Calder Hall

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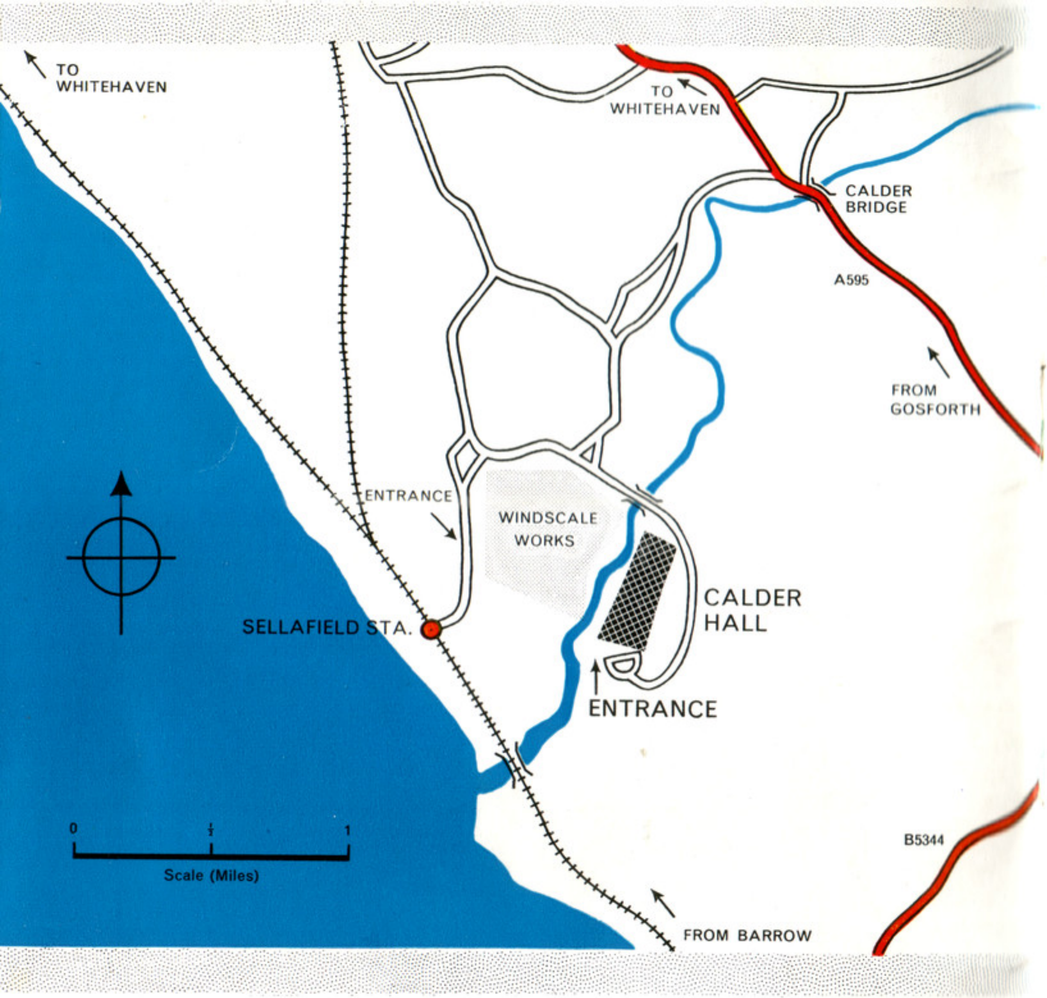


How to get to Calder Hall . . .

CONTENTS

1: FOREWORD

The commissioning of Calder Hall marked the dawn of the age of nuclear power and its opening by Her Majesty the Queen on 17th October, 1956, was greeted with world-wide acclamation. It was the world's first full-scale nuclear power station, and the success with which it has been operated, at steadily increased rates of heat output, proves the soundness of the original design and the skill with which it has been built and operated.

This booklet explains to the interested visitor the construction, operation and significance of Calder Hall. Several thousand visitors are welcomed every year for conducted tours round the reactors.

Parties can be conducted round Calder Hall by arrangement with the Visits Liaison Officer, Windscale and Calder Works, United Kingdom Atomic Energy Authority, Sellafield, Cumberland.

2: SUMMARY

How a Calder Reactor Works.

Inside the reactor heat is released by splitting uranium atoms — nuclear fission. Uranium is the only element found in nature containing atoms which can be made to split, if hit by a slow neutron. The split divides the atom into two, and releases heat and two or more high-speed neutrons. These fast neutrons are slowed down by a graphite moderator surrounding the uranium fuel. Some of them then hit and split further uranium atoms. And so a chain reaction is brought about. The chain reaction is regulated by the use of neutron absorbing control rods.

