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THE UNITED KINGDOM ATOMIC ENERGY AUTHORITY

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OF THE UNITED KINGDOM
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Anglo-French agreement on reprocessing

British Nuclear Fuels Limited (B.N.F.L.) and Saint Gobain Techniques Nouvelles (S.G.N.) announced on 6th December their agreement to form an association to combine their nuclear fuel reprocessing technology. The association will offer joint services for the study, design and construction of future large capacity reprocessing plants such as the one projected in Japan. An extension of the association to include German companies such as the Uhde-Lurgi Group is at present under consideration.

The formation of this association follows the setting up of United Reprocessors GmbH in 1971 to market nuclear fuel reprocessing services in Europe.

Background note

B.N.F.L.: British Nuclear Fuels Limited was formed on 1st April, 1971 and has the nuclear fuel production and reprocessing responsibilities previously controlled by the U.K.A.E.A. Among its various establishments is the nuclear fuel reprocessing plant at Windscale.

S.G.N.: Saint Gobain Techniques Nouvelles was incorporated as an independent company in 1961. In addition to its other engineering activities S.G.N. has a long record of close relations with the French Commissariat à l'Energie Atomique (C.E.A.) and has been entrusted with engineering and construction of the La Hague and Marcoule plants in France. S.G.N. has also acted as architect engineer for Eurochemic at Mol. S.G.N. is at present engaged in the construction of a reprocessing plant at Tokai Mura in Japan.

Achema 1973

The U.K.A.E.A. will be taking part in the Achema Exhibition, at Frankfurt, from 20th to 27th June 1973, with three exhibits from Harwell, in Halls 1c, 4 and 6, which will contain displays on Chemical Process Equipment, Nuclear Science and Technology, and Measurement, Control and Automation.

OBITUARY

Sir Basil Schonland

We regret to report the death on 24th November of Sir Basil Schonland, C.B.E., F.R.S., Director of A.E.R.E., Harwell, from 1958 to 1960.

Sir Basil who was aged 76, was born in South Africa and educated at St. Andrews College and later at Rhodes University College, Grahamstown.

In the 1914-18 war he joined the Signals Corps of the Royal Engineers and served in France between 1915 and 1918.

After the war he went to Gonville and Caius College, Cambridge, where he was a George Green Scholar and a College Exhibitioner. He then joined Lord Rutherford in the Cavendish Laboratory.

He returned to South Africa as a Lecturer and later became Professor of Physics in the University of Cape Town.

In 1936 he was appointed the first Director of the Bernard Price Institute of Geophysics in Witwatersrand University and carried out his well-known work on lightning. He was elected F.R.S. in 1938.

He joined the South African Corps of Signals as a Brigadier in 1941 and when he came to Britain in that year renewed his friendship with Sir John Cockcroft, who at that time was Chief Superintendent of the Air Defence Research and Development Establishment and was temporarily responsible for the Army Operational Research Group located at Richmond, Surrey. Sir John Cockcroft persuaded Sir Basil Schonland to take over the post of Superintendent, and under his direction the operational research group carried out important work on the effectiveness of anti-aircraft radar and measures required to improve its performance. His interests broadened during the war and he became Scientific Adviser to General Montgomery during his command of the 21st Armoured Group, and later he became Scientific Adviser on Operational Research to General Eisenhower.

On his return to South Africa in 1945 he was appointed Science Adviser to the Prime Minister, General Smuts, and became the first President of the South African Council for Scientific and Industrial Research.

In 1954 he returned to Britain as Deputy Director of A.E.R.E. and he remained at Harwell until his retirement. In 1958 he succeeded Sir John Cockcroft as Director and in 1960 became Director of the Research Group.

He was awarded the Hughes Medal of the Royal Society in 1945 for his work on atmospheric electricity and the Faraday Medal of the Institution of Electrical Engineers for his work in nuclear energy in 1962. He held a number of honorary degrees. In 1968 he published *The Atomists 1805-1933*.

Centrifuge Study Association

The increasing concern in many quarters over future supplies of enriched uranium has led to growing interest in the progress of German-British-Netherlands co-operation on the use of the gas centrifuge method for this purpose.

URENCO and CENTEC, the two companies set up to further the industrial exploitation of the centrifuge process, with the support of the three Governments, propose to establish a Study Association in collaboration with interested agencies and industrial enterprises and to provide them with specific information on the gas centrifuge method. In the next few weeks interested agencies and enterprises will be invited to participate in the Association. Arrangements will be made to keep the Commission of the E.E.C. fully informed of developments.

The detailed arrangements for the Association and the proposals for its studies will be the concern of URENCO and CENTEC and of its future participants. Major decisions will however be taken in consultation with the three Governments, who will need to ensure that proper assurances can be obtained regarding the protection of classified information and the observance of international obligations.

URENCO and CENTEC hope that the steps they are taking will be a major contribution to the creation of centrifuge enrichment capacity to meet growing power demands, and the need to exploit indigenous resources.

Agencies and enterprises interested in becoming participants in the Association are invited, in the first instance, to make their interest known by writing to the General Manager, URENCO Limited, 40, West Street, Marlow, Buckinghamshire.

Atomic Energy Authority (Weapons Group) Bill

The following extract is taken from the debate preceding the second reading of the Bill in the House of Lords on 16th November, 1972.

THE SECRETARY OF STATE FOR DEFENCE (LORD CARRINGTON), My Lords, I beg to move that this Bill be now read a second time. The purpose of this Bill is to transfer the activities of the Atomic Energy Authority's Weapons Group, together with its associated property, rights and so on—in practice, the Atomic Weapons Research Establishment at Aldermaston and its outstations—from the Authority to the Ministry of Defence.

I should like to say right at the outset that the Bill does not involve any change in responsibility for nuclear weapons policy, but I will return to that point later. Perhaps I may begin by reminding your Lordships of the arrangements for nuclear weapons research and development in the United Kingdom.

After the last war, this kind of work was first undertaken in part of what is now the Royal Armament Research and Development Establishment. However, the work demanded extensive and highly specialised facilities, and so a separate research and development establishment—the Atomic Weapons Research Establishment—was set up at Aldermaston. And in 1954 this establishment was transferred to the newly created Atomic Energy Authority, where it formed the basis for the Weapons Group. This now comprises not only Aldermaston but also a sizeable outstation at Foulness, and a few very small units mostly in the Aldermaston area. The main task of the Group, some four-fifths of its total effort, is research, development and production work on explosive nuclear devices for use in nuclear weapons; but the Group also undertakes some civil nuclear work as part of the Authority's programme, as well as some non-nuclear work on behalf of various Government Departments and outside customers.

As your Lordships know well, the problem of how best to organise Defence procurement has been with us for a great many years. When we came into office we set up a Project Team under Mr. Derek Rayner to study this problem, and its recommendations were published in a White Paper in April, 1971. The fundamental recommendation was that Defence procurement activities should be brought together into a single organisation within the Ministry of Defence; and this has been implemented by the setting up of the Procurement Executive inside my Department, embracing all aspects of Defence procurement from research through to production. An essential feature of the new organisation, to which I attach great importance, was the bringing together into the same organisation of all the Research and Development establishments concerned with defence. Apart from simplifying the policy control and direction, this has enabled a start to be made on rationalising the facilities and resources of the various establishments, and we are at present engaged in consultations with the Staff Associations and Unions on our proposals for the first stage of rationalisation.

One of Mr. Rayner's recommendations was that the Atomic Weapons Research Establishment should be brought within my Department. Following consultation with the Atomic Energy Authority during the summer of 1971, to see how best the functions of the A.W.R.E. could be rationalised with those of the other research and development establishments, the Government decided that this could be effected only if the Atomic Weapons Research Establishment were brought under the same management as the other establishments. I accordingly told your Lordships, in my Statement on 5th August last year, of our decision to transfer the A.W.R.E. to the Ministry of Defence. This Bill is to give the effect to that decision. Perhaps I may very briefly explain to your Lordships the principal provisions of the Bill.

Clause 1 gives effect to the main purpose of the Bill, and it provides that from the appointed day those activities of the Weapons Group which involve work on explosive nuclear devices will be carried out by the Ministry of Defence and not by the Authority, unless the Authority is specifically authorised or a contract placed with it to do such work. It also transfers the property and so on—everything connected with the property—of the Group to the Secretary of State for Defence, with the exception of patents and other industrial property to which I will return later.

Clause 2 deals with the effects of the transfer on the people at present employed in the Weapons Group. We want all the people engaged on work now performed by the Weapons Group to continue their jobs in the Ministry of Defence, and this clause terminates their contracts of employment with the Authority and enables them to be taken into the Civil Service. There have been consultations with the Civil Service Commission and I can say that all the Weapons Group employees will be offered immediate and continuing employment in the Civil Service.

My officials have been consulting with the staff and trade union representatives about the terms and conditions of service for staff who will be transferred, and I am happy to say that good progress has been made towards reaching agreement. Some adjustments to present terms and conditions will be necessary, but the general principle will be maintained that, taken as a whole, terms and conditions after the transfer shall be no less favourable than those provided for in existing contracts.

The terms and conditions of non-industrial staff in the Authority and Civil Service are already very similar in many respects. There are, however, certain differences, the most important of which concern superannuation and retiring age. The Authority's main pension schemes, unlike that of the Civil Service, are contributory; non-industrial staff pay contributions at the rate of 6 per cent of their salary, and to allow for this their salaries are in general 7 per cent higher than in the Civil Service. This means that their net pay is marginally higher—about one-half of 1 per cent—and also that their pensions, being based on gross pay, are 7 per cent higher. At the same time, the normal minimum retiring age for men is 65 instead of 60. We have therefore agreed that non-industrial staff should be able to remain in the Authority's pension scheme, with the associated pay and retiring age provisions, if they so wish. Clause 2 provides the necessary powers; and I should like to add the assurance that there is no question of staff who opt to stay in the Authority's scheme being compelled at some future date to change to the Civil Service scheme.

The case of industrial employees is rather different. Their pay and grading structure has evolved on different lines from that of the industrial Civil Service, and we are examining this to ensure that the transfer from one structure to the other goes smoothly. Where the rate for the job in the industrial Civil Service is higher, those concerned will get the benefit; in other cases, existing pay rates will be retained until they are overtaken. Understandings have been reached between my Department and trade union representatives on these and other conditions of service. Clause 2 also preserves the powers of Authority constables who are transferred with the Weapons Group and taken into the Civil Service.

My Lords, Clause 5, together with the Schedule, deals with the principles governing the exchange of information covered by patents and other technical information between the Secretary of State and the Authority. In general, the Bill leaves the ownership of existing patents and technical information with the Authority. This is because it has been found impracticable to segregate those patents which are relevant to the Weapons Group from those relevant to the civil activities of the Authority. There is, however, an important exception made under paragraph 3 of the Schedule, which is that information relating to explosive nuclear devices will become the property of the Ministry of Defence. But the Authority will be required to make available to the Secretary of State such facilities as he may need for the use of the patents remaining the property of the Authority. On the other side of the coin, the Bill also provides for access by the Authority to information of which custody and control will pass to the Ministry of Defence with the transfer of the Weapons Group. I think this is an important point, as the Government are anxious to ensure that the transfer of the Weapons Group does not impede the exploitation by the Authority of peaceful applications of nuclear energy.

Clause 6 is a logical consequence of the decision to transfer A.W.R.E. and its activities away from the Authority. The Authority's powers under the Atomic Energy Authority Act 1954 to produce, use and dispose of atomic energy and to carry out research were subject to the restriction that they were not permitted to develop or to produce any weapon or part of a weapon except in accordance with arrangements made with the then Minister of Supply and now with the Secretary of State for Defence. However, Section 2(2) of the 1954 Act empowered the Authority to conduct on their own initiative experimental work which might lead to improved types of explosive nuclear assemblies for use in weapons. Now that the responsibility for carrying out all work on explosive nuclear devices and the facilities for undertaking it are to be put into my Department, this power is now redundant and is repealed by Clause 6. Additionally, Clause 6 widens the prohibition placed on the Authority, in that it provides that they are not to undertake and work on explosive nuclear devices, whether for warlike applications or otherwise, except in accordance with arrangements made with the Secretary of State.

My Lords, I will not dwell on the financial arrangements which are the subject of Clause 8, except to say that the net cost to public funds will be affected by the Bill only to the extent that, as I explained in dealing with Clause 2, there are some differences in the terms and conditions of service of employees of the Atomic Energy Authority and those of the Civil Service. Since negotiations are still in progress I cannot put a figure to this, but it seems unlikely that the cost will increase by more than £200,000 a year.

My Lords, perhaps I may end by making some rather more general comments. First, I hope that the transfer can take effect from 1st April, 1973, both for organisational reasons and so that we can end the uncertainties for the staffs concerned. Following my Statement on 5th August, 1971, it was suggested that to place the production of warheads for nuclear weapons directly under the control of the Secretary of State for Defence, and no longer under a separate Minister responsible to the Cabinet for nuclear matters generally, raises a point of constitutional significance. I think that this criticism overlooks the fact that in this very important area the responsibility for policy has been, and under the proposed new arrangements will continue to be, a collective responsibility of Her Majesty's Government. This applies as much to decisions on the nuclear weapons programme as to decisions on strategy, and this responsibility would in no way be lessened by the measures now proposed.

The Secretary of State for Defence is, and will continue to be, the departmental Minister responsible for giving effect to the Government's approved policy. At present, the development and production by A.W.R.E. of nuclear warheads required for the weapons programme is carried out under contracts placed by the Ministry of Defence with the Authority. After the transfer this will become a matter for direct management within the Ministry of Defence. In other words, there will be a change in the administrative methods, but no change in the essential responsibility. The work of the Weapons Group is predominantly military, and I am quite sure that it is right to bring it into the Ministry of Defence along with the other Defence research and development establishments, and under a single management organisation. It is only in this way that we can so use our resources as to meet the needs of Defence programmes in the most efficient and flexible way.

But in stressing the predominantly military nature of A.W.R.E. I am by no means overlooking the considerable contribution which it has made to basic nuclear technology, nor the extent to which the skills and special facilities at Aldermaston have been used to great advantage in some aspects of the civil nuclear power programme. Civil work at present carried out at A.W.R.E. accounts for about a fifth of the establishment's effort. Part of this is devoted to the Authority's research and development programme on the fast breeder reactor, most of which, of course, is carried out in the Authority's Reactor Group.

I can assure your Lordships that this work, together with the other civil work at A.W.R.E., will continue uninterrupted: the expertise and facilities at A.W.R.E. will be made available to the Authority and the Department of Trade and Industry under contracts which they will place with the Ministry of Defence. I am particularly concerned that my Department should maintain close relations with the Authority and the Department of Trade and Industry, just as it has in the past in connection with its military programme. All we are doing is simply reversing the present contractor-customer roles. Your Lordships may wonder about the effect that this transfer will have on the remainder of the

Authority, and I can say here that the remaining part of the Authority—that is, the Reactor and Research Groups and the Safety and Reliability Directorate—will retain a vital role in the further development of nuclear reactors and other civil applications of nuclear research.

