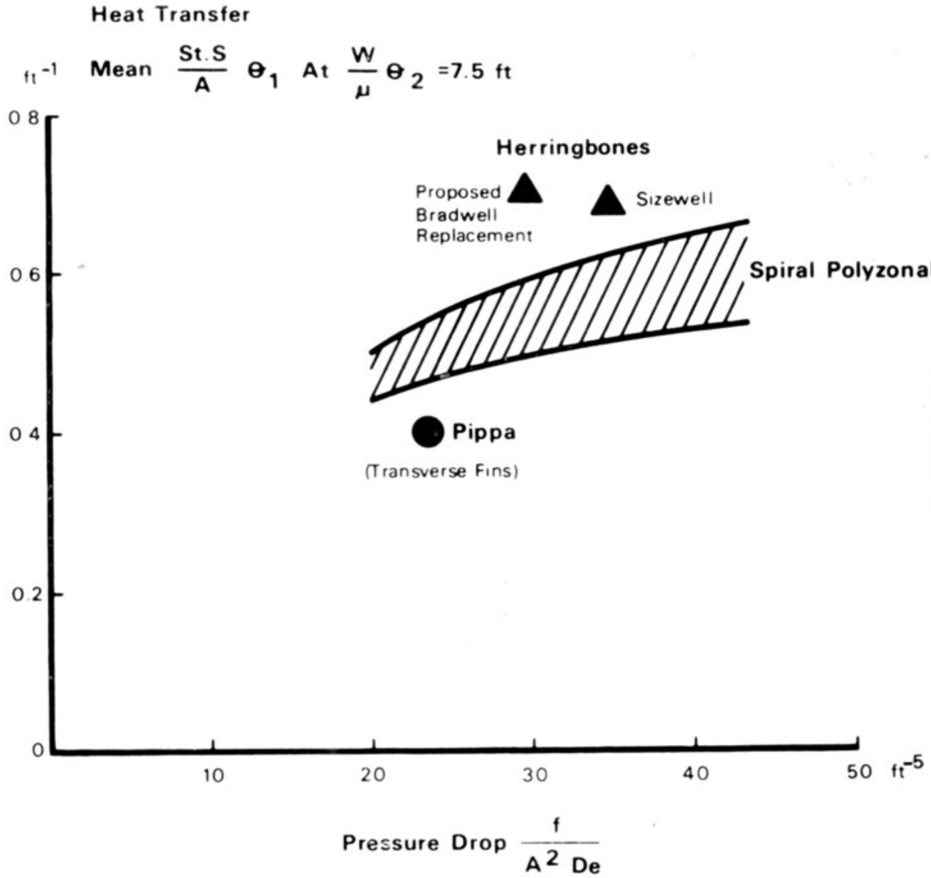

Fig. 2. Advance in heat transfer characteristics of Magnox fuel elements.

Key

St	Stanton number
S	Heat transfer surface area ft.^{2}/ft.
A	Flow area, ft.^{2}
θ_1	$Pr^{0.5}/K0.25$
Pr	Prandtl number
K	Thermal conductivity of gas divided by thermal conductivity of metal (Magnox)
W	Mass flow rate, lb./sec.
μ	Viscosity, lb./ft.sec.
θ_2	$Pr^{0.5}K^{1.25}$
f	Friction factor (Fanning's definition)
De	Equivalent diameter, ft.

more later. To engineers, these pressures are not very high but in reactor pressure circuits novel conditions exist because of the great volume of gas which is contained at these pressures at temperatures which may exceed 400°C, and because the pressure vessels are subject to irradiation as well as temperature and pressure cycling over the reactor life.

Prestressed concrete pressure vessels

A significant development in the first generation of reactors has been the introduction of prestressed reinforced concrete pressure vessels in place of the steel containment vessels used in the first nine British stations. Prestressed concrete vessels have two major advantages over steel vessels; firstly, they permit an integral design of reactor system in which the core, biological shield, heat exchangers or boilers, and gas circulators are all contained in the concrete vessel. The ducts, which contain the high pressure coolant in systems using steel pressure vessels, are thereby eliminated and so is the possible risk of a duct failure and sudden consequential release of coolant. Whereas failure of some components of steel pressure circuits had to be accepted as credible, it is considered that multiple steel prestressing cables will make catastrophic failure of the concrete pressure vessel incredible, so that only slow depressurisation due to failure

Fig. 3 Prestressing cables at Oldbury.

of small-bore auxiliary pipework need be considered. Figure 3 illustrates the size and number of prestressing cables in the Oldbury pressure vessel. Secondly, concrete pressure vessels have the advantage that they permit larger units to be constructed and this helps to reduce capital costs per kilowatt of capacity.

Engineering design to achieve these technical improvements has been accompanied by intensive laboratory research and monitoring of operational plant to provide accurate and reliable data on the changing physical and chemical characteristics under service conditions of reactor materials, particularly steels, concrete and graphite. Rigorous inspections have shown that after 10 years of operation Calder Hall and Chapelcross reactors are in good condition and so are the Generating Board's reactors after five years' service.

Fault studies

When commercial reactors were designed, it was known that neutron flux variations would occur throughout the core under dynamic and steady state conditions, but a detailed knowledge of flux distributions was required to enable reactors to operate safely at their limiting temperatures without risking that fuel elements might exceed their permitted maximum temperature. An important part of nuclear power development in Britain has therefore been the study, theoretically, experimentally and operationally, of the kinetics of power reactors under normal and fault conditions. Computers have been valuable in these calculations and the overall benefits have been:

(a) a deeper understanding of flux distributions, and the ability to predict flux patterns more accurately;

(b) a relaxation of restrictions on the upper operating temperatures in reactor cores; and

(c) more reliable data on which to base improved designs of control and protection systems.

Economies of scale

As I mentioned earlier, economies of scale needed to be exploited in the first nuclear power programme. Figure 4 illustrates how capital cost per kW sent out have fallen as station capacities have increased.

Civil engineering design improvements have contributed to the falling capital costs per kW s.o. as more compact station layouts have been achieved, for example, by combining two reactors within one

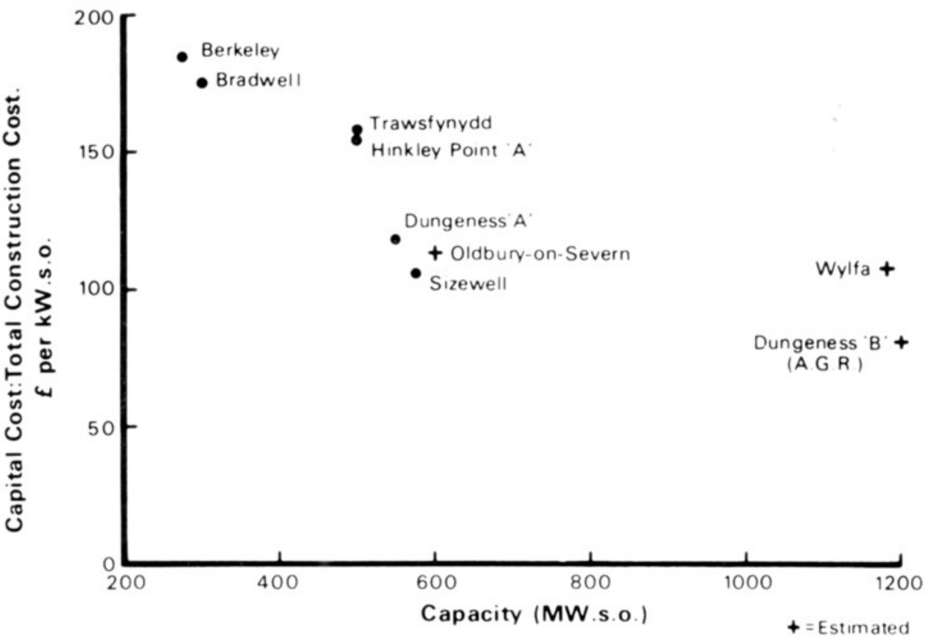

Fig. 4. Fall in nuclear capital costs per kW s. o. with increasing station capacity.

building, integrating reactor and turbine halls, reducing the number of gas circulators and centralising control rooms.

I think you will agree that the later stations are also aesthetically more pleasing.

Commissioning

The Generating Board, like all highly capital-intensive organisations, have the incentive to see that plant is commissioned and achieves design output rapidly. Commissioning of the first four stations in the Generating Board was understandably protracted as engineers, and reactor and health physicists began to understand more about full-scale reactors before they were raised to power. At this stage, nuclear stations were like large pilot plants where numbers of scientists and engineers were gaining experience which was to stand the Board in good stead as subsequent stations were constructed. For example, increasing knowledge of the physics of reactor systems has enabled reactor commissioning to be accelerated without sacrificing safety precautions. Better organisation of work has also accelerated commissioning, for example, the rate of loading of fuel elements into reactors was increased by a factor of 3·6 between the commissioning of Bradwell in 1962 and Sizewell in 1966. Because of our better knowledge and organisation it was possible to commission the second reactor of Dungeness A station in just over three months from fuel loading, compared with 13 months for the first reactor at Berkeley. (This period of 13 months was not wholly spent in commissioning Berkeley; part of the time was used to engineer modifications to the novel and complex equipment.)

The Advanced Gas-cooled Reactor

I have shown how scientists and engineers collaborated to develop the potential of Magnox reactors and to reduce capital and operating costs simultaneously, but the relatively low gas outlet temperature of the first generation of nuclear stations made it necessary to seek a major development if a notable improvement in thermal efficiency and generation costs were to be achieved. So the United Kingdom Atomic Energy Authority, which had been carrying out research and development into improved fuels and canning materials, decided in 1957—five years before Berkeley and Bradwell Power Stations were commissioned by the Board and British manufacturers—to construct an Advanced Gas-cooled Reactor (AGR) at Windscale. The AGR is a logical development of the Magnox reactor because it too has a graphite moderator and carbon dioxide coolant. The major difference is that whereas the Magnox reactors use natural uranium rods canned in magnesium aluminium alloy, the AGR uses slightly enriched fuel—ceramic uranium oxide rods, each encased in a stainless steel can and assembled in clusters within a graphite cylinder.

