Calder Hall Power Station

No. I

Calder Hall " A " power station will be formally opened by Her Majesty the Queen on October 17th, three and a half years after the design team started work on the scheme. It is the first nuclear power station to generate electricity on an industrial scale. The main plant consists of two gas-cooled graphite-moderated natural uranium reactors, the heat from which is taken by the coolant, carbon dioxide under pressure, to heat exchangers where steam is generated for the four 23MW turbo-alternators. The reactor is designed for the production of plutonium as well as the generation of electricity. An identical station, known as Calder Hall " B," is under construction on an adjoining site and is due to be completed in 1958.

THE opening of Calder Hall power station by Her Majesty the Queen on October 17th will mark an epoch in the history of power development. For Calder Hall is the first power station in the world to generate electricity on an industrial scale from nuclear energy. Moreover, Calder Hall is the forerunner of a group of nuclear power stations which will constitute the first stage in Great Britain's ten-year programme for the construction of twelve nuclear power stations by 1965. The first group of these stations will be advanced versions of the Calder Hall design, based on the gas-cooled, graphite-moderated natural-uranium reactor. They will, however, have the benefit of current technical improvements, including up-rating of the reactors.

To view these developments in perspective we should look briefly at the origins of Calder Hall. The British organisation for atomic energy development began at the end of 1945, when, under the ægis of the Ministry of Supply, there was set up the Atomic Energy Research Establishment at Harwell, and a production division having its headquarters at Risley in Lancashire. Although the main task at Risley was the large-scale production of the fissile material, plutonium, a good deal of attention was given to the problems of power generation from reactors. Windscale, the first British plant designed to produce plutonium on an industrial scale, was a graphite-moderated, natural-uranium pile, developed from the BEPO pile at Harwell. Since the only object was the output of plutonium, the pile was air cooled and the hot air was discharged to atmosphere.

For power generation, however, thermal efficiency was important, and much of Risley's effort was devoted to investigations of heat transfer from the canned fuel to various gaseous coolants, including carbon dioxide under pressure in a steel vessel containing the reactor core.

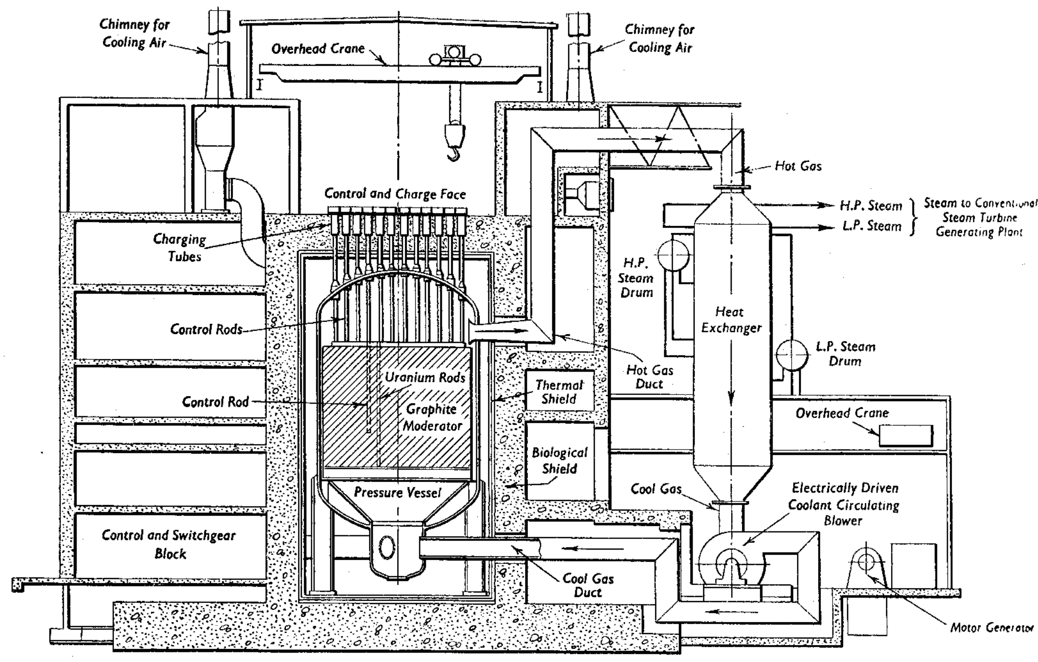

Fig. 1—Section of one of the piles at Calder Hall " A " power station, showing the reactor core, pressure vessel, thermal and biological shields and one of the four heat exchangers

In the meantime research work was being done at Harwell on reactors for power production and in 1951 a group was established there to prepare a design study for a reactor suitable for power generation. Natural uranium was to be used for fuel but the other main parameters, the moderator and coolant, were to be the subject of study. In the event graphite was chosen as the moderator, mainly because of the existing " know how " and because the possible alternatives, beryllium and heavy water, were not produced on a commercial scale in Great Britain. Gas cooling was preferred to liquid cooling because gases absorb far fewer neutrons. On grounds of cost and availability, carbon dioxide was chosen once it had been established that the gas would remain stable at the reactor operating temperatures and that the reactivity of carbon dioxide with the graphite moderator would not be excessive. Work was also done on the fabrication of the fuel element and on its canning.

Early in 1952 the design study for the gas-cooled graphite-moderated reactor had reached a stage when industrial participation was desirable. Engineers from the Ministry of Works, from the British Electricity Authority (now the Central Electricity Authority), and from manufacturing firms, including C. A. Parsons and Co., Ltd., Babcock and Wilcox, Ltd., and Whessoe, Ltd., were invited to co-operate.