To take the heat away for conversion into electricity, carbon dioxide gas is blown through the reactor core in which the controlled chain reaction is maintained. The heated gas is used to raise steam in heat exchangers. The steam powers conventional turbine driven alternators which produce electric power.

Calder Construction and Performance.

Design study work began in 1951 on a dual purpose reactor system, to produce plutonium for defence purposes and electricity for peaceful purposes. Construction of the first two reactors and turbine hall, now known as Calder A, began in 1953. Before Her Majesty the Queen opened these on 17th October, 1956, work had begun on a second pair of reactors and a second turbine hall, immediately adjacent and known as Calder B. Exceptionally high standards of welding, purity, accuracy and cleanliness were required, as well as care in programming the work and ingenuity in surmounting complex and novel problems for the first time.

Since the start of operation, heat and thus steam output have been increased steadily to well beyond the original design expectation : and reblading the turbines has increased the net electrical output capacity from 34.5 MW to 45 MW per reactor. However, there is still surplus steam for process steam and space heating on the site.

A further improvement is that the shut-down period for fuel changing and maintenance has been more than halved. In addition, the reactors are used as a test bed to gain advance experience by simulating conditions in nuclear power programme stations.

Development from Calder.

The four-reactor station at Chapelcross in Dumfriesshire is virtually a repeat of Calder Hall and was built for the same purposes. But, even before Calder A was commissioned, the Government decided, in 1955, to embark on a nuclear power programme divorced from plutonium production : such was the confidence in the Calder design. This programme was subsequently accelerated in 1957 and then extended, in 1960, to reflect short-term trends in the relative economics and availability of coal, oil and nuclear power. All the eight large nuclear power stations built or under construction in Britain under that programme are direct developments from Calder. They are known as " gas-cooled graphite moderated reactors ", or as " magnox " reactors, because of the magnesium alloy fuel cladding.

Developments arising from the research programme include an Advanced Gas-Cooled power reactor system, of which an experimental example has already been built at Windscale and a High Temperature Gas-Cooled Reactor system at Winfrith in Dorset. An alternative reactor system, the experimental fast breeder reactor, cooled by liquid metal, began operation in December, 1959, at Dounreay, Scotland.

A Tour of a Calder Reactor and Turbine Hall.

Silence, cleanliness and absence of smoke and smell are the striking features of a nuclear as compared with a fossil-fuelled station, as will be found when you stand on the pile cap or top of the reactor. The fuel element charge and discharge machines and the small control rod motor housings are conspicuous. You may also see T.V. cameras or other special equipment for examining the inside of the reactor. In the burst cartridge detection room below you will see the " sniffers " which, making noises like crickets, sample the gas in each channel every thirty minutes to detect escape of radioactivity from the fuel element cans. Below that, again, in the Control Room, the reactor controller is able to take whatever action is called for by the readings on the various dials and recorders.

At ground floor level you will pass the powerful blowers forcing the gas coolant through the reactor core : but you will not get as close to the less accessible heat exchangers on the outside of the reactor. In the equally noisy turbine hall, you might almost imagine that you were in an ordinary power station ; and you will notice the dump condensers for shedding unwanted steam. As each of the reactors is the same, you will not miss anything by visiting only one.

3: HOW A CALDER REACTOR WORKS.

All electric power stations, whether nuclear or oil- or coal-fired, use fuel to produce heat, which is converted to steam, which drives electricity-producing turbo-alternators. The turbine, which is rather like a set of paddle wheels driven by steam, drives the alternator or electricity generator. The real difference between a nuclear and other power stations lies in the way the heat is obtained.

The burning of coal to produce heat is a chemical reaction involving the *combination* of different kinds of atoms to form groups or clusters. A nuclear reaction involves the more fundamental process of *splitting* atoms. Whereas many materials will produce heat by chemical reaction, only very few types of atom can be made to split or " fission ". The best known substance in which fission can take place is uranium, or more precisely the U.235 isotope.

Most elements consist naturally of a mixture of two or more isotopes : that is of atoms which are alike in their number of protons and electrons but differ in the number of neutrons within their nuclei. It is the protons and electrons which determine the element and its chemical properties. The number of protons and neutrons determines its atomic weight, which is expressed as a figure on the atomic scale. This is based on the atomic weight of hydrogen which is 1.

In its natural state the element uranium contains 139 atoms with atomic weight of 238 to every one of weight 235.