This change enables both the cans and the fuel to operate at much higher temperature and leads to two important benefits. Firstly, the maximum gas outlet temperature can be raised to over 600°C and, secondly, the rate of heat released from the fuel is very considerably increased, so that a given size of reactor can produce much more power, which is clearly a major economic benefit. Although AGR fuel elements are more costly than Magnox fuel they will produce approximately 7·5 times as much electricity as an equal weight of Magnox fuel. In addition, the ceramic fuel is chemically inert, whereas Magnox elements are combustible under certain conditions.

Although the Windscale AGR was constructed as a test bed for AGR fuels, its original design output of 27 MW(e) was comparable with the 35 MW(e) of the Calder Hall reactors. In the four years since the Windscale AGR reached its design output, the most noteworthy characteristics have been its very high availability of about 85 per cent. and excellent fuel irradiations.

Design improvements incorporated in AGR reactors will also simplify their operation. This is especially true of fuel handling facilities. Whereas in Magnox reactors a single standpipe affords access to a group of fuel channels, and requires the use of a grab and cable which have to operate round awkward bends; in the AGRs, which have many fewer fuel channels, each channel is individually accessible and all the fuel in a channel can be lifted out in one string without using a grab and cable in the most severe reactor environment. Again, the core design enables low temperature coolant gas to pass through the moderator so that its temperature is less than the maximum temperature in Magnox reactors, thus easing materials problems and, incidentally, providing a greater thermal capacity in the core which could be advantageous under some fault conditions.

In 1965, towards the end of Britain's first decade of nuclear power, the Generating Board placed an order for the first commercial AGR station, at Dungeness B, which will consist of two reactors of 600 MW(e) each. The reactors will have prestressed concrete pressure vessels as have the last two stations in the Magnox programme. Earlier this year, the Board ordered a second AGR station of 1,250 MW capacity which will be built at Hinkley Point.

Safety

So far I have not said much about the safety of nuclear operations. I shall now deal with this important topic before summing up the position at the end of the first decade.

The subject of the safety of nuclear power stations has not hit newspaper headlines or TV screens because, since Calder Hall was opened, the main newsworthy item about commercial power reactors is that there has been virtually nothing sensational or untoward to report! This absence of news, although fortunate, is not a chance result. Rather, it is a tribute to the attention paid by the United Kingdom Atomic Energy Authority, the nuclear power consortia, the Generating Board, government departments and manufacturers to safeguards for both plant and people.

There have been no accidental releases of radioactive substances, no incidents affecting the public, and irradiation doses sustained by nuclear operating personnel have been well below the levels permitted under the regulations of the International Commission on Radiological Protection. Perhaps the most significant items of "non-news" are two comments which were included in a report to the Ministry of Power stating that "no plant defects had aroused concern about the safety of the Generating Board's reactors" and "on no occasion when there should have been a reactor trip, has protection equipment failed".

The reliability of reactor protection equipment has progressively increased and equipment has been developed to make plant safety rely less and less on the assumption that operators will take appropriate action in all circumstances. For example, the Generating Board and a manufacturer have developed an automatic "servo-reset" temperature tripping amplifier, whose reliability is such that any one

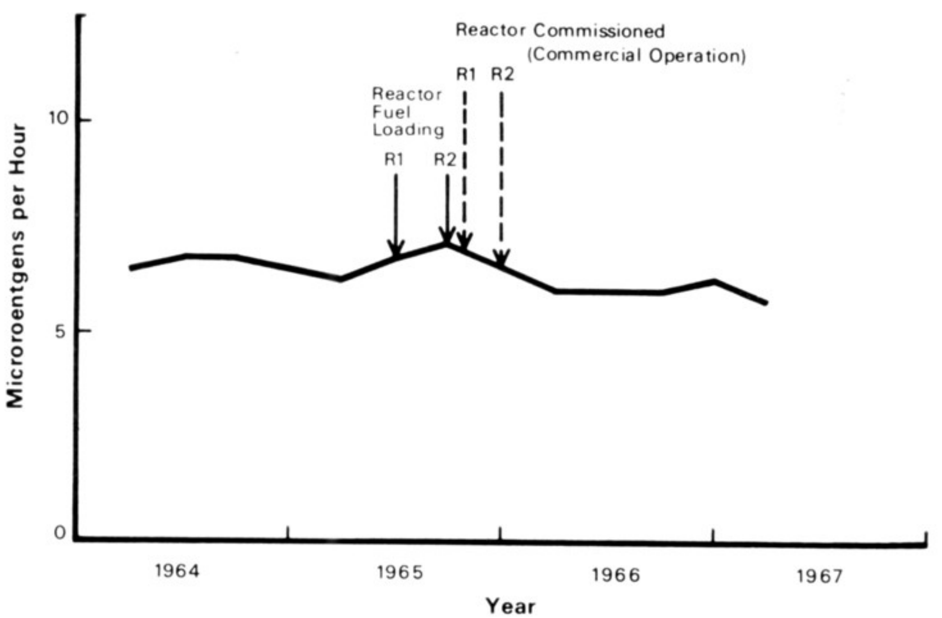

Fig. 5. Background radiation near a nuclear station before and after commissioning.

amplifier will probably fail to operate correctly less than once in 20 years. (The amplifier is of course not used singly but is at least triplicated.) The Board, again in collaboration with a manufacturer, have developed a "laddic" magnetic logic device to replace relays in reactor tripping systems and there have not been any failures in more than two million component hours of use.

Perhaps I can best give you some indication of the detailed attention given to nuclear health and safety by mentioning several other aspects of this subject:

At least one year before nuclear fuel is brought to a new nuclear power station, the Generating Board begin a district survey covering an area within a 20-mile radius of the station to determine background levels of radiation and the radioactivity of soil and plants in the area. Surveys consist of gamma radiation measurements and the analysis of samples of milk, soil and herbage for iodine 131, strontium 89 and 90, and caesium 137 isotopes, which would be specially relevant if fission products were to be released. Similar surveys are regularly made from the time nuclear material is brought to the site to compare measurements with those made before nuclear operations began. Figure 5 indicates the changes in total radiation around a nuclear site before and after operations commenced.

It is interesting that where there has been a demonstrable increase in background radiation and radioactivity at some distance from a station, similar increases have been found throughout the country and are known to be due to fall-out from atomic weapon testing. Figure 6 shows the effect on background radiation at a site in the U.K. of the fall-out from nuclear weapons tests in the northern hemisphere.

Particular attention is paid to the controlled release under Government authorisations of radioactive isotopes in nuclear wastes, as some living organisms can concentrate chemical elements which might subsequently be ingested by people or domestic animals. For example, the total quantity of radioactive material discharged from Bradwell Power Station is strictly limited and a very low zinc 65 component is specified because the station is close to beds of oysters which can concentrate zinc by a factor of a quarter of a million.

Clearly, uninformed or misinformed local opinion could hamper the Generating Board's essential operations and it is in the interests of the public and the Generating Board for the latter to ensure that local authorities and other interested bodies know the implications of establishing a nuclear power station. The Board have found that Local Liaison Committees, consisting of representatives from nearby local authorities, water companies, river boards, Ministry and C.E.G.B. staff, and representatives from such bodies as the National Farmers' Union, help to establish good relations around a nuclear station and provide a forum for dispelling unwarranted apprehensions, and for discussing problems and plans for action in the unlikely eventuality of a nuclear incident.

To ensure the safety of operations personnel, as well as the public, the Generating Board use many instruments to determine radiation levels and doses. These instruments must be reliable and accurate, so the Board have established at their Berkeley Nuclear Laboratories dosemeter calibration facilities which are used by other organisations. The Board also have a Central Radiochemical Laboratory which has recently collaborated in intercomparison analytical procedures arranged by the International Atomic Energy Agency to determine strontium 90 and caesium 137 isotopes in vegetation, soil and dried milk.

To ensure that nuclear stations are operated in accordance with the rigid codes of practice which are mandatory for nuclear licensed sites, each station has a Health Physics Section which is concerned with radiological protection. These Sections are backed by the Headquarters Nuclear Health and Safety Department, which is intimately associated with reactor safety and the radiological protection of staff and public from the plant design stage onwards.

The transport of irradiated fuel elements from a nuclear station to Windscale for reprocessing, after they have been discharged from a reactor, is an interesting example of the attention paid to the safety of the Board's staff and of the public. Irradiated fuel is safely handled in special steel flasks made of thick steel and which weigh about $5{\cdot}1 \times 10^4$ kg when loaded and contain approximately $2{\cdot}5 \times 10^3$ kg of irradiated fuel. Flasks are loaded by remote control whilst immersed in water in deep cooling ponds where the spent fuel elements

