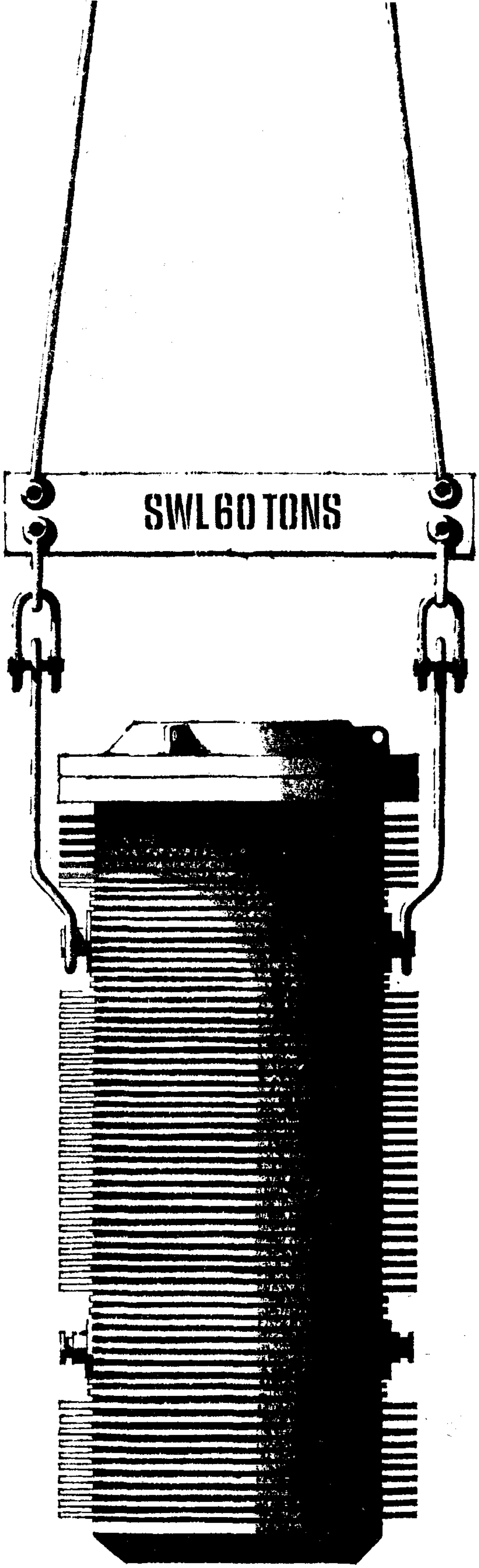
ATOM

Number 136 / **February 1968**

MONTHLY INFORMATION BULLETIN OF
THE UNITED KINGDOM ATOMIC ENERGY AUTHORITY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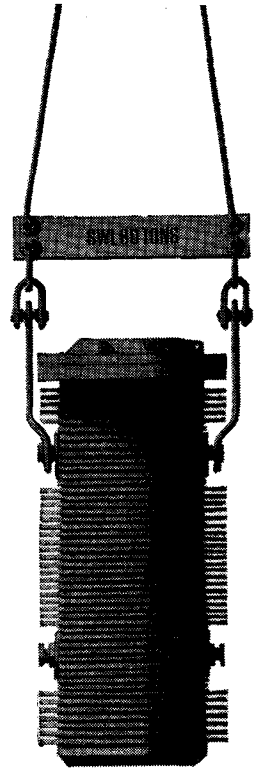

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OF THE UNITED KINGDOM
ATOMIC ENERGY AUTHORITY

NUMBER 136

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Contents

ATOM
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New Year Honours

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

C.B.E.
Mr. W. J. Challens, Assistant Director, Chief of Warhead Development, Aldermaston.

O.B.E.
Mr. G. R. H. Geoghegan, Chief Technical Manager, Capenhurst.

M.B.E.
Mr. A. G. Clarke, Higher Executive Officer, Accounts Branch, London Office.
Mr. A. E. Baller, Principal Process Supervisor, Springfields.

B.E.M.
Mr. L. H. Davies, Non-Tech. II, Aldermaston.
Mr. W. Gallagher, Craft Foreman (Tech. II), Risley (Reactor Group).
Mr. G. R. Page, Skilled Craftsman/R. & E. Mechanic, Harwell.
Mr. M. Spedding, Process Worker, Windscale Works.

Health physics school

THE ninth annual Summer School in Health Physics (Radiation Protection) will be held at Imperial College from 1st July to 12th July 1968.

Topics covered will include basic physics, biology, radiobiology and genetics; an assessment of the hazards to the worker and the population; derivation of safe working levels; medical supervision of radiation workers; legal, administrative and public relations aspects; monitoring and monitoring services; control of radiation and contamination hazards; neutron hazards; radiological protection in large and small establishments; special problems of nuclear power stations, factories, hospitals and high energy machines; transport of radioactive materials; disposal of radioactive wastes; and a survey of accident and emergency conditions.

The fee for the course, which is non-residential, is 25 guineas. Initial enquiries should be addressed to the organiser, Dr. H. D. Evans, Imperial College, London, S.W.7.

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

Desalination R. & D.

As announced on 19th December, the Minister of Technology has authorised a further grant in support of the desalination research and development programme. It extends the programme to March, 1971, at an estimated cost of £4m. Almost half this sum will be used to finance work by the Authority's industrial collaborators.

The desalination programme began in April, 1965, when the U.K.A.E.A. assumed responsibility for research and development into methods of desalination of salt water at the request of the Ministry of Technology under Section 4 of the Science and Technology Act. £1.3m. was allocated to cover three years' work with two principal objectives: —

(a) to exploit fully the development potential of the multi-stage flash distillation process;

(b) to explore alternative methods of desalination which might supersede the multi-stage process in the long term.

The major emphasis was put on the first objective which has been pursued in close collaboration with Weir Westgarth Ltd. The second objective was initially solely a U.K.A.E.A. responsibility, but industrial partners have now been identified.

In pursuit of the first objective, the Authority in collaboration with Weir Westgarth, completed a design study for a 30 million gallons per day plant utilising 10 m.g.d. unit modules which identified cost sensitive areas in plant capital and operating costs. A programme of work utilising expertise in the fields of heat transfer, fluid flow and material properties available within the Atomic Energy Establishment, Winfrith, Atomic Energy Research Establishment, Harwell, the Authority's Engineering Group, and Weir Westgarth, was undertaken to investigate these areas.

Ideas generated from this programme are now being evaluated on plant-replica rigs at the new sea water test facility, built as part of the joint programme at Troon, Ayrshire. The results of this work provide the U.K. with the capability of offering nuclear powered desalination plants incorporating our developed Advanced Gas-Cooled and Steam Generating Heavy Water reactors.

Under the second objective of the programme three promising routes have been identified:

1. Work on electrodialysis in collaboration with W. Boby Ltd., has resulted in a much improved design of plant. A small pilot plant was constructed which has been in operation for six months. The design shows considerable capital and operating cost reductions over previous designs.

2. A design and costing study by A.E.R.E., Harwell, and Simon Carves showed the secondary refrigerant freezing process to be extremely promising and again identified the cost sensitive areas. Large laboratory scale experiments are being conducted on specific aspects of the process.

3. The development of seawater and brackish water membranes for the reverse osmosis process has been the responsibility of A.E.R.E., Harwell, who are now working in conjunction with Portal Holdings Ltd. on the development of suitable membrane supports and engineering geometries.

Although many of the benefits of the programme have not yet reached the stage of commercial application, the competitive position of Weir Westgarth in export markets has already improved substantially. Towards the end of the first programme it became evident that a further programme of work would still further increase the benefit accruing to British industry. This programme has been drawn up by the Authority in conjunction with our industrial partners, other Government Departments and the Programmes Analysis Unit of the Ministry of Technology and the Authority to ensure the maximum economic benefit to the United Kingdom.

19th December, 1967

Plasma physics school

A Summer School on plasma physics will be held at Culham Laboratory from 15th to 26th July, 1968.

Tuition is free, but charges will be made for accommodation and meals. Application forms and further details are available from The Summer School Office, Culham Laboratory, Abingdon, Berks. Closing date—11th March, 1968.

Nuclear marine propulsion

5th December, 1967

MR. HOOLEY asked the Minister of Technology when he proposes to act on the recommendation of the Select Committee on Science and Technology that a departmental committee be convened to examine the possibilities of nuclear marine propulsion in the light of the experimental work being carried out in other industrial countries.

Mr. Benn: I will consider the Committee's recommendation that a departmental committee should be reconvened, but I would point out that the responsibility for the Atomic Energy Authority, for the nuclear industry, for the manufacture of marine engines and for shipbuilding have all been brought together in my Department. My Department is in touch with all the interests closely concerned and I intend to re-examine the position in order to ensure, so far as possible, that we are in a position to embark on a major project as soon as it appears that commercial demand for such ships justifies the considerable cost involved.

Fast breeder reactors

5th December, 1967

DR. DAVID OWEN asked the Prime Minister if he will put forward proposals for establishing a European Development Corporation for the exploitation of fast breeder reactors.

The Prime Minister: Her Majesty's Government have made clear that we would welcome European co-operation in the development and exploitation of fast reactors and are already in touch with other European countries to this end.

Astrophysics research

5th December, 1967

DR. ERNEST A. DAVIES asked the Minister of Technology if he will give an assurance that the programme of research on astrophysics undertaken at the Culham Laboratory of the United Kingdom Atomic Energy Authority will be continued.

Mr. Benn: Careful consideration has been given to the future of the work on solar and stellar ultra-violet spectroscopy undertaken by the Atomic Energy Authority's Culham Laboratory using rockets provided by the Science Research Council, and of associated laboratory work of astrophysics interest. It is generally agreed that this work, which forms a part of the national space research programme, and is of outstanding scientific importance, should be continued. I am informed that, following discussion between the Atomic Energy Authority and the Science Research Council, it is proposed that the Science Research Council should from an early date begin to take over responsibility for the work of this group. Consultation with the staff interests concerned on this matter is now taking place.

Nuclear power programme

11th December, 1967

MR. MCGUIRE asked the Minister of Power (1) what action he is taking over the proposal made to him by the Coal Industry National Consultative Council that there should be an independent inquiry into the technical and financial aspects of the nuclear power programme;

(2) what action he is taking as regards the recommendation of the Select Committee on Science and Technology that there should be an independent inquiry into the cost comparisons between nuclear power and conventional stations.

Mr. Marsh: I am considering the Select Committee's Report, but very careful studies have already been made. They have involved the Atomic Energy Authority, the Central Electricity Generating Board (with more experience in this field than any similar body in the world) and the Chief Scientist's Division of the Ministry of Power. I know of no "independent" body with a comparable degree of expertise or experience.

Magnox stations cost

11th December, 1967

MR. MCGUIRE asked the Minister of Technology if he will make a statement setting out the full costs of the work done by the Atomic Energy Authority on the Magnox series of nuclear power stations; and what he estimates to be the effect on the operating costs of those stations of being required to carry the charges.