A U.235 atom will split if hit by a slow neutron. The split will produce two parts known as fission products : and two or more fast neutrons and heat. The new fast neutrons have a preference for the numerous U.238 atoms but, if they are slowed down, some of them will hit and split the fissionable U.235 atoms ; and so maintain a chain reaction. Graphite is a moderator, that is it slows down or moderates the speed of fast neutrons. Therefore, the units of uranium fuel are surrounded by graphite in the reactor; and the chain reaction is prevented from dying out. On the other hand, the rate of reaction is prevented from running wild by controlling the number of available neutrons with neutron absorbing boron steel rods. These are moved in and out of the reactor from the control room by small electric motors which stick up through the pile cap floor. They are electromagnetically suspended so that they drop fully home by gravity, to shut down the reactor in the event of electrical failure. This is one of many safety devices. The normal movement of the control rods is very finely controlled and can be measured in hundredths of an inch.

Meanwhile, some slow neutrons are caught by U.238 atoms instead of bouncing off them. This process transmutes naturally-occurring uranium into a man-made metal : plutonium. Plutonium atoms will split when hit by neutrons, so that it can, in more advanced reactor systems, be used as a fuel like uranium. The traces of plutonium in irradiated fuel elements taken from the reactor are separated from depleted uranium and waste fission by-products, and refined into plutonium metal, in large plants in the adjacent Windscale Works.

To start the reactor, the charge machine lowers six fuel elements individually on top of one another into each of the 1696 fuel channels in the graphite core. The control rods are then slowly raised. After they are withdrawn a certain amount, the reaction will increase without further movement of the rods. At this stage the reactor is said to have " gone critical ".

Each of the ten thousand-odd fuel elements consists of a natural uranium metal rod about 40" long and approximately 1" in diameter sealed in a finned magnesium alloy can. The objects of the can are to contain the waste fission products and plutonium, to assist heat transfer and to prevent oxidation of the uranium by the gas coolant. The reliability in operation of the reactor depends heavily on the purity of the metal rod and the efficiency of the sealing and heat transfer properties of the can. The rods are made at the Springfields factory of the U.K.A.E.A. near Preston, where they are also sealed into cans made by government factories and private industry.

The reason for the fins on the fuel element cans is the same as for the fins for air-cooling a motor cycle engine, namely to assist heat transfer. In a reactor, however, carbon dioxide gas is blown through the fuel channels under pressure to take away the heat into heat exchangers outside the reactors. The heated gas passes down the heat exchangers and yields its heat to an interwoven, independent tube system containing water, which is converted into high pressure and low pressure steam. The steam drives conventional turbines which drive conventional electricity-generating turbo-alternators. The differences between the actual gross and the net electrical output exported to the national grid system are mainly accounted for by the electricity consumed in driving the gas blowers and ancillary equipment.

In essence, then, a Calder reactor consists of a large stack of graphite bricks with channels running through it containing some ten thousand sealed uranium fuel elements in which heat is produced by fission. The heat is taken away by forcing carbon dioxide gas through the system. Unless faults develop, such as tiny leaks in the fuel elements, the reactor can go on working day and night for two or three years on the same charge of uranium.

As will be seen in the next section, the reactor core is heavily shielded by a welded steel pressure vessel and a concrete biological shield, to protect the operators outside from the intense radiation inside. For the same reason, the machine for unloading irradiated fuel elements, the fuel element discharge machine, is very heavily shielded. It weighs some 60 tons, whereas the charge machine weighs only 12 tons.

4: CALDER CONSTRUCTION AND PERFORMANCE.

(a) Construction.

Work began in August, 1953 and the timetable required the first reactor to be in operation within less than three years. Very careful planning of the work was needed so that men, materials and equipment were all in the right place at the right time. Similar careful planning had been used before for the construction of uranium, diffusion and separation plants and for the (later abandoned) Windscale piles ; and was to be used again later for the Chapelcross station. In every case the work was finished on time.

The weight of the reactor core, the turbines, the blowers and the heat exchangers required heavy foundation work. Each reactor foundation raft is a slab of concrete 130 ft. long, 104 ft. wide and 11 ft. thick, containing 10,000 tons of concrete. Each of the 24 ft. high concrete plinths on which the turbo-alternators rest weighs 1,800 tons and was formed in one continuous operation in six hours.

On the reactor raft the octagonal concrete biological shield was built in stages ; 7 ft. thick, 46 ft. between opposite walls and 90 ft. high and truly vertical to within ½ inch. The high density concrete was checked by sampling each batch before use. Concrete shrinks as it dries and so, to avoid distortion, as little water as possible was used in the mixing. The problem of providing enough cranes and hoists to move the building materials without allowing the lifting equipment itself to get in the way was met by careful advance planning. The actual operations were rehearsed on scale models of the cranes and buildings.