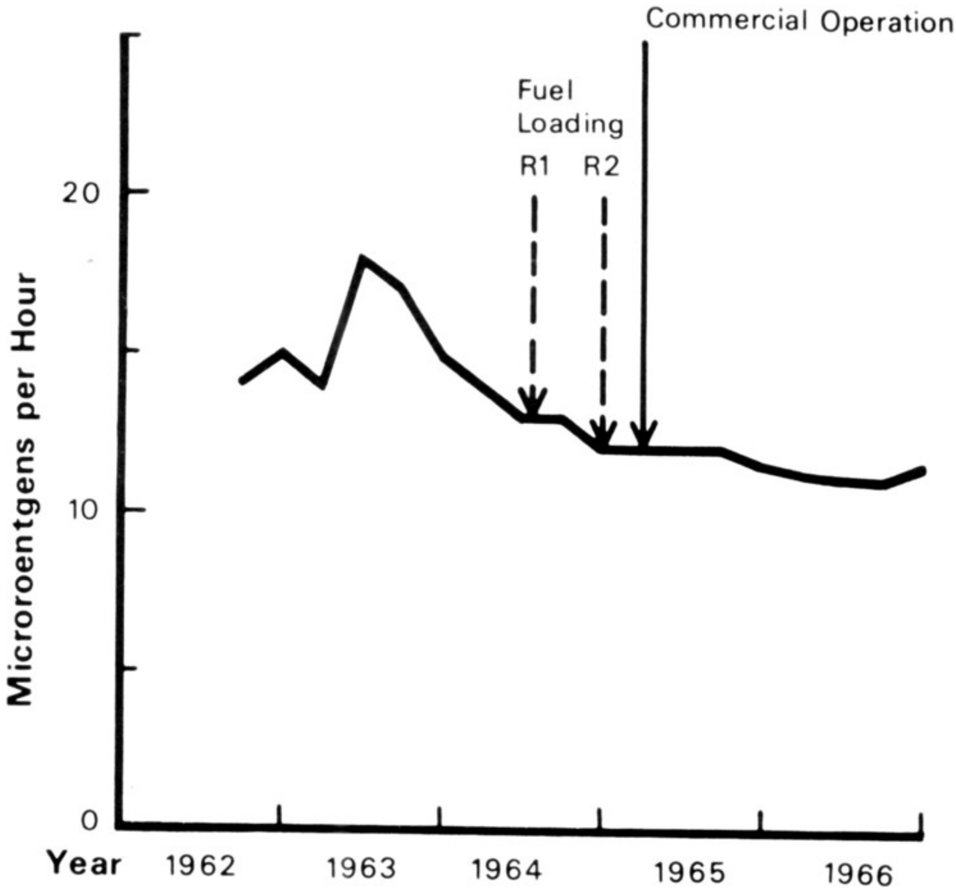

Fig. 6. Effect of above-ground nuclear weapon tests on background radiation near a nuclear power station site in the U.K.

*Note: The decrease in background radiation from mid-*1963 *consequent on the lull in nuclear weapon tests above ground. Radiation continued to fall even when reactors were loaded and commissioned.*

have rested for 120 days for radioactivity to decay. When the flask is filled the outside is thoroughly decontaminated and monitored before it is transported by road at a speed restricted to approximately 19 kmph to the nearest rail head where it is transferred to a wagon for transit to Windscale. The routine nature of this operation, which excites little interest among the public, underlines the regard paid by the Board to their responsibilities for safety.

The situation at the end of the first decade

By the end of 1966 Britain was operating nine Magnox stations with a total capacity of 3,460 MW; in addition, two further Magnox stations with a capacity of 1,740 MW, and one AGR station with a capacity of 1,200 MW were under construction. In aggregate, the operating stations represented over 90 reactor-years of nuclear power experience.

Over the decade the eight reactors at Calder Hall and Chapelcross provided over 60 reactor-years of service at a consistently high load factor which has averaged over 98 per cent. between scheduled refuelling operations. Reactors at Berkeley, Bradwell and Hinkley Point stations all delivered greater than their design outputs at annual load factors of approximately 80 per cent., and during the three winter months from November 1966 to February 1967 they had average load factors of about 96 per cent. In the introduction to this paper I stressed that nuclear reactors must have high availabilities if

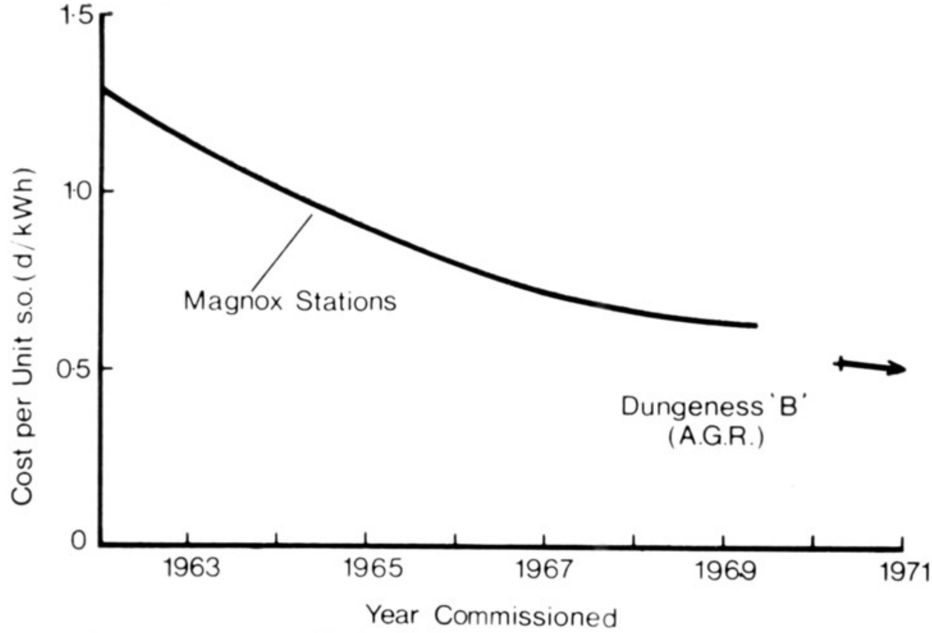

Fig. 7. Nuclear generation costs.

nuclear power is to become economic. The above figures are evidence that the aim has been realised.

In addition, experience of the performance of Magnox fuel elements has enabled the target irradiation of 3,000 MW/Te and a dwell-time in the reactor of five years to be raised in stages to 3,600 MWD/Te and a dwell-time of six years. This advance has the benefit of reducing both fuel costs and fuel handling charges.

In Figure 4 I illustrated how capital costs per kW of nuclear stations has fallen. Similarly, generating costs are falling and, as one would expect, reduced capital costs per kW directly influence generation costs. Figure 7 indicates the trend.

The position at the end of the first decade was that British nuclear stations had produced more electricity than the rest of the world's nuclear stations added together. Many novel problems have had to be faced; not all are solved and no doubt additional problems will arise in future, but on the whole they have been fewer and most have been less difficult to solve than had been anticipated. In fact experience indicates that nuclear reactor systems present less of an operating problem than some of the more conventional plant, for example large turbo-alternators and their auxiliary plant.

The main point is that Britain had developed confidence in the safety of its nuclear plant and in the ability of nuclear reactors to work reliably at high load factors. Furthermore, this confidence in nuclear power had been expressed by investing over £700 million in nuclear stations and nuclear fuel.

The second decade

I have deliberately used a large part of this lecture to survey the first decade of nuclear power experience because it is from this solid basis that Britain has entered the second decade and expects to reap the technical and economic benefits from its earlier research, design, development and operations studies.

Early in the new decade, by 1969 in fact, Oldbury and Wylfa power stations, which are the last two Magnox stations and also the first two with prestressed concrete pressure vessels, will be commissioned and the first nuclear power programme of just over 5,000 MW capacity will have been achieved.

A year later the first of two 600 MW Advanced Gas-cooled Reactors at Dungeness B is scheduled to commence commissioning and this station will be the first in Britain's second nuclear power programme, which aims at the installation of

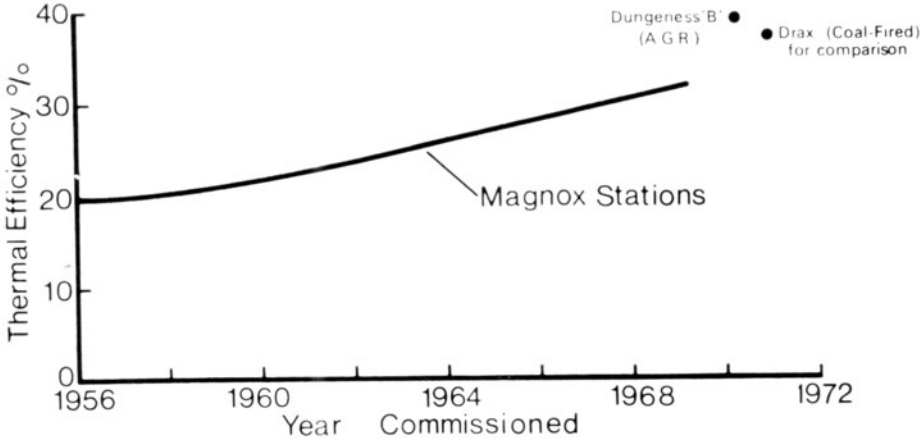

Fig. 8. *Thermal efficiency of nuclear power stations.*

8,000 MW of nuclear plant in the six years from 1970 to 1975.

Advanced Gas-cooled Reactor development potential

I have illustrated how nuclear costs are falling and I must emphasise that generation costs for the first AGR station are not at the bottom of a cost curve which is levelling out. There is no doubt that AGR fuel, reactors and complete stations have development potential which Britain means to exploit. Thus, improved fuels are already being considered, coolant gas pressures will be raised—for example at Dungeness B the pressure will be about 30 atmospheres, but the second AGR station, Hinkley Point B, will operate at over 40 atmospheres. As was the case for Magnox and conventional stations, economic benefits from large-scale construction will also be obtained as station sizes rise from 1,200 MW at Dungeness B to the planned 2,500 MW (four 625 MW reactors) at Heysham. A reduction of up to 20 per cent. in generation costs over the first five years of AGR experience would not surprise us.

Exploiting the technology of large turbo-alternators

Much of the development potential and generation cost reduction will, of course, be attributable to improved reactor and fuel technology, but another significant factor must not be overlooked. Dungeness B will be the first British station—conventional or nuclear—to have 660 MW turbo-alternators. The economic advantages of using larger turbines was recognised long ago, and British plant manufacturers have collaborated with the Generating Board to design 500 MW, 550 MW and now 660 MW sets. The large increase in coolant gas temperature which the AGR affords will enable us to achieve the same steam conditions of 163·0 kg/cm² and 560°C that are available in the latest conventional stations. Thus, benefits from developments associated with conventional plant can now be married to those from advancing nuclear technology. Figure 8 shows how the thermal efficiency of nuclear power stations has increased since Calder Hall; the estimated thermal efficiency of the best conventional station in 1971 is given for comparison.