Mr. Benn: Total expenditure on the

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Mr. Benn: Total expenditure on the

development of the Magnox system for civil use amounted to about £20 million. Just over half related to the development of fuel elements and in respect of this, appropriate surcharges are included in fuel prices. If charges were imposed sufficient, when discounted to 1967, to cover the remaining cost of development of the reactor system itself, the average cost of generation from Magnox stations would rise by about 0·007d. per unit, assuming 20 years' life and 75 per cent. load factor.

Select Committee Report

11th December, 1967

MR. MCGUIRE asked the Minister of Power what reply he proposed to make to the observation made by the Select Committee on Science and Technology that he delayed sending to the Committee documents prepared by his Department setting out the basis of calculation of nuclear power costs.

Mr. Richard Marsh: I am still considering the Select Committee's Report.

Hunterston

11th December, 1967

MR. HUNTER asked the Secretary of State for Scotland what estimate he has made of the effect on the price to consumers of electricity in the South of Scotland Electricity Board's area of the increase in the capital cost of the Hunterston A nuclear power station.

Mr. Ross: The final price of this station has not yet been determined.

Mr. Hunter asked the Secretary of State for Scotland what effect devaluation is estimated to have on the operating costs of the advanced gas-cooled reactor station Hunterston B; and what effect it will have on the costs of the coal-fired station at Longannet.

Mr. Ross: It is too early to estimate the effect of devaluation on the costs at these generating stations.

12th December, 1967

MR. HUNTER asked the Secretary of State for Scotland what he estimates to be the effect on the average price paid for electricity by domestic and industrial consumers throughout the South of Scotland Electricity Board area of achieving the forecast savings of cost expected from building the Hunterston B advanced gas-cooled reactor power station, by comparison with a coal-fired station of the same capacity, assuming that all other factors remain unchanged.

Mr. Ross: The annual saving in the mid-1970s is estimated by the Board to be about £3.5 million, representing 0.03d. per unit.

Mr. Eadie asked the Secretary of State for Scotland what will be the extra capital cost of the nuclear power station Hunterston B by comparison with a coal-fired power station of the same capacity.

Mr. Ross: The estimated capital cost of Hunterston B is £87.5 million. The capital cost of a coal-fired station of similar capacity would be about £60 million.

Waste disposal

12th December, 1967

MR. MCGUIRE asked the Minister of Power if he will state the costs of disposing of radioactive waste from nuclear power stations, and describe the methods used; and whether the costs are charged against the stations concerned.

Mr. Freeson: The costs of dealing with radioactive waste at power stations are included in the capital and operating costs of the stations concerned and are not readily separable. I understand that the costs of processing wastes in irradiated fuel elements are allowed for by the Atomic Energy Authority in the price paid to the Generating Boards for the re-purchase of such fuel.

Devaluation effect

12th December, 1967

MR. KELLEY asked the Minister of Power what effect he estimates devaluation will have on the operating cost of the advanced gas-cooled reactor nuclear power stations, Dungeness B and Hinckley Point B; and what effect it will have on the operating costs of the coal-fired stations at Cottam and Drax.

Mr. Marsh: It is too early to estimate, but a significant difference appears to be unlikely.

A.G.R. savings

12th December, 1967

MR. EADIE asked the Minister of Power what he estimates to be the effect on the average price paid for electricity by domestic and industrial consumers throughout Great Britain of achieving the forecast savings of cost expected from building advanced gas-cooled reactor nuclear power stations with a total capacity of 8,000 megawatts, over a programme of coal-fired stations, assuming that all other factors remain unchanged.

Mr. Marsh: At the present average cost of coal to the Central Electricity Generating Board, the annual savings would be more than £30 million or about 0.03d. a unit in the mid-1970s. It is not possible to predict the effect on the price of electricity to particular classes of consumer.

Non-nuclear research

12th December, 1967

MR. J. E. B. HILL asked the Minister of Technology if he will specify work outside the atomic field currently being undertaken by the Atomic Energy Authority, showing the expenditure of public money involved in the current financial year of each major area of activity.

Mr. Benn: I tabulated in the OFFICIAL REPORT of 9th May, 1967, a list of the major areas of research outside the atomic field being undertaken by the Atomic Energy Authority. Major projects started since then are Atmospheric Pollution, which will cost about £50,000 in the current year, Tribology, Heat Transfer and Fluid Flow, and Computer Software and Applications (Linesman Mediator), on which smaller amounts will be spent this year.

Capital investment cuts

12th December, 1967

MR. MCGUIRE asked the Minister of Power what effect the proposed reduction in capital spending by the nationalised industries will have on the construction of nuclear power stations.

Mr. Marsh: Final decisions have not yet been taken, but the effect will probably be to defer the start of one power station.

Mr. McGuire: In view of the lower capital cost involved in building conventional power stations, will my right hon. Friend look again at the high cost which will be involved with devaluation in building nuclear power stations? Surely this is a further reason for a review of the White Paper?

Mr. Marsh: I am sure my hon. Friend will ensure that that point does not escape my mind in the next few weeks. We have this in mind, but a power station is built to last for a long time—30 years.

A.G.R. royalty

12th December, 1967

Mr. McGuire asked the Minister of Technology if he will state the total costs of the past work done by the Atomic Energy Authority for the advanced gas-cooled reactor series of nuclear stations; and why those costs are not being fully recovered in royalties.

Dr. Bray: The Authority's expenditure to 31st March, 1967, on the development of the Advanced Gas-cooled Reactor system amounted to £89 million. Whether a royalty of 0·014d. per unit will recover these costs in full depends on how many such stations are built and how much electricity they generate.

Seaton Carew

12th December, 1967

MR. WILLEY asked the Minister of Power whether a decision has yet been taken on the proposed Seaton Carew power station.

Mr. Marsh: No, Sir.

Mr. Willey: Can my right hon. Friend say whether he will be able to make a statement before the end of the year? Is it a fact that the National Coal Board has offered a long-term contract at very much reduced prices? Can my right hon. Friend make a statement about the cost benefit analysis which has been made on this?

Mr. Marsh: I do not think that these discussions will take very much longer. Many of my hon. Friends wanted this job to be done properly to take into account all the various factors in this, and the National Coal Board's application will be one of them, though it is sometimes suggested that if there is coal at this price it would be useful to purchase it anyhow.

Mr. Leadbitter: Will my right hon. Friend bear in mind that this matter of considering the building of the power station has gone on for many months? The fact is that 2,000 jobs will be provided by constructing the power station, and it is therefore imperative that a decision be made which will mean that

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The design of the Steam Generating Heavy Water Reactor

The following report by H. Cartwright, Director of Water Reactors, U.K.A.E.A. Reactor Group, Risley, was presented at the I.A.E.A. Symposium on Heavy Water Power Reactors in Vienna, 11th-15th September, 1967.

Summary

THE 100 MW(e) Steam Generating Heavy Water Reactor at the U.K.A.E.A.'s establishment at Winfrith Heath in Dorset will be opened by H.R.H. Prince Philip, Duke of Edinburgh, on 23rd February, 1968.

The paper reviews the main features of the design. It discusses the way in which the unitised system of construction of parts of the reactor and the concentration in off-site manufacture can be applied to larger commercial units.

The paper also refers to the type of manufacturing facilities that are required for this reactor system.

Now that nuclear power has come to be accepted in many parts of the world as being economically competitive with the older conventional methods of electricity generation, it has to be recognised that the task of introducing a new thermal reactor system has become more difficult. The new system may have excellent development potential. It may, when judged on a basis of economic utilisation of world resources, be a more efficient user of uranium or a better producer of plutonium than established reactors. But, however attractive these arguments may be, the critical test is in commercial competition with other reactor systems, and with conventional plants, against the requirements of an electricity producer. These requirements are usually a demand for low generation costs coupled with high plant reliability and availability.

An electricity utility may be prepared to take additional risks in order to introduce nuclear power. But gas/graphite and light water reactors are already being offered on a commercial basis, backed up where necessary by warranties to meet the customer's requirements. This is the challenge more advanced thermal reactors have to face. Not only has their attractive technology to be crystallised in competitive prices and generation costs but they must be capable of being engineered in a manner that will convince a customer that he can expect to obtain a plant as reliable as any of the more established systems. It is with this particular aspect that this paper is largely concerned.

The Steam Generating Heavy Water Reactor was chosen for development because it was believed that it could be competitive with other thermal reactor systems. That belief has become more certain as development has proceeded. Also, experience with the design and construction of the Winfreth plant, coupled with extensive design work on larger commercial plants, shows that the major parts of the plant require no more than well established engineering techniques for their manufacture, construction and erection. The more novel parts of the system, i.e., the reactor core components, can be shop manufactured, thus reducing the work on site to straightforward erection procedures. Above all, the channel tube assemblies can be of standard dimensions for the range of station outputs at present of interest, and methods of manufacture on a production scale have already been established for the Winfrith reactor. Thus, though the S.G.H.W.R. is an advanced thermal system, its engineering has gone well beyond the development stage.

Equally important is the breadth and soundness of the technology on which performance and fuel management are based. These are the subjects of two separate papers to this conference which also underline the firm technical basis for the S.G.H.W.R. system.

The S.G.H.W.R. system

The first serious study of pressure tube reactors in the United Kingdom was started in 1957. It was only after an examination of several systems using heavy water moderation that the S.G.H.W. reactor was chosen for development. The broad objective at the time these studies began was to identify a reactor with potential for low fuel costs and low capital cost. The latter pointed to an enriched system, but the former indicated a need to keep fuel enrichment levels low.

The first concept studied was a gas-cooled heavy-water moderated reactor with an indirect steam cycle. This allowed full use to be made of the United Kingdom's growing knowledge of gas heat transfer data and of fuel technology from the research and development programme supporting the design of the gas-cooled graphite-moderated reactors. This concept, however, had too high a capital cost to meet one of the main objectives. An obvious step was to seek economies by changing the coolant to steam which could be fed directly to the turbine. Although lower capital costs were possible by this means, steam cooling required a steel fuel cladding, and fuel enrichments had to be higher than was considered to be acceptable in order to offset the high neutron absorption in the core. Both the gas-cooled and the steam-cooled reactors were examined in considerable detail by a design team before they were finally rejected.

From steam cooling, it was a comparatively short step to allowing boiling in the core and to the concept of the S.G.H.W.R.

The S.G.H.W.R. has been described in a number of papers to international conferences [Ref. 1, 2, 3]. The heavy water moderator is contained in a calandria through which pass the pressure tubes which contain the fuel elements. The heavy water is not pressurised and forms a separate circuit from that of the main coolant, which is light water. This light water coolant is pumped up over the fuel elements in the pressure tubes and boils in the core, the steam formed being separated from the recirculating water in an external circuit. The steam passes directly to the turbine and the condensate is returned to the reactor to be mixed with the recirculating water. The fuel is uranium dioxide and the fuel cladding zircaloy. The system is in part moderated by the coolant, about 30% occurring in the light water and the remainder in the heavy water.

An interesting, and a potentially important, economic feature is that the pressure tube arrangement allows scope for designing reactors with either on- or off-load refuelling.