The building up of the biological shield and the erecting inside it of five hundred 6" thick mild steel plates each weighing 3 tons, to form the thermal shield, had to go on before the components of the pressure vessel were available for assembly. This meant that all those components had to be hoisted up over the biological shield and lowered inside it.

First, ten great steel legs, in the form of inverted A's, and then the bottom manifold carrying the return gas ducts were lowered inside after welding on site. Next the bottom dome of the pressure vessel had to be lowered on to the " A " frames, after being welded into a unit upside down on the site. The lower ring section was inserted next and welded on to the bottom dome. Then the " diagrid " went in—a great ring of criss-cross steel girders to carry the whole weight of the graphite and uranium fuel (well over 1,000 tons). It had to be located inside the bottom dome exactly over the supporting " A " frames outside the vertical rings. Lastly, the upper dome and the top dome were hoisted over and welded up.

The hoisting of these lifts of up to 90 tons was done by a 100 ton derrick on a 90 ft. tower, affectionately known as " the big stick ". The plates of the steel pressure vessel are 2″ to 4½″ thick. At the time fabrication in those sizes and site welding to those thicknesses was no mean achievement.

The completed vessel was stress relieved by being heated to 500°C. and allowed to cool slowly. It was also pressure tested to 135 lbs. per square inch to ensure safety at a working pressure of 100 lbs. per square inch.

Following this, the fuel charge tubes were welded to stubs in the top dome, to a high degree of accuracy because of the fine limits required for lowering or raising fuel elements through single tubes to each of 1696 channels many feet below.

One of the main requirements during construction is cleanliness. For this reason the inside of the pressure vessel was scrupulously cleaned as a preliminary to laying 58,000 graphite bricks of various shapes to form the reactor core and moderator—approximately 36 ft. across by 27 ft. high. Each brick was numbered and vacuum cleaned before being passed into the vessel through one of the top gas ducts ; and each man had to change all his clothes in a special changing room before going in to lay bricks. These careful precautions were taken in order to avoid any possibility of neutron absorbers or other extraneous matter being left inside the reactor core. At this stage of construction the wiring of the thermocouples (which form an integral part of the system of reactor control) was carried out. After the graphite was laid and the thermocouples wired, gas sample tubes for the burst cartridge detection gear were placed in the fuel channels, and the reactor was complete.

The lid had then to be put on the steel thermal shield and the concrete biological shield box containing the pressure vessel. Bailey Bridges were erected to span the top of the walls. Angle strips were hung in place to form ledges on which the 6″ steel plates of the thermal shield would rest. Then more angles were fixed to support a separate 1″ thick steel floor six inches above the plates. This became the permanent shuttering (the frame which forms a mould for the concrete) for the 8 ft. thick concrete shield, which was poured onto this floor in four pours. Apart from the lack of room for manoeuvre due to the projecting charge tubes, other difficulties were that the shuttering had to be concaved to compensate for the convex sag of the Bailey Bridge supports ; and that careful sealing was necessary to avoid concrete seeping round the tubes. When the concrete was set the bridges were removed.

At each of the four corners of the reactor building, an 80 ft. high heat exchanger weighing 200 tons was lifted on to its concrete plinth after being welded, stress relieved and pressure tested on site. Each heat exchanger contains about 11 miles of tubing which carried 11 million studs for increasing the heat transfer surface. The banks of tubes were welded into the heat exchanger shells on site under the same strict standards of control and cleanliness as in the graphite laying. The heat exchangers were so designed that the welds joining the water tubes to the vessels were outside the vessels, to minimise risk of an internal leak with the reactor in operation. It is particularly important to avoid this because the heat exchanger represents the boundary between the clean steam for the turbines and any radioactivity which might be present in the carbon dioxide coolant gas.

Also round the core building, work was proceeding on the control room, fuel preparation room and gas-blower houses (one blower per heat exchanger). Further away, the turbine hall, the 300 ft. high cooling towers, the electrical sub-station and the office building were following their course of conventional construction.

The finishing touches on the pile cap were the placing of the 48 boron steel control rods and their driving gear, and the installation of the charge and discharge machines and overhead crane which services them.

The first reactor went critical in May 1956 and Calder Hall A was officially opened on 17th October, 1956. Construction of Calder B began in August, 1955. Its first reactor was commissioned in the summer of 1958 ; and the other in March, 1959.