Station siting

The total cost of generating electricity and transmitting it to the load centres is affected by the location of a power station which determines the distances over which power must be transmitted to load centres. So far nuclear stations have been built at remote points on the coast, partly because of Government requirements that such stations should be sited in areas of low population density and because they need large supplies of cooling water. The improved inherent safety of AGR stations is among factors likely to change the situation. Developments have also been made in methods of safety assessment, particularly by the application of probability theory. Furthermore, the Dungeness AGR will need only slightly more water per unit sent out than a contemporary coal-fired station; an important consider-

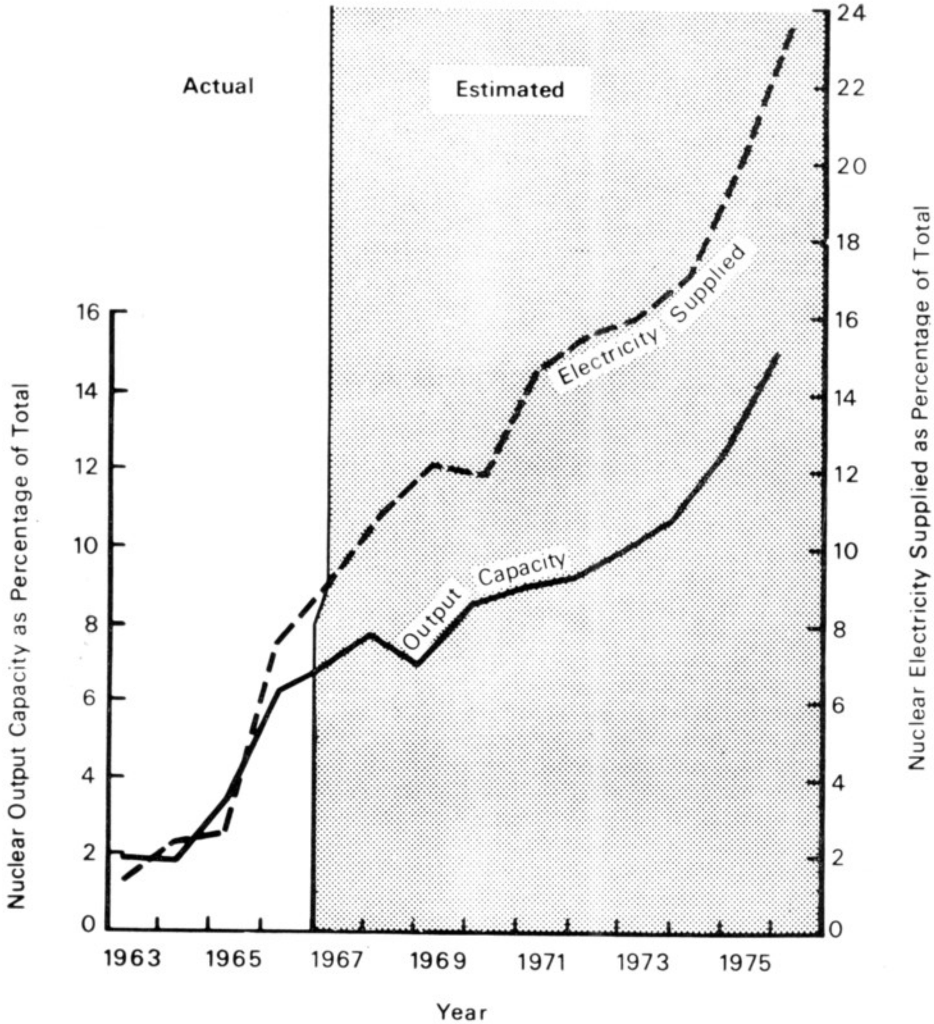

Fig. 9. Growth in proportions of nuclear plant and units generated by nuclear stations.

ation when searching for future nuclear station sites. It is hoped that these factors will lead to a relaxation of conditions for siting nuclear stations and allow more urban sites nearer to the load centres to be used.

The Fast Breeder Reactor

The second decade will also see another major British nuclear development. I refer to the planned commissioning in 1971 of the United Kingdom Atomic Energy Authority's prototype Fast Breeder Reactor (FBR) now being constructed by British manufacturers to the U.K.A.E.A. requirements at Dounreay. Although called a prototype, the design output from this reactor will be 250 MW(e) which is almost double the design rating of each Magnox reactor at Berkeley power station.

The fuel for the Fast Breeder Reactor is mainly plutonium, an artificial fuel produced as a by-product in the Magnox reactors. The intense heat generated in the reactor core is transferred to a liquid sodium coolant and thence to the steam generator. Outside the core is a blanket of uranium 238, much of which will be converted by irradiation to yield more plutonium than is consumed in the core. Hence the term breeder reactor.

Much of the FBR technology is novel and Britain has already accumulated eight years of operating and research experience with the experimental 14 MW(e) FBR at Dounreay. Providing that the performance of the 250 MW prototype fulfils expectations, Britain is likely to be the first country to operate a commercial FBR station; perhaps towards the end of the 1970s, but this is looking beyond the scope of this lecture.

Other reactor systems

Although, ultimately, the FBR system may have advantages over other systems, and at present the AGR with its development potential is attractive, the Generating Board have not closed their mind to the potential of alternative reactor systems. The Board have to judge the point at which the benefits from marginal improvements in the proven and well-understood technology of graphite-moderated, gas-cooled reactors should stop and capital be expended on alternative systems such as the Boiling Water Reactor, Pressurised Water Reactor or possibly the Steam Generating Heavy Water Reactor. The advantages of replication in building nuclear power stations have been obvious, and perhaps it needs saying that so far Britain is the only country in the world which has built and successfully operated duplicate nuclear reactors. The Board may decide, for a later station in the second nuclear programme, again to invite tenders for alternative types of reactor system. They have kept in touch with the development of the Steam Generating Heavy Water prototype reactor built by the U.K.A.E.A. at Winfrith and have also participated in its design. As this prototype with an output of 100 MW(e) is expected to be operating by the end of 1967, valuable experience will have been gained before the Generating Board will need to consider tenders for a commercial station of this type, but at present it is too early to judge whether the SGHW system will be competitive for the size of station in which the Generating Board are interested.

Conclusions

Nuclear power stations are now operating, being commissioned or built, in many countries. Britain, with about 115 reactor-years of commercial experience, has shown that nuclear reactors can achieve design outputs and operate safely at high availabilities and high load factors, so we believe we can claim that "the man with experience is not at the mercy of the man with an argument".

A little over one generation since Chadwick discovered the neutron in 1932, the British view is that investment decisions in nuclear plant can be made on economic as well as on technical grounds, and that during the rest of this decade the economic advantages of nuclear plant will become more evident. Figure 9 shows how the proportion of nuclear plant on the Board's systems has grown and is likely to grow until 1975 when the proportion of nuclear plant is expected to be 15 per cent. and, as nuclear plant will be operated to meet base loads, it is expected that nuclear stations will provide 25 per cent. of the units sent out.

Figure 9 refers only to the Generating Board's system; it does not include U.K.A.E.A. or South of Scotland Electricity Board plant but the trend is clear. Britain invested hundreds of millions of pounds in nuclear stations in the first decade and, to arrive at the position shown for 1975 in Figure 9, is prepared to invest £550 million to construct the 8,000 MW of plant in the second nuclear power programme.

PLUTO's tenth anniversary

PLUTO, one of the Harwell materials testing reactors, has now been operating for 10 years. PLUTO is similar in design to the DIDO reactor, also at Harwell, which went critical in the previous year. Other reactors of similar design were subsequently built at Dounreay and abroad in Denmark, Australia and Germany. PLUTO was built primarily to accommodate large engineering rigs and loops and incorporates a number of large-diameter holes. One loop was that developed and installed in 1961 for testing prototype fuel elements for the DRAGON reactor. Neutron beam and the associated diffraction equipment is also in use and is now being automated. Otherwise there is a continuous programme of irradiation of reactor material involving about 30 experiments. The power has been raised through 8 MW (1958), 10 MW (1959), 15 MW (1962), 20 MW (1965) to 22 MW in 1966.

PLUTO first went critical on 25th October, 1957.

Factors affecting costs of export nuclear power stations

The following paper by G. R. Bainbridge, United Kingdom Atomic Energy Authority; D. Pashley, Nuclear Design and Construction Limited; D. T. H. Rowlands, Atomic Power Constructions Limited; and C. V. Wagstaff, The Nuclear Power Group Limited, was presented at the Symposium on International Extrapolation and Comparison of Nuclear Power Costs, organised by the International Atomic Energy Agency, in London, 9th-13th October, 1967.

WITH the increasing interest throughout the world in nuclear power as a means of competitive power generation, and in the face of the number of different reactor systems available, greater focus has been placed on the costing of nuclear power stations. The direct and operating costs frequently quoted are unfortunately far from comparative, and generally serve to confuse by having a multiplicity of different bases.

In this paper the more important factors which affect the cost of a nuclear power station are discussed with a view to assisting potential buyers of nuclear power stations to choose between the available alternatives and minimise their essential outlay. An appendix is provided illustrating the many factors which must be taken into consideration.

Factors affecting prime cost

The main items determining the prime cost of a nuclear power station, and which often permit wide differences to arise between the costs for alternative designs, are:

1. Specification
2. Extent of supply
3. Site conditions
4. Manufacturing requirements

and 5. Contract price date

Specification

A clearly drafted specification can help to reduce wide differences in the standard or quality of the power stations offered, though a very detailed one should only be attempted by a well-staffed and experienced organisation. It may be too late to consider this matter after a contract has been placed and detailed drawings become available. Terms in the specification such as "to the satisfaction of the Engineer" can be variously interpreted and lead to significantly different costs. Where there is limited past experience between the customer and the tenderers, price variation clauses inevitably appear in the offers, which make comparisons almost impossible without detailed assessment of the designs.