In the Commons

Electricity generation

13th November, 1972

MR. HARDY asked the Secretary of State for Trade and Industry what was the share of the electricity generation requirement occupied by coal, oil, gas, nuclear energy and hydro-electric schemes in the United Kingdom in 1971; and what is the expected share for each of the above in 1976.

Mr. Emery: The shares in 1971 were approximately as follows:

	Percentage of total electricity generated
Coal	65
Oil	23
Gas	1
Nuclear	10
Hydro	1
	100

I will not speculate upon the shares to be expected in 1976, as these will depend on so many circumstances—including growth of demand and such unpredictable factors as the weather.

Transport security

23rd November, 1972

DR. JOHN A. CUNNINGHAM asked the Secretary of State for Trade and Industry if he is satisfied with the security arrangements for the shipment of plutonium and other substances to and from Windscale; and if he will make a statement.

Mr. Emery: Under the Atomic Energy Acts, 1954 and 1971, the responsibility for the security arrangements for the shipment of plutonium and other substances to and from Windscale rests with the United Kingdom Atomic Energy Authority and British Nuclear Fuels Limited. I am satisfied that the Authority and the company ensure that there are very strict arrangements for the transport of nuclear materials to and from Windscale, and that these arrangements are kept under review.

Atomic Energy Establishment Dounreay

29th November, 1972

MR. RUSSELL JOHNSTON asked the Secretary of State for Trade and Industry whether he will make a statement about the future of the Atomic Energy Establishment at Dounreay.

Mr. Tom Boardman: The Atomic Energy Establishment at Dounreay is engaged on a continuing programme of work on the sodium-cooled fast reactor and will be for many years. As the House was informed on 8th August, the Government see this type of reactor as the main element, in the long term, of our generation of electricity by nuclear power and intends to proceed as rapidly as possible with its development. A large part of the development work will be carried out at Dounreay. The 250 megawatt (electricity) prototype fast reactor is nearing completion there and will be commissioned next year.

Radioactive wastes disposal at sea

6th December, 1972

MR. WINGFIELD DIGBY asked the Secretary of State for the Environment if he will list the provisions in the new Convention which prohibit dumping in the sea of atomic waste, even in containers.

Mr. Eldon Griffiths: Article IV and Annex I prohibit the deliberate dumping of high level radioactive wastes except in serious emergencies. Article VI and Annex II require special permits for other radioactive wastes, taking full account of the recommendations of the International Atomic Energy Agency. In Article XII the parties pledge themselves to promote measures to protect the marine environment against radioactive pollutants from all sources, including vessels.

Select Committee on Science and Technology

8th December, 1972

MR. NEAVE asked the Secretary of State for Trade and Industry when he will publish his reply to the Second and Third Reports from the Select Committee on Science and Technology 1971-72, on the non-reactor research and development activities of the Atomic Energy Authority and the Department of Trade and Industry Research Establishments.

Mr. Peter Walker: My observations on both Reports are contained in a White Paper published today as Cmnd. 5176.

Status of the Steam Generating Heavy Water Reactor

The following paper by J. Moore, U.K. Atomic Energy Authority, D. Hicks, U.K. Atomic Energy Authority, N. Bradley, The Nuclear Power Group Ltd., and I. T. Rowlands, British Nuclear Design and Construction Ltd., was presented to the Third International Technical Meeting of Nuclear Industries (Nuclex '72) in Basle, Switzerland, 16th to 21st October 1972.

Summary

The S.G.H.W.R. is a direct cycle boiling light water reactor with a heavy water moderator. Distinguishing features are the use of pressure tubes instead of a large pressure vessel, provision of emergency cooling water as a spray operating directly on to fuel pins and the absence of moving mechanical components in the core.

Operation of the 100 MW(e) Winfrith reactor for almost five years has shown the system to be reliable and accessible for in-inspection and maintenance. Dynamic characteristics and fuel and materials performance relevant to current commercial designs have been demonstrated.

Introduction

The Steam Generating Heavy Water Reactor is a direct cycle boiling water reactor using light water coolant and heavy water as the principal moderator. The fuel design and coolant technologies are similar to those in conventional B.W.R.s, and the basic reactor design has the following distinctive characteristics.

1. The pressure vessel is replaced by Zircaloy pressure tubes of simple geometry and well understood metallurgical properties.
2. Under pressure circuit failure conditions the reactor has the good safety characteristics inherent in pressure tube reactors. Emergency cooling water is supplied as a direct spray along the whole length of each fuel element.
3. The reactor has a zero void coefficient making it relatively insensitive to changes in steam/water content in the core.
4. There are no moving mechanical components in the core, control is achieved by adjusting moderator height and chemical shim in the moderator. This form of control in conjunction with the fuel management scheme causes only small local power steps in fuel rating during fuel life, typically a maximum of 6 per cent.
5. Easy access for refuelling permits rapid replacement of faulty fuel and adoption of a fuel cycle requiring modest fuel burn up, average discharge irradiation 20,000 MWD/te.

Low enrichment UO_2 fuel, 2 per cent, is employed. Enrichment leads to significant reductions in heavy water inventory, about a factor 3, and results in steam void coefficients that are small and negative. Control and safety problems associated with large reactivity or power distribution changes due to steam voids are therefore avoided.

The S.G.H.W.R. was developed by the combined resources of the U.K.A.E.A. and the British nuclear industry and established as a proven reactor system by almost five year's operation of the 100 MW(e) power plant at Winfrith Heath. The plant has been supplying power to the British grid system since December 1967.

The Winfrith reactor was designed as a demonstration plant for large reactors of 500 MW(e) upwards. In particular the pressure tube and fuel element design were optimised for a large reactor and increases in design power are achieved simply by increasing the number of these proven modules. The required increase in size of other components such as the heavy water tank or calandria and recirculating pumps is well within the limits of normal engineering practice.

S.G.H.W.R. design

The fuel element consists of 36 pins of UO_2 fuel with Zircaloy cans and a central hollow tube through which the emergency cooling water is supplied to spray directly on to the fuel pins. A neutron shield and a sealing plug are located above and con-

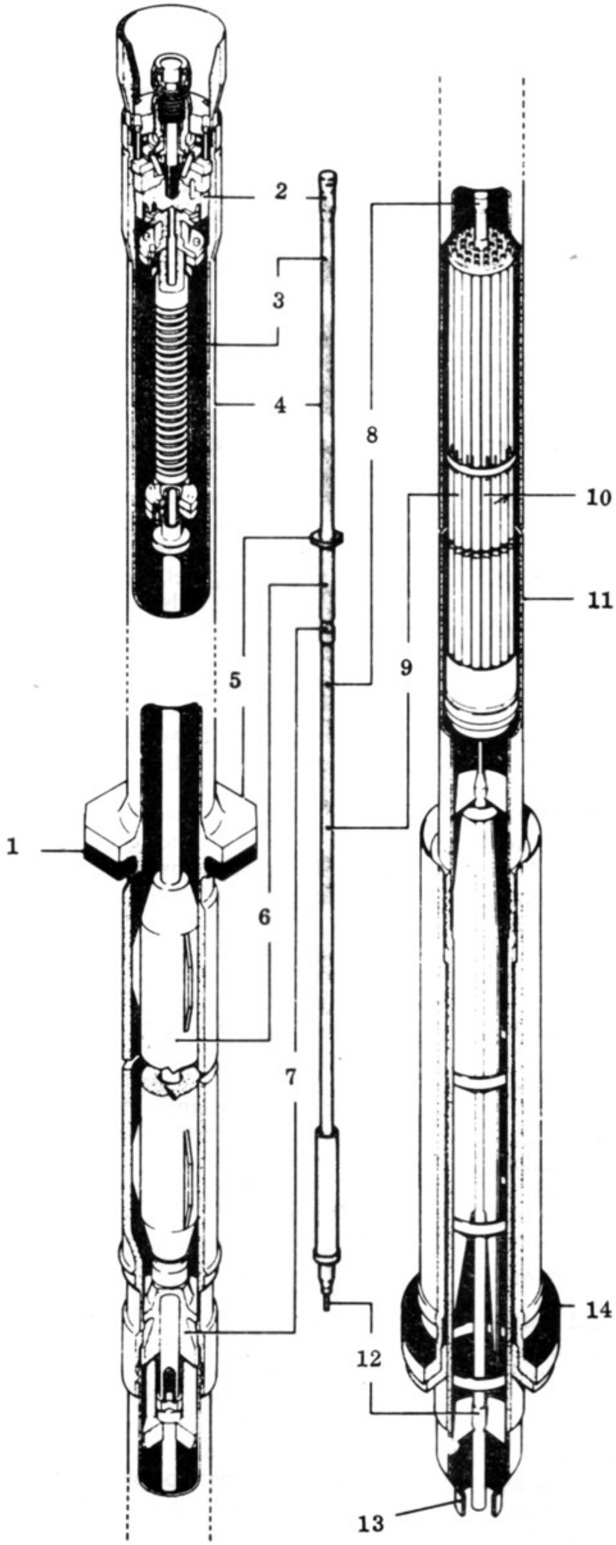

Fig. 1. *S.G.H.W.R. pressure tube arrangement.*

1 *Top shield seal*
2 *Seal plug and housing*
3 *Plug stringer tie rod*
4 *Standpipe*
5 *Channel support flange*
6 *Plug stringer*
7 *Fuel stringer—plug stringer coupling spigot*
8 *Fuel stringer—plug stringer coupling socket*
9 *Fuel assembly*
10 *Fuel pins (36)*
11 *Zircaloy pressure tube*
12 *Emergency cooling water pipe*
13 *Channel inlet tailpipe*
14 *Bottom shield seal*

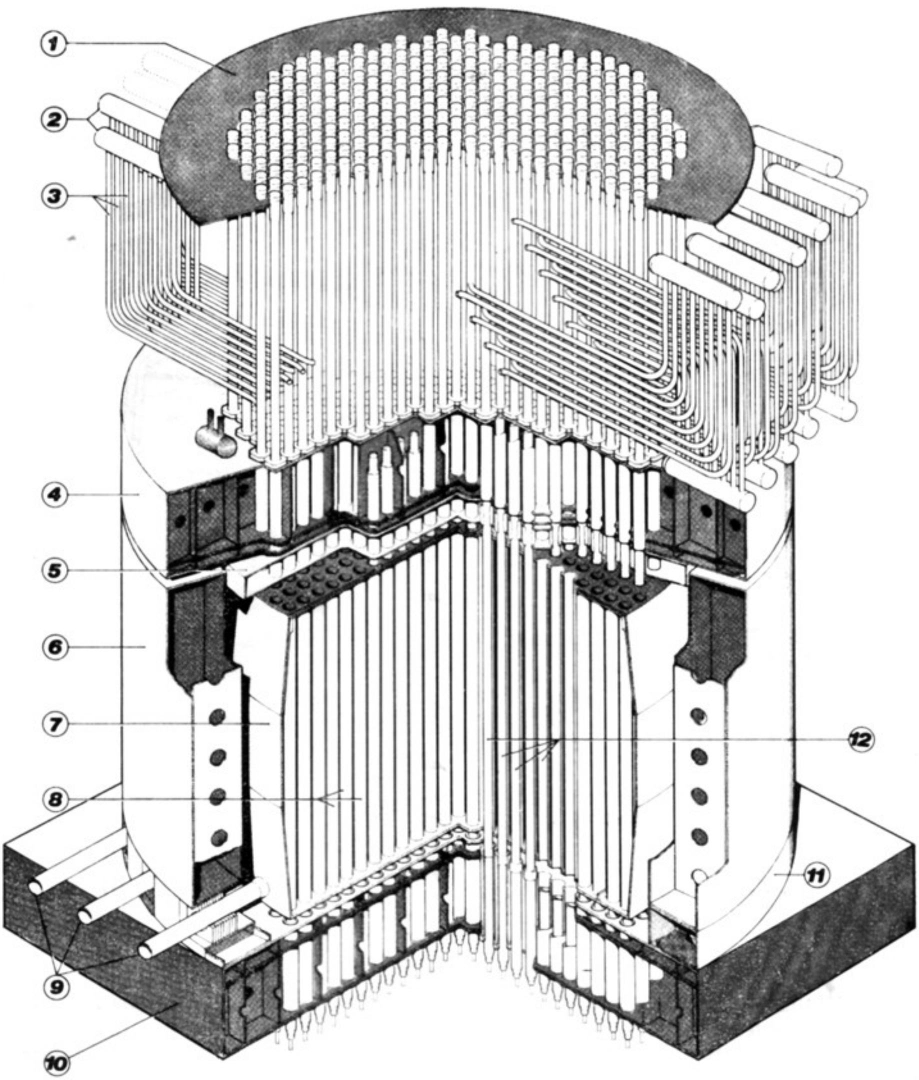

Fig. 2. *Reactor core arrangement.* 1 *Channel pitch plate* 2 *Channel outlet headers* 3 *Channel outlet risers* 4 *Upper neutron shield* 5 *Auxiliary neutron shield* 6 *Radial shield* 7 *Calandria* 8 *Calandria tubes* 9 *Service connections to calandria* 10 *Lower neutron shield* 11 *Auxiliary radial shield* 12 *Pressure tubes.*

nected to the fuel element. Refuelling is off load with direct access to each pressure tube. The arrangement of fuel and pressure tube is shown in Figure 1.

The Zircaloy pressure tube is connected to steel pipework by rolled joints. The tube assembly is supported from the top of the upper neutron shield and guided by a seal at the lower neutron shield. The assemblies pass through an aluminium calandria tank containing heavy water with a CO_2 filled gap between pressure and calandria tubes. The gap reduces heat transfer and permits the heavy water temperature to be held below about 80°C.

The calandria pressure tube assemblies and the neutron shields form an integrated structure, Figure 2. The neutron shields are fabricated steel structures containing light water and also steel shot in the cylindrical shields. They completely surround the core to prevent neutron activation of all components outside the core and to allow access to the primary containment for inspection and maintenance with the reactor shut down.