The Winfrith Project (Fig. 1)

The main parameters of the Winfrith design are given in the appendix. Early optimisation studies showed that the dimensions of the pressure tubes within the core (i.e. the channel tubes) could be kept constant over a wide range of reactor outputs without significantly affecting the economics of the system. This was an important factor in fixing the size of the prototype at 100 MW(e). It allowed channel tubes to be used which it was expected would be full size for future commercial reactors. All later studies have supported this expectation. Other points that were taken into account when sizing the prototype were the need to build on a scale that would give worthwhile manufacturing and construction experience, and the advantage of having an output that would give appreciable revenue from electricity sales which could be set against the costs of plant operation.

The fuel elements are rod clusters the full length, 12 feet (3,660 mm), of the reactor core. With full length pins, it is possible to incorporate space within each fuel can, but outside the core, for the storage of fission products, thus avoiding the generation of high gas pressure. Each fuel element is made up of 36 rods of uranium dioxide pellets 0.57 in. (14.5 mm) diameter clad in zircaloy-2 tubes which have a minimum wall thickness of 0.025 in. (0.71 mm) to give a can stable against the coolant pressure. The pins are suspended from a top grid and spaced at intervals along their length by intermediate grids. The grids are attached to a zircaloy-2 tube 0.050 in. (1.27 mm) thick in the centre position of the cluster, which, in addition to acting as a structural member, is also the sparge pipe for distribution of emergency cooling water.

The calandria is made of an aluminium alloy and is of an all-welded construction, thus eliminating the possibility of heavy water leaking from joints. A gas gap between the calandria and the channel tubes insulates them from one another.

The Winfrith reactor is provided with an on-load refuelling machine. This is

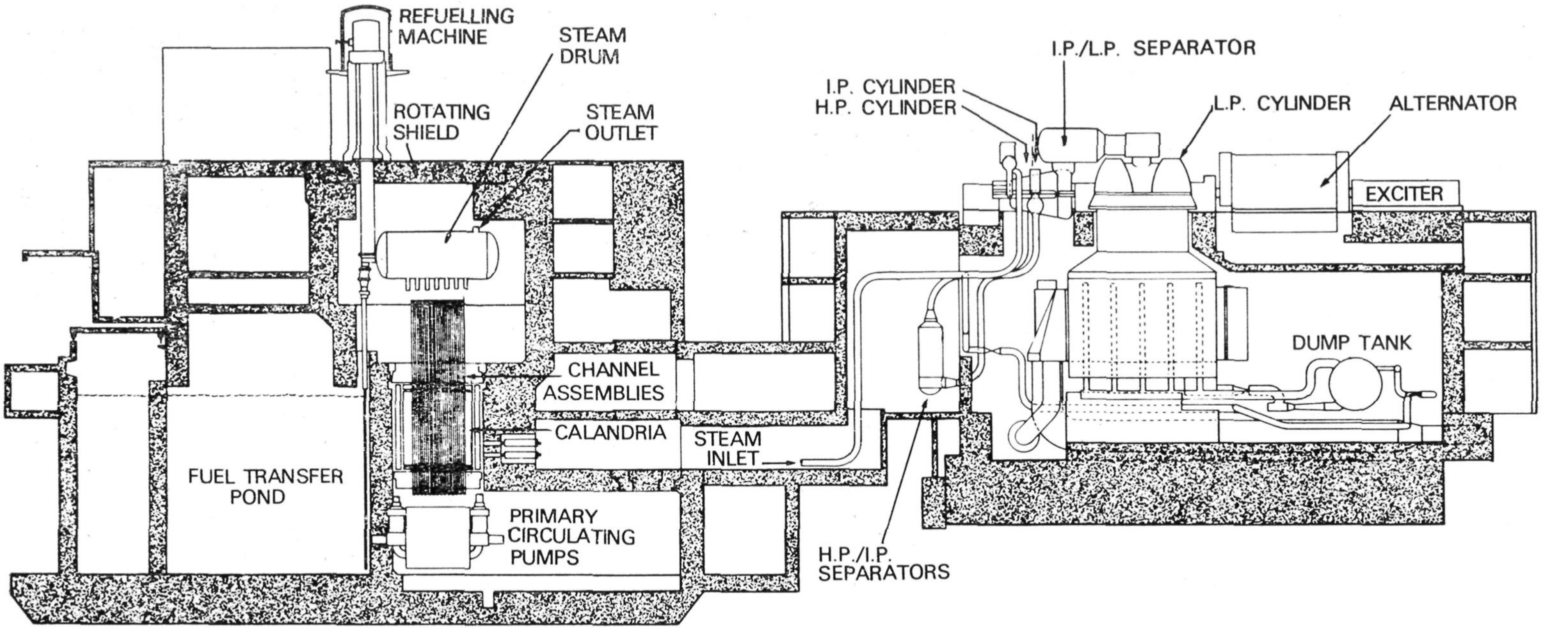


Fig. 1. *Section through the Winfrith prototype.*

supported above the reactor core by a pair of rotating shields which allow the machine to be positioned over any channel and which themselves form part of the primary containment.

Advantage is taken of the moderator being a liquid. Reactivity, and hence reactor power, is controlled by varying moderator height. On shut-down the moderator is dumped to a drain tank and long-term changes of reactivity in the core are compensated by changes of boron poisoning in the heavy water. Rapid shut-down cannot be achieved simply by moderator draining. The available head from calandria to drain tank is no more than 25 feet (7,625 mm) and the required flow would require large outlet ports and either large control valves or a complex gas pressure balancing system. Therefore, to meet the requirement for faster shutdown, moderator draining is supplemented with a liquid shut-down system in which a boric acid solution is injected by gas pressure into closed tubes within the calandria. As this system is made up of pipes and valves, it allows greater flexibility in design layout than would a solid rod control system with its associated rod drives, and it does not interfere with the access to the channel tubes for fuel loading.

The calandria is enclosed and supported by the neutron shield tanks. These serve a dual purpose. They limit the activation of the primary circuit components and other reactor parts outside the core when the reactor is in operation and they provide shielding against gamma activity from the core when the reactor is shut down. Their use allows maintenance personnel to have access to the primary circuit area when the reactor is not in operation.

The Winfrith reactor is provided with a vented form of containment. In the unlikely event of primary circuit rupture, the pressure build up in the primary containment is vented by a system of lutes through a pond to the turbine hall which forms a secondary containment. The lutes reseal before significant quantities of fission products can be released and they are then held at slightly below atmospheric pressure [Ref. 4].

Construction experience

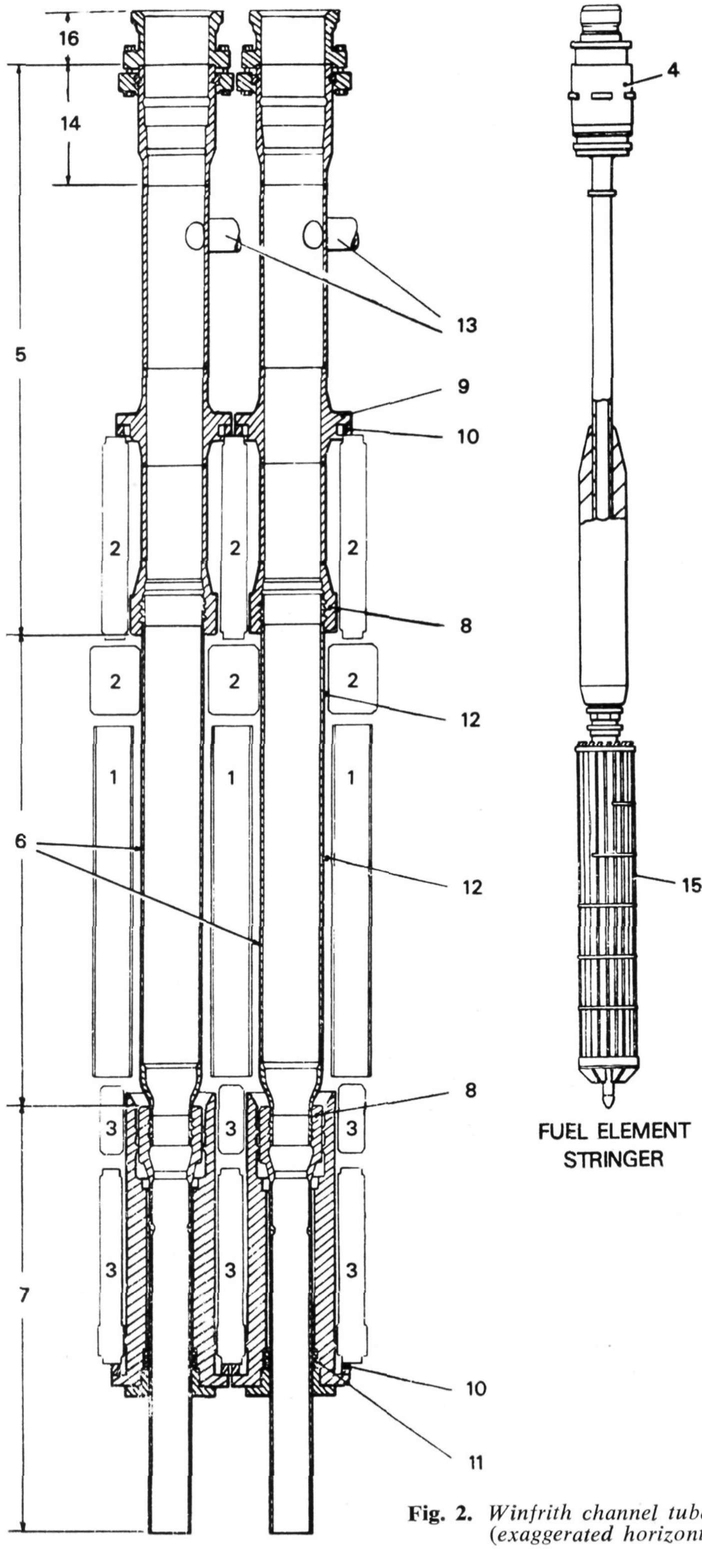
A significant part of the capital cost of any power station, nuclear or conventional, is the cost of doing work on the site. Much of this is unavoidable. Civil engineering and building construction, cable laying, major pipework erection, to name only a few examples, can only be done *in situ*. However, operations such as these are familiar ones and site work can be planned based on a wide background of experience.

A new type of plant may demand novel erection techniques. Therefore, if it is to compete economically with more established plants, it is just as important to ensure that the methods of construction required do not carry a risk of high costs or delays to construction schedules, as to strive for economies by the technical excellence of the scientific development programme.

If any novel fabrication techniques are needed and if these can be carried out in the contractors' works, then even a new type of system may become little more than a routine construction job on the site. There will not be need to provide special site construction facilities or workshops, nor to find men with special skills or experiences to work on site in conditions with which they are probably not familiar.

Outside the reactor core, a pressure tube reactor is not novel plant. It is largely pipework, drums, tanks, valves and circulating water pumps with associated electrical services and instrumentation. In the Winfrith S.G.H.W.R., it is only the reactor core itself, i.e., the calandria and the channel tube assemblies, together with parts of the neutron shield tanks, which are either novel or precision engineering fabrications and where the materials being used, i.e., aluminium magnesium for the calandria and zircaloy for the pressure tubes, are not common for site construction. For the Winfrith project, these were made off site at the various manufacturers' works.