Engineering design studies were then made for a full-scale reactor to generate well over 100MW of heat. Detailed designs emerged for the core, which was to have vertical fuel channels because of the weight to be carried in the pressure vessel, without distortion of the channels at high temperatures ; similarly, designs were evolved for the pressure vessel itself ; for the heat exchangers in which heat steam was to be generated at two pressures ; and for the gas circulators and turbines.

Early in 1953 the Government decided to build a reactor for the dual function of producing plutonium and generating electric power. From that point the project became the responsibility of the Industrial Division at Risley. The design organisation began work in the spring of 1953 ; the building and civil engineering contract was placed on July 22, 1953 ; next week, within three and a half years of the start of the work, the power station is to be formally opened.

In Calder Hall power station there are two gas-cooled, graphite-moderated, natural uranium reactors. The usable heat from each reactor is transferred by the coolant, carbon dioxide gas operating on a pressurised closed cycle, to four heat exchangers in parallel. Steam is generated in two separate circuits in each of the heat exchangers and is supplied to four turbo-alternators in a turbine hall which is sited between the two reactor buildings, as can be seen from the accompanying illustrations. Each reactor is enclosed in a cylindrical pressure vessel with domed ends ; the four heat exchangers are symmetrically disposed with respect to the reactor. Centrifugal circulators force the coolant upwards through the vertical channels in the reactor core and the hot gas is ducted from the top of the pressure vessel into the heat exchangers, the coolant circuit being as indicated in the accompanying sectional drawing.

As already indicated steam is generated at two pressures in separate circuits in the heat exchangers, and is fed separately to the high-pressure and low-pressure cylinders of the turbine. This arrangement is more efficient than a single-pressure steam cycle : it allows the cooled gas to be returned to the reactor at a lower temperature than would otherwise be possible and, therefore, a greater heat output can be obtained from the reactor with a given mass flow of coolant. To enable the reactor to be operated independently of the electrical load two separate dump condensers are installed. These dump condensers are capable of handling the full steam output of the station, by-passing the turbines. The station is served by two cooling water towers which are of conventional reinforced concrete construction, with split basins and a common pump house. The half-basin capacity is 687,500 gallons. Each tower has a capacity of 3,000,000 gallons per hour.

Reactor

The reactor consists of a graphite lattice structure which has a nominal core diameter of 31ft and a height of 21ft, and is contained in a cylindrical pressure vessel. To simplify the graphite structure and the design of the coolant circuit, vertical channels were adopted for the control rods and fuel elements.

The fissile material is natural uranium with a density of 18·7 grammes per cubic centimetre (or 0·676 lb per cubic inch), and the fuel elements are rods 1·15in diameter and 40in long. Each fuel element is enclosed in a magnesium alloy can with an inside diameter of 1·165in and an outside diameter of 1·30in. To increase the heat transfer area the outside surface of the can is in the form of a single-start helical fin with an overall diameter of 2·125in. One end of the can is sealed by a plug and end cap and the other by an end cap and spacer, which locates the next can in the same channel. There are 1696 fuel element channels, 4in in diameter, in the graphite structure, and each channel can house four fuel elements. The annular channels between the graphite moderator and the fuel elements and the control rods constitute passages for the coolant flow.

The weight of the graphite structure is 1200 tons and it is supported on a structure consisting of an I-section beam in the form of a ring with intersecting I-section beams, making up a rectangular lattice or grid.

Across the members of the lattice are bolted 4in thick steel base plates which have holes in them to coincide with the channels in the graphite. These base plates support the graphite through a number of races, which allow for differential thermal expansion of the grid and graphite. The weight of graphite and grid is taken by brackets through the walls of the pressure vessel on to ten inverted A-frames (Fig. 2) which rest on the thermal shield. These A-frames are loosely bolted to the brackets on the pressure vessel and on to the thermal shield, the three contact surfaces of each A-frame being radiused. Thus allowance is made for radial thermal expansion of the pressure vessel and grid, when the A-frames roll slightly out of the vertical and the bolts ensure that the rolling surfaces do not slip.

Pressure Vessel

The design of the pressure vessel, which is 40ft in diameter and about 60ft high, posed some interesting problems. Because of the need to extract heat from the reactor at a sufficiently high temperature for steam raising it was desirable to choose the highest practicable operating pressure for the coolant. The maximum practicable wall thickness for the pressure vessel was therefore desirable. On the other hand, the pressure vessel, because of its size, had to be fabricated on site. The wall thickness was therefore limited to a value which could be satisfactorily welded. At the time the vessel was being designed it was considered that 2in was the maximum thickness of metal that could reasonably be welded on site to the required standards, subject to radiographic inspection.

Accordingly, 2in welded steel plate was used for the pressure vessel. All the fabrication was done on site, the vessel being built up in five main sections, namely, the bottom dome, the grid structure for supporting the graphite, the two parallel cylindrical sections and the top dome. When completed, each of the five sections was transported to the final erection area, where a 100-ton crane lifted them and lowered them through the roof of the reactor vault. After each section was lowered into place the final welds were done *in situ*. Each butt weld was subjected to 100 per cent radiographic inspection and all important fillet welds were examined by crack-detection methods.

Upon completion of welding the pressure vessels were thermally insulated and stress-relieved by radiant heat derived from a network of tubing which was rigged up inside the vessels and supplied with electricity, the peak loading being 1½MW. After several days the soaking temperature of 550 deg. Cent. was reached and was then maintained for eight hours before allowing the structure to cool slowly and evenly.