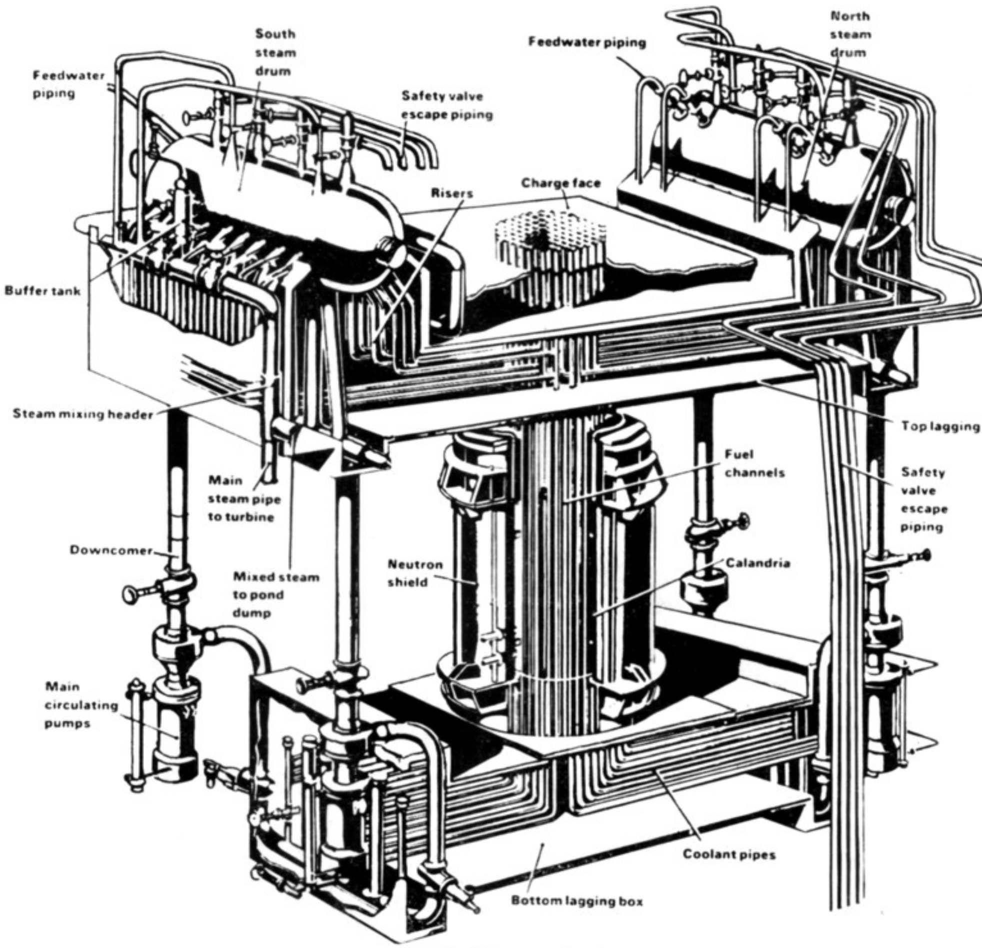

Fig. 3. *Primary circuit.*

The arrangement of the primary coolant circuit containing circulating pumps and steam drums is shown in Figure 3. Water chemistry is controlled to be neutral and purity is maintained by a full flow ion exchange system in the return condensate line from the turbine. Also a proportion of the primary coolant flow, equivalent to 4 per cent of the steam flow, is passed through ion exchange beds. In the Winfrith reactor, pipework is stainless steel and the steam drum has a stainless steel lining whereas commercial designs incorporate a mild steel primary coolant circuit.

Ease of access for refuelling gives flexibility in choice of refuelling intervals. For the standard fuel management scheme refuelling would be $\frac{1}{8}$th of the core every six months with the reactor shut down over a weekend. To refuel, the reactor is shut down and depressurised and the refuelling machine is connected to a channel where it unlatches the seal plug and then replaces irradiated fuel with new fuel. The Winfrith reactor refuelling machine operates on a dry charge face whereas in the commercial designs illustrated the charge face is located in the bottom of a refuelling and fuel storage pond. Figures 4 and 5 show the general arrangement of the plant including facilities for removing irradiated fuel. Irradiated fuel would normally be stored in the pond for 6 months and removed in a transport flask via the containment building air-lock during the next plant outage for refuelling.

The main parameters for 2 typical commercial designs of 509 MW(e) and 625 MW(e) are presented in Table I.

Operational characteristics

Power output is controlled by raising and

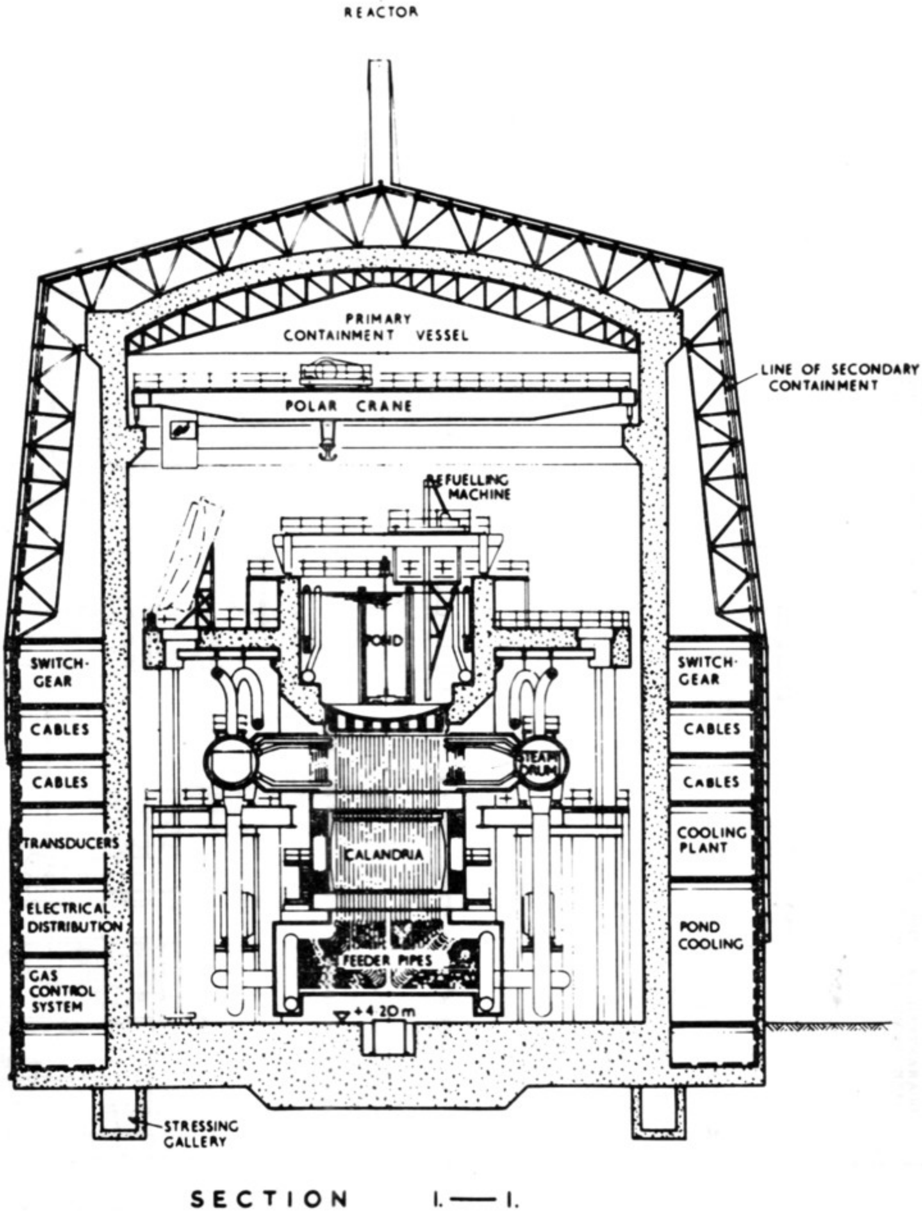

Fig. 4. *Section through reactor building.*

lowering moderator height in the calandria tank. Commercial designs have interlattice tubes containing krypton gas to adjust macroscopic radial power distribution and to correct xenon instability in high output reactors. Long term changes in reactivity that occur during fuel burn up are compensated for by adjusting boric acid content in the heavy water. Boric acid is removed by flowing moderator through anion exchange beds and regenerating through the BRANDY process (boron recovery and electrodialysis).

The automatic control system provides load following characteristics similar to those of conventional stations. Changes in electricity demand operate the turbine control valve to change steam flow rate and the resultant change in pressure in the steam drums produces a signal that is used

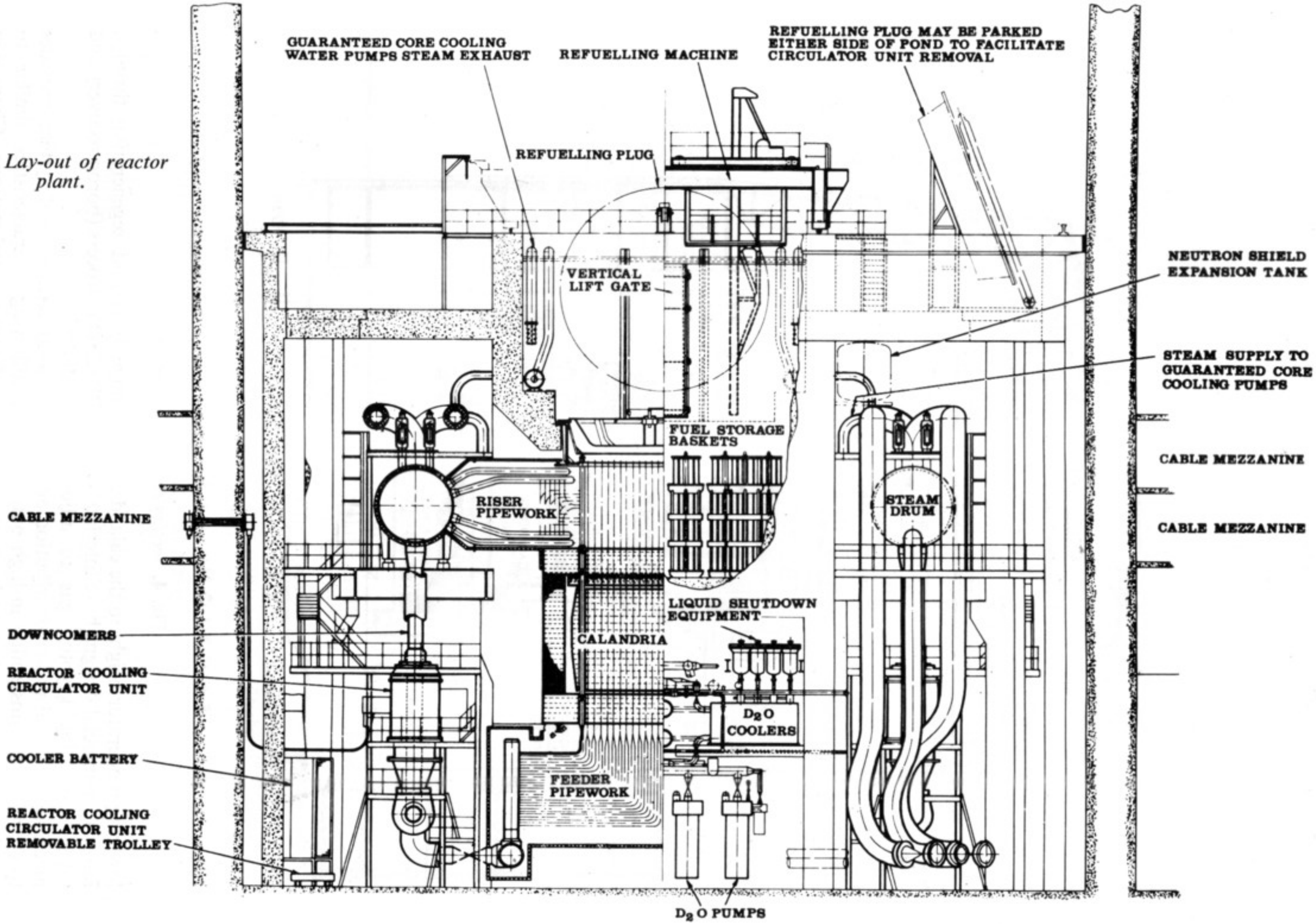

Fig. 5. *Lay-out of reactor plant.*

Table I

Commercial S.G.H.W.R. typical design parameters

Electrical output nett	MW(e)	509	625
Electrical output gross	MW(e)	540	660
Reactor heat output	MWth	1580	1900
Average fuel rating	MW/teU	20.4	19.77
Coolant mass flow through core	kg/s	6647	8177
Steam flow to turbine	kg/s	806	970
Steam pressure at steam drums	Bar abs	55	55
Average coolant quality at inlet to steam drum	wt%	12.1	11.9
Final feed temperature	°C	194	194
Sub-cooling at core inlet	J/g	60	60
Number of pumps per reactor (per circuit)		4(2)	6(3)
Power of pump motors	kW	1410	1172
Number of channels		416	516
Lattice pitch	mm	260	260
Pressure tube internal diameter	mm	130	130
Calandria tube internal diameter	mm	180	180
Overall diameter of calandria	mm	6820	7505
Overall height of calandria	mm	4160	4160
Number of shutdown tubes		48	64
Number of gas control rods		56	64
Weight of uranium in core	te	80.7	100.1
D_2O inventory	te	115.5	141.5
Maximum channel power	MW	5.3	5.3
UO_2 centre temperature	°C	1910	1910
Channel outlet coolant quality	wt%	22.6	22.6
Fuel can diameter	mm	16	16
Fuel can length	mm	3880	3880
Number of pins/cluster		36	36
Average initial enrichment	%U-235	2.096	2.139
Average enrichment replacement fuel	%U-235	2.096	2.105
Average discharge irradiation of initial fuel	MWD/teU	11816	12729
Average discharge irradiation of replacement fuel	MWD/teU	20679	20730

to change reactor power and so restore pressure. Stored energy in the steam drums enables accommodation of a step change in power demand up to 10 per cent and larger changes in demand can be met at a rate of 10 per cent minute between 40 and 100 per cent full power. Inherent plant stability permits manual control during maintenance of the automatic control equipment.

Reactor steam may be dumped to the main turbine condenser via a bypass capable of accepting 100 per cent flow for a short period and 40 per cent flow for an extended period. In the event of sudden loss of electrical load, the dump valves are opened, the reactor power is automatically reduced and a reactor trip avoided. The governor system and condenser dump system permit the turbine to provide the station auxiliary load upon loss of the grid network load, the excess steam being bypassed to the condenser and the reactor automatically reducing power to 40 per cent load.

Winfrith reactor experience has shown the following timescales for start up from the hot pressurised state and from the cold unpressurised condition.

Operation	*Hot Start Hrs*	*Cold Start Hrs*
Approach to critical	—	0.5
Raising pressure and temperature	—	3.0
Turbine warm through and run-up	0.3	1.5
Power raising	0.7	2.0
Start-up checks	—	2.0
	1.0	9.0

Ability to operate under power cycling conditions and to respond to rapid load changes has been demonstrated on the Winfrith plant.

A programme of daily power cycling in

which power has been cycled between 70 and 100 per cent full power has been in progress during the past year with 220 cycles at the time of writing. Dynamic tests have confirmed the ability of the automatic control system to meet required performance and a series of kinetic measurements have been made to establish the accuracy of theoretical models.