Manufacture of the calandria was a critical activity in the overall construction schedule [Ref. 5]. It was one of the first reactor components required on site and therefore time for design and fabrication was short. In addition, a high standard of dimensional accuracy was required to ensure that the gas gap of 0.75 in. (19 mm) between calandria and pressure tubes would be maintained when the core was



1. *Calandria*
2. *Upper neutron shields*
3. *Lower neutron shields*
4. *Seal plug*
5. *Steel standpipe*
6. *Zirconium pressure tube*
7. *Steel tail pipe*
8. *Expanded joint*
9. *Channel support flange (bolted to neutron shield)*
10. *Thermal insulation block*
11. *Sealing bush*
12. *Gas insulation bush*
13. *Coolant offtake pipe*
14. *Sea plug housing*
15. *Fuel element*
16. *Refuelling machine connection piece*

Fig. 2. *Winfrith channel tube assemblies (exaggerated horizontal scale).*

assembled with the channel tube assemblies supported from the upper neutron shields.

Though the calandria itself was not one of the major cost items, it was obvious that delays in its fabrication could cost money by causing delays to the whole reactor construction programme. There was no immediate manufacturing experience of a similar fabrication to which reference could be made though the contractor had considerable experience of other large scale aluminium work. In order, therefore, to ensure that the calandria manufacture did not become an experiment in fabrication two things were done: a full length half-diameter-sized calandria was built as a proving vessel just ahead of the main fabrication, and a partial wooden mock-up was built full scale.

Access to the inside of the calandria was not easy and the mock-up enabled the access for welding to be studied and a number of modifications were made as a result of this. Manufacture of the proving vessel preceded that of the main vessel by only a few weeks. Welders were therefore able to try out and to establish the necessary techniques on the proving vessel first and then move across to the corresponding work on the calandria itself, confident that they knew what to do.

Though the calandria and the neutron shield tanks had to fit together, with the holes for the channel tubes accurately aligned, they were in fact made at different contractors' works. The accuracy of assembly was ensured by the use of a set of " packed-bored " templates, one of which was used by the calandria manufacturer and two by the manufacturer of the neutron shield tanks. One of the templates was later used during erection on site.

As a result of these measures, none of which is particularly novel, no difficulties were experienced with the manufacture of these components and the erection on site proceeded smoothly and easily and to programme.

The channel tube assemblies (Fig. 2) posed a different type of problem [Ref. 6]. Whereas there was only one calandria to be made, there were over 100 channel tube assemblies to be fabricated. And, though the active height of core is only 12 feet (3,660 mm), a complete channel tube assembly with its upper standpipe and lower tail-pipe is approximately 35 feet (10,700 mm) long. It therefore required the setting up of a production line to produce the assemblies to the required accuracy at a rate of 30 per month. Rolled joints were used between the upper and lower steel portions of each assembly and the zircaloy pressure tube, and an extensive programme of development and test work was carried out to prove these joints.

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

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

300/350 MW(e) Commercial Plant

It has already been mentioned that the core length and diameter of pressure tube for the Winfrith reactor were chosen as the result of early optimisation studies of different reactor outputs in the expectation that this size of channel could be standard for a wide range of reactors. This choice was made some years ago. Although at the time the first optimisation studies were done, there was much less accurate data available (cost as well as scientific and technical data) than there is today, current work shows no reason for wishing to make a change. Hence the design of larger commercial power stations can be based on reactor cores using similar channel tubes to those at

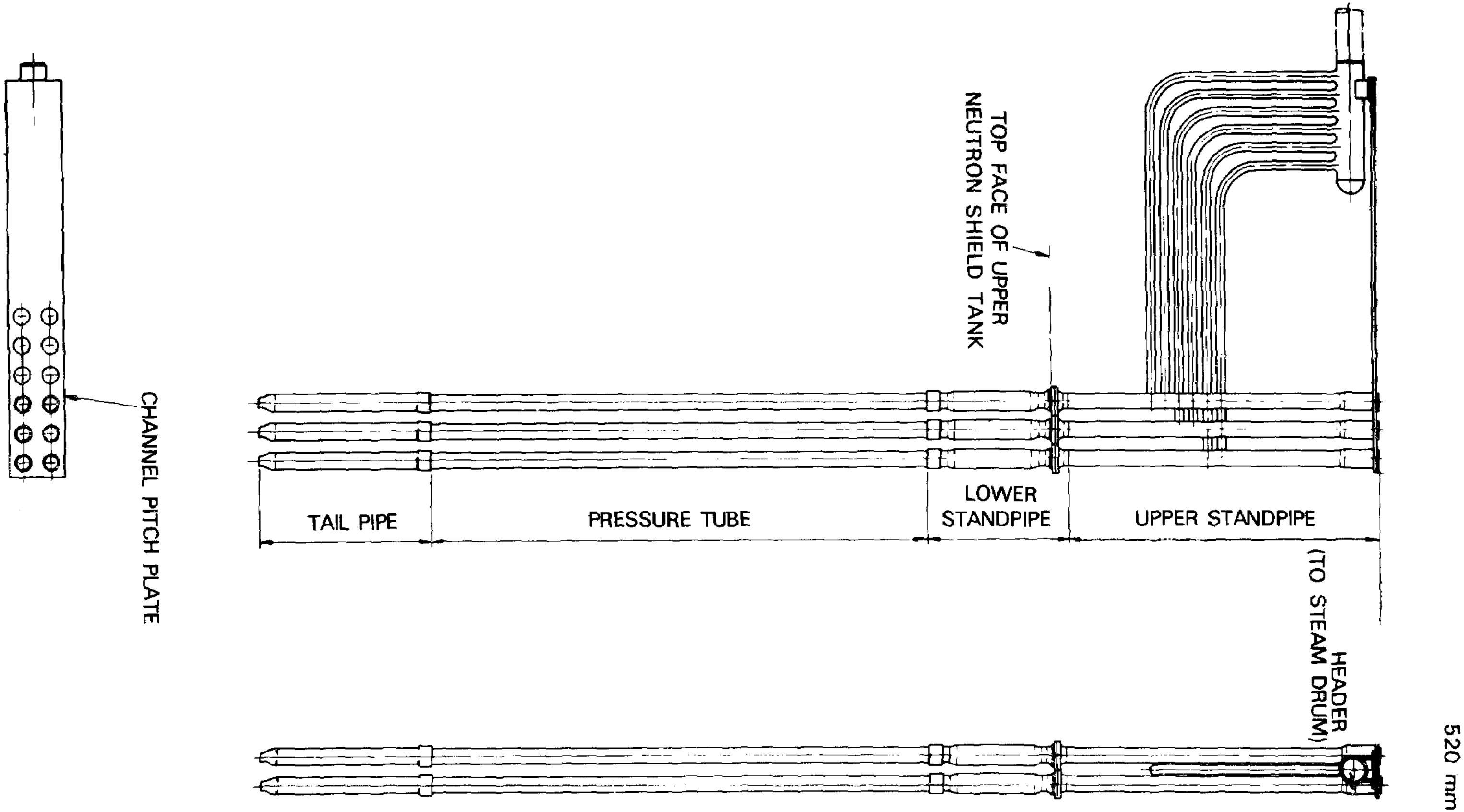


Fig. 3. *Grouped channel assemblies for commercial SGHWR.*

Winfrith. Not only does this give scope for some standardisation in core components but it also means that fuel elements for commercial plants can be loaded into the Winfrith reactor.

It is easy to over-rate the advantages of standardisation, and carried to its limit it implies a fossilisation of design. But the channel tube assemblies are a key item in the engineering design of the S.G.H.W.R. Undoubtedly with this type of component, required in several hundreds, the best engineering results are obtained by progressive evolution, based on experience of design, manufacture and erection, detailed cost studies and value analysis. Commercial reactor designs are able to take full advantage of Winfrith experience and it can be said that the design of this essential component is already established and fully developed.

For the past two years besides carrying out irradiation studies of typical S.G.H.W.R. fuel pins, very extensive heat transfer and pressure drop experiments have been carried out in out-of-pile loops on S.G.H.W.R. type fuel clusters. The major rig for this work has been the 6 MW rig at Winfrith in which dry-out tests have been carried out on full size electrically heated clusters. The effects of design variations have also been studied. One result of this work has shown that the present design of fuel element can be considerably up-rated whilst still maintaining adequate dry-out margins. A number of channels in the Winfrith reactor have been connected to an additional pump which will boost the coolant flow to these channels. The fuel in these channels will be irradiated at the higher rating from the time the reactor goes to power. In addition, the 6 MW rig is to be provided with additional electrical power and from early next year it will be capable of carrying out dry-out tests up to 9 MW heat in a single channel.

The building complex for the Winfrith prototype is considerably larger than that required for a 100 MW(e) plant. This is because the dimensions were fixed before the precise requirements had been established. Buildings of approximately the same size could house a plant of 300/350 MW(e) and parameters of such a station are also shown in the appendix.

The design of such a station has received considerable attention. An important question to be answered in increasing the output of the reactor has been whether the concept of manufacturing core components off site, with correspondingly simple site erection, could be maintained. This had obviously worked well for Winfrith, could it be maintained or even extended for a larger commercial unit?

The most awkward single component is the calandria and there clearly could be limits set by transportation difficulties or regulations on the size of component that

Table 1 Schedule of welds

Item No.	Location	(a) Winfrith Prototype 100 MW(e)	(b) Commercial SGHWR 350 MW(e)
1.	**Feeder connections**		
	Number of site welds ..	200	308
	Outside diameter	3.5″ (90mm)	3.5″ (90mm)
	Wall thickness	0.16″ (4mm)	0.24″ (6mm)
2.	**Pump discharge**		
	Number of site welds ..	36	18
	Outside diameter	16.0″ (410mm)	28.0″ (710mm)
	Wall thickness	0.87″ (22mm)	1.06″ (27mm)
3.	**Downcomers**		
	Number of site welds ..	14	12
	Outside diameter	12.0″ (305mm)	32.0″ (810mm)
	Wall thickness	0.5″ (13mm)	1.25″ (32mm)
4.	**Riser connections**		
	Number of site welds ..	200 200	52
	Outside diameter	3.5″ (90mm) 4.5″ (115mm)	9.6″ (245mm)
	Wall thickness	0.16″ (4mm) 0.18″(4.6mm)	0.87″ (22mm)
5.	Total no. of site welds ..	650	390