Extent of supply

It is natural enough for a customer to ask "What am I getting for my money?". To get an answer, a detailed examination of the extent of supply for each offer must be undertaken. Exclusion from an offer of items in the cooling water system, in the essential supplies, or in the area of the station and generator transformers might not be readily observed, but to make good the deficiency in these items could cost several pounds sterling per kilowatt. The basis of supply of the plant must also be considered since many items may be on a manufacture and deliver basis, leaving erection and setting to work to be arranged by the customer.

The output from a given extent of supply is also important. The actual design capability may be 30-40 MW different from the nominal output, and an adjustment to the specified output may be needed to get a true cost comparison between designs.

Other adjustments may be required for differences in the necessary fuel stocks, the stock of spare equipment to ensure that comparable load factors will be achieved, or the power which would need to be brought-in to replace any shortfall in availability due to some inherent design feature such as off-load refuelling.

Site conditions

It is possible to delete from a comparison, though not from an absolute cost determination, some common site items. Significant cost differences can arise, however, between designs having different thermal efficiencies and hence different cooling water requirements; or different turbine speeds or characteristics requiring different ground support or transmission line matching equipment. If different sites are essential for alternative designs the costs of transmission lines and transmission of energy should be taken into account; this latter aspect is assuming more importance with the trend of siting some nuclear power stations near load centres.

The nature of the site, its location and access facilities may give rise to cost differences. Some designs could be more suited to a coastal site than to a river with limited flow; others may be more readily constructed on shingle or sand, while good load bearing rock would probably provide a cheaper construction for any design.

Manufacturing requirements

Many countries have important industrial resources and are keenly interested in manufacturing as much as possible locally. In these cases the cost of a significant proportion of the plant is subject to local conditions, taxes and productivity. In similar situations cost comparisons cannot be based on the direct conversion of currency values, and prices must be built up bearing in mind local construction requirements and methods. At the same time the impact of additional features such as local practices and design codes can be incorporated.

Contract price data

Adjustments may be required to get a proper comparison between cost figures for different contract price dates. There has generally been considerable escalation of prices for plant in recent years, which has varied from country to country. This aspect could therefore be important in any international comparison of offers from different countries, as escalation post contract price date is generally paid by the customer.

Factors affecting contractor's on-costs

Many items for which the contractor must include a sum of money in his tender price require careful consideration if the offer prices are to be kept low and comparison between designs is to be attempted. These factors include:

1. Conditions of contract
2. Guarantee
3. Risks
4. Terms of payment
5. Contract handling
6. Construction time
7. Construction methods and codes
8. Inspection
9. Commissioning

Conditions of contract

There is no valid reason for making the general conditions of contract more onerous than those for a fossil or hydro-power station. There are well established sets of such conditions available for international trading such as:

(i) U.N.E.C.E. Conditions 188A.
(ii) F.I.D.I.C. Conditions of Contract (International) for electrical and mechanical works.

Guarantees

The guarantees requested should be carefully related to the extent of supply. For a complete station the cost will be higher if separate guarantees are called for on components, because this can place unnecessary restraints on the designers as well as increasing the overall margins in the plant as a whole. Thus, the performance guarantees are better restricted to the output and efficiency of the whole station.

Any guarantee of the construction period should be associated with an unambiguous extension-of-time clause in the general conditions of contract, releasing the contractor from responsibility for delays which are beyond his control. Without such a clause the contractor will be encouraged to add a contingency amount to his price.

The only other necessary guarantee is the conventional cover against defects in design, materials or workmanship during the 12 months following the satisfactory completion of guarantee tests.

It is to be expected that the fuel supply contract will be a continuing one after the plant contractor has completed his obligations. It is therefore prudent to call for a separate guarantee of fuel life, which can be given in the form of a guaranteed fuel cost associated with a specified fuel management scheme.

Guarantees covering the availability of the plant are sometimes suggested. The form of these guarantees, and the precise wording to govern implementation, are of great importance if the guarantee is to be of any value.

The unit sizes of power plant have increased rapidly in recent years, and statistics on availability are not adequate to provide a suitable basis to determine what additional money is required to meet a specific guarantee.

Risks

There should be a clear point in time at which each risk passes from the contractor to the customer.

A special risk in the building of a nuclear station arises from the presence of radioactive substances. Most countries have legislated for this risk to fall on the reactor owner. The extent to which some part of such risk can be passed to the contractor during the time he is handling radioactive materials varies, but the division of responsibility can be made quite clear. In particular, reference can be made to the national legislation concerned (see International Conventions on Civil Liability for Nuclear Damage, I.A.E.A. Legal Series No. 4—1966).

Terms of payment

Because of the large sums of money involved the contractor will require progress payments during construction. These will reflect the actual progress of work if they are to serve the purpose of assisting the contractor with minimum cost to the customer. It must be realised at the outset, however, that any advance estimate of the rate of progress can be inaccurate, and that checking the progress of work to assess payments due may involve a large amount of administrative work.

The contractor normally expects these progress payments to cover at least 90 per cent. of the price, with release of the bulk of any retention money at completion of construction and the remainder in two instalments (i) after the guarantee tests and (ii) at the end of the defects guarantee period.

Payments made during the construction period have a significant effect on the overall cost of the station, so the customer is advised to be in a position to assess what this cost will be.

Contract handling

This is an expression often used in its widest sense, thus creating a pretext for contractors and customers to have large staffs. However, if regarded as a single financial function which can be operated by an accountant the costs are often considerably reduced.

Construction time

Because of the interest paid during construction the length of the construction period has a significant effect on the ultimate cost of the station and the generating cost, particularly when interest rates are high. It should be noted, however, that if the construction period specified is unrealistically short the contractor is encouraged to add a contingency amount into his price for item delays.

Construction methods and codes

Where a choice exists experience so far has shown that it is cheaper and more efficient to manufacture in workshops rather than on the site, so that site construction will mean bringing together the largest pieces of plant that can be transported. Cranage is then required on site to lift the heaviest items and very probably some site assembly of large shop-fabricated items. The fact that cranage is available will influence the design of smaller items and the package form of manufacture becomes an advantage. Studies nevertheless indicate that it does not seem possible or sensible to plan for a construction period for a single reactor of less than about three years.

Inspection

Inspection should be limited to the minimum which is absolutely necessary after consideration of:

(i) Effect on nuclear safety of subsequent failure.

(ii) Any novel features incorporated in the plant.

(iii) Compliance with accepted codes or national statutory requirements.

(iv) Accessibility for repair or replacement after failure.

(v) Design criteria and inbuilt safety factors.

Non-destructive testing can be very expensive, particularly for certain types and configurations of welds. Careful consideration of design details may therefore result in reduction in the cost of the testing procedures.

Inspection is also necessary to ensure that the plant can be built in association with other items of plant at the site. Hence the correct specification of terminating points and cross reference to adjacent items is important.

Commissioning

Nuclear data at the period when the first commercial nuclear power stations were designed was often tentative or incomplete. Considerable uncertainty existed regarding requirements for absorbers, the ability to shape neutron fluxes, temperature limitations and so on. Elaborate and lengthy commissioning programmes resulted.

Measurements can now be limited to those required to confirm predictions, and much of the plant testing is done during the construction period, leaving only the co-ordinated performance testing for the commissioning period.

Factors affecting customer's on-costs

These factors include:

1. Interest during construction
2. Land purchase and site development
3. Other direct contracts
4. Administration
5. Taxes and insurance during construction
6. Escalation

While some of these items can be estimated as a percentage of the contract price, others, such as land purchase and administration, are definitely not. The practice of adding a percentage in early calculations is not advisable unless care is taken to arrange that the percentage will decrease as a function of station output and will also take account of design type.

Interest during construction

The interest rates on short-term loans may be more in favour of the customer than the contractor and so some careful thought about the way in which the progress of the project is to be financed can be repaid by reduced costs.

Land purchase and site development

In many respects the considerations of ultimate site capacity for nuclear power stations with superheat turbines are now little different from those for fossil fuelled stations except for the differences arising from fuel storage. The advent of the reinforced concrete pressure vessel has led to an inherently safe reactor which creates no pollution and makes possible the economical use of sites very close to centres of population and industry. The purchase of an exclusion area round the site is not necessary for some designs of reactor.

Other direct contracts

This raises the general question of the wisdom of separating parts of the station for direct contract. Because of the integrated nature of the design and site construction it should be carefully considered whether any advantage obtained by placing such direct contracts is outweighed by the diminution of the responsibility of the nuclear contractor in design and site construction.

Administration

The decision on the extent to which a nuclear department is established is primarily an economic one, since a utility unable to do its own supervisory work will find that consultancy services are easily negotiated.

Taxes and insurance during construction

It is of great importance that the responsibility for the payment of taxes is made quite clear. It is sometimes possible for a purchaser of a major power plant to get some relief from import duties. It is worth considering whether these and other taxes, variously known as sales tax, transfer tax, transmission tax, etc., are better handled centrally by or on behalf of the customer and removed altogether from the contractor's price.

There can be no doubt about the cost advantage in handling the site works insurance centrally, provided this can be achieved within local laws which are sometimes restrictive. As the contractor is fully responsible for the plant up to the time it is taken over by the customer this insurance should be covered by him. The contractor should make sure that there is a proper reflection in his sub-contractors' prices for deletion of what would normally be their insurance responsibility.

Escalation

In industrialised countries customers are generally familiar with formulae for price adjustment. It should therefore only be necessary to specify that formulae should be based on specified nationally published indices for both labour and material. The

TABLE 1

Cost Comparison by Present Value Method

			Nuclear A	Nuclear B
1.	Capital Cost	£/kW	60	56
2.	Fuel Inventory Cost		12·5	13·6
3.	Final Fuel Credit		— 1·5	— 1·6
4.	Nett Replacement Fuel		25	30
5.	Availability Adjustment—say		Nil	8*
6.	Other Works Costs		6	6
7.	Insurance		3·5	3·5
	Total ...		105·5	115·5

*Annual off-load maintained and refuelled.

simplicity of the formula method of adjustment will outweigh the extra administrative cost of checking actual cost rises by more detailed methods. The check of civil construction cost rises is also well established routine in most countries.