Safety

Inherent safety features in the basic reactor concept are

(1) the use of pressure tubes instead of a pressure vessel
(2) zero void coefficient

The good safety characteristics of pressure tube water reactors under severe fault conditions have been described for a number of designs, for example the Russian steam generating graphite reactors[1].

In principle pipework can be arranged to make all the reactor coolant inventory available to feed a breach in the primary coolant system. Component and pipe sizes can be chosen to give required slow rates of depressurisation and adequate cooling of fuel by reactor coolant during the critical initial phases of circuit depressurisation transients. In these circumstances emergency cooling water would not be required to limit initial fuel temperature excursions but only to secure long term post accident cooling.

In typical S.G.H.W.R. designs these properties of pressure tube reactors are utilised to the extent that severe fuel temperature transients result only if a steam drum is assumed to fail or if flow 'stagnation' or 'steam blocking' conditions are postulated to occur in the fuel channels during a loss of coolant accident. It can be shown that such events are highly improbable, but even so they can be accommodated without having to place reliance upon complex flow stability and heat transfer calculations. This is achieved by the spray cooling system, which cools the fuel by spraying it along its entire length and which has sufficient heat transfer capability to deal with loss of all primary coolant flow within the first seconds of a loss of coolant accident.

With regard to the Zircaloy pressure tube itself, it is a simple pressure container with well understood stress distributions. Comprehensive development work has shown that the length of crack in a pressure tube required to cause rapid crack propagation is about 40 times the tube thickness—8 to 10 cm in a 5 mm thick tube. Outleakage of coolant would be detected before a crack could grow to its critical length and so prevent gross failure of a pressure tube.

The zero void coefficient of reactivity enables either rapid increases or decreases in the circuit pressure to be accepted without any consequent reactivity excursions being induced in the core. Thus the reactor can accept loss of the turbine without the necessity to trip the reactor.

The main engineered safeguards incorporated in reactor design are

(1) ECW provision as spray cooling
(2) Use of borated liquids for emergency shutdown
(3) Moderator dump for emergency shutdown
(4) Double containment

The spray cooling system has been described.

The liquid shutdown system is designed to deal with rapid loss of coolant accidents. It has a reactivity capacity of 4 per cent and it shuts down the reactor in 2 seconds. Its reliability has been demonstrated by about 2000 test firings on the Winfrith reactor without a single failure. The moderator dump system which shuts down the reactor in 50 seconds is itself capable of protecting the reactor against the more frequent faults such as loss of power supplies to primary coolant circulators. These faults require high integrity shutdown capability that is assured by the diversity of shutdown systems.

The Winfrith reactor has a reinforced concrete containment building that would be vented during the early stages of a major depressurisation accident followed by sealing of the building and diversion of further release from the primary coolant circuit through a water lute and a chemical clean up plant. Commercial designs employ full containment typical of light water reactor practice with a prestressed concrete primary containment building designed to accommodate the full pressure developed by release of all light water coolant. A light secondary containment building is provided to divert any outleakage from the primary containment to a chemical clean up plant.

Reactor design has been systematically

analysed to determine the probability of fault sequences and protective systems have been provided to give the required integrity of protection determined by the probability criteria proposed by Farmer[2] and by "maximum credible accident" criteria.

All parts of the reactor coolant circuit are well within the range of conventional manufacturing experience, and the highest standards of quality control can be specified and achieved. All pressure parts are capable of inspection and replacement during service, including the pressure tubes themselves as is evidenced by the replacement of six tubes in the Winfrith reactor after more than two years' service.

Operating experience

The Winfrith S.G.H.W.R. was constructed and commissioned on the planned timescale of four and a half years to attain full power operation in January 1968. Operating experience since then has demonstrated reliability and flexibility of the reactor concept and the reactor has been used to provide a wide range of technical data to confirm commercial design. Operational history of the reactor has been reported previously[3] and is summarised in Figure 6. Comments in this paper are restricted to highlighting the main points of interest.

Plant availability was seriously affected during the first year's operation by mechanical faults in the ion exchange plant causing flow bypass resulting in high copper and iron content in the feedwater. This lead to deposition of copper and iron oxides around the primary circuit and in particular as "crud" on fuel element surfaces to cause fuel failures that necessitated plant outage for refuelling. Since remedying the defects in the ion exchange plant, water chemistry has been excellent and planned refuelling has been effected twice per year as proposed for commercial designs.

Early difficulties with water chemistry control provided useful experience in two technical areas. Firstly examination of irradiated fuel provided a good understanding of processes that cause crud formation and its effect on fuel performance, and secondly activity build up in the primary circuit necessitated chemical cleaning of the circuit. Both of the primary circuits have been successfully cleaned together with the fuel in the core by a proprietary reagent of ammonium citrate/oxalate. Activity levels in different parts of the circuit were reduced by factors 5 to 20.

Ease of access to the primary circuit and ability to make repairs has been demonstrated by

(i) repairs to minor leaks primarily associated with packing on valve glands
(ii) replacement of a pipe bend that developed a leak due to fretting wear caused by a file left in during construction
(iii) removal and replacement of 6 experimental pressure tubes

The four primary coolant circulators have provided trouble free operation. One was replaced in 1971 for detailed examination and found to be in excellent condition. Bearing failures on the heavy water circulators necessitated power reduction to 80 per cent prior to making repairs at a planned reactor shutdown.

Activity build up in the turbine has not interfered with access for maintenance or required shielding to protect operating personnel. Inspection of the rotor in 1970 identified some cracks later shown to be due to use of material of more than specified hardness and in April 1972 the rotor had to be returned to the manufacturers for repairs following failure of one of its blades.

Heavy water leakage is small, currently 0.3 per cent of the total inventory and extrapolation to a commercial plant shows negligible contribution to energy costs.

The average load factor for the plant is 50 per cent which includes outages associated with experimental facilities and the overall availability excluding experimental requirements is about 75 per cent. Availability during the 1971/2 Winter, when emphasis was placed on power production, was 97 per cent.

Fuel and materials performance

Early research and development and design work established reactor physics, heat transfer and expected fuel performance data required for overall plant design and identified novel engineering features requiring development. The main content of the programme that has been in progress since the early 1960s has concentrated on intensive study of the following features

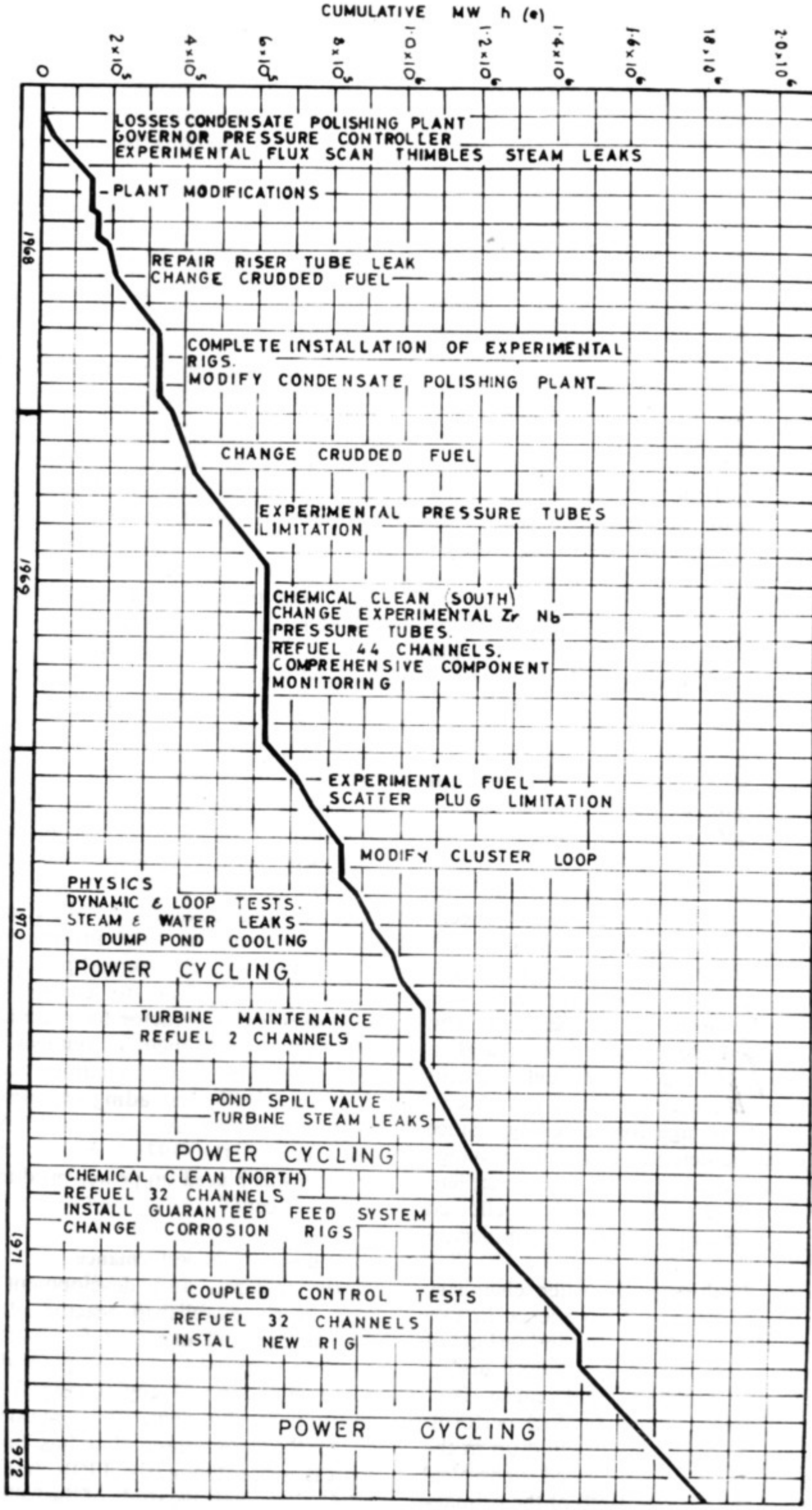

Fig. 6. *Winfrith S.G.H.W.R. generation.*

(1) detailed establishment of design and performance of the pressure tube plus fuel unit; pressure tube properties; hydraulic, heat transfer characteristics, fuel performance
(2) performance optimisation by fuel management and statistical analysis of form factors and dry out margins
(3) water chemistry and corrosion of primary coolant circuit materials

A substantial development programme with materials specimens in Materials Test Reactors, the Dounreay Fast Reactor and in the Winfrith reactor has evaluated the properties of Zircaloy pressure tubes. In particular the effects of irradiation and exposure to reactor coolant on tube creep, embrittlement and corrosion have been established with confidence. Tube strain due to creep by irradiation and pressure temperature effects is expected to be less than 1.5 per cent in a 30 year reactor life which is very much less than strain to failure. Experiments to date have established strains up to 8.5 per cent without failure. Embrittlement effects cause critical crack lengths of 10 cm and corrosion would reduce tube thickness by about 0.1 mm during reactor life. Experimental results have been previously reported[4].

Experiments in heat transfer facilities including full size simulation of the 36 pin fuel element with up to 9MW electrical heating have determined detailed heat transfer properties and established methods for calculating conditions that could cause dryout in coolant subchannels within the fuel element. The experimental programme has included running an instrumented fuel element into dryout in an experimental loop in the Winfrith reactor. In this experiment temperatures attained in dryout were modest, less than 600°C, and results confirmed that short excursions into dryout during a loss of flow transient would be unlikely to cause significant fuel damage. The programme led to choice of differentially enriched fuel elements (outer ring of fuel pins of lower enrichment) to achieve similar fuel rating in all pins and to move onset of dryout away from outer pins so making onset of dryout insensitive to eccentricity of a fuel element within its pressure tube. The effectiveness of the spray cooling system has been determined by experiments with full size simulation of fuel elements using indirectly heated pins. Experiments have covered a range of temperatures and pressures to evaluate conditions during the worst conceivable fault conditions.

Except for failure of 32 fuel pins due to crud formation during early operation with poor water chemistry, fuel irradiation experience has been good. There have been 16 additional fuel failures consisting of nine in experimental fuel elements and seven in standard elements that led to some minor changes in fuel manufacturing specifications. There have only been three fuel pin failures since June 1970, all in special experiments. Average fuel burn-up in a fuel element is a maximum of about 10,000 MWd/te and detailed fuel examination gives confidence that the design burn up of 20,000 MWd/te for commercial reactors is conservative. Irradiation experiments with up to 80 kW/m linear fuel rating indicate that the basic fuel pin design is suitable for substantial uprating from the current design choice of 48 kW/m nominal maximum. For safety assessments it is assumed that statistical scatter on all data could cause a local peak of 60 kW/m.

Calculations predict capability of fuel to accept daily power changes for full fuel life and ability to do so has been partially demonstrated by the 220 daily power cycles to date. Also, Winfrith reactor experience and calculation of cladding stress and strain during single event power steps shows that there is an adequate margin on known cladding ductility and stress corrosion characteristics to accept the small local power steps (up to 6 per cent) that would occur due to fuel management and reactor control in a commercial reactor.

Experimental work is in progress to evaluate the effects of high temperature excursions on fuel elements. The relationships between can temperature, fission gas pressure and onset of "ballooning" or rapid can strain have been established for loss of coolant transients. Current reactor design meets the following stringent requirements for the so called "stagnation" accident—breach of the inlet pipework of a size that draws coolant from both ends of the reactor core.

(i) instantaneous loss of primary coolant flow through the core and loss of coolant from the core in less than 1 second.
(ii) heat transfer capability from the spray cooling system to deal with the temperature transient on the fuel cladding by preventing "ballooning" of the cladding.

The development programme includes further evaluation of this fault to identify some coolant capability from the primary circuit to ease the current restrictions on fuel ratings and permissible fission gas pressure inside fuel pins.

Water chemistry

The use of carbon steel instead of austenitic stainless steel for water systems has received considerable attention in recent years. Canada has chosen carbon steel for the CANDU and B.L.W. reactors, recent B.W.R.s have no stainless steel clad on the upper regions of the pressure vessel and there has been considerable experience with fossil fuelled plant in Germany with neutral water in carbon steel circuits including oxygen dosing in the feed train.

Incentives to use a carbon steel primary circuit in the S.G.H.W.R. are to reduce costs and to avoid stress corrosion cracking in stainless steel pipework that could occur by ingress of chloride from sea water cooling. The Winfrith reactor was constructed with stainless steel pipework because there was insufficient data to justify choice of carbon steel at the time. However, facilities to obtain experience with carbon steel under operating conditions were provided by installing an independent carbon steel coolant circuit associated with one reactor channel and by use of a carbon steel feed heater operating in the temperature range 130 to 160°C. These carbon steel units have operated completely satisfactorily.