Testing of the vessel under air pressure instead of hydraulic pressure was deemed to be feasible because of the protection afforded by the concrete radiation shield surrounding the pressure vessel. Hydraulic testing, on the other hand, would have overloaded the supporting structure. To minimise the potential hazard of air testing, strain gauges were used during the test to indicate the general stress level and to serve as a check on those areas where locally high stresses might be expected. Brittle lacquer was used as a coarse check. About 350 gauges were used on the first test, where, after a preliminary run (from zero, to 50 lb per square inch, to zero) to check drift, pressure was applied in increments to 135 lb per square inch gauge. At each pressure stage a full set of readings was taken from the strain gauges and any which showed that stresses were significant were checked more frequently. Brittle lacquer was examined at each stage after pressure had been dropped 10 lb per square inch gauge from that at which strain gauge readings had been taken and stresses calculated; dimensional changes were recorded concurrently. The initial cold air test was followed by a vacuum test; when the vessels were loaded with graphite the cold air test was repeated to 115 lb per square inch gauge, this being followed by a hot test to the same pressure with air at a temperature of 284 deg. Fah.

The main contractor for the pressure vessels was Whessoe, Ltd., Darlington. The inspection service, some details of which are given above, was provided by Lloyd's Register of Shipping, Land Division. This service covered a survey of the pressure plant, that is, reactors, heat exchangers and gas ducting, including valves and expansion bellows, during construction, and testing in the manufacturer's workshops and on site. The material used for the manufacture of the pressure vessel was Consett "Low-Temperature Aluminium-Killed High Manganese" mild steel. It was chosen for its good impact ductility at low temperature and its consequent suitability for site welding and because its lower transition temperature is raised by irradiation.

The pressure vessel is surrounded by a concrete biological shield, the sides of which are 7ft thick, while the top is 8ft thick. This shield is octagonal in plan and the inner faces are lined with a thermal shield built up of steel plates 6in thick; similar plates form the floor and roof of the thermal shield.

Between the thermal shield and the concrete wall there is a 6in gap. To remove the heat generated in the thermal shield air is blown up this gap and is discharged from twin stacks in the roof. A view, looking down into the reactor chamber during the construction of the thermal shield, is shown in Fig. 2. Plates for the thermal shield were supplied by the English Steel Corporation, Ltd., Sheffield, and by the Steel Company of Wales, Ltd., Port Talbot.

Charge and Discharge of Fuel Elements

Charging and discharging of the fuel elements is done from the floor of the charging chamber (illustrated in Plate 2), which forms the roof of the reactor shielding. Access to the fuel channels is obtained through branches which extend upwards, from the top dome of the pressure vessel, through the roof shield, to the floor of the charging chamber. Each branch in the pressure vessel serves sixteen fuel channels. Loading and unloading is done through a charging chute which is lowered by an overhead crane into the required pressure vessel branch. The chute can be actuated to enable each fuel channel to be connected, in turn, with the floor of the charging chamber. A charging machine is then positioned over the top of the charging chute.

Each reactor is equipped with two mobile machines for charging and two machines for discharging, the two latter being provided with heavy shielding so that the "hot" fuel elements can be handled in safety. In each machine there is a detachable magazine containing enough fuel elements to fill four channels. The machines are electrically-propelled and equipped with a winch for raising and lowering the elements. A variable-speed reversing motor drives the winch at operating speeds up to 175ft per minute, with provision for creep speeds near the ends of the travel. In operation the element is held by an automatic electrically-operated grab which is fitted to the end of the hoist cable.

The hoist cable also carries the necessary wires for operation and remote indication of the state of grab, showing whether the grab is open or closed, whether it is in contact with an element and whether it is carrying an element.* On the machine there is also indication of the grab depth, the amount of slack cable and of the position of the magazine. There are interlocks to prevent maloperation and safety devices to stop the motor in the event of slack cable or over-tension. Control levers and indicators are grouped on each machine so that all motions can be controlled by an operator seated on the machine.

To give any machine access to any of the vertical channels parallel steel rails are fitted in the floor. Any machine can travel along a set of rails under its own power and can be transferred from one set of rails to another by a traverser which moves along rails at right angles to the parallel tracks.

A typical sequence of operations for discharging and charging fuel elements in a reactor is as follows. First the plant is shut down and depressurised. Then the cover plate on the required charge tube is removed and a temporary valve and gland assembly is fitted in place of the cover plate. The shield plug is withdrawn through the gland and is replaced by a guide chute, whereupon the temporary valve and gland is removed; loss of coolant is prevented by a valve on the chute. Next a purged discharge machine is aligned over the guide chute and connected to it. The chute and machine valves are then opened and the grab is lowered to seize the element and hoist it into the magazine. The magazine is then moved one pitch and the cycle is repeated until all the elements are removed from the channel. After closing the chute and machine valves the discharge machine is moved away from the chute and its place is taken by a charge machine from which fresh elements are loaded into the empty channels.

To dispose of the spent elements the discharge machine is moved by the traverser over a circular well. The shield is removed from the bottom of the discharge machine and the sliding door which normally covers the well is drawn aside. An electric hoist then lowers the magazine containing the spent elements. At the bottom of the well, near ground level, the magazine is immersed in water contained in a thick-walled cast iron tank which is wheel mounted and is electrically propelled to the storage pond.

* Paper, "Mechanical Engineering Features of the Calder Hall Nuclear Power Station," Fifth World Power Conference, Vienna, 1956.