Cost implications of operating requirements

Operating practices

These vary widely between different utilities, but there is a common operating and maintenance objective to get the maximum station output reliably and consistent with safety using normal power station engineering practices.

The specification of fully automatic control may increase the station cost, and so a view must be formed about the possible effect on plant availability and running costs. Specification of local controls, instrumentation, start-up and alarm systems can also increase costs and so requires careful thought.

Other factors affecting costs include the methods of implementing safety regulations and arrangements for shift working.

Operational and periodic maintenance

Current AGR designs have facilities for on-load refuelling and overhaul of many core components. This means that minimal plant outage is required, principally for the purpose of statutory inspection, e.g. of boilers, and overhaul of turbine-generators.

A large utility with a policy to provide a reliable service and to minimise capital investment in new plant may aim at high station load factors and reliability by providing generous standby equipment and extensive maintenance facilities with large numbers of staff. To reduce capital and running costs a small utility may arrange for contractors to do planned station maintenance and repairs; hence permanent workshops and maintenance facilities can be kept to a minimum.

Staff complement and other works costs

For most utilities a staff complement of 60 on a four-cycle shift arrangement should be adequate for operation of a 300-1200 MW single unit station. Shift operators would need to be experienced to undertake control of day-to-day maintenance.

In such a case the works cost breakdown is roughly:

		%
(i)	Wages	22
(ii)	Staff expenses	2
(iii)	Contract labour	8
(iv)	Specialist services	3
(v)	Chemical services, oil and water	10
(vi)	Stores and replacements	20
(vii)	Nuclear plant insurance	35
		100

The total cost would, at U.K. cost rates, be £0·5—£1 million per annum.

The cost of specialist training, though usually an extra to the basic power station, is not large, involving a small number of key senior grades only in doing specialised training at contractors' works and at operating nuclear power stations.

Spares

Recommendations, with delivery periods, for maintenance and breakdown spares can readily be obtained from a contractor, and although some spares must be available prior to commissioning, the cost in the operating budget is modest.

TABLE 2

Station Selection Affected by Changes in Ground Rules

Station ...				A	B	C
Capital Cost ...			£/kW	75	60	45
*Fuel Cycle Cost ...			d/kWh	0·08	0·13	0·18
*Operation, maintenance and insurance			d/kWh	0·036	0·036	0·036
Interest Rate % p.a.	Amortisation Period years	Load Factor %			d/kWh	
10	20	65		0·497	0·478	[0·459]
*7½	25	75		0·363	[0·362]	0·363
5	30	85		[0·264]	0·278	0·291

[ ] Preferred design based on generating cost.
* Ground Rules applicable to Basic Costs.

Licensing and insurance during operation

Most contractors are prepared to support a utility to obtain the necessary licences for operation, at no extra cost. There will, however, be utility operating costs for nuclear risks insurance.

Total cost comparison

When comparing the likely cost of electricity from alternative generating stations with significantly different characteristics it is desirable to carry out a system analysis in which the effects of the alternatives on total system costs through the years are considered. This is based on year by year calculations of the total system cost of alternatively meeting the demand for electricity, and is worth applying when the alternative new stations have different cost and operating characteristics. However, it is only appropriate when the generating system is integrated through a transmission network. The method is unnecessarily involved when dealing with, say, two nuclear stations, which have fairly similar costs and operating characteristics, in a situation when the nuclear component is a fairly small proportion of the total installed capacity.

In comparing alternative nuclear systems it is normally sufficient to assume a common discounted average lifetime load factor (except in-so-far as different availabilities produce a variation) and to assess costs either by comparing the present values at the commissioning date or the cost per unit calculated on an annuity basis. An example is shown on Table 1.

These present value totals can be expressed as average costs per kilowatt-hour either by converting into an annual sum by the annuity method and then dividing by the units sent out in a year or (more directly) by dividing by the discounted units sent out during the life of the station.

To arrive at the cost input data for these comparisons, great care is required to select appropriate economic assumptions or ground rules. These ground rules include:

(i) The rates of interest on capital, including short-term interest rates during construction.
(ii) The station life (i.e. the amortisation period) assumed.
(iii) The load factor.

Because nuclear stations are still more capital intensive forms of electricity generation than fossil stations, the rate of interest taken has a significant influence in a comparative assessment. Similarly, insufficient care in selecting other ground rules can jeopardise a proper comparison.

An illustration of how changing these ground rules can affect the generating cost is shown in Table 2.

The three ground rules, interest rate, amortisation period and load factor, affect the capital components of cost, that is station cost and initial fuel inventory. It is therefore essential to ensure when costs are quoted for different systems that common ground rules have been used, or at least where they differ they can be properly substantiated. Some of the other ground rules which affect the capital component were mentioned earlier, e.g. taxes, import duties, accounting conventions, insurance and capital investment rebates. Where capital or generating costs are claimed for a system a thorough examination of whether these components have been included is required.

There is also a range of ground rules mainly affecting the fuel cycle costs of nuclear stations which include:

(a) Those affecting the cost of fissile, fertile or moderator materials and their preparation for use in the reactor, e.g. ore prices, separative work costs, fuel fabrication costs, plutonium credits, heavy water prices, re-processing costs.
(b) Those affecting delivered prices of fuels, e.g. transport charges, customs duties, taxes, reserve stocks.
(c) Technical assumptions such as irradiation levels, fuel management techniques, refuelling arrangements and method of dealing with the last charge.

Illustrative figures for the effects of variations in ground rules are shown in Table 3, relating to a power station costing an all inclusive £60/kW, at the date on power and having a generating cost of 0·36d/kWh including a fuel cycle (inventory plus replacement) cost of 0·13d/kWh.

The figures quoted are for variations from the basic conditions shown, which are not, of course, all cumulative in their effect.

Assessment factors

When considering the purchase of a nuclear plant there is generally no satisfactory substitute for inviting tenders and thoroughly assessing the alternatives offered. This requires assessment work in four main areas:

1. Engineering
2. Safety
3. Performance
4. Development potential

In each area the assessment has the objective of seeking out the features which are inadequate or in excess of requirements, and hence have cost implications which in many cases can be quantified.

Engineering

It is important to realise that the assumptions with regard to load factor can have a significant effect on the costs assessed for a nuclear power station. High load factors are not obtained automatically with any nuclear plant, and an engineering assessment is required to decide the load factor likely to be achieved in practice, which may be different from what the supplier claims. The load factor attained by a station can be influenced by two basic considerations. Firstly its running cost, and its consequent position in the merit table. Because nuclear stations have low running costs they will be higher in the merit table than fossil fuelled stations, and there will be considerable incentive to run them at as high a load factor as possible. Towards the end of even a nuclear station's life it may, however, only operate at low load factors if newer nuclear stations with even lower merit order costs have been introduced. Secondly, the availability of the station will affect the load factor it obtains. The availability will itself in turn be affected by fixed

TABLE 3

Variations in Generating Cos

		Basic Data	Variation	Effect d/kWh
Amortisation Period	Years	20	+ 5	− 0·025
Load Factor	%	75	+ 5	− 0·020
Interest Rate	%	7½	+ 1	+ 0·025
Ore Cost	£/kg	6	1	± 0·008
Separative Work Cost	£/kg	12	1	± 0·004
Fuel Fabrication Cost	£/kg	20	1	± 0·002
Fuel Reprocessing Cost	£/kg	5	1	± 0·002
Plutonium Credit	£/g	2	1	± 0·008
Irradiation	MWd/T	20,000	2,000	± 0·009
Mean Rating	MW/T	15	5	± 0·013
Enrichment Levels	%	1·7	0·1	± 0·008

features of the design and engineering; for example, the size, type and spare capacity of plant, the maintenance requirements and refuelling requirements may all affect the load factor. The engineering aspect in the assessment of designs offered is therefore extremely important in any cost assessment.

Another important consideration is a close examination of the manufacture and construction procedures proposed for key plant to ensure that the station will be completed to programme.

When examining the reliability of proposals it is convenient to consider the designs offered under various broad headings, e.g.:

(i) Plant in normal operating environments and at normal working conditions.

(ii) Plant and equipment which in the event of failure either cannot be easily reached for repair, perhaps because it is within a containment dome or behind radiation shielding, or can only be approached after considerable time delay and/or at considerable expense.

(iii) Plant and equipment which can be repaired or replaced fairly easily but whose failure leads to station shutdown.

(iv) Plant and equipment working in severe conditions, e.g. of temperature difference or cycling, or turbulent coolant flow.

It is axiomatic that simple and robust engineering is preferred and often marginal capital cost increases can be justified by reliable performance. A nuclear power station with low running costs but relatively high capital investment must be run to as high a load factor as possible and engineering reliability assessment plays a large part in giving confidence in an economic comparison made of different systems.

Safety

A price consideration for an electricity utility will be the siting of the station, since restrictions on the freedom of siting can be extremely costly. The utility will want to site the station as near to a load centre as possible and this is particularly true with a nuclear station where fuel transport to the station is a minor matter. In the case of a coal station, however, an economic assessment including fuel transport charges, cost of transmission lines and energy transmission costs may show that the station should be sited close to the mine and away from the load centre.

This freedom of siting will be directly related to the safety of the station. For example, the 2500 MW Heysham AGR station to be built by the C.E.G.B. in the U.K. is to be sited within a few miles of Lancaster, the county town of Lancashire, with a population of about 50,000 people, and with a large chemical industry and the site of a new university. The Heysham site is also within a few miles of the large holiday town of Morecambe, with a fixed population of about 40,000 which is considerably increased during the summer months. A coal station, or a nuclear design with a less well proven power system, would be less acceptable there unless plant improvements could be included, possibly incurring appreciable additional cost.

This freedom of siting has two obvious advantages: one in the reduction in the cost of installation of long transmission systems to reach the load centre, and secondly, the reduction of transmission line losses (the station has to produce fewer MW).