Comprehensive corrosion data on carbon steel has also been obtained from a five year development programme that included use of a nuclear fuelled loop in the Dounreay Materials Test Reactor. Tests included a range of flow velocities, temperatures and oxygen concentrations and also a study of the effects of losing control of water chemistry. These tests showed that for design conditions with neutral water, the corrosion rate is less than 3 microns/year and no problems arise from pitting attack, crevice corrosion, galvanic corrosion or intergranular attack. The protective films formed can withstand conductivity excursions to several hundred micro siemens/metre for several days. Sulphuric and nitric acids, their calcium and magnesium salts, acetic acid and carbon dioxide at ppm levels failed to produce any adverse effects on the protective film.

Except for the first year's operation with inadequate control of water chemistry, the Winfrith S.G.H.W.R. has operated with excellent water chemistry. A light deposit of less than 30 microns thickness builds up on fuel surfaces during the first few weeks of operation with new fuel and then stabilises at about that thickness.

Conclusions

Operation of the 100 MW(e) Winfrith reactor has shown the S.G.H.W.R. to be a reliable reactor system. The fuel, dynamic and materials technology of the system have been demonstrated on the identical components used in current designs of large units. Experience has demonstrated capability for routine inspection and maintenance of even the most highly active regions of the reactor so giving good assurance of the security of the plant investment and its integrity to the required standards. Ability to replace pressure tubes and to chemically clean the primary coolant circuit have been demonstrated.

Distinguishing features of the S.G.H.W.R. are the use of pressure tubes instead of a large pressure vessel, provision of emergency cooling water as a spray operating directly on to fuel pins and the absence of moving mechanical components in the reactor core. These features together with favourable reactor physics properties and the provision of a containment building designed to accept failure of the primary coolant circuit make the S.G.H.W.R. a very safe reactor.

The fuel element is generally similar to other boiling water reactor fuel and shares the wide base of technology now established. Winfrith irradiation experience of fuel in all respects typical of that specified for commercial units has given excellent performance to date. The operational demands upon the fuel compare favourably with those of other water reactors and the burn up required is modest. The use of pressure tubes allows rapid access to individual fuel channels and simple shutdown refuelling with minimum outage results. In consequence, considerable flexibility exists in the fuel management programme at marginal cost.

The reactor can operate either on base load or two shift operation and the control characteristics enable it to operate as a load following power station. Proving of the fuel for load following duty is well advanced.

Commercial designs incorporate the fuel element, pressure tube and channel units that have been proved during successful operation of the Winfrith reactor since 1967. The required output is obtained by choosing the required number of these identical modules and the modular concept permits fabrication at works of all reactor components.

References

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2. *Siting Criteria—new approach* by F. R. Farmer, IAEA Symposium, Vienna, April 1967. SM-89/34.

3. *Operational Characteristics of the S.G.H.W.R.* by Smith, Dickson and Pickman, Geneva Conference 1971.

4. *Irradiation effects in zirconium alloy pressure tubes* by R. W. Nichols *et al*, Geneva Conference 1971.

Courses at Harwell

The following courses are due to be held by the Education Centre, A.E.R.E., Harwell, Didcot, Berks. Further information and enrolment forms can be obtained on application. The fees shown are exclusive of accommodation.

Electron Microscopy and Micro Probe Analysis (at Aston University)
2nd to 6th April, 1973.
For scientists in research and development laboratories, with or without experience of the techniques. Run jointly with the Department of Physics and Metallurgy of Aston University. Fee: £60.

Advanced Reactor Technology
30th April to 25th May, 1973
Advanced power reactor technology for experienced physicists and engineers. The main emphasis is on reactor systems already developed or now being developed for industrial exploitation. Fee: £290.

Process Instrumentation
2nd to 13th April, 1973
Intended for engineers working on the instrumentation of process plant, nuclear reactors and scientific apparatus or who have a direct interest in the subject. Fee: £120.

Advanced Radiological Protection
5th to 30th March, 1973
For the experienced health physicist to extend his understanding of the underlying philosophy and scientific bases of his profession. Attention is also given to the managerial and professional responsibilities of the health physicist. Fee: £240.

Introduction to Reinforced Plastics
19th to 21st March, 1973
For engineers who require an understanding of the properties and potentialities of reinforced plastics.
The emphasis is on the use of carbon fibres in highly stressed parts. Fee: £30.

Practical Vacuum Techniques
I Basic Vacuum Systems
13th to 16th March, 1973
For junior scientific staff and technicians engaged in experimental work who require practical instruction in the assembly and operation of a vacuum system. Fee: £24.
II Performance of Vacuum Equipment
26th to 29th March, 1973
For scientists and technicians who need a practical understanding of the characteristics of vacuum components and systems. The course follows on from Basic Vacuum Systems, and illustrates the practical applications of some of the topics of Vacuum Technology II. Fee: £24.

Camac Instrumentation
20th to 22nd March, 1973
For engineers, scientists and others who have a direct interest in the subject of real-time operations with computers and other processing devices for measurement and control. Fee: £45.

Vacuum Technology I
26th February to 2nd March, 1973
For designers and users of vacuum equipment who have an elementary knowledge of vacuum producing and measuring equipment, system assembly, choice of materials, leak detection and measurement and principles of the mass spectrometer. Fee: £60.

Transport of Radioactive Materials
3rd and 4th April, 1973
A two-day symposium for those who have the problem of transporting radioactive or fissile materials by sea, air or road, or have responsibilities to the public for safe transit of these loads. Fee: £24.

Advances in automatic welding control

By D. White, A. Woodacre and A. F. Taylor, Reactor Fuel Element Laboratories, Reactor Group U.K.A.E.A., Springfields. *This Report was presented at the 'International Conference on Welding Research related to power plant' held at the Marchwood Engineering Laboratories, Central Electricity Generating Board, 17th-21st September, 1972. This paper has also been issued as TRG Report 2336(S).*

Summary

The development at the Reactor Fuel Element Laboratories, U.K.A.E.A. Springfields, of a computer-based welding process control system, was aimed initially at the TIG welding of the end seals of nuclear fuel elements. The system provides for mixed multi-station operation with on-line real-time capability and can be used either as a research tool or for production requirements at competitive costs.

The operation of the control system, the form of power source and servo motor control units are described. Typically, continuous or pulse-arc welding sequences can be digitally programmed in 0.1 sec increments, with current in 0.5 A increments up to a maximum of 256 A; up to three servo motors can be operated with speeds selected in 0.1 per cent increments of their maximum. Up to six welding parameters can be monitored digitally at speeds from once every 10 ms. Some applications are described and it is shown that the equipment has wider uses outside the nuclear fuel element field. High quality industrial welding requirements can also be met and the system is not limited to the TIG process.

Introduction

During investigations of joining processes at the Reactor Fuel Element Laboratories, U.K.A.E.A. Springfields, considerable effort has been devoted to developing automatic control techniques for fusion welding in establishing a high level of quality control for TIG welding the end seals of nuclear fuel elements. Some of the early work has been reported [1, 2]. The latest control system developed is computer-based and once the basic hardware is provided it offers a whole range of different methods of operation simply by modifying the software.

It has been argued that the problems of controlling arc welding processes make it difficult to achieve satisfactory results even at exorbitant costs. However, during this work many opportunities arose for assessing other engineering applications and it has been demonstrated that the equipment as now developed is equally applicable wherever high quality welding is required.

Background

In the manufacture of nuclear fuel elements, welding is one of the most critical operations. In particular, welds are required at both ends of the fuel pin to hermetically seal the fuel inside the container. The penalty of failure of these seals in the reactor is quite high and it is imperitive that all potentially defective seals are eliminated. As it is not possible adequately, to 100 per cent confidence limits, to test non-destructively the end seals, attention has been paid to establishing a high level of quality control. A particular aspect of quality control was the decision to adopt process control systems and avoid using skilled welders. Fuel elements have been manufactured in this country for over 20 years but it is only within the last 10 years that more sophisticated weld control systems have been developed. The initial approach was to use cam-operated micro-switches in conjunction with commercial power sources. However, the limitations imposed by the earlier units led to the development of step controlled power sources with plugboard programming and, later, punched tape control. Equally, monitoring of the process had progressed from the simple use of meters through chart recorders and oscilloscopes to digital output via punched tape or teletype. The Mk IIIA welding controller, Phase II, described here became possible as a result of the ready availability of small competitively priced computers which could operate satisfactorily in an industrial environment. The introduction of a memory store and the manipulative capability (in software terms) of these devices has permitted real advances in process control techniques, with significant economic advantages if the system is fully exploited.

Briefly, some of the advantages are:

(i) greatly simplified procedures for the preparation. execution and optimisation in engineering terms of welding programs,

(ii) automatic on-line monitoring and ranging of selected parameters with decimal read out. The monitored data are printed out in decimal form at the end of each weld in order to check the program and facilitate optimisation procedures. This information provides guide lines whereby it is possible to ascertain the degree of correlation between the "on-line" data and the weld quality,

(iii) mixed multi-station operation with remote process stations uniquely interfaced to the master controller,

(iv) random access with mixed multistation capability, at present applicable to TIG, TIG wire feed and plasma welding processes,

(v) pulsed arc welding without additional hardware,

(vi) three digital-to-analogue channels which automatically ensure X Y Z or equivalent capability.

The welding control system

The Mk IIIA welding controller incorporates a small digital computer (Digital Equipment Ltd. computers type 8/S or 8/L) which has been suitably interfaced to control and monitor the peripheral equipment. A general view of the welding equipment is given in Fig. 1. A block diagram of the system is given in Fig. 2. Equipment working in conjunction with the controller are a solid state switched d.c. power source for supplying the welding current, Fig. 3, d.c. servo motor generators which, via digital commands, provide the program speeds, and a changeover matrix for controlling the transfer requirements.

A welding program must specify the weld current and the speeds of rotation of the motors for specified times. Each time period is called a 'block' and a welding program comprises a number (up to a maximum of thirty) of these blocks. The function of the welding controller is to output each block, i.e. current and speed, for a time interval specified in each block of the welding program. The weld current demand is delivered to the power source in the form of a nine-bit word, and the power source translates this digital demand into the appropriate value of weld current, i.e., the power source acts as a digital-to-analogue converter. Currents in the range 0 to 256 A in increments of 0.5 A can be demanded. The required speed of rotation of

Fig. 1. *General view of welding equipment showing* 1. *Tube to tube-plate welding gun mounted on manipulator* 2. *X Y Z manipulator* 3. *Butt welder* 4. *General purpose manipulator* 5. *Computer-based control unit.*