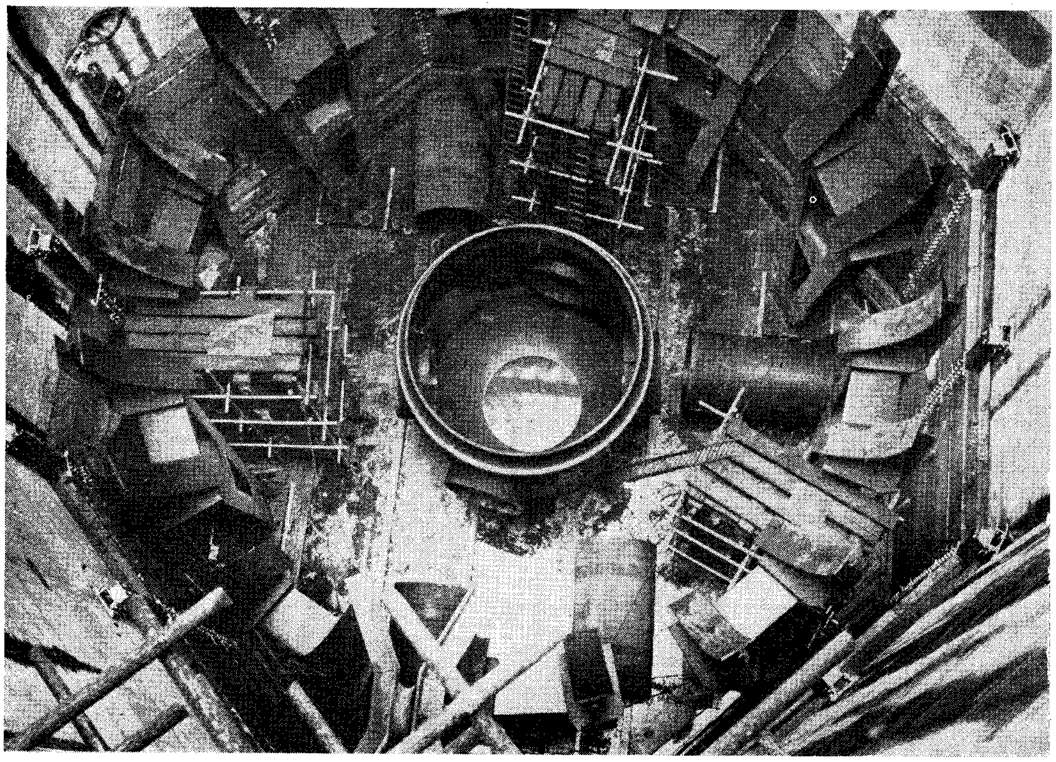

Fig. 2—Reactor chamber at Calder Hall during erection of thermal shield plates. On the floor of the chamber is the inlet manifold, whereby coolant from the four heat exchangers is admitted to the bottom of the pressure vessel. The octagonal chamber is 45ft across and 80ft high

Control Rod System

Four main considerations, some of them mutually conflicting, affected the design of the control rod mechanism, operating in vertical channels in the reactor core: reliability of operation; failure to safety under all conditions; limitation of space, and the fact that the mechanism would operate at a high temperature in a CO_2 atmosphere free of oxygen and water vapour and liable to neutron bombardment. The fourth requirement gave rise to serious lubrication problems.

To meet these requirements a control rod system for Calder Hall power station was developed by Metropolitan-Vickers Electrical Company, Ltd., for the U.K. Atomic Energy Authority. The design evolved combines the functions of control and shut-off and sixty such actuating mechanisms have been supplied for each of the two piles.

The boron control rod assembly weighs 130 lb, has a working travel of 21ft, and is suspended from the control mechanism by a special low-cobalt flexible stainless steel cable, edge wound between the side cheeks of a drum. This drum is operated through spur and bevel gear trains by a synchronous motor. Because the control rods operate in vertical channels gravity fall can be used when the rods are required for shut off and an electromagnetic clutch is, therefore, incorporated in the mechanism to allow free fall of the rods. An eddy-current brake is also included in the system so that a high launching speed can be achieved, with slow touch down. Indication of the rod position is given remotely by a magslip position indicator.

Since the whole mechanism (including motor, clutch, brake, winch and gearbox and position indicator) is enclosed in the CO_2 coolant circuit no pressure seals are required on rotating shafts or suspension cables: glass-to-metal seals were used to take the only other external connections, the electric cables, through the pressure casing.

In the absence of oxygen normal lubricating oils are unsuitable and in the absence of water vapour graphite lubrication is equally unsatisfactory. After considerable research the problem was solved by the use of a dry lubricant in the form of a molybdenum disulphide (MoS_2) treatment.

Control Rod System Performance.—The system provides for the operation of the control rod actuating mechanisms in two groups:

(1) "Coarse" operates up to sixty actuating mechanisms.

(2) "Fine" operates up to four actuating mechanisms.

For "coarse" operation three control rod speeds are available:

(*a*) In (fast) 50in per minute maximum (2·1cm per second).

(*b*) In (normal) 5in per minute maximum (0·21cm per second).

(*c*) Out (normal) 0·5in per minute maximum (0·021cm per second).

With all the rods moving together the "out" speed limits the maximum rate of release of reactivity to 2×10^{-6} per second.†

For "fine" manual control an approximate maximum "in" and "out" rod speed of 50in per minute is possible. During the period of commissioning only, fast speeds "in" and "out" are made available by the incorporation of special test equipment.

The shut-off performance of each rod is:

(1) Initial acceleration not less than 2ft per square second.

(2) Maximum speed 4ft per second.

(3) A travel of 18ft 6in in a time not greater than five seconds.

(4) Touchdown speed not greater than 6in per second.

Design of Actuating Mechanism.—The actuating mechanism is shown in Fig. 3.