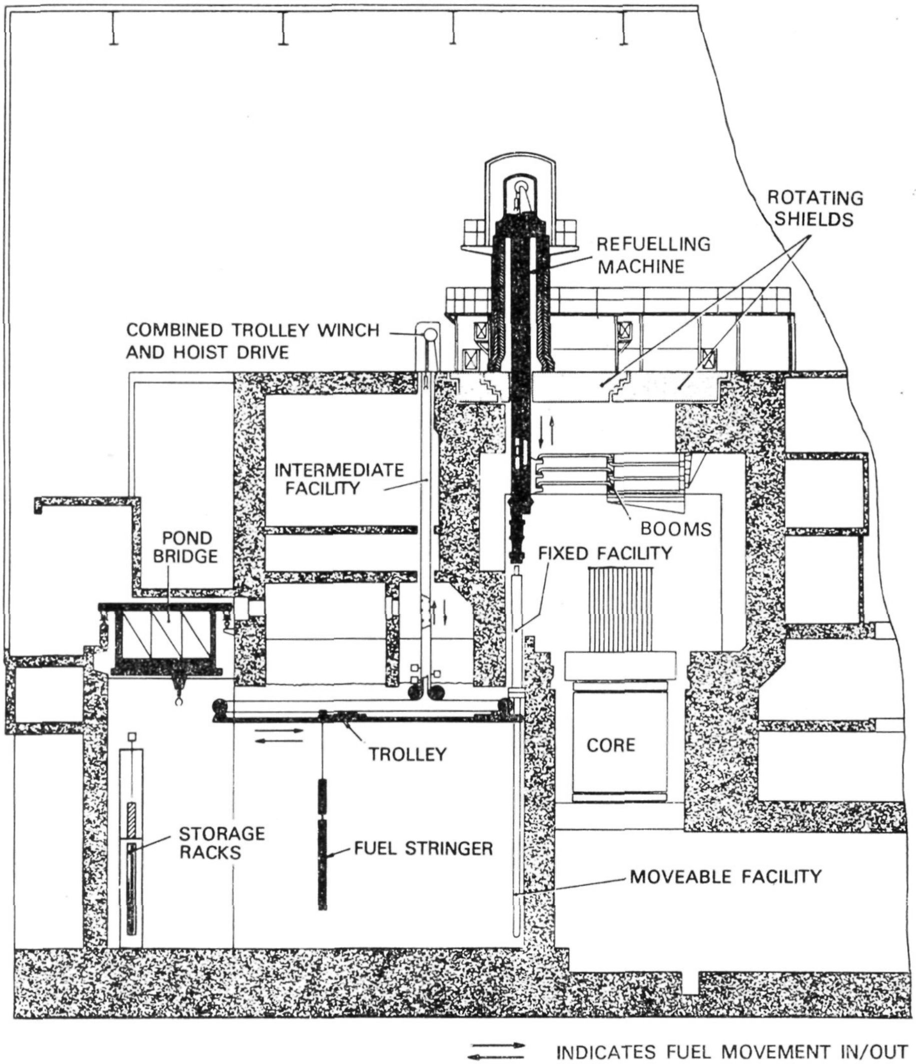


Fig. 4. *Fuel handling route on Winfrith prototype.*

could be moved as a single unit to site. Attention has therefore been directed to the design of calandrias which can be transported to site as a split unit and which require only bolting together and perhaps seal welding on site. There is now no doubt that this is a perfectly satisfactory method of construction and in fact assembly of a calandria in two halves makes works fabrication simpler as there is considerably better access for internal welding.

A simplification in core erection can be achieved by welding the channel assemblies to headers, in groups of six or twelve, and shipping these as units to site instead of sending each channel assembly singly (Fig. 3). Though the necessity to lower the assemblies through the calandria means that the assemblies can only be headed at the upper end, this can substantially reduce the number of welds to be made on the primary circuit at site. In a typical layout the number of pipe welds on a commercial 350 MW station is actually less than those on the Winfrith plant (Table 1).

An important advantage of a pressure tube reactor is the relatively easy access to individual channels and hence to individual fuel elements. This makes on-load or off-load refuelling possible.

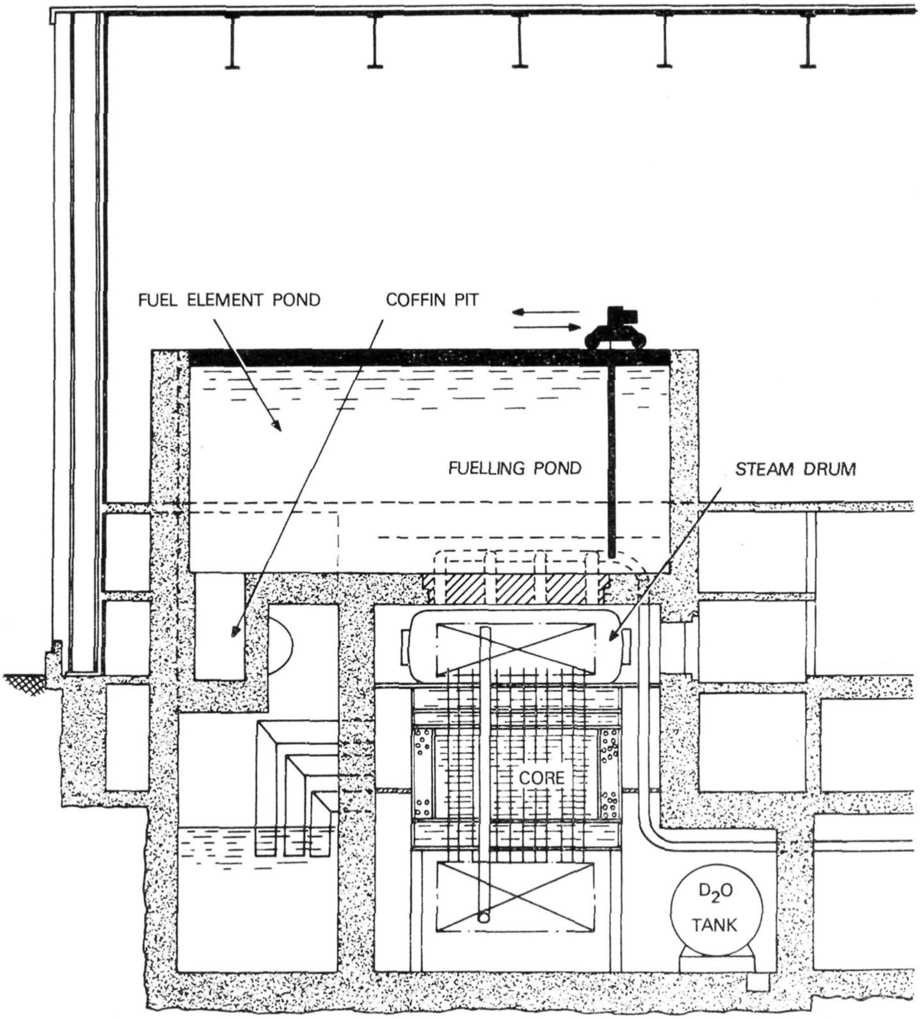


Fig. 5. *Off-load refuelling arrangement for commercial SGHWR.*

Although on-load refuelling has been provided at Winfrith (Fig. 4) the current designs for commercial stations in the medium output size of 300/350 MW(e) have concentrated on off-load refuelling. An on-load refuelling machine is a major plant item and will cost around £1M. While this may only make a small addition to the specific cost of a large reactor, it becomes increasingly significant at smaller outputs and requires to be off-set by either an improved fuel cycle or better station availability, or a combination of both.

The simple off-load refuelling scheme shown in Fig. 5, with the pond above the core, enables fuel to be moved within a few hours of the plant being shut down. A quarter of the core of a 350 MW(e) station could be replaced in about a weekend. In these circumstances, the off-load system is unlikely to carry a significant availability penalty and it is a simpler and cheaper arrangement with fewer routine demands on operation and maintenance personnel.

The layout shown in Fig. 5 is for a station with a vented containment similar to Winfrith. This particular form of containment is not, however, a feature of the S.G.H.W.R. as such, as the reactor can be housed in any form of containment, for example, pressure containment with a separate turbine hall. Indeed, in some countries such a containment may be preferred as it may have already been used and accepted for other water reactor systems or it may fit more easily into a split contractual arrangement in which a nuclear island only is supplied.

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

The Winfrith experience in the manufacture of the calandria showed that with careful planning the fabrication of this vessel to close tolerances on a tight schedule was no problem to a contractor experienced in aluminium work. Also no difficulty was experienced with the upper and lower steel neutron shield tanks, which had to be bored to match the calandria tubes and which were made separately from the calandria in a boiler maker's works. The manufacture of the channel tube assemblies was carried out by a contractor accustomed to doing large scale engineering work to accurate dimensions. It involved the setting up of a special production line with its associated jigs and fixtures. But, apart from the special expanding tool for making the zirconium to steel joints which had been proved in a separate development programme, the techniques required of the contractors, i.e., accurate machining, fitting, jigging and welding, were the ones used in his normal class of work.

The most difficult single piece of equipment to make for the Winfrith plant was the refuelling machine, important details having to be proved and tested as design and manufacture proceeded. Though the manufacture of future machines will clearly benefit from the work done for the Winfrith machine, an off-load system only requires very simple hoists and these do not constitute a manufacturing problem.

In general, therefore, it may be said that the construction of an S.G.H.W.R. does not demand manufacturing skills or fabrication facilities beyond those that would be required for the construction of conventional plant. In

Appendix Part 1 Parameters for 100MW(e) Winfrith Prototype and 350MW(e) Commercial design

Parameter		Winfrith Prototype 100MW(e)	Commercial Design 350MW(e)
Heat balance			
Alternator output	MW(e)	100	377
Station net electrical output	MW(e)	92	350
Station net thermal efficiency	%	30.3	31.15
Reactor thermal output	MW(th)	292	1082
Reactor description			
Core diameter	in. (mm)	123 (3120)	206 (5216)
Core height	in. (mm)	144 (3660)	144 (3660)
Lattice pitch (square)	in. (mm)	$10\frac{1}{4}$ (260)	$10\frac{1}{4}$ (260)
Calandria diameter	in. (mm)	146 (3700)	235 (5976)
Calandria height	in. (mm)	156 (3960)	156 (3960)
Pressure tube internal diameter/ thickness	in. (mm)	5.14/0.2 (130/5.1)	5.14/0.2 (130/5.1)
Calandria tube outside diameter/ thickness	in. (mm)	7.25/0.13 (184/3.3)	7.25/0.13 (184/3.3)
Number of circulating pumps		4	4
Power plant			
Steam pressure-turbine stop valve	lb/sq. in. (kg/cm²)	900 (63.3)	900 (63.3)
Steam temperature-turbine stop valve	°F(°C)	532 (278)	532 (278)
Steam flow rate to turbine	lb/hr. (kg/sec.)	1.19×10^6 (150)	4.47×10^6 (562)
Condenser pressure	in. (mm) Hg	28.6 (32.2)	26.8 (30)
Final feed water temperature	°F(°C)	390 (199)	392 (200)

addition, the types of manufacturing operations and erection procedures involved are straightforward and within the bounds of existing experience. As such they are capable of being tightly planned.

Conclusion

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

If any new thermal system is to succeed, it must at some stage of its development be capable of satisfying, in competition with other systems, both nuclear and conventional, the exacting demands of electricity supply companies who have their own responsibilities to meet and who cannot be expected to buy reactors on the basis of some future advantages which bring no apparent advantage to the utility at the time of purchase. The S.G.H.W.R. is now at this stage and it is considered that the experience gained in the development, design and construction of the Winfrith prototype has fully established the engineering of this advanced reactor system.