Performance

The assessment of the claim made for the performance of a nuclear station can be a very complex matter, and the utility will partially safeguard itself in this respect by requiring guarantees of electrical output, with adequate penalty clauses should this not be met. On all U.K. stations to date design performance has been exceeded. Coupled with the actual output of the station will be an assessment of the fuel cycle proposed, the fuel enrichments and the effects on the costs of generation quoted, together with aspects of the control system. The guarantees offered may not compensate for a shortfall in output performance which may not be easily made good in a short time. A cost penalty may have to be debited against an inadequate offer.

Development potential

A narrow approach concerning a single station only can be useful in some respects, but it can be seriously misleading to fail to consider later advances in technology. There are many less tangible credits which can be, and should be, placed in favour of a particular proposal and the fact that these cannot always be precisely quantified is no remit to ignore them. Amongst these is the question of development potential.

It may be helpful to consider this under two general headings. Firstly there is the potential in the system. For example, the early U.K. choice of the graphite moderated gas-cooled system took into account the development potential inherent in such a system. This potential leads to successive improvements, and it is necessary to make a careful evaluation to see if that system has the potential to give progressively lower operating costs, or if it has already been as fully developed as might be expected. Secondly, one can look at the particular plant and assess the potential it has to incorporate improvements as they come along, an aspect which is particularly relevant to fuel development.

Conclusions

Meaningful comparison of nuclear power station tenders depends upon adequate preparation at the enquiry stage to specify clearly what is required, particularly in respect of extent of supply, site conditions and manufacturing arrangements.

A comparative assessment will require cost adjustments for items such as the guaranteed power output and the contract date.

Positive directions for dealing with guarantees, risks, taxes and insurance will reduce the contractor's on-costs.

Early consideration of the customer's on-costs can be repaid by lower costs.

Pre-tender discussion between the customer and possible contractors can be advantageous and would ease the problems of subsequent comparative assessment of offers by minimising the cost adjustments needed for differences in interpretation.

From engineering, safety, performance and development potential assessments a modification list should be prepared which must be applied to a comparison between tenders.

Comparison of cost of generation requires the selection of appropriate ground rules. This applies to rules affecting fuel cycle costs as well as interest rate, amortisation period and load factor.

APPENDIX

Factors affecting costs of nuclear power stations

1. *Factors affecting prime costs:*
   - (i) Specification
   - (ii) Design codes
   - (iii) Design life
   - (iv) Extent of supply
   - (v) Site conditions
   - (vi) Manufacture:
     - material and equipment availability
     - local industry
     - labour rates and productivity
     - taxes
   - (vii) Contract price date
   - (viii) State of development and replication
   - (ix) Siting and safety
   - (x) Safeguards
2. *Factors affecting contractor's on-costs:*
   - (i) Conditions of contract:
     - guarantees
     - risks
     - terms of payment
   - (ii) Contract handling
   - (iii) Construction time
   - (iv) Construction methods and codes
   - (v) Inspection
   - (vi) Financing
   - (vii) Commissioning
3. *Factors affecting customer's on-costs:*
   - (i) Interest during construction
   - (ii) Land purchase and site development
   - (iii) Other direct contracts
   - (iv) Administration
   - (v) Taxes and insurance
   - (vi) Escalation
4. *Factors affecting operations:*
   - (i) Operating practices
   - (ii) Operational and periodic maintenance
   - (iii) Staff complement
   - (iv) Staff training
   - (v) Spares
   - (vi) Insurance
5. *Total cost comparison:*
   - (i) Ground rules
   - (ii) Assessment factors:
     - engineering
     - safety
     - performance
     - development potential
   - (iii) Capital cost of plant
   - (iv) Cost of fuel inventory
   - (v) Cost of replacement fuel

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 to the Centre.

Two-Phase Heat Transfer
8th to 12th January, 1968

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.

Lecturers on Radioisotope Work in Schools
8th to 19th January, 1968

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. The emphasis throughout will be on the practical introduction of radioisotope methods into the chemistry, physics and biology syllabus. Fee: £26 5s. exclusive of accommodation.

General Isotope Course
22nd January to 16th February, 1968

Intended to give a good practical introduction to the use of radioisotopes in research and technology, with particular concern for the problems of the students. Opportunities for carrying out work in connection with students' own needs. Fee: £105 exclusive of accommodation.

Pulse Techniques in Nuclear Particle Counting
29th January to 2nd February, 1968

Arranged for U.K.A.E.A. graduate staff, this course will be of interest to others working in the field. Fee: £26 5s. exclusive of accommodation.

Magnet Design
12th to 16th February, 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.

Radiological Protection
19th to 23rd February, 1968

Designed to give users of radioactive substances and radiations in industry, research or teaching a broad introduction to the principles and practice of radiological protections, with a strong emphasis on practical considerations. Fee: £26 5s. exclusive of accommodation.

Advanced Techniques in Non-Destructive Testing
4th to 6th March, 1968

Based on new techniques and approaches to non-destructive testing that have been developed by the U.K.A.E.A. Designed for users in other industries who should be familiar with the scope of the subject and the basic procedures in common use. Fee: £26 5s. exclusive of accommodation.

Radioisotope Methods in Chemistry
4th to 22nd March, 1968

Intended to give graduate chemists a sound introduction to radioisotope methods. There is scope for carrying out individual experimental work. Fee: £78 15s. exclusive of accommodation.

High Voltage Technology
13th to 21st March, 1968

Intended for graduate engineers and scientists who are new to high-voltage technology, or whose experience has been limited to a specialised aspect. Fee: £36 15s. exclusive of accommodation.

Process Instrumentation
18th to 29th March, 1968

Intended for graduates who are working on the instrumentation of process plant, nuclear reactors and scientific apparatus or who have a direct interest in the subject. A visit will be arranged to a process plant or a power station where modern control techniques are being applied. Fee: £52 10s. exclusive of accommodation.

Cheap energy for the future

Professor Sir Ronald Edwards, Chairman of the Electricity Council, made the presentation at the Annual Prizegiving of the Winfrith Apprentices School on Friday, 3rd November. The following is an extract from his speech.

"THOSE who are apprenticed here in Winfrith have the great privilege of undertaking their training in one of the most advanced and sophisticated industries in the world. We hear a lot nowadays about the 'brain drain' of young scientists and engineers, and it is often put down to a lack of opportunity in this country. This is no doubt true of some sectors of the economy—though I hope it will not be true for very much longer—but it is most emphatically not true and never has been true of the electrical engineering and electricity industries, and above all it is not true of the nuclear energy industry. In this field this country can hold its head high. I do not need to tell you that in each of the last two years Britain has produced more electricity from nuclear power stations than the rest of the world put together. This will not always be so, because other countries are now realising that nuclear power is the key to cheap electricity. But it is an achievement of which we ought to be proud and which should stiffen our determination to stay well ahead of the rest of the field.

"We should be under no illusion that this is going to be easy. The prizes for leadership in this field are enormous and the rivalry will therefore be intense.

"Bearing in mind all that has been done in this field by the A.E.A., the Consortia, the plant manufacturers and the electricity supply industry, it seems to me sad that the difficult issues that we have had to face in settling the fuel policy of this country for the next decade have led to an unfortunate disputation about nuclear energy. We are a self-critical nation and this is a sign of our maturity. But self-criticism should not go too far.

"Even in the first nuclear programme major reductions in capital costs, and therefore in generating costs, are being achieved. The net reduction over the last six or seven years amounts to 40 per cent. in spite of continuous inflation and that is a very impressive performance.

"The nuclear station at Sizewell in Suffolk has been generating power for more than a year at a total cost of 0·7d. per unit, which is about the same as the modern coal-fired station just coming into operation at Tilbury. In three years' time the first of the advanced gas-cooled reactor stations will be producing energy at a total cost significantly below that of contemporary coal-fired stations anywhere—even those which are sited where coal is cheapest.

"Nuclear energy so far as my industry is concerned must win its laurels on purely economic grounds. It is the duty of my colleagues and I to produce power as cheaply as we can.

"The coal industry has served this country well and, indeed, will continue to serve it well. Certainly my industry will be using coal to the end of the century at least. I have the greatest admiration for the drive, skill and determination with which my colleague Lord Robens has led and is leading his industry in this difficult time. It may be that as the coal industry is pruned of its expensive parts and concentrates on production with high productivity at low-cost Yorkshire and East Midlands pits, we shall see a future downward trend of coal prices. Nothing would please us more than significant reductions in the cost of coal, because nearly 80 per cent. of our present generating capacity is coal-fired. As each planning decision on new power stations comes along coal will get as fair an opportunity as natural gas, oil and nuclear energy. Price over the long term is for us, and the whole community, the crucial factor.

"I can understand the fears which the march of new technology has aroused in the coal industry and I am the first to agree that miners must not be thrown on the scrap-heap just because their skill is no longer required. But it would not be the right answer to this important problem to turn our backs on technological progress. It is generally recognised that one of the major causes of this country's current economic difficulties is our reluctance to apply new ideas and techniques. Don't let us make that mistake any longer, the rest of the world will not and we cannot afford to.

"We must strive now that we have cheap sources of power—and we have, in addition to nuclear energy, natural gas from the North Sea—to use this cheap energy to lower the cost and speed up the development of industries that will improve our balance of payments and enable this country to drive ahead with a higher rate of production, towards a higher standard of living.

"I have spent some time on this rather serious subject instead of providing you with jokes and light-hearted remarks quite deliberately. I have done so because it is most important that you who are going to start your careers in engineering, many of you in nuclear energy, should understand the issues that face this country. We are not going to have an easy time, we are going to have to struggle very hard indeed. Cheap energy is going to be an important factor in our future; if we are to get this and harness it, hard work, first-rate training and, above all, willingness to accept change, are cardinal."

British standard on nuclear reactor containment

A NEW British Standard which covers the design, construction, inspection and testing of steel reactors containment structures made of carbon and low alloy steel suitable for temperatures not exceeding 300°C has just been published.