A synchronous driving motor of the variable reluctance design is used; it has a three-phase wound stator, class "H" insulated, and an unwound rotor, and it was chosen to meet the following requirements:

(1) Synchronous operation.

(2) Positive holding torque at standstill.

(3) No brushgear, to give greater reliability.

(4) High torque-to-volume ratio.

(5) Capable of working in an ambient temperature up to 100 deg. Cent.

(6) Capable of running at low speed so that a small gear ratio could be employed to permit back driving by the rod during shut-off.

A solenoid clutch is fitted between the motor shaft and the remainder of the mechanism, to disengage the rotor of the motor from the system, thereby reducing the inertia to be accelerated during shut-off. The clutch is operated by six solenoids energised from the same supply as the motor. If the rotor of the motor should fail to be disengaged when the supply is opened, then shut-off action will still result because the de-energised motor is back-driven. If there is loss of drive, an emergency winding handle can be attached which mechanically engages the clutch.

The eddy-current brake, which provides controlled fall of the rod, consists of two sets of permanent magnets with alternately opposed north and south poles. An eddy-current copper-clad steel disc rotates in the air gap between the magnets. The braking torque on the disc is controlled by varying the air gap magnetic flux with a magnetic shunt mechanically operated from a cam. The correct rate of fall under shut-off conditions is programmed by the profile of the cam. From the motor the drive is via single-stage spur gearing and right-angled bevel gears, giving a total reduction of 20 : 1.

Linear measurement of the rod position is provided by a transmitter magslip driven by a gear train from a cable-driven measuring wheel. A lever-operated switch with a "follower" wheel on the winding cable detects "no-tension." This switch is used in conjunction with a second switch operated by the magnet shunt control cam to detect "over-run or lost rod." The second switch is also used to check that the cam is correctly set.

After tests had been completed on individual components extensive life tests were carried out on two actuating mechanisms which were run in an atmosphere of pure dry CO_2 with not more than 0·01 per cent by volume O_2 impurity at a pressure of 100 lb per square inch. In Fig. 4 we show the actuating mechanisms seated on the test pressure vessels, lagged to simulate the thermal effects of the biological shield; heating was incorporated equivalent to the heat flow up a charge tube. The actuating mechanisms were run for successive tests at the highest rod speed of 50in per minute and reversed automatically at the top and bottom of the rod travel. During the tests the following main points were studied: wearing properties of gears and bearings treated with MoS_2, temperature rises, effects of thermal cycling and the functional operation of components. Special measuring techniques were developed to obtain this information without opening up the actuating mechanism.

Design of the Control System.—The control system provides for the raising and lowering of the control rods by the variation in frequency and phase-sequence of the three-phase a.c. supplies to the driving motors of the actuating mechanisms. A range of frequencies 0 c/s to 1·3 c/s, with a constant voltage of 40V r.m.s., is employed; the zero-frequency condition is used for "holding" the rods.

"Coarse" and "fine" control supplies to any of the actuating mechanisms are selected by means of changeover switches mounted in distribution cubicles. These switches are connected to the main and auxiliary busbars to which are fed "coarse" and "fine" supplies, respectively.

† Paper No. 15, "Equipment for Control of the Reactor," Symposium on Calder Works Nuclear Power Plant, British Nuclear Energy Conference, 1956, Bowen and Ghalib.

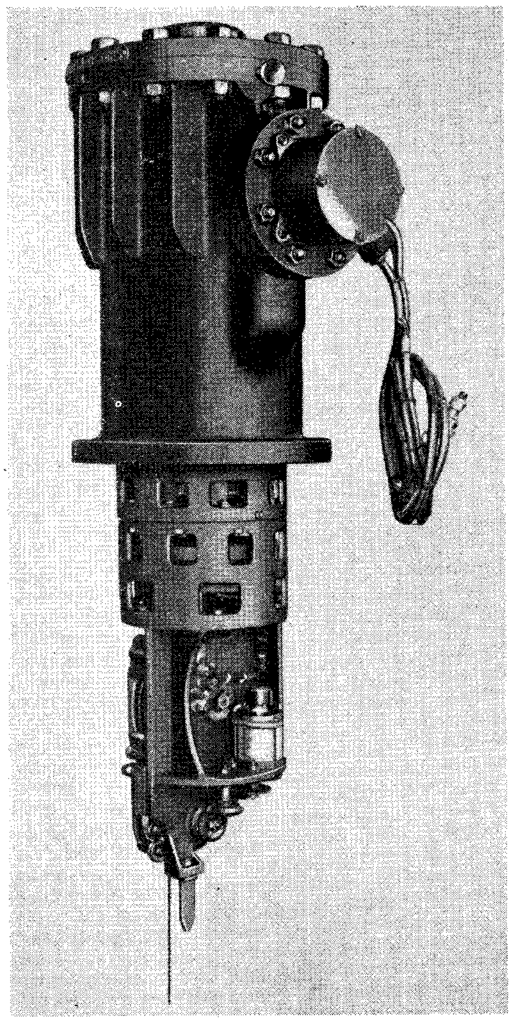

Fig. 3—Control rod actuating mechanism. The cable carrying the control rod is driven through spur and bevel gears by a synchronous motor. An eddy current brake provides controlled fall

The coarse supply is generated by one of two identical frequency converter sets—the other frequency converter set being purely on stand-by duty. Operation of the frequency converter sets is carried out from a machine operator's control desk. Position control of the "coarse" rods *en bloc* is provided by means of a control switch and a magslip indicator, giving rod travel which is transmitted from the frequency-converter set.