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Appendix Part II Parameters for 100MW(e) Winfrith Prototype and 350MW(e) Commercial design

Parameter		Winfrith Prototype 100MW(e)	Commercial Design 350MW(e)
Fuel			
Fuel material		UO_2	UO_2
Pellet diameter	in. (mm)	0.57 (14.5)	0.57 (14.5)
Can material		Zircaloy-2	Zircaloy-2
Can thickness (nominal)	in. (mm)	0.028 (0.71)	0.028 (0.71)
Number of elements in cluster		36	36
Fuel length	in. (mm)	144 (3660)	144 (3660)
Weight of U per channel	TeU	0.198	0.198
Performance			
Fuel average rating	MW(th)/TeU	14.3	17.8
Coolant pressure at core inlet	lb/sq. in. (kg/cm²)	970 (69.0)	970 (69.0)
Coolant inlet temperature	°F(°C)	527 (275)	533 (278.4)
Coolant outlet temperature	°F(°C)	538 (281)	543 (284.1)
Heat to coolant (maximum channel)	MW(th)	3.8	5.0
Coolant mass velocity (maximum channel)	lb/ft²hr	2.18×10^6	3.2×10^6
	(kg/cm²sec)	(0.296)	(0.434)
Steam exit quality (maximum channel)	%	11.3	10.75
Maximum can temperature	°F(°C)	554 (290)	554 (290)

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.

An appreciation course for management 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.

Science and Mathematics Teachers

1st to 5th April, 1968

Intended to give a background knowledge of current developments in some of the subjects investigated at A.E.R.E. and provoke interest in recent applications rather than to provide material directly applicable to a school syllabus. For science teachers the course will cover some applications of nuclear physics, particularly those at A.E.R.E. For mathematics teachers the course will comprise a series of lectures with the emphasis on practical mathematics at A.E.R.E. with particular reference to the impact of computers on the formulation and solution of problems encountered in scientific research. There will also be an alternative section giving an introduction to the use of radioisotopes in schools in the physics, chemistry and biology syllabus. Fee: £3 3s. exclusive of accommodation.

Measurement of Radioactivity

22nd April to 10th May, 1968

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

Advanced Reactor Technology

22nd April to 17th May, 1968

Designed for experienced physicists and engineers. The main emphasis will be on reactor systems already developed or now being developed for industrial exploitation. The first week of the course will be at A.E.R.E., Harwell, followed by one week at the Calder Operation School and two weeks at A.E.E., Winfrith. Fee: £105 exclusive of accommodation.

Magnet Design

29th April to 3rd May, 1968

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

Radioisotopes in food processing

Part 2 Analytical and tracer techniques

This article, by R. M. Longstaff, Wantage Research Laboratory, UKAEA, is the second of two that appeared originally in Food Processing and Marketing. *The first,* Radioisotope Instruments, *was published in the January issue of* ATOM.

HAVING considered the application of radioisotopes to instruments which can be useful tools in the processing and packaging of food, it remains to consider the use of radioactive substances in analysis, and as tracers.

Analytical applications

Some low-energy radiations are preferentially absorbed by heavier elements (more properly, by those of high atomic number). This principle is used industrially in analytical gauges for laboratory analysis or automatic on-stream monitoring of elements such as sulphur or lead in hydrocarbons, chlorine in water or solvents, or clay in paper. The same principle is being developed for rapidly determining the lean-to-fat ratio in meat samples, by measuring the oxygen content: this is much higher in lean meat than in fat, largely because of the water present in the meat. If work at the British Food Manufacturing Industries Research Association is successful, the technique may eventually be developed for on-line control of, for example, sausage-meat production. Gauges of this type cost from £1,200 and accuracies range from about ± 5 per cent. to better than ± 0.1 per cent. depending largely on the materials involved. Another class of analytical gauge, available in portable form, depends on the excitation by isotope-produced radiation of the fluorescent X-rays characteristic of a particular element in a sample; these are particularly useful for the heavier elements (chromium and upwards) and are used mainly in the mineral and metals industries. In suitable cases they will measure a constituent present at levels of 1 per cent. or even less, in measuring times of only a few minutes; they usually require little or no sample preparation. They are limited, however, to determining one element at a time, and matrix variations can influence the results. Subject to these limitations, there may be applications for X-ray fluorescence gauges in the food industries, although none have so far come to the author's notice. Costs of these instruments range from about £750 upwards.

Gas chromatography is a particularly sensitive analytical technique, which is increasingly being used for detecting and measuring small traces of volatile organic substances such as odours or flavours, or toxic residues from pesticides. One very sensitive type of detector head is in fact a radiation detector (ionisation chamber) containing a small radioactive source. The response of the detector to the radiation depends critically on the purity of the gas passing through it, and concentrations as low as 1 part of foreign material in 100 million of carrier gas can be measured. Detectors of this type are standard fittings on some gas chromatography instruments.

A widely-used smoke and fire alarm system, operating on similar principles, detects the arrival of traces of combustion products in the detector head; it is claimed to be insensitive to the normal build-up of tobacco smoke concentration and the presence of dust, as well as to climatic temperature changes.

An ingenious system for measuring the lean-to-fat ratio in meat, based on a principle different from that described above, uses the small amount of radioactivity present in ordinary potassium. This element is present in significant amounts in the lean meat only, so the total amount of radiation characteristic of potassium that is emitted by a live animal or a carcase is related to the amount of lean meat that it contains. The level of radiation is extremely low, so very sophisticated—and therefore expensive—equipment is needed to measure it and the device is at present only suitable for research (Fig. 1).

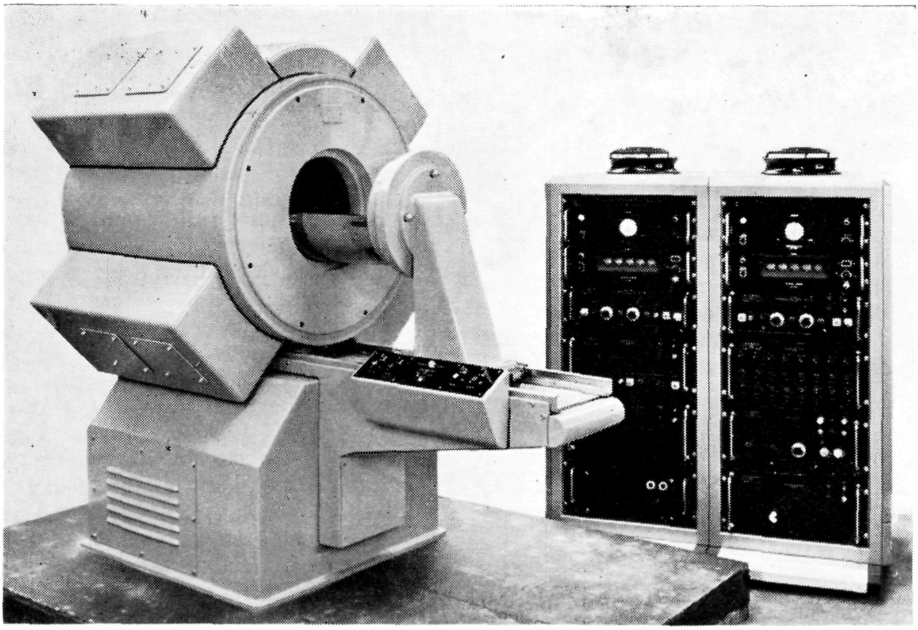

Fig. 1. *Low-level counting equipment for measuring the lean and fat content of meat; samples of up to 80 lb. can be accommodated in the heavily-shielded detector.*

Plant maintenance

In the well-known technique of gamma-radiography a small radioactive source is used in place of the more conventional X-ray machine for the non-destructive examination of welds, castings and assemblies. The capital outlay is much lower than for an X-ray set, and the source in its shield is small and portable and it needs no power supply. If required it can provide an all-round beam for circumferential or multiple radiography. A very useful device that is less well-known is the portable pipe-wall thickness gauge. Radiation from a small source is scattered back from the metal wall into a detector, the amount detected increasing with the wall thickness up to a limit of about $\frac{7}{8}$ in. (for steel). If the reading is low it may indicate that internal corrosion has taken place. The instrument costs about £150 complete. (Fig. 2).

Safety and legal requirements

Because radioactivity can be a potential and particularly insidious hazard to health it must be kept under proper control, and in all countries laws have been brought in to govern its use. In the U.K. the Radioactive Substances Act of 1960 governs the acquisition, use and disposal of radioactive materials and the Ionising Radiations (Sealed Sources) Regulations, 1961, apply to the use of radioactive sources in all premises subject to the Factories Act of 1961. The administration of these acts falls respectively under the Ministry of Housing and Local Government and the factory inspectorate of the Ministry of Labour. These authorities must be notified in advance, and the appropriate formalities completed, before a user may acquire or use a radioactive source. However, exemptions exist under the 1960 Act and the 1961 Regulations in respect of certain sources and applications, and as a result some radioisotope instruments (though not all) are exempt from control. The suppliers of the instruments are in a position to know, and advise upon, the manner in which the regulations apply to the instruments they market, and to assist users in obtaining any necessary authorisations. Generally speaking, radiation levels are kept so low, and the source itself is so well sealed and secured in the construction and installation of the instrument, that compliance with the regulations is seldom found to be burdensome.

Although radioactivity itself is hazardous it should be emphasised that there is no risk whatever of the radiations given out by a radioisotope instrument making anything else radioactive: to return to the analogy of light, exposure to sunlight may cause severe sunburn but it can never make a person glow in the dark afterwards. The rather widespread misunderstanding of this simple fact is probably one of the main reasons why radioisotope instruments are not used as extensively as their economic value would justify. It is understandable that this applies particularly strongly in the food industry, where managements may also fear an adverse reaction from the public to the use of radioactivity. However, many firms—including some of the giants of the industry—have installed radioisotope instruments without any apparent detriment to their public image. Such firms have usually found that the entire capital investment has been paid off in a few months by increased productivity and lower wastage, often with an improved product as a bonus. If the psychological stumbling-block of fear were to be removed, many more firms would undoubtedly be quick to secure their share of these benefits.

Tracers

Minute amounts of radioactive substances can be used as tracers for studying the movements and distribution of bulk materials on plant or laboratory scale. Conventional (inactive) tracer studies depend upon some easily recognised property of a material, such as its colour or smell; less directly, its fluorescence under ultra-violet light, or a characteristic chemical reaction or spectroscopic quality, may be used. The material itself may

Fig. 2. *A portable radioisotope thickness gauge for detecting internal corrosion in pipework.*

lack any suitably recognisable characteristic, and a foreign material such as a dye may have to be added—perhaps only to be removed again at a later stage. Most tracer techniques of this kind demand access to the material studied and many of them, especially if they are to be quantitative, will demand physical or chemical examination of samples. Generally speaking, the more sensitive or the more accurate the determination, the longer and the more involved will be the procedure. On the other hand the use of radioactive substances as tracers can very often greatly simplify the work and at the same time increase its effectiveness. Radioactive materials can be detected in quantities which are often as little as one millionth of the smallest quantity of the same substance that can be detected by ordinary physical or chemical means. Moreover, since the radiations are sufficiently penetrating to find their way out from the bulk material, sometimes even through vessel walls, the need for sampling can often be eliminated. Finally, as the radiations arise from the nuclei of the tracer atoms their emission is totally unaffected by the physical or chemical state of the tracer. Since it is vital that the tracer shall follow the bulk material reliably, it is best (if possible) to convert a sample of the bulk into radioactive form by neutron bombardment in a reactor—a process which usually has no significant effect on its other properties. Where this cannot be done the development of nuclear energy has brought onto the market radioactive isotopes of practically every chemical element, in almost any desired state of chemical combination or physical form. It is, therefore, possible to find a suitable radioactive material to use as a label for tracing the movement of practically any process material. Instruments for detecting and measuring the radiation range from about £50 to £1,000 or more, according to function and sophistication.