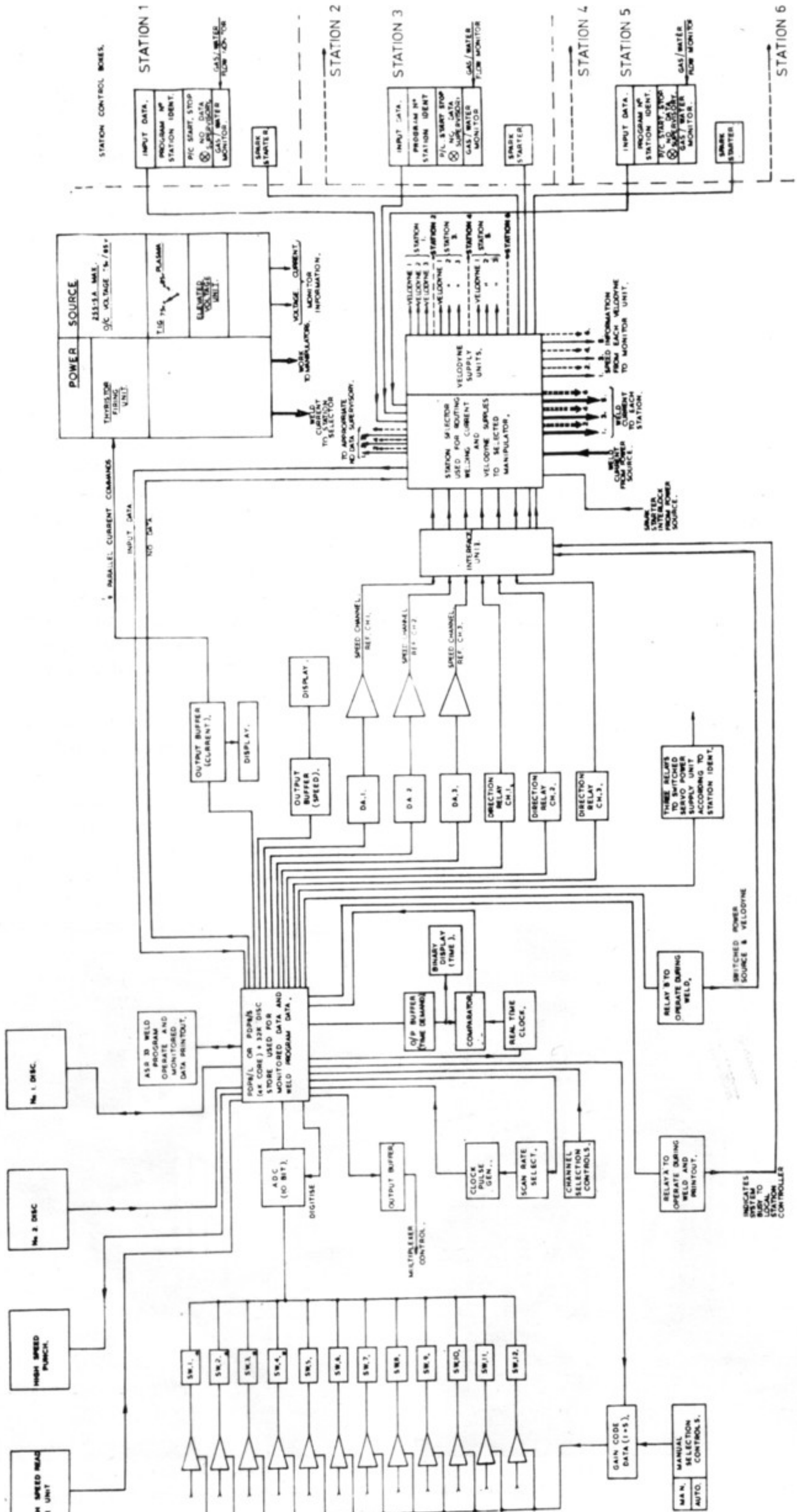


Fig. 2. *Block diagram of the Mk III multi-station welding process controller.*

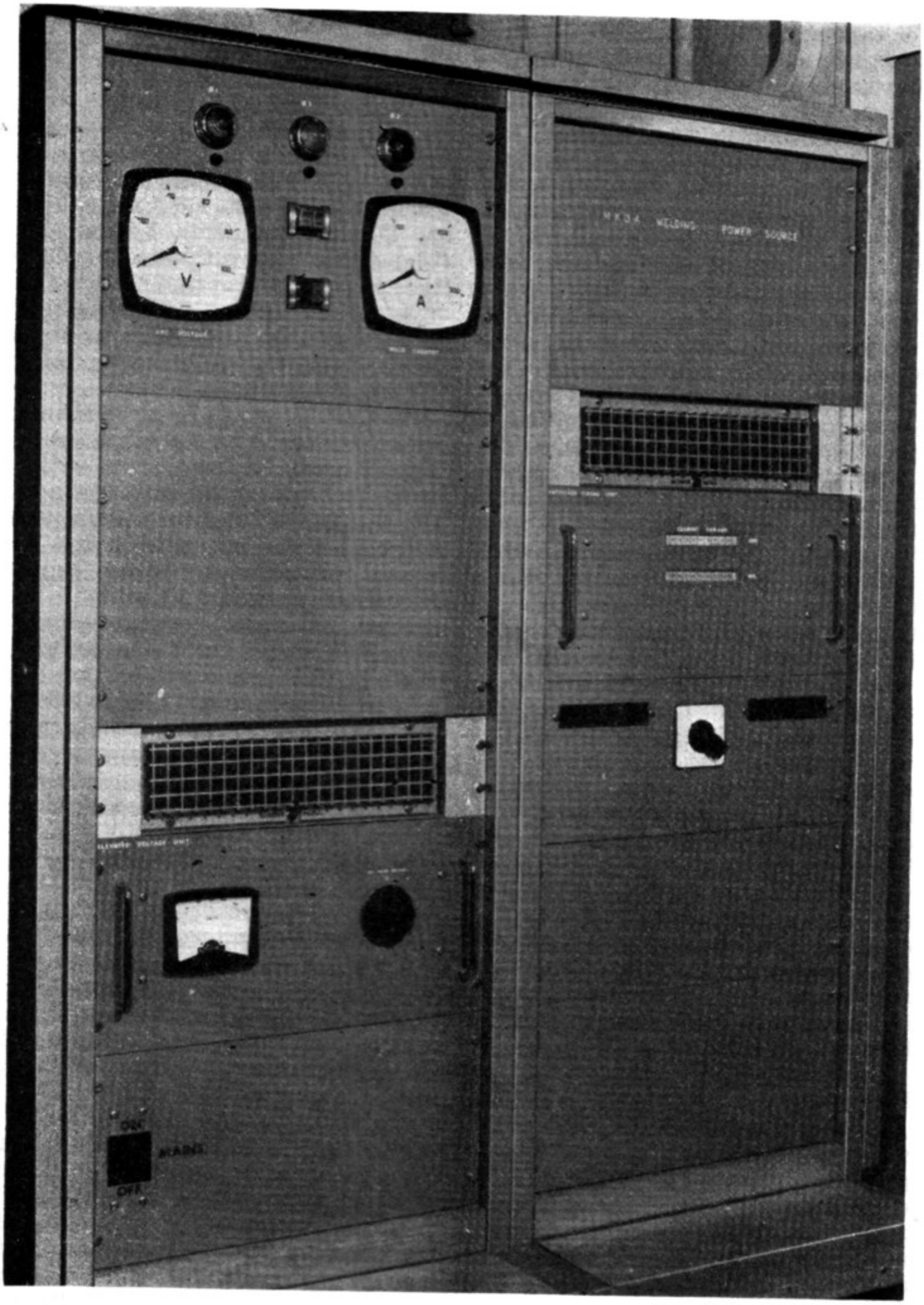


Fig. 3. *Digital power source.*

the 'work' is achieved by supplying a voltage reference signal derived from the output of a digital-to-analogue converter to the d.c. servo motor generators. Speeds are available in the range 0 to 5120 rpm in increments of 10 rpm.

During welding, the weld parameters, i.e., current, speed of rotation and arc voltage, are monitored by the system. Each parameter is scanned in turn at a frequency selected by the operator, and converted into a digital equivalent. The digital values are stored by the computer until the weld is completed. The recorded weld parameters for each block can then be printed on a teleprinter under the appropriate headings together with the time they were recorded.

The system is best explained by describing a typical welding operation. Assume that a suitable welding program has been loaded, and that a program replay has been requested to ensure that the loading operation is correct. Before welding is initiated the operator must select the required sampling rate and the weld parameters to be monitored. When welding is started, the current and speed demands, as defined in the first block of the welding program, are delivered to the current source and d.c. servo motor generators respectively. Simultaneously, current and speed demands are displayed in binary format on the illuminated front panel of the controller. Once an arc has been established, a start signal is delivered automatically to the controller. On receipt of the start signal the controller begins to time the current and speed demands for a period defined in the first block of the welding program. The time demand is displayed on the front panel. During this operation the monitor system will scan the weld parameters and store the digitised information. When the defined time period has expired the controller selects the current and speed demands in the next block of the program and outputs the new values for the required time periods. The time, current and speed demands are again displayed on the front panel of the computer, and the weld parameters are scanned at the predetermined rate. This procedure is repeated until the welding program has been completed.

Power source

A 9-digit, solid state switched power source is incorporated and, as a slave peripheral, is under direct digital command of the computer, no manual or other adjustments to the power source being necessary. Power supplies at various voltages are available and are derived from a 415 V, 4-wire system which feeds a star-delta transformer and a 3-phase bridge rectifier. Alternative open circuit voltages of 75 V and 85 V (to cater for plasma) are available and the positive output goes to the workpiece. The welding current demands are defined by 9 binary digits as follows:—

0.5, 1, 2, 4, 8, 16, 32, 64, 128 = 255.5 A.

The current is selected by solid state switches, namely thyristors, as described below.

Thyristor switching system

The twenty thyristors in the power source equipment are arranged in two banks of ten; there are ten 'ON' thyristors and ten 'OFF' thyristors. Each current channel, except for the 128 A channel, has one 'ON' and one 'OFF' thyristor. The 128 A channel has two 'ON' and two 'OFF' thyristors arranged in parallel. Each 'ON' thyristor is associated with a resistive element which is a non-inductive woven tape mat capable of dissipating up to 5 W/m^2.

The 'ON' thyristor, when fired, allows a current as defined by the associated resistive element to flow to the welding torch. To block off the current from the 'ON' thyristor in accordance with program requirements, a commutating circuit has been introduced in the lower current channels (i.e., channels 0.5 A to 16 A). The commutating circuit comprises an inductor, damping resistor and capacitor series parallel connected between the cathodes of the associated 'ON' and 'OFF' thyristors. The inductor and damping resistor limit the voltage recovery rate at the thyristor cathodes which in turn will prevent refiring due to excessive capacitive current.

A single current channel operating sequence is as follows. Assuming the 'ON' thyristor is conducting and the 'OFF' thyristor non-conducting, one side of the commutating circuit capacitor, P1, will be, for example, at an arc voltage of −15 V. Neglecting other factors, assume the other side of the capacitor, P2, has been charged up, through the appropriate resistor, to the supply voltage of −75 V. If the 'OFF' thyristor is now fired, P2 will rise instantaneously from −75 V to 0 V, whilst the other side of the capacitor, P1, will rise from −15 V to + 60 V. Thus the 'ON' thyristor is reverse biased and will cease to conduct provided this condition is held for a period in excess of the switch off time of the thyristor—typically 25 μs. By the same reasoning, when the 'ON' thyristor is fired, the 'OFF' thyristor will be cut off. Note that as reverse current is required during the 'switch off' period of the thyristors, a reverse biased diode is connected across the power pack.

The minimum value of capacitance C required to produce the commutating action is given by:—

$$C \geqslant \frac{1.4\, t_o\, I}{V} \text{mfd}$$

where t_o is the turn off time in microseconds

I is the load current in amps

V is the source voltage

The arc for welding is initiated by a spark starter and an elevated voltage unit, see below, which are interlocked out of circuit until a current demand has been made by the computer. The interlock is released by an arc sensing relay to permit arc initiation which is then followed by a signal to the computer to start the time sequence of the welding program.

The operational sequence of the arc sensing relay is as follows:—

(i) One side of a relay is connected to the negative line of the power source via a series diode. The other side is connected to a potential divider across the power source, the output of which is preset to half the pack voltage, normally—37.5 V.

(ii) When the power source is energised, the full open circuit voltage appears at the output thus activating the relay which then operates the interlocks.

(iii) When the welding arc has been established, the power source output reduces to the arc voltage of, say, 15 V. The potential divider ensures that the series diode is now reverse biased and hence the relay will de-energise and signal a command to the computer.

(iv) The two load resistors connected across the relay provide a current path for the 'ON' thyristors before the arc has been established.

Elevated voltage unit

This unit reinforces, with a high energy pulse, the ionisation produced by the spark starter. The unit is not normally required but is beneficial when a shroud gas such as helium is used. The pulse voltage is variable from zero to 300 V giving an output current of 70 A peak falling to 5 A in approximately 10 ms. The unit incorporates various suppression devices to nullify the effects of interference on external logic circuitry. The external diode protects the thyristors from high reverse voltages.

Spark starter

The spark starter facilitates ionisation of the gap between the torch electrode and the workpiece. The starter is a 'one-shot' device generating a single high voltage spike. Extensive filtering of the mains supply, and siting of the starter remotely at the manipulator, reduces to an acceptable minimum the electrical interference generated by the resulting spark. The amplitude and width of the spike is determined by the resistance of the external torch and work leads. It is typically 5 kV and in the microsecond range.

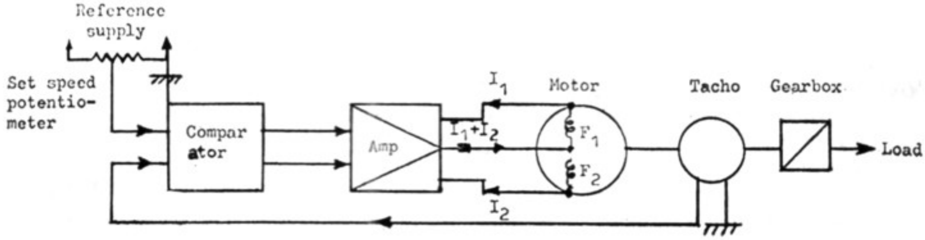
D.C. servo motor generator

The system is capable of controlling the speed and direction of rotation of three types of d.c. servo motor. They have two speed ranges—0 to 1,000 rpm and 0 to 5,000 rpm. For ease of monitoring, the 0—5,000 rpm range has been calibrated for a theoretical maximum speed of 10,000 rpm.

The technique of controlling speed is by differential variation of the field currents supplied by the servo amplifier. See diagram below.

The feed back signal for the servo system is derived from a tachogenerator attached to the output shaft of the servo motor.

In the Mk IIIA system the reference signal is supplied by an external digital-to-analogue converter interfaced to the controlling computer. The signal is in nine increments from 0 to +10 V representing speeds of 12.5, 25, 50, 100, 200, 400, 800, 1,600, 3,200 rpm. The supplies for the motor armature are derived from a conventional d.c. power pack energised via a relay on command from the computer thus ensuring the motor will not in-



advertently rotate if the input reference is removed.

A facility to energise the armatures manually is incorporated in the speed control system in order to check for amplifier unbalance—which can result in creep of the servo motor. This facility is in the form of an armature on/off push-button and is located on the changeover matrix main cabinet.

To accommodate the two speed ranges, switching of the summing resistors in the system comparator is carried out by the computer. The computer also simultaneously switches ranges on the external digital voltmeter used for visible speed indication.

Because of the varying electrical requirements of the three servo motors, current limiting resistors are introduced automatically into the armature supplies. Other equalising functions are carried out automatically by the computer.

Motor reversal is achieved by transposing the polarity of the supplies to the armature and the return feedback signal from the tachogenerator via appropriate relays. This function is under computer control. The tachogenerator feedback signal is routed through a suitable potential divider to the computer to enable on-line monitoring of motor speed to be carried out.

Changeover matrix for mixed multi-station operation

The welding controller incorporates a changeover matrix system which interfaces between the controller, the solid state switched power source and the remotely operated manipulators or welding process stations.

Briefly, before, during and after a welding program the matrix performs the following duties:—

(i) Switches the single power source output to each manipulator as required.
(ii) Supplies the power requirements for the three servo motors.
(iii) Numerically identifies to the controller the manipulator about to use the system and indicates the program number required.
(iv) Provides remote control facilities thus ensuring simple foolproof operation at each manipulator.
(v) Accepts signals from the controller logic determining the type of servo-motor required (x, y or z).
(vi) Incorporates a programming procedure for the automatic selection of the speed, speed range and direction of rotation of each servo-motor.
(vii) Ensures, upon completion of the welding process, that the power supplies are disconnected from the manipulator as soon as possible so that safe handling and inspection of the specimen are possible.
(viii) Automatically resets the system after print-out of the monitored data.
(ix) Provides visual indication when the remote control buttons have been operated.

In addition to performing the above duties, the matrix embodies the following safeguards:—

(i) Avoids the possibility of two manipulators simultaneously calling up the system.
(ii) Allows only the relevant spark starter to operate when arc initiation occurs.
(iii) Contains interlocks to prevent a manipulator operating until the essential services such as inert gas, water, etc., are available.
(iv) Indicates to the operator if non-existent welding programs are being requested.
(v) Provides manual shut down facilities should a fault condition arise.
(vi) Provides indication at the manipulators on stand-by to show when the system is in use.
(vii) Ensures that the system is operational or 'live' for the shortest possible time.