"Fine" control supplies are provided by two sine-potentiometers mounted in the cubicles shown in Fig. 5. Each sine-potentiometer is basically a resistor chain fed by d.c. and tapped to give a sinusoidal distribution of potential. The tapping points are taken out to studs on a face plate from which three sets of brushes pick off an output three-phase supply at a frequency equal to the rate of rotation of the brushes. Position control of the "fine" rods is carried out at the reactor control desk by means of manual drives to the sine-potentiometers. Rod travel is given by "M" type indicators operating from the outputs of the sine-potentiometers.

A three-phase voltmeter was developed to give a direct reading of the equivalent r.m.s. voltage down to zero frequency; it is the larger of the two instruments which can be seen in Fig. 5. The voltmeter uses a three-to-two-phase transformation, thereby requiring only two moving-iron elements on the same shaft.

Each frequency converter set consists of a 37·5 h.p. induction driving motor, a 22kVA salient pole a.c. generator; a differential gearbox and a 19·4kVA frequency converter mounted in line on a common bedplate. The motor is started direct-on-line by closing the 415V circuit breaker; it is designed to deliver full load torque even if the terminal voltage falls to 50 per cent of its normal value. Furthermore, the a.c. generator is excited from the 50V station battery which enables the stored energy of the frequency converter set to maintain continuity of the output supply for the maximum time when running down in the event of fault conditions on the 415V a.c. supply.

The frequency converter has no stator winding, is rotor fed and gives a three-phase output of 40V r.m.s. with frequencies 0 c/s to 1·3 c/s. Its input supply from the a.c. generator is taken to the rotor through six sliprings. A three-phase output is taken from brush arms arranged around the commutators. The power required to drive it (equal only to its friction and windage losses) is supplied by the induction motor through the differential gearbox. If the input and output shafts of the gearbox are rotating at the same speed, the frequency converter is running in synchronism with the a.c. generator and the output derived from its commutator is of zero frequency. The values of current drawn from the three output brushes will depend on the positional relationship between the rotors of the two machines. If a decrement of speed is fed into the differential gearbox through its pilot motor section (described later) the frequency converter runs sub-synchronously with respect to the a.c. generator and a three-phase supply can be drawn from its commutator, the frequency corresponding to the difference in rotational speeds of the two machines. If an increment of speed is fed into the gearbox the frequency converter will run super-synchronously with respect to the a.c. generator and, again, a three-phase supply will be available at its commutator with a frequency corresponding to the difference in rotational speeds of the machines, but having a phase sequence which is the reverse of that obtained with sub-synchronous running. The voltage of the output is

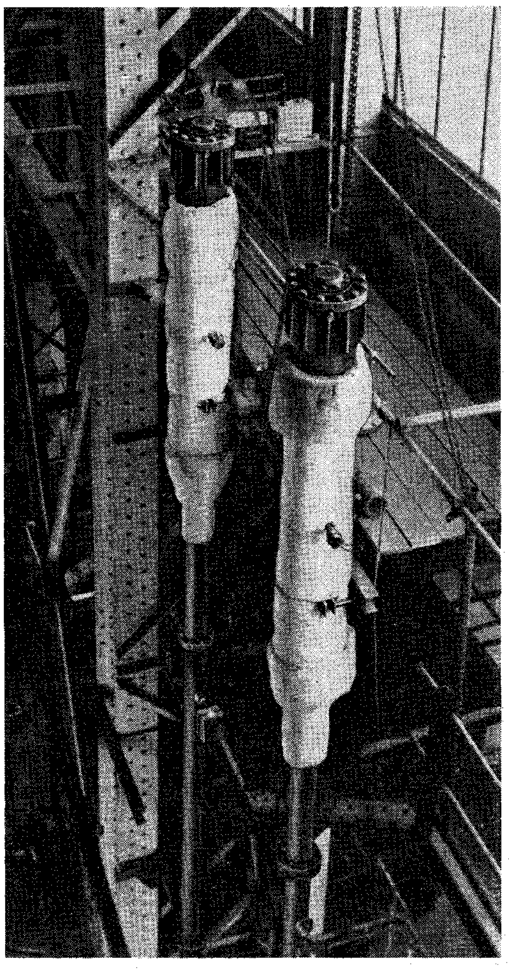

Fig. 4—Two control rod actuating mechanisms are shown here seated on test pressure vessels

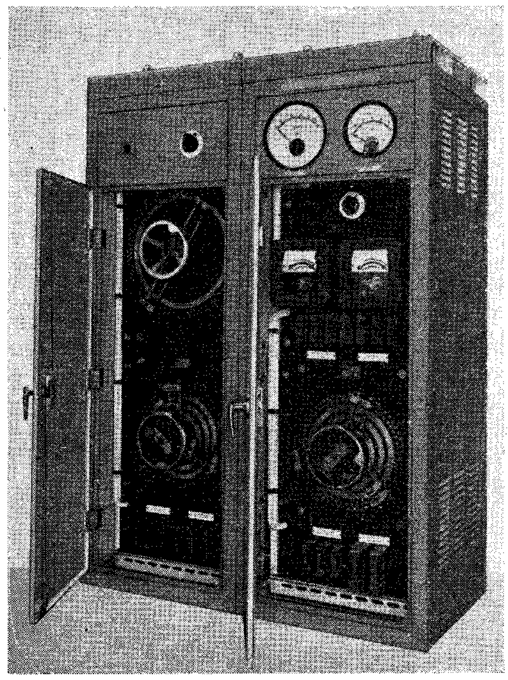

Fig. 5—Main sine-potentiometer cubicle containing two sine-potentiometers for providing "fine" control supplies to the control rod actuating mechanisms

independent of the frequency converter speed and is determined purely by the a.c. generator excitation.