Produced after study of relevant ISO documents—in particular, the proposed Safety Code submitted by the U.S.A.—*BS* 4208: *Carbon and low alloy steel containment structures for stationary nuclear power reactors*—rationalises the approach to design and requires detailed design appraisal in the light of each external loading and modes of failure. Pressure-relieved structures are not excluded, provided that they are of a form that contains the fission products or ensures their safe disposal.

A number of appendices gives general guidance of foundation and support requirement, thermal insulation, lighting and missile protection and facilities for periodic inspections. Among these, Appendix A, an appendix on roof loading and wind loads, amplifies the requirements of CP3, Chapter V. The new standard is a companion publication to BS 3915 dealing with carbon and low alloy steel pressure vessels for primary circuits of nuclear reactors.

Copies of BS 4208 may be obtained from the BSI Sales Office 101-113 Pentonville Road, London, N.1. Price 60s. each.

APACE centre courses

THE training courses staffed by the experienced engineers in the Aldermaston Project for the Application of Computers to Engineering (APACE) have now been running a year, and the following will be offered in the first quarter of 1968:

Computer Appreciation Course for Engineers—3½ days, fee £35.
No. 10 9th-12th January
No. 11 13th-16th February
No. 12 26th-29th March

PABLA Course for Design Engineers—4 days, fee £40.
No. 4 26th February-1st March (mid-day).

APT Users Course—3½ days, fee £35.
No. 7 16th-19th January

FORTRAN Programming Course for Engineers—5 days, fee £50.
No. 5 29th January-2nd February

Network Analysis Practitioners Course—2 days, fee £20.
No. 5 5th-6th March

2 CL Users Course—5 days, fee £50.
No. 2 5th-9th February
No. 3 1st-5th April

All the above courses, excepting that for 2 CL users, were briefly described in the September 1967 issue of ATOM. The 2 CL System is a numerically controlled machine tool computer program similar in function to the APT program, but limited to 2 axes contouring and 1 axis line milling. The program is computer independent as far as possible, and will be freely available to any user. The course is designed to train part-programmers in the 2 CL language.

The content of the Computer Appreciation Course has recently been broadened and now includes practical exercises in simple program writing, and also demonstrations of the IBM 2250 Graphics Console, the Milwaukee-Matic series EB Machine, and the Benson-Lehner Electro plotter.

These courses are held at the APACE Centre. Further information about them or APACE consultancy services may be obtained from The Secretary, APACE, U.K.A.E.A., Blacknest, Brimpton, near Reading, Berks. (telephone Tadley 4111, Ext. 5951/5873).

A.E.A. Reports available

THE titles below are a selection from the November, 1967 "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 who receive copies of U.K.A.E.A. unclassified reports.

AEEW-M 715
A Comparison of the Predicted and Observed Low Energy Radiation from the Thorax of a Normal Human Male. By R. G. Spright. 1967. 6 pp. H.M.S.O. 1s. 6d.

AEEW-R 502
Measurements of Material Buckling and Detailed Reaction Rates in a Series of Low Enrichment UO_2 Fuelled Cores Moderated by Light Water. By W. A. V. Brown, W. N. Fox, D. J. Skillings, C. F. George and G. D. Burnholt. September, 1967. 138 pp. H.M.S.O. 19s.

AEEW-R 531
MAGOG—A three-dimensional, two-group Diffusion Code with Burnup. By D. Hopkins and D. B. Oakes. September, 1967. 41 pp. H.M.S.O. 7s.

AEEW-R 539
The Rapid Calculation of Frequency Responses for Linear Systems Involving Time-Delayed Terms (Fortran Program FRP Mk 2). By H. M. Sumner. July, 1967. 40 pp. H.M.S.O. 6s.

AWRE 0-8/67
Resolution Corrections to Neutron Spectrometry by the Pulsed Source Time of Flight Technique. By W. J. Paterson and K. L. Shutler. September, 1967. 17 pp. H.M.S.O. 3s.

AWRE 0-52/67
The Life of Tritium Targets under Deuteron Bombardment in an Accelerator. By D. L. E. Smith. September, 1967. 17 pp. H.M.S.O. 3s.

AERE-M 1956
Subroutine Heitler. By A. Foderaro. September, 1967. 22 pp. H.M.S.O. 3s. 6d.

AERE-R 5452
Analysis of Some Experimental Binary Alloys Using X-Ray Fluorescence and Chemical Methods. By P. W. J. Garbon, R. Parker and J. Watling. August, 1967. 9 pp. H.M.S.O. 2s. 6d.

AERE-R 5492
Approximate Equations for the Diffusion and Flow of Gases in Porous Media. By G. F. Hewitt. August, 1967. 27 pp. H.M.S.O. 4s.

AERE-R 5536
SCAT and SLAB: Two Computer Codes for the Computation of Thermal Neutron Scattering Cross-Sections. By P. Hutchinson and P. Scholfield. September, 1967. 53 pp. H.M.S.O. 8s.

AERE-R 5547
A Catalogue of 30MeV Gamma Activation Products. Part 1, Sodium to Molybdenum. By C. A. Baker, G. J. Hunter and D. A. Wood. September, 1967. 44 pp. H.M.S.O. 7s.

TRG Report 1500(R)
Marine Nuclear Reactors. A Lecture given at a Branch Meeting of the Institution of Mechanical Engineers, Barrow, 1st December, 1966. By S. Rigg and J. Kay. 1967. 32 pp. H.M.S.O. 4s. 6d.

TRG Report 1548(W)
Experience in Testing Installed Fission Product Trapping Plant with Methyl Oxide. By J. J. Hillary, L. F. Gate and K. Gurney. July, 1967. 10 pp. H.M.S.O. 2s. 6d.

Nuclear medicine display

RADIOACTIVE materials are being increasingly used in medical diagnosis, therapy and research. Some of these applications were described in the Radiochemical Centre's displays at the exhibition associated with the International Nuclear Medicine Symposium at Imperial College from 25th to 27th September.

There were two displays. One described the use of radioisotopes to detect abnormalities in tissue, including cancers. This is a rapidly developing field of nuclear medicine. The radioisotope is given to the patient in a form which concentrates in the organ to be studied. The radiation from the isotope can be detected by electronic equipment and a picture of any abnormal intake can be obtained (conversely, the absence of any abnormality can be confirmed). The display includes scans of the thyroid, lungs, kidney, brain, bones and lymphatics.

The other exhibit was a technical display covering radio-chemicals for dynamic clinical studies, intralymphatic injections for radiotherapy, and details of scanning agents. The Radiochemical Centre produces an enormous range of materials, guaranteeing their purity and activity for delivery anywhere in the world.

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

U.K.A.E.A. at Atomfair

THE U.K.A.E.A. participated in this year's Atomfair in Chicago from the 6th-8th November. The stand featured Production Group's integrated nuclear fuel service and Reactor Group's experience in the development of nuclear power reactors.

Production Group's experience in meeting world-wide demand for nuclear fuel services, which include production enrichment, reprocessing and transport from door-to-door of new, irradiated and reprocessed fuels, enables them to offer their products and services at prices competitive with any in the world.

Nuclear electricity generation in the U.K. already exceeds 85,000,000,000 units and the display included descriptions of the U.K. Nuclear Power Programme and Reactor Group's work on the Steam Generating Heavy Water Reactor and Fast Reactors.

Background notes

Production Group's products or services (or both) have been used by Australia, Austria, Argentina, Belgium, Burma, Canada, Denmark, Finland, France, Germany, Holland, India, Iran, Israel, Italy, Japan, Norway, Pakistan, Spain, Sweden, Switzerland, South Africa, United Arab Republic, U.S.A. and Yugoslavia.

Production Group's service is fully integrated, which means that the Group, as well as making, enriching and reprocessing all kinds of fuels, takes responsibility for transport operations, including route planning, insurance, indemnities, and customs clearance, and ensuring that international safety regulations are fully met. Irradiated fuel has been transported from Australia, Canada, Denmark, France, Germany, Italy and India.

The fuel manufacturing plant at Springfields, near Preston, Lancs., and the reprocessing plant at Windscale, Cumberland, are the largest of their kind in the world.

Springfields produces about 250,000 fuel elements per year.

The reprocessing plant at Windscale is designed for a capacity of 2,000 tonnes of irradiated fuel per year.

Production Group's gaseous diffusion plant at Capenhurst is currently being modified to provide the low enrichment needed for advanced power reactors. On completion of modifications the plant will also be able to meet export requirements.

Highly enriched fuel is also produced and reprocessed at the Dounreay Experimental Reactor Establishment.

The Steam Generating Heavy Water Reactor started up recently and is expected to achieve full power operation before the end of this year.

Construction of the 250 MW(e) Prototype Fast Reactor at Dounreay is proceeding to programme and is expected to be on power in 1971.

The U.K.A.E.A. stand was designed by Hulme Chadwick, A.R.I.B.A., A.R.C.A.

RIPPLE for Sweden

THE Atomic Energy Research Establishment, Harwell, has installed, with the co-operation of the Swedish Board of Navigation and Shipping, a RIPPLE (Radioisotope Powered Prolonged Life Equipment) generator in the Stockholm archipelago. The generator provides electricity for a flashing navigation light marking a group of rocks called Tegelhallorna which are a hazard to shipping entering and leaving the port of Stockholm. It went into operation on 10th October, 1967.

The generator is on loan to the Swedish Board of Navigation and Shipping for a period of five years to provide evaluation in service conditions.

In RIPPLE generators heat from decay of the isotope strontium-90 is converted to electricity by an assembly of thermocouples. The generators are constructed to a very high standard of physical integrity and will continue to provide power for at least five years without attention of any kind.

Similar generators have already been installed and are powering marine lights off Dungeness and on the Sjaeland coast of Denmark. An earlier version has been employed underwater by the U.S. Navy. Two demonstration generators are in operation, one having nearly completed three years.

RIPPLE generators are being manufactured in the United Kingdom by Submarine Cables Ltd., of Greenwich, London, (an A.E.I. Co.) under a licence from the U.K. Atomic Energy Authority.

31st October, 1967

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