Safety in tracer studies

Since the products of the food industry are specifically intended for consumption it will be obvious that special care is necessary in the use of radioactive tracers in this industry and, largely for this reason, their use here has been far smaller than in other industries. This limitation has been reinforced by a very understandable fear that consumers might react unfavourably to the knowledge that radioactive materials were deliberately introduced into food. However, as described earlier, all radioactive materials lose their activity at a characteristic rate, and some have halving times of as little as a few hours or days; this makes storage of the labelled product for ten to twenty halving times perfectly practicable, so that when released for consumption its activity is so low as to be no longer even detectable. This, and the control that is exercised under the Factory Act and the Radioactive Substances Act, ensure that there can be no grounds for fear that a material containing a significant amount of radioactivity may find its way onto the market.

Where it is not practicable to introduce a radioactive tracer as such into the process stream for valid reasons of radiological safety, it is sometimes possible to use an inactive tracer which may subsequently be detected by, for example, neutron activation analysis. Alternatively, the sample may be reacted with a radioactive reagent and the reaction product assayed radiologically. Both of these methods, however, miss the essential simplicity of the direct measurement.

The scope of industrial radioactive tracer techniques can best be illustrated by a number of examples. While most of these are in fact taken from the food industries, some techniques, not yet to the author's knowledge applied in this particular field, are illustrated by examples from certain other industries.

Plant kinetics

Radioactive tracers have been used successfully to study plant kinetics in many processing industries. In the food industry they have been applied in particular to sugar refining processes—probably because the large scale of the plant used not only makes effective tracer studies especially necessary, but also lends itself particularly well to such studies. In a Polish refinery the upward movement of beet chips in a continuous diffuser, and the simultaneous downward movement of the extracted liquor have been studied. The tracers used were sodium-24 as soda-glass needles inserted in individual chips, and lanthanum-140 as an EDTA complex dissolved in water for the liquor. Detectors were installed externally at various points along the diffuser. The rates and directions of movement of chips and liquor were found to vary substantially through the diffuser in a manner which earlier investigations with dyestuffs had failed to reveal; in particular it was found that a considerable amount of fresh feed water was entrained and carried away with the spent chips. The operation of a 20,000 gallon Bach subsider was studied in Australia, using a single injection of bromine-82 (as KBr in water) into the raw sugar feed liquor. External radiation detectors were fitted on each of the six outlet pipes. Although bulk flow rates were virtually the same for all outlets, substantial differences between each were observed in the times of arrival and clearance of the tracer, and in the amounts of tracer carried by each pipe. This indicated poor mixing, and pointed the way to improving the feed system. In an investigation on two Dorr thickeners in a Swedish plant the liquor was labelled with sodium-24 as bicarbonate solution, and the mud with lanthanum-140 co-precipitated as hydroxide during carbonation. Both tracers were added with incoming slurry and were detected externally at outlet tubes. The experiment revealed significant differences between the plants, as well as between individual zones of each; further, it gave a quantitative measure of the extent of recycling of the mud.

In a test on a tea-blending plant a small amount of tea was itself used as a tracer. This was bombarded by neutrons in the reactor BEPO at Harwell to convert some of the sodium atoms in the leaf into the radioisotope sodium-24; previous experiments had shown that no significant amount of activity would be produced in any of the other elements present. The active sample was put through the blending and packaging machines along with the other constituents of the blend, and the filled packages were monitored individually to check that each contained the appropriate fraction of the total amount of activity added. All the packets from the radioactively-labelled batch were stored until the sodium-24 had decayed to a level no longer detectable—a process taking less than one week.

Other factory studies have included measuring the minimum time for mixing of chocolate by conching, using sodium-24 activated in the process material; establishing optimum mixing times for a single product in different types of mixer; studying catalyst recycling in hydrogenation plants; studying the throughput and recycling characteristics of bulk mixing and blending plants; measuring the efficiency of dispersion of mineral additives, using a neutron activated component of the mix; and studying holdup, dead volumes and material carry-over in a variety of process plants.

The use of radioactive tracers to measure the flow of liquids in pipes and ducts is the subject of a forthcoming British Standard Specification. Although suited to large-scale operations its potential value in the food industry is probably somewhat limited.

Filtration, ventilation and wear

The efficiency of filters can sometimes be studied by radioisotope techniques, either by activating a sample of the actual solids intended to be held back by the filter, or by preparing and using a radioactive material of suitable particle size distribution for the desired test. Radioactive krypton-85 gas is sometimes used as a tracer in ventilation studies, and in the study of air or gas flow in pipes and ducts. It is also used in the form known as "kryptonates" for studying wear-rates and local overheating in machinery, etc. Krypton-85 is chemically inert and presents a minimal radiological hazard. Other wear studies are by neutron activation of some part of the bearing or grinding surface followed by detection of activity in the lubricant or ground product. Very rapid results are obtainable by comparison with conventional techniques, and dismantling is obviated.

Leak detection

The use of radioactive tracers for detecting leaks in pipes is very well established and a number of different techniques are available. Usually for factory work the tracer takes the form either of a dilute solution of sodium-24 as activated bicarbonate, or of a sealed pellet of activated soda-glass enclosed in a flexible plastic or rubber ball which fits the pipe snugly. The tracer is introduced into the pipe upstream of the suspected leak, and by applying pressure it is forced along the pipe as far as the leak. Here in the case of the ball it will come to rest because it cannot pass through the leak and there is no flow of water to carry it along the pipe beyond; and in the case of the solution the tracer will find its way out into the surroundings. In either case its continued presence in the immediate neighbourhood of the leak is readily detectable, even through a foot or more of masonry or a correspondingly greater thickness of soil. Leaks in concentric pipe systems—*e.g.* water-jacketed process pipes —can sometimes be detected by passing a pulse of radioactive solution through the system and comparing the amounts and transit times of the activities following the proper route and the leak path. Leaks in vessels can often be located by introducing a radioactive tracer—usually one that gives out non-penetrating radiation—and monitoring the exterior.

Radioactive tracer studies sometimes yield surprising results. In one investigation a suspected leak in a very large vat proved to be no leak at all—the substantial drop in the level of the contents was found to be attributable to change in temperature.

Laboratory applications

It is usually possible to use radioactive tracers more freely in a laboratory than on a production plant, partly because the scale of operations is smaller and partly because there need be no question of the products ever reaching the public.

In the dairying industry radioactively-labelled milk and other dairy products have been used to evaluate the efficiency of cleansing agents and methods, and to compare different metallic and other surfaces for ease of cleaning. In the vegetable canning industry labelled detergents or wetting agents have been used to evaluate rinsing processes for detergent-washed asparagus tips, peeled apricots, tomatoes and peaches, and pickled olives. In other investigations bacteria labelled with phosphorus-32 have been used as biological tracers in research on the cleaning of food cans prior to filling. Insecticides labelled with carbon-14 and phosphorus-32 have been used to measure toxic residues in foodstuffs, and to evaluate processes for removing them. Calcium-45 has been used for studying the physical structure of butter, sodium-24 for studying the diffusion of salt into cheese during manufacture, and iodine-131 for establishing the most satisfactory manner of incorporating iodine into table salt. Krypton-85 has been used for measuring leaks in the seams of cans.

Contrary to general belief, a small radiochemical laboratory is neither difficult nor particularly expensive to set up and operate.

Procedure

It will be clear from the above examples that radioisotope tracer investigations of factory processes are usually carried out on a " one-off " basis to solve a particular problem. It is, therefore, unlikely that a company would have occasion to repeat any particular investigation frequently, or indeed to carry out a great number of tracer studies in any one factory. However, a large company with several factories may feel that it is worth while building up a team and equipping them to do work of this kind as and when the occasion arises. Facilities exist within the Atomic Energy Authority, and at a number of Universities and Colleges of Technology, for training professional and other staff in the fundamentals of radioactivity and in the techniques of its use. Radioactive chemicals can be purchased from the Radiochemical Centre at Amersham, and neutron irradiations of a customer's own materials can be arranged through the same organisation. Measuring apparatus and other necessary equipment can be purchased through normal commercial channels. Very little is usually needed in the way of shielding and handling equipment or other special facilities.

If on the other hand a firm does not wish to become directly involved to this extent it is usually possible to arrange for an outside organisation to carry out the work on a contract or consultancy basis. The Wantage Research Laboratory of the U.K. Atomic Energy Authority offers such a service, and information on other similar services can be obtained from the Ministry of Technology Regional Offices or from local Industrial Liaison Officers. The Radiological Protection Service, jointly operated by the Ministry of Health and the Medical Research Council, is always able and willing to give constructive advice on safety matters. In all cases initial sanction to acquire, use and dispose of radioactive materials will have to be obtained from the Ministry of Housing and Local Government, and in appropriate cases from the Factory Inspector also. It is always advisable to clear the radiological safety aspect at the earliest possible stage.

Economics

It is very difficult to give firm figures for the savings achieved by tracer investigations, and to balance these against their costs. However, two examples will illustrate the order of costs involved. In the first a water leak was reported in an old and extensive system of 3 in. pipes; no drawings were in existence and the pipes were covered by a heavy reinforced concrete raft. Water was being lost at the rate of 300,000 gal./week and it was not possible to isolate the leak from the rest of the system, which was in constant use. All efforts to locate the leak had failed and an outside organisation was called in. Sodium-24, as irradiated glass pellets contained in a rubber ball, was used as a tracer and the leak was found without difficulty: it turned out to be a fracture in a part of the pipe situated beneath 3 ft. of reinforced concrete. The investigation took two days in all to carry out, including the preliminary survey, and the total cost to the factory owners was under £70. The leak, if it had been allowed to continue, would have added £1,500 per year to the factory's water bill.

The other example relates to a large chemical firm which employs its own team of 25 specialists, equipped to make use of the full range of radioisotope techniques. It is their experience that savings of £1,000 or more frequently arise from a single investigation requiring only about one man-day of effort. Where a tracer study succeeds in reducing off-stream time or removes a limitation to production, annual saving can be many times this figure.

A.E.A. Reports available

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

AERE-AM 105
A Rapid Determination of Protactinium-233 (Di-Isobutyl Carbional and Methyl I Sobutyl Ketone Extraction). By W. Jenkins, J. W. McMillan and T. B. Rees. October, 1967, 6 pp. H.M.S.O. 1s. 9d.