The system is designed to move the rods "in" when the frequency converter is running sub-synchronously so that in the event of a failure of drive to the frequency converter the system will fail to safety by moving the rods "in."

Any normal three-phase relationship between the zero frequency voltages at the frequency converter output terminals can be achieved when the machine is running synchronously by operating the differential gearbox to bring the rotors of the a.c. generator and frequency converter into the correct relative position; this relationship is partly dependent on the load.

The differential section of the gearbox is of the sun and planet epicyclic type. Drive to the third member of the differential is through an irreversible worm from a small pilot motor via one of three permanently meshed gear ratios selected by individual electromagnetic disc clutches having stationary windings. An electromagnetic brake is applied to the third member shaft when no drive is selected by the coarse control switch on the reactor control desk. An indicating dial attached to the main gearbox housing indicates the position of the differential cage which can be manually moved over a restricted angle to facilitate paralleling of the two frequency converter sets during change-over. Indication of the coarse rod travel is also transmitted from the differential gearbox to the reactor control desk.

To ensure continuity of the coarse control supply at the main busbars during change-over of the frequency converter sets it is necessary to parallel the incoming frequency converter set before transferring the load. The line contactors are interlocked to ensure correct paralleling of the incoming set and the control selector switch is automatically interlocked so that the incoming set must be carrying the load before the outgoing set is tripped off the main busbars.

A magslip indicator associated with each actuating mechanism shows the position of each rod. The indicator also carries two lamps which indicate "no-tension" and "lost or overrun rod," which are operated from the switches in the actuating mechanisms via fault-finding relay circuits.

Two safety circuits detect the following :—(1) Faults which necessitate de-energising the actuating mechanisms and dropping the rods, so initiating a shut-down of the reactor. (2) Faults which prevent further movement of the rods.

An emergency shut-down of the reactor is initiated from the emergency push button on the reactor control desk or from one of the shut-down circuits. All the line contactors and 415V circuit breakers are opened, thus removing the control supply from the main busbars and thereby de-energising the actuating mechanisms so that the rods give shut-off action. At the same time, the sine-potentiometer supply is tripped so that the fine rods also give a shut-off action.

The main turbines and a.c. generators are tripped from relays operating on under-voltage at the main busbars, so preventing the turbines being motored.

(To be continued)

Symposium on Calder Works

A SYMPOSIUM of nineteen papers on the Calder Hall plant will be held by the British Nuclear Energy Conference, on November 22 and 23, 1956, at the Central Hall, Westminster. Particulars are obtainable from The Secretary, British Nuclear Energy Conference, 1–7, Great George Street, Westminster, London, S.W.1.

Session 1 : *Introduction and General Design* (*November* 22*nd*, 10 *a.m.*–12.30 *p.m.*)—Chairman, Sir John Cockcroft. (1) "The Place of the Calder Hall Type of Reactor in Nuclear Power Generation," by Sir Christopher Hinton. (2) "The 1951–53 Harwell Design Study," by R. V. Moore and B. L. Goodlet. (3) "The Design and Construction of the Plant," by R. V. Moore.

Session 2 : *Technical Research Problems* (*November* 22*nd*, 2 *p.m.*–5 *p.m.*).—Chairman, Sir John Cockcroft. (4) "Heat-Transfer Experiments on the Fuel Elements," by P. Fortescue and W. B. Hall. (5) "Experimental Physics," by P. W. Mummery. (6) "Shield Design," by C. C. Horton and W. Bonsall. (7) "Basic Design of Reactor," by G. Packman and B. Cutts. (8) "Early Metallurgical Problems," by R. A. U. Huddle and L. M. Wyatt. (9) "Metallurgical Developments," by L. Grainger and A. B. McIntosh.

Session 3 : *Engineering Design* (*November* 23*rd*, 10 *a.m.*–12.30 *p.m.*).—Chairman, Mr. W. L. Owen. (10) "Design and Construction of Reactor Vessel," by G. Brown, M. J. Noone and R. F. Bishop. (11) "Uranium Fuel Handling," by K. H. Dent and G. W. Grossmith. (12) "Design of Important Plant Items," by A. T. Bowden and G. H. Martin. (13) "Steam-Cycle Analysis," by W. R. Wootton. (14) "Design and Construction of Heat Exchangers," by H. Morris and W. R. Wootton.

Session 4 : *Light Engineering and Electrical* (*November* 23*rd*, 2 *p.m.*–4.30 *p.m.*).—Chairman, Mr. J. Eccles. (15) "Equipment for Control of the Reactor," by S. A. Ghalib and J. H. Bowen. (16) "Detection of Faulty Fuel Elements," by E. Long, J. M. Laithwaite and K. W. Cunningham. (17) "Reactor Control and Instrumentation," by R. J. Cox and K. R. Sandiford. (18) "System Control and Protection," by E. Anderson and J. H. Bowen.

Session 5 : *Future Developments and Summary* (*November* 23*rd*, 5.30 *p.m.*–7.15 *p.m.*).—Chairman, Sir John Cockcroft. (19) "Future Developments of Gas-Cooled Reactors," by R. V. Moore.