Software

The computer configuration and software comprise briefly:

Computer PDP-8/L

Word length	12 bits
Memory	4096
Cycle time	1.6 μs
Add time	3.2 μs
In-out transfer rate	7 500 000 bits/sec

Disc file

Storage capacity	32768 words
Data transfer rate	39 μs
Average access time	20 ms

Programs

Input
Replay
Shape
Control

From the latter description of the operation of the equipment it will be seen that

Table I. *Typical weld program.*

```
TYPE PRGMF NO=38
STORAGE SPACE AVAILABLE


PRGMF NO=38


Y/N/* IS USED TO ANSWER YES/NO/NOT USED


CURRENT RANGE Ø-1ØØA? Y
CURRENT RANGE Ø-1ØØØA? N


              CHANNEL 1

SPEED RANGE Ø-1ØØØ RPM? *


              CHANNEL 2

SPEED RANGE Ø-1ØØØ RPM? Y
SPEED RANGE Ø-1ØØØØ RPM? N

TACHO OUTPUT 5V/1ØØØ RPM? N
TACHO OUTPUT 21V/1ØØØ RPM? Y


              CHANNEL 3

SPEED RANGE Ø-1ØØØ RPM? N
SPEED RANGE Ø-1ØØØØ RPM? Y

TACHO OUTPUT 5V/1ØØØ RPM? N
TACHO OUTPUT 21V/1ØØØ RPM? Y


FEEDBACK?N
```

	1	1	N1	N2	N3	SR
BØ1	ØØ1.Ø	Ø3Ø.Ø	ØØØØR	ØØØØR	ØØØØR	1ØMS
BØ2	ØØ3.Ø	Ø7Ø.Ø	ØØØØR	ØØØØR	ØØØØR	2ØMS
BØ3	Ø75.Ø	Ø7Ø.Ø	ØØØØR	14ØØF	85ØØF	5ØMS
BØ4	ØØ2.Ø	Ø6Ø.Ø	ØØØØR	ØØØØR	85ØØF	1ØMS
BØ5	ØØ2.Ø	Ø5Ø.Ø	ØØØØR	ØØØØR	85ØØF	1ØMS
BØ6	ØØ2.Ø	Ø4Ø.Ø	ØØØØR	ØØØØR	85ØØF	1ØMS
BØ7	ØØ2.Ø	Ø3Ø.Ø	ØØØØR	ØØØØR	85ØØF	1ØMS
BØ8	ØØ2.Ø	Ø2Ø.Ø	ØØØØR	ØØØØR	85ØØF	1ØMS
BØ9	E					

Table II. *Monitor print-out.*

DATA SCAN PROGRAM

WHICH MODF DO YOU REQUIRE? OT
PRGME NO=Ø3

T	I	V	2
BØ1			
ØØØØØ	41·9	11·3	ØØØ
ØØØ84	49·1	1Ø·7	ØØØ
ØØ168	49·5	1Ø3	ØØØ
BØ2			
ØØØØØ	49·4	1Ø·1	516
ØØØ84	49·7	1Ø·1	493
ØØ168	49·7	1Ø2	493
ØØ252	49·7	1Ø2	493
ØØ336	49·4	1Ø·5	493
BØ3			
ØØØØØ	41·7	Ø9·5	493
ØØØ84	4Ø·2	Ø9·7	493
ØØ168	4Ø·1	1ØØ	493
ØØ252	39·9	1ØØ	493
BØ4			
ØØØØØ	39·4	Ø9·3	493
ØØØ84	3Ø·5	Ø9·8	493
ØØ168	3Ø·5	Ø9·9	494
ØØ252	3Ø·5	Ø9·9	493
BØ5			
ØØØØØ	21·3	Ø9·2	495
ØØØ84	2Ø·5	Ø9·4	495
ØØ168	2Ø·5	Ø9·4	493
ØØ252	2Ø·5	Ø9·7	493
BØ6			
ØØØØØ	15·5	Ø9·8	493
ØØØ84	1Ø·2	1Ø·4	495
ØØ168	1Ø·2	1Ø·4	495
ØØ252	1Ø·2	1Ø·5	493

the software provides conversational programs to load the computer with welding routines and for replaying stored welding routines.

Basically there are four programs—(i) Input (ii) Replay and (iii) Shape which act as links between the welding operator and the computer, and (iv) Control, which is the main software used by the computer to perform the weld routines stored by program Input.

Program Input is used to load the computer with welding routines. By the operator answering YES/NO to various questions the required ranges for monitoring can be designated and stored. The weld routine is loaded by the operator typing values in an automatically generated table in an easily read and understood form. The information can also be stored by using a pre-prepared punched tape, this being quicker and less prone to typing errors.

Program Replay enables the operator to replay stored weld routines in either tabular form for direct checking or in punched tape form to enable the weld routine to be stored outside the computer and conveniently loaded back (see program Input) at a later date if required.

Program Shape is used when a weld routine is being replayed in punched tape form. The program punches the weld routine number on to the tape a few inches ahead of the tape proper so that it can be simply read and identified by the operator.

Program Control identifies the station calling the system and the requested welding routine number. During welding, operator selected parameters are monitored and stored for later print-out. Because of the vast amount of monitored data the information is stored at the rate of 1 in every 4 samples or 1 in every 8 samples depending upon which version of program Control is being used.

Operation

The system installed at R.F.L. Springfields will operate up to six different manipulators and provide fifty-five different weld programs. The operator needs no knowledge of computer operation or computer languages. Instead he has three basic functions under direct control, (i) program Input, (ii) program Replay and Shape, (iii) program Control.

Program Input

To put a program in to the computer store it is necessary to press the program Input button and immediately the teletype will start printing a series of questions which require answers such as Yes, No, Not used, or appropriate figures. A typical program is shown in Table 1 where it can be seen that after selecting the appropriate program number it is necessary to select the current and speed ranges and the appropriate tachogenerator output for the

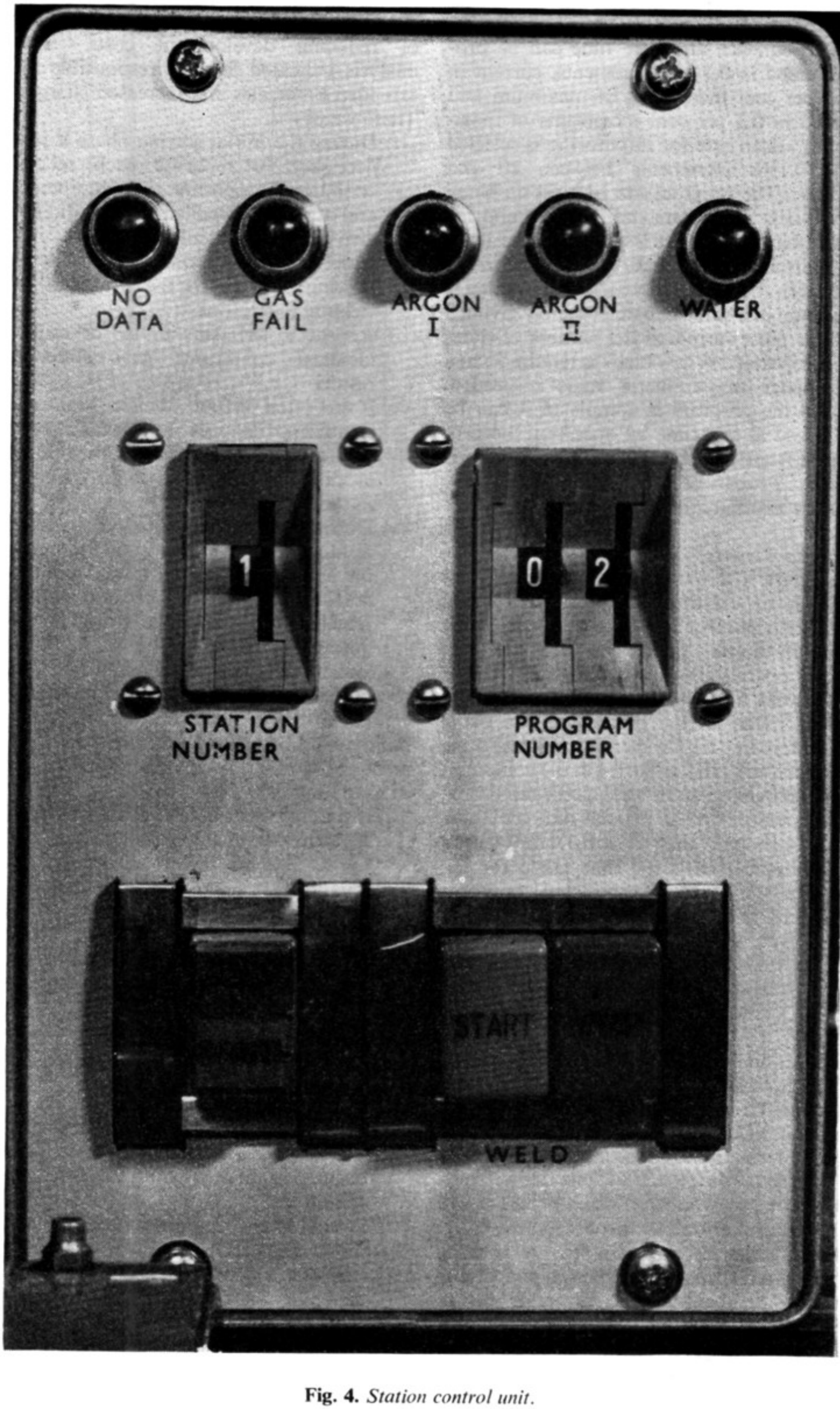


Fig. 4. *Station control unit.*

motor used. The table shows the actual weld sequence and here time can be programmed in 0.1 sec increments, current in 0.2 per cent increments of maximum and speed in 0.1 per cent increments of maximum. Scan rate for monitoring is selected in 10 ms increments between 10 and 70 ms. The program can be built up block by block up to a maximum of 30 and for each block line that is printed there is an opportunity to check and if incorrect, rectify. A program for pulse arc welding is built up in a similar manner merely giving a single pulse form and the number of times it is repeated. A new block is required when a change in parameter value is needed. Once the program is completed it can be checked at any time by operating the program Replay button. Once the program is in store it can be used at any time at any of the manipulators connected.

Program control

Figure 4 shows a station control unit giving, for example, station number 1 and program number 02 which can be selected on two thumb-wheels. Once this has been done, operation of the start button initiates the weld sequence. Whilst the weld is being made all the parameters are being monitored at the selected scan rate and the information is being stored in the computer. On completion of the weld all the monitored information can be printed out, see Table II. Although this is satisfactory on a development basis the time taken for full analysis is rather protracted and for production application would be unsuitable. However, the software can be altered to check that all parameters are within specified tolerances and simply give a GO NO-GO indication at the end.

Application to research and development

The most common method of investigating the welding conditions for a new weld joint is to judge by experience, select possible suitable conditions and then to investigate the effect of interacting variables on the product. Such a program will give information on the acceptable tolerance ranges of the variants. A proving program is then required possibly involving a considerable number of welds before final conditions can be recommended. Prior to the development of the sophisticated control equipment, analysis of a welding development program was carried out in order to establish the possibility of reducing development costs. This analysis indicated features responsible for extended timescales and increased charges. These were:—

(i) During the initial sorting phase it was necessary to replicate each set of conditions to ensure that equipment and other uncontrolled variants did not give misleading results.

(ii) Considerable time was spent merely in making changes to the programs of welding conditions.

(iii) Repeat experiments under ostensibly identical conditions gave differing results.

(iv) It was often difficult to effect slight but significant changes in welding conditions, e.g., during tail-off because of lack of flexibility and/or reproducibility in the equipment.

(v) During the waiting period between welding and evaluating the samples, the equipment was not always used to maximum capacity because of a reluctance to alter the program sequences.

From these results it appeared that one could specify the requirement of welding equipment such that considerable economics could be achieved during a development program. A specification would include the following:—

(i) it should be possible to change welding sequences very simply and quickly and to be able to revert accurately and reliably to previously different sequences,

(ii) the power source and controller should be capable of operating a number of different welding heads and manipulators in random sequence,

(iii) the controller and the power source should operate in a highly reproducible manner,

(iv) included in the equipment should be some method of monitoring the conditions at the welding head and comparing them with the demand conditions.

The equipment described here has met the above specification and it is interesting to assess the benefit subsequently accrued. In general, manipulators involved in widely different programs can be operated from the one power source and controller. Queuing is no problem where weld times are short in comparison with setting up

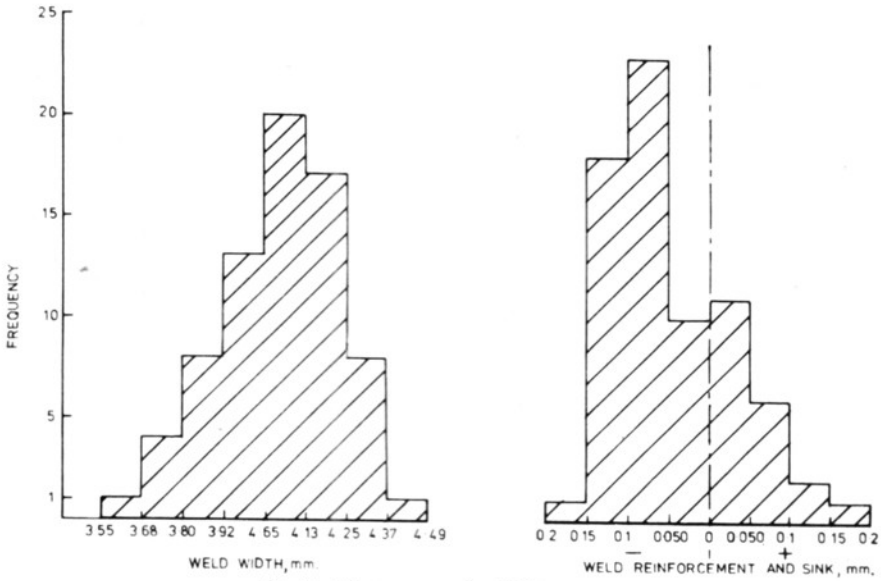


Fig. 5. *Histograms of weld dimensions.*

times. A high degree of confidence was developed in the experimental staff by knowing that a previous program could be called in seconds and that this program would be reproduced faithfully.

The monitored information clearly indicated that the major variations when using conventional equipment resulted from variability in its performance. Other features such as degree of fit, cleanliness and materials variants, whilst affecting the weld, were not causing inconsistencies to the same extent. Consequently it became possible to carry out iterative programs during the sorting phase without the necessity to replicate individual sets of conditions with intermediate evaluation. The number of specimens involved in the first stages can be reduced by factors of 2 or 3 and analysis of the variants becomes much easier.

Whilst it is difficult to generalise on the cost and timescale of welding development the potential savings can be indicated from one particular program. This included the study of the effect of the fits of the parts, the relative position of the parts, electrode composition, tip shape, alignment with joint, arc gap and the effect of argon flow rates and flow patterns. This particular program involved half of the experimental effort over one third the length of time compared with an equivalent program. It is note-worthy that the experimentalists had no experience of the type of joint configuration. As the work of the Laboratory changed in nature it became necessary to provide new manipulators of different characteristics. Normally these would have required an equivalent number of high quality welding power sources and controllers. In the event, the manipulators were connected to the Mk IIIA controller and power source in a multi-station configuration and the savings and capital costs were almost equivalent to the replacement cost of the development equipment, which has since been used on a wide range of development programs. The ability to store programs and to recall these as required, together with keeping permanent records and all monitored information either in the raw or processed form, has proved a boon both during development and also during subsequent production phases when problems have necessitated a re-appraisal of the information obtained during development.

General application

To illustrate the use of this equipment, three typical TIG welding applications can be considered, (i) a fuel element end seal (ii) a 3 metre long butt weld in a high nickel alloy sheet (iii) a tube to tube-plate weld in low alloy steel.