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

AERE-R 5575
Radioactive Fallout in Air and Rain. Results to the Middle of 1967. By R. S. Cambray, E. M. R. Fisher, W. L. Brooks and D. H. Peirson. November, 1967. 49 pp. H.M.S.O. 7s.

AERE-R 5601
Stability of Fuel Rod in a Narrow Annular Coolant Channel Against Thermal Buckling. By J. Woodrow. September, 1967. 18 pp. H.M.S.O. 3s.

AERE-R 5616
Application of a Sealed-Tube Neutron Generator to the Determination of Copper and Silicon in Aluminium Alloys. By T. B. Pierce, J. W. Edwards and D. Mapper. October, 1967. 9 pp. H.M.S.O. 1s. 9d.

AERE-R 5617
The Determination of Ruthenium in Uranium Carbide-Ruthenium and Plutonium Carbide/Uranium Carbide-Ruthenium Cermets. By G. J. Weldrick, A. J. Wood, D. Crossley, G. Phillips and G. W. C. Milner. November, 1967. 14 pp. H.M.S.O. 2s. 6d.

AERE-R 5627
Critical Inelastic Scattering of Slow Neutrons from a Binary Liquid Metal Mixture (Bi-Zn). By P. A. Egelstaff and G. D. Wignall. October, 1967. 17 pp. H.M.S.O. 3s.

AWRE 0-63/67
Neutron Cross-Section of Copper in the Energy Range 0.0001 eV to 15 MeV-Sources of Data for Files 249 to 251 in the UKAEA Nuclear Data Library. By K. Parker and S. M. Offord. 77 pp. December, 1967. H.M.S.O. 11s.

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work can start within the first few weeks of the new year.

Mr. Marsh: My hon. Friend has highlighted a particular problem. He is in favour of a nuclear-powered station. Many of my hon. Friends favour a coal-fired power station. I shall do what I can as quickly as possible to reach a compromise between them.

Sir G. Nabarro: Will the right hon. Gentleman confide in the House of Commons about the comparative cost of a coal-fired station at Seaton Carew, and a nuclear-fired station? Does he not recall that many of us on both sides of the House believe that coal ought to be used at this new station, and not nuclear power?

Mr. Marsh: There is a strong view that this should be a coal-fired station. This controversy has gone on for a long time. As I understand it, hon. Members on both sides of the House want a proper cost benefit analysis done in relation to which is the best station to put there. It does not necessarily follow that if we do not have a nuclear-fired station at Seaton Carew we have a coal-fired station on that site. It might well be elsewhere.

Power station costs

13th December, 1967

MR. WOOF asked the Minister of Power what estimate he has made of the capital cost per kilowatt of an additional coal-fired power station of 2,000 megawatt capacity at West Burton, compared with the proposed nuclear station at Seaton Carew and the nuclear station now being built at Dungeness B.

Mr. Freeson: The estimated capital cost of Dungeness B (for 1200 MW) is about £110 per kilowatt. Typical capital costs per kilowatt for additional 2000 MW stations would be about £65 for coal-fired and about £95 for nuclear. These estimates include interest (at 8 per cent.) during construction and, for nuclear stations, the initial fuel charges.

Mr. Concannon asked the Minister of Power what is the estimated cost per unit sent out by the coal-fired power station at Ratcliffe-on-Soar compared with the cost of the nuclear station at Dungeness B; and when the two stations will be operating.

Mr. Freeson: The generation cost at 75 per cent. load factor and 8 per cent. interest rate is estimated to be 0·54d./kWh for Ratcliffe and 0·56d./kWh for Dungeness B. The estimates are not comparable because much of the capital expenditure at Ratcliffe took place when prices were lower. Ratcliffe is expected to be commissioned in 1968 and Dungeness B in 1970.

High temperature reactor

14th December, 1967

DR. DAVID OWEN asked the Prime Minister if he is aware of the interest being shown in Belgium in the high-temperature reactor; and if he will ensure that everything is done to encourage a collaborative European effort for its commercial exploitation.

The Prime Minister: My hon. Friend will know of the Government's wish to pursue technological co-operation in Europe and also that we have recently taken an initiative which will enable the DRAGON project to continue. If however he has any specific points he would care to put to me I would be very willing to consider them.

Dr. David Owen asked the Prime Minister if he will consider promoting the commercial development of the high-temperature reactor by encouraging its possible use in relation to the proposed aluminium smelter plants.

The Prime Minister: Under the contracts which the aluminium companies are currently discussing with the Generating Boards, electricity will be provided at the effective cost of generating it in a modern power station. It is for the Generating Boards to consider what type of station is most appropriate.

Desalination

19th December, 1967

MR. DALYELL asked the Minister of Technology what work he is doing on desalination under Section 4 of the Science and Technology Act.

Mr. Benn: On 27th April, 1965, my predecessor asked the Atomic Energy Authority to assume responsibility for research and development into methods of desalination of salt water for civil use.

The Authority drew up a three-year R. and D. programme with two principal objectives: first, to exploit the development potential of the British multi-stage flash distillation process, and secondly, to explore alternative methods of desalination which might show improvements on the multi-stage flash process in due course.

The first objective has been pursued in close collaboration with Weir Westgarth Limited, and significant reductions in cost have been obtained. Many of the benefits of our initial programme have not yet reached the stage of commercial application. But Weir Westgarth's have won three overseas orders this year amounting to a total capacity of more than 5 m.g.d.

The second objective has led to work on electro-dialysis in collaboration with William Boby Limited and has resulted in the construction of a new design of pilot plant, which shows promise for commercial exploitation.

Simon-Carves Limited, have collaborated with Harwell in a design study for a desalination plant based on a freezing process and a range of experimental facilities is being commissioned at Harwell.

The third advanced process studied in collaboration with Yarsley Laboratories and the A. D. Little Research Institute employs reverse osmosis, particularly suitable for brackish waters. Portal Holdings Limited are also collaborating in the development of this system.

The R. and D. programme will be completed within its original estimated cost of £1.3 million of public money, of which some 20 per cent. has been used to finance work by the Authority's industrial collaborators.

I have now approved a second programme of work by the Authority at an estimated cost of £4 million over the period ending 31st March, 1971, of which almost half will be used to finance agreed programmes of work by the Authority's industrial collaborators. The programme will also include a continuing study of desalination plants powered by nuclear reactors for which commercial designs have been prepared during the first programme and which are continually being up-dated.

I am sure the House will join with me in wishing success for this second programme.

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

Finding the Dounreay Fast Reactor leak

The long series of tests to find the position of the liquid-metal coolant leak in the Dounreay Fast Reactor primary circuit has, as previously announced, been rewarded with success.

It is now known that the leak is at, or very near, the point where the outlet duct leading to No. 10A heat exchanger leaves the reactor vessel. It is probable, too, that the leak is on the side of the duct nearer to No. 9B circuit and slightly higher than the centre line of the duct. It is believed that the leak has been pinpointed to within a circle of about three inches radius.

The considerable success of the final stages was achieved only by the endeavours of a great many people at Dounreay, and all who contributed are commended for their efforts. Preparations for repair are now going ahead rapidly, the first step being to cut into No. 10A duct. Once this is done it may be possible to locate the leak with even greater precision, if not actually to inspect it by optical means. A decision can then be made as to the exact method of cutting out and replacing the faulty part of the reactor.

Knowledge of the leak's position was obtained in two ways. In the first series of tests, the reactor circuit was pressurised with helium to 50 p.s.i. and samples of gas taken from the leak jacket every 30 minutes. The rate of build-up of helium gave a measure of the size of the leak. Then, each of the heat exchangers in the vault was pulled slightly to one side or was swung gently on its support. This was done to each heat exchanger in turn while still sampling the jacket for helium. These tests resulted in a reasonably clear indication that No. 10A circuit was at fault, though its immediate neighbours could just possibly have been the culprits.

In the second test, a pool of liquid metal was placed in the reactor vessel up to the level of the outlet ducts. The leak jacket was pressurised and, with a sensitive microphone clamped on to the nearest accessible point of each outlet duct (eight ft. from the reactor vessel), attempts were made to detect the noise of bubbles escaping into the sodium-potassium coolant in the vessel. This noise could be heard quite clearly on headphones connected to the microphone on No. 10A duct, much less clearly from the neighbouring duct on each side of this one, and not at all on any other duct.

Finally, an adaptation of the second method was used to locate the precise position of the leak. To do this the time taken for the sound of the bubbles to pass through the stainless steel to microphones on two different ducts was compared. The difference in time amounted to no more than one 5,000th of a second and it was this that enabled the leak to be pinpointed within a three-inch circle. The technique is somewhat similar to that used to locate the centres of earthquakes: as far as is known, nothing of the kind has ever been used before in the reactor field.

14th December, 1967

Heat transfer and fluid flow services

Many problems in the design and development of engineering plant involve heat transfer and fluid flow. At the request of the Minister of Technology, under Section 4 of the Science and Technology Act 1965, the Authority have started a new service at Atomic Energy Research Establishment, Harwell, to assist industrial firms facing such problems.

The service offered will be in two parts:—

(a) *A design information service*
In return for an annual fee, participating firms will receive reports incorporating critically-assessed design information and data. They will also have access to limited consultancy services and to an information service.

(b) *Consultancy and testing services*
Research and development, consultancy and testing services will be available to individual firms on a repayment basis.

Some longer range supporting research will be conducted on problems chosen in consultation with industry, as having wide design or operational importance.

To assist in planning the service, a survey was carried out with assistance from central trade associations, of the requirements of about 30 chemical and process contractors, chemical plant operators and boiler and heat exchanger manufacturers. This established the needs of the industry and the pattern of service best fitted to meet them.

The work will be done in full co-operation with other Authority laboratories, Ministry of Technology laboratories—particularly the National Engineering Laboratory, East Kilbride—and University departments.

The service will be operated by the Chemical Engineering and Process Technology Division under the general direction of Mr. A. S. White (Division Head) to whom enquiries should be addressed at A.E.R.E., Harwell, Didcot, Berkshire.

Background note

During the past ten years, the Chemical Engineering and Process Technology Division at Harwell, in co-operation with other Authority laboratories, has carried out a wide range of engineering research and development projects on heat transfer and fluid flow problems as they affect the design of nuclear plant—such as the Steam Generating Heavy Water Moderated Reactor System (S.G.H.W.R.).

The new service now being offered is based on the experience and knowledge gained and will take advantage of the wide range of engineering equipment built up to meet the needs of the atomic energy programme.

The amount of information and data on heat transfer and fluid flow currently being published by organisations all over the world is now so large that critical selection, assessment and presentation in the form most useful to the designer or the operator is becoming a major problem. The new service offers special help, backed by the full resources and experience of the Authority, in this particular field.

20th December, 1967

Post-Graduate Education Centre Syllabus

The Harwell Post-Graduate Education Centre has published a new booklet giving details of courses and lectures to be held during the coming year. Copies of the booklet are available from the Education and Training Centre, Building 455, A.E.R.E. Harwell, Didcot, Berks.