North of Scotland Hydro-Electric Schemes

No. VIII : THE GARRY AND MORISTON SCHEMES—PART I*

The adjoining catchments of the Garry and Moriston rivers in Inverness-shire have for many years been recognised as favourable sources for the development of hydro-electric power. The North of Scotland Hydro-Electric Board's developments here will yield about 383 *million kWh annually, from an installed capacity of* 106*MW. The design of the two schemes is described in this article.*

THE hydro-electric works in Glen Garry and Glen Moriston give us a noteworthy addition to this series of articles on Scottish water power. The two schemes, taken together, are large by comparison with others in Scotland, and they include various technical innovations. The Garry scheme is the more advanced of the two, and is now substantially completed and is due to be inaugurated to-day, October 5th. The upper section of the Moriston Scheme is almost as advanced (power is expected from it soon), but the lower section will not be producing power until next year. The Garry scheme includes, amongst its more interesting technical features, a rockfill dam at Quoich (shown in Fig. 1), and a horizontal turbo-alternator set—largely an experimental arrangement—in its upper power station. In the Moriston scheme, the Trief process, using blast-furnace slag, has been used for the mass concrete of the two dams of the upper section and some other works. And the two power stations of the scheme are being built underground, with similar hydraulic characteristics so that three identical 16MW turbo-alternator sets can be installed as the principal generating plant of the scheme.

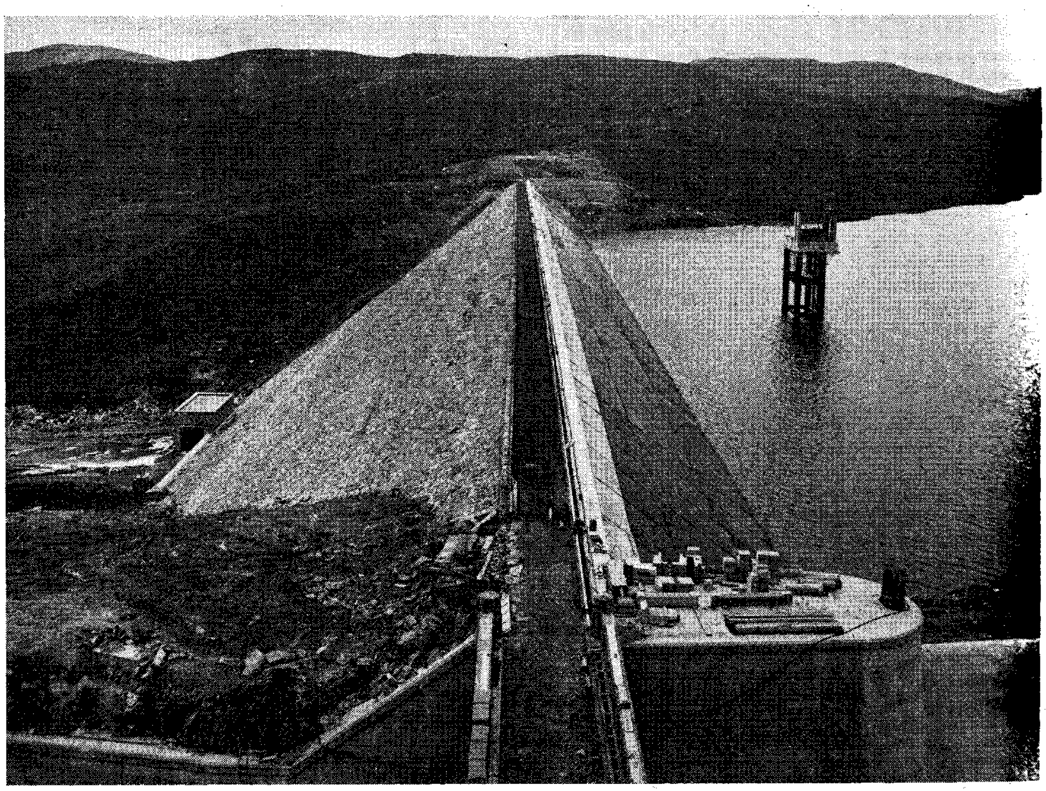

Fig. 1—Quoich rockfill dam. The reinforced concrete slabs on the upstream face comprise the sealing membrane. The downstream face is of hand-packed stone ; the bridge in the foreground spans the spillway channel

Although the two schemes are nominally distinct, it is convenient to consider them together here, particularly on account of the history of their promotion, in which a familiar theme in the promotion of Highland hydro-electric schemes recurs. Bills for the West Highland scheme, and the Caledonian scheme, as the development of the Garry and Moriston rivers was variously called, were placed before Parliament four times in the decade or so before the war, and as often rejected. It was not until after the formation of the North of Scotland Hydro-Electric Board that the Garry and Moriston schemes could go ahead.

The Board's schemes for the two rivers did not differ radically from the earlier rejected schemes, but paid much more attention to "amenity" and to the needs of agriculture and salmon. These matters do not go to the heart of the pre-war opposition, however, and it may be of interest to recall here some facts from THE ENGINEER of March 27, 1936, at the time when the first attempt at promoting the Caledonian scheme had just been rejected. The Bill had been promoted by the British Oxygen Company with the object of utilising a source of cheap power for the manufacture of calcium carbide. Manufacture of carbide in Britain was considered a national asset by the Bill's supporters ; but its opponents considered that a factory should, instead, be erected in South Wales, which was then a distressed area. We described the proposals in some detail, showing the various works on a map, and pointing out that the scheme would be capable of generating about 50,000 h.p. continuously, i.e. about 327×10^6kWh

* No. I : "An Introductory Survey," appeared July 14, 1950 ; No. II : "The Loch Sloy Project," July 21-August 4, 1950 ; No. III : "The Fannich Project," June 8-15, 1951 ; No. IV : "The Mullardoch-Fasnakyle-Affric Project," April 11-25, 1952 ; No. V : "Some Schemes for Local Supply," October 16-23, 1953 ; No. VI : "The Tummel Garry Scheme," September 2-23, 1955 ; No. VII : "The Shira Scheme," April 20-27, 1956.