Tube end seal

A typical fuel element weld seals the ends of a reactor control rod tube where the AISI type 316 stainless steel is 21.6 mm

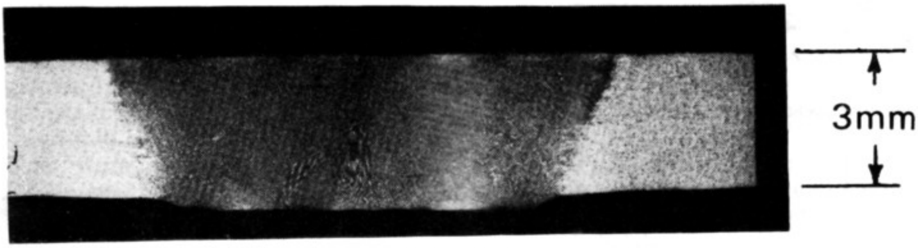


Fig. 6. *Section of butt weld in Nimonic PE16.*

o.d. and 1.2 mm wall thickness. A plain butt weld joint is used with a small amount of integral filler incorporated in the machined end cap. The manipulator designed for this application holds both items in driven collets, one of which is lightly spring loaded to keep the components in contact whilst still permitting axial movement due to thermal expansion. The joint must not only be leak tight with full penetration and be free of major defects, but also the weld bead surfaces must be kept within close dimensional limits. The weld is made at ~ 50 A reducing to 10 A before final arc extinction in a total weld time of 40 sec. The degree of dimensional control achieved is shown in Fig. 5 which shows distribution curves comparing the spread of dimensions of weld width and surface reinforcement or sink obtained. For a mean weld width of 4.1 mm, 95 per cent of the results would be expected to lie between ± 0.35 mm. For the weld surface the mean level is a slight sink with 95 per cent of the results within ± 0.15 mm.

Butt welded sheet

For welding 3 mm thick Nimonic PE16 sheet both TIG welding with added filler wire and pulsed TIG welding without filler have been examined. With thicker material and hence a larger weld pool, dimensional control becomes more difficult and with continuous TIG a backing bar is necessary to control the weld underbead within tight limits (Fig. 6). However, the use of pulsed techniques makes the problem of dimensional control easier and it is possible to maintain uniform small underbeads without resorting to backing bars. Stainless steel permits much easier control of weld geometry than the PE16 alloy where small changes in material quality can have a profound influence on weldability.

Tube to tube-plate

Of more direct interest to the general theme of the Conference is the application of the equipment to tube to tube-plate welding for heat exchangers. Preliminary evaluation of the sequences to be used for the heat exchangers of the Prototype Fast Reactor at Dounreay was undertaken at R.F.L.: a typical example is the evaporator unit fabricated from 2¼ Cr/1 Mo low alloy steel. The header plate was of unstabilised material and was 0.4 m thick whilst the U tubes were of niobium-stabilised material 24.5 mm dia. × 2.25 mm wall thickness.

A butt-fillet type of joint was examined and in all some 500 welds or simulations were made in examining the influence of fourteen major variables and checking consistency in the optimised weld program. The major requirement of the weld was to obtain a satisfactory profile with smooth transition from tube-bore to tube-plate hole and smooth reinforcement on the outside of the weld bead. The consistency achieved with the optimised procedure developed is shown in Fig. 7. Mechanical features such as the fit of the tube in the tube-plate and electrode setting with respect to the joint were found to be critical in ensuring consistency but the importance of obtaining precise control over the rate of heat input was also demonstrated particularly in avoiding weld cracking in the final current decay area. Cracking was always associated with grain boundary films of iron-niobium eutectic and could be avoided by modifications to the current tail-off sequence effectively to alter the local cooling rate and hence the thermal stresses. The flexibility of the control system readily permitted the examination of different current decay forms in order to arrive at the most suitable. It was also important to ensure a stable decay to less than 16 per cent of full weld current in order to eliminate the cracking.

Monitored data during welding could show that the sequence was being maintained within required limits and the arc

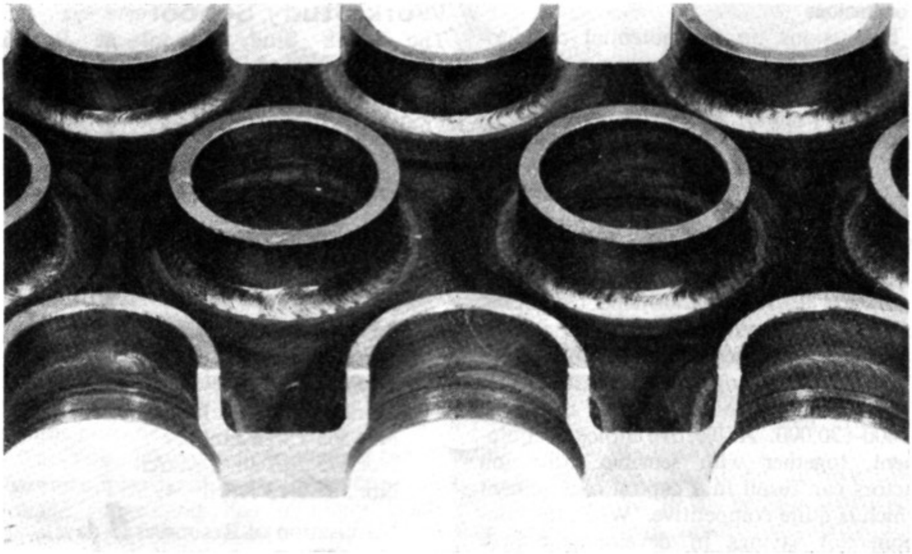


Fig. 7. *Tube to tube-plate welds.*

voltage particularly was very sensitive to variations which could significantly affect weld profile. For example, failure in the gas seals within the gun which may degrade the argon purity and any variations which may alter the arc gap are readily detected as changes in arc voltage.

Industrial use at Bristol Aerojet Ltd.

A twin installation to that at U.K.A.E.A. Springfields has been in use at Bristol Aerojet in Banwell, Somerset for about 18 months. Bristol Aerojet provides a design, production and research facility to the Ministry of Defence (Aviation Supply) for rocket motor and high pressure vessel hardware. The equipment has been of great benefit for producing components of all sizes and provides an invaluable tool for research and development applications.

The inherent advantages of the Mk IIIA welding process controller in consistently providing an accurate reproducible welding program has reduced weld repairs and rejects. It has also resulted in an overall increase in the quality assurance of the finished product.

One of the best examples of the advantages resulting from the use of the welding controller is the Waxwing 28 in. dia. Rocket Motor which was the third and final stage launched vehicle for the all British Satellite Project. The motor is produced in two halves, a boss is welded into each half to facilitate location of the nozzle and satellite, the sub-assemblies are then welded together to form the complete motor. The circumferential weld is approximately 78 in. long, the material is an 18 per cent Ni, 9 per cent Co, 4 per cent Mo, 1 per cent Ti, maraging steel which is 0.065 in. thick at the joint position. Provision of test pieces for developing the correct welding technique seemed expensive; however, with the equipment a program was developed using a single set of motor parts. The development welding program was written so that after the production of a short length of weld at one set of conditions, the conditions were changed as welding proceeded. Using this technique it was possible to cover the complete range of all the possible welding variables in one weld. Subsequent examination of this weld revealed the correct conditions to be used. By conventional semi-automatic techniques the operator gave his undivided attention for the 22 minutes it took to make the weld. This became completely unnecessary when the component was produced with the Mk IIIA controller.

The equipment has been used to date on ferrous and non-ferrous materials with plasma, continuous TIG and to a lesser extent the pulsed TIG welding processes using single and multi-pass welding techniques. A special purpose wire feed unit has been developed to facilitate control of the addition of filler wire for multi-pass applications.

Conclusions

Discussions on the potential of automation in welding frequently develop into semantics and considerable time can be spent in arguing about the meaning of automation. What has evolved at R.F.L. Springfields is a philosophy on the solution of welding problems in relationship to a study of the basic causes of the problems. The equipment necessary for applying this philosophy can vary from the complex configuration described in this paper to simpler, less expensive versions designed for specific application. Consequently the capital costs will vary according to the flexibility required and this would normally be within £5000-£30,000. A selective choice of equipment, together with sensible utilisation factors can result in a capital requirement which is quite competitive. When the consequential savings in development programs are taken into account a positive economic saving can result.

Ultimately an automation system requires a real-time feed back or feed forward capability. In the R.F.L. Mk IIIA equipment this capability exists and consequently the feasibility of introducing these concepts will depend on the existence or development of suitable front end transducers. Although outside the scope of this paper it is perhaps pertinent to say that evidence to date shows promise of a real-time loop being feasible for some applications in the not too distant future. Looking even further ahead, one can envisage the possibility of applying the configuration to a learning mode. When this situation arrives, it can be said that automation in welding is an established fact. One sees that future developments will be attractive and scientifically exciting and no doubt as the number of workers in this field increases and more evidence accumulates, the point will be reached where welding is no longer an art but truly a science.

Acknowledgements

The authors acknowledge the assistance of their colleagues in the development work associated with this topic. The co-operation of Bristol Aerojet Ltd. is also gratefully acknowledged.

References

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2. TAYLOR, A. F., and BARLOW, A. F. Journal of the Institute of Metals, Nov. 1964.

Work Study School

The Work Study School at British Nuclear Fuels Ltd., Risley, will be holding the following courses in the coming months:

Appreciation Courses in Work Study

for Supervisors (5 days)
No. 568 29 Jan-2 February

for Shop Stewards (5 days)
No. 562 8-12 January
No. 585 2-6 April

for Middle Management (5 days)
No. 583 26-30 March

Management Courses

Management and Incentives (5 days)
No. 563 15-19 January
No. 575 26 Feb.-2 March
No. 587 9-13 April

*Utilisation of Resources (5 days)
No. 569 5-9 February
No. 579 12-16 March

*Work Study for Designers (5 days)
No. 584 26-30 March

Work Study Practitioners

Basic Training for Practioners (3 weeks)
No. 574 19 Feb.-9 March

Simplified Data (Lathe and Milling) (5 days)
No. 567 29 Jan.-2 Feb.
Basic Work Data (10 days)

No. 586 2-13 April
Method Study (10 days)
No. 580 12-23 March

Synthetic Data (5 days)
No. 564 15-19 January
*Statistics (5 days)
No. 573 19-23 February

*Policy on Principles (5 days)
No. 566 22-26 January
No. 577 5-9 March

Details of the above courses are found in the General Prospectus of the Work Study School, which is available from the Manager, The Work Study School, British Nuclear Fuels Ltd., Risley, Warrington, Lancs. Tel: Warrington 35953, ext. 3367/8.

Some of the above courses are restricted to B.N.F.L. and U.K.A.E.A. employees, whilst others are open to students from other industries.

*New Courses.

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

Thermocouple device

The Reactor Development Laboratory, Windscale, have devised and produced, in conjunction with Interskill Ltd., Milton, Cambridge, special multiway thermocouple plug and socket connectors designed to transmit thermocouple signals reliably and effectively to control instrumentation.

The design overcomes disadvantages which are inherent in using conventional, multi-contact electronic plugs and sockets for this purpose.

These disadvantages lie in the fact that a thermocouple signal is in the micro-milli voltage range and has infinitely small current so that even a slight oxidation of the contacts is not readily broken down. This results in high and variable impedances which in turn lead to unreliability and inaccuracy of the indicated temperature. Standard plug and socket connectors also introduce junctions of other metals which can produce undesirable thermal e.m.f.'s.

The new Windscale design embodies circuit contacts of chromel and alumel. The contacts take the form of a knife edge in the socket and a plane strip contact in the plug. The contact area is deliberately made small so that high contact pressure can be applied whilst, at the same time, ensuring easy insertion and withdrawal of the plug from the socket.

In use, the socket is connected to the thermocouples from the temperature source and is designed to accept 1 mm diameter, but can be made to accept 1.5 mm diameter, mineral-insulated, metal-sheathed thermocouples. The sheath is supported firmly by a rubber insert and the conductors pressed into spring clips which are an integral part of the knife edge.

The plug is designed to accept heavier flexible thermocouple cable or compensating cable from instruments via cold junction reference points. The conductors are fixed to the strip contact by means of insulated grub screws.

The overall dimensions of a 7-way unit are approximately $1\frac{1}{2}$ in. dia. by 2 in. high and for a 19-way unit $1\frac{3}{4}$ in. dia. by $2\frac{1}{4}$ in. high.

A number of these connectors have been in use on the Windscale Advanced Gas-cooled Reactor since the latter part of 1969, and have been entirely trouble free.

The plugs and sockets are made under licence by Interskill Limited, 121-123, Cambridge Road, Milton, Cambridge.

20th November, 1972

QUALTIS

A subscription information service covering all aspects of material quality testing is to be provided by the Harwell Nondestructive Testing Centre.

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Further information can be obtained from: Qualtis Manager, The Nondestructime Testing Centre, A.E.R.E. Harwell, Didcot, Berks. Tel.: Abingdon 4141. Ext. 2470.

Background note:

The Nondestructive Testing Centre was set up in 1967, to assist industry to solve their quality technology problems by carrying out specific investigations for individual companies, by developing new and improved N.D.T. techniques for wider industrial benefit and by providing a consultancy service. *22nd November, 1972*

A.E.A. Reports available

The titles below are a selection of the reports published during the past two months and available through H.M.S.O.

AEEW-M 1136
Comparison of Leap, Tor and Slab, Programmes for Computing the Scattering Law $S(\alpha, \beta)$ from a Phonon Frequency Function. By A. T. D. Butland, October, 1972. 23pp. HMSO £0.50. SBN 85182 012 3

AEEW-R 813
Thermal Neutron Scatter by Graphite Assuming the Crystal has an Isotropic Structure. By A. T. D. Butland, October, 1972. 40pp. HMSO £1.00. SBN 85182 009 3.

AEEW-R 814
A Comparative Study of Various Light Water Scattering Models used in Thermal Reactor Calculations. By A. T. D. Butland and C. T. Chudley. October, 1972. 39pp. HMSO £1.00. SBN 85182 010 7.

AEEW-R 815
The Specific Heat of Graphite. An Evaluation of Measurements. By A. T. D. Butland and R. J. Maddison. October, 1972. 19pp. HMSO £0.50. SBN 85182 011 5.

AERE-Bib 181
Liquid Crystals for Non-destructive Testing. By M. A. Wall. October, 1972. 12pp. HMSO £0.50. SBN 7058 0292 2.

AERE-M 2521
A Method for Determining the Density of Milligramme Samples of Fibres. By B. E. Chidley. September, 1972. 9pp. HMSO £0.50. SBN 7058 0242 6.

AERE-R 6724
Studies of the Analysis of Airborne Particulate Material by Radioactivation and Sodium Iodide Spectrometry. By D. H. F. Atkins, E. M. C. Fisher and L. Salmon. October, 1972. 25pp. HMSO £0.50. SBN 7058 0252 3.

AERE-R 6830
Thermal Diffusion Phenomena in Non-stoichiometric Oxide Fuels. Part 1. Evidence of Gas Oxygen Transport in UO_{2+x} from Axial and Radial Temperature-Gradient Experiments. By M. G. Adamson and R. F. A. Carney. October, 1972. 42pp. HMSO £1.00. SBN 7058 0272 8.

AERE-R 6831
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