(b) **Performance.**

(i) **Output.**

Heat output per reactor has been increased from a designed 180 MW by stages to 225 MW per reactor (an overall improvement of 25%). The original designed output of the turbo-alternators was 21 MW subsequently improved to 23 MW without modification of the original design. The increase in heat output of the reactors has led to a programme of turbine reblading further to increase the capacity of each turbine to 27 MW (electrical)—an improvement of 28% over the original designed output. These increases have been built up gradually, and not at the expense of reliability or safety. They are testimony to the skill of the designers, constructors, operators and fuel element makers, and to successful co-operation between the many specialised interests involved.

Apart from electricity, the reactors continue to produce, in the fuel elements, plutonium as required for military and other purposes. In addition, large quantities of cobalt have been irradiated in the reactors for commercial use. Lastly, there is still surplus steam after powering the increased electricity output. This is used to provide process steam and space heating on the Windscale site.

(ii) **Maintenance.**

From a maintenance engineer's point of view, the reactors present problems which are different in degree rather than in principle from maintenance problems of conventional power plants. The three main differences are, that work may be restricted by radiological health and safety factors (because of radioactivity and radioactive contamination), that the high cost of the plant makes it vital to cut down " outage " (that is shut-down time) ; and that the complexity of circuits and components presents exceptional problems of co-ordination in maintenance.

The achievement of the plant engineers is that they have more than halved the period of shut-down for fuel changing without any sacrifice of safety or reliability. One reactor has successfully completed twelve months' continuous operation at full load for 95.6% of the time. Load factors of well over 80% overall have been achieved by all the reactors and compare favourably with conventional power station achievement.

The main obstacles to rapid overhaul are that some jobs have to be completed before others can start and that some items involve dovetailing of work by mechanical, electrical and instrument engineers. The key to the answer is maintenance planning. The planning engineer works out an interlock of work to complete constituent jobs in such a way

that an overall completion date is calculated in advance. This analysis of the job is presented on a bar-chart (a bar-chart is a sort of multiple, horizontal equivalent of the vertical graph often used to represent progress in raising funds for charities). The planning engineers record actual against target progress daily during the course of the shut-down period. The maintenance engineers work round the clock if a set-back makes this necessary to secure completion of their job by the scheduled date. Failure to meet a date could throw out the remainder of the programme.

A conventional example of the interlocking of work is the shut-down maintenance on the gas circulators, or blowers. The mechanical staff remove the casing, while the electrical staff remove the brush gear to enable the commutator to be turned. When that has been done the electrical staff undercut the commutator segments, while the mechanical staff dismantle the remainder of the mechanical portion of the blower to check and adjust shaft alignment. The electrical staff then remove, clean and re-varnish the driving motor. Electrical and mechanical re-assembly follows simultaneously. The radiological aspect is illustrated by the fact that the inside of the blower casing will be contaminated. Special precautions, including the wearing of protective clothing and breathing apparatus, safeguard people working inside the casings.

The facts that some safety circuits must be available for instant use even when the reactor is nominally shut down, and that each circuit has to be tested as a unit after re-assembly, illustrate what has to be contended with on the instrument side. The safety circuits are designed to ensure that the reactor will " fail to safe " (i.e., shut down automatically) in the event of a fault. The difficulty in meeting this requirement is shown by the fact that there may be three or more circuits to initiate a particular " trip ", just in case a fault should develop in one of them.

(iii) **Experiments.**

A considerable amount of experimental work has been undertaken on the Calder reactors, particularly for the civil power programme. While it is not possible to simulate exactly conditions in commercial power reactors, it has been possible to gain advance experience, particularly with regard to fuel elements. It was, for example, re-assuring to find that Calder Hall fuel elements have proved reliable throughout periods of irradiation in the reactor several times longer than they were designed to sustain.

Two representative examples must serve to illustrate the variety of experimental work undertaken.

Fuel changing on commercial nuclear power stations is done with the reactors on power. This means that fuel elements in channels adjacent to those in which fuel elements are being changed would be subjected to changes of temperature—known as thermal cycling. It also means that the new fuel element being inserted would be subjected on insertion to a rapid increase in temperature. How would the fuel elements react ? To find out at Calder (where fuel changing takes place with the reactors shut down) it was necessary to simulate on-power fuelling. The thermal cycling test was performed by oscillating adjacent control rods up and down for approximately 13,000 cycles. Adjustment of the gas flow and use of a spare control rod mechanism for insertion and positioning of the test element enabled the required conditions to be simulated for the on-load insertion experiment. Subsequent examination of the test elements revealed no ill-effects in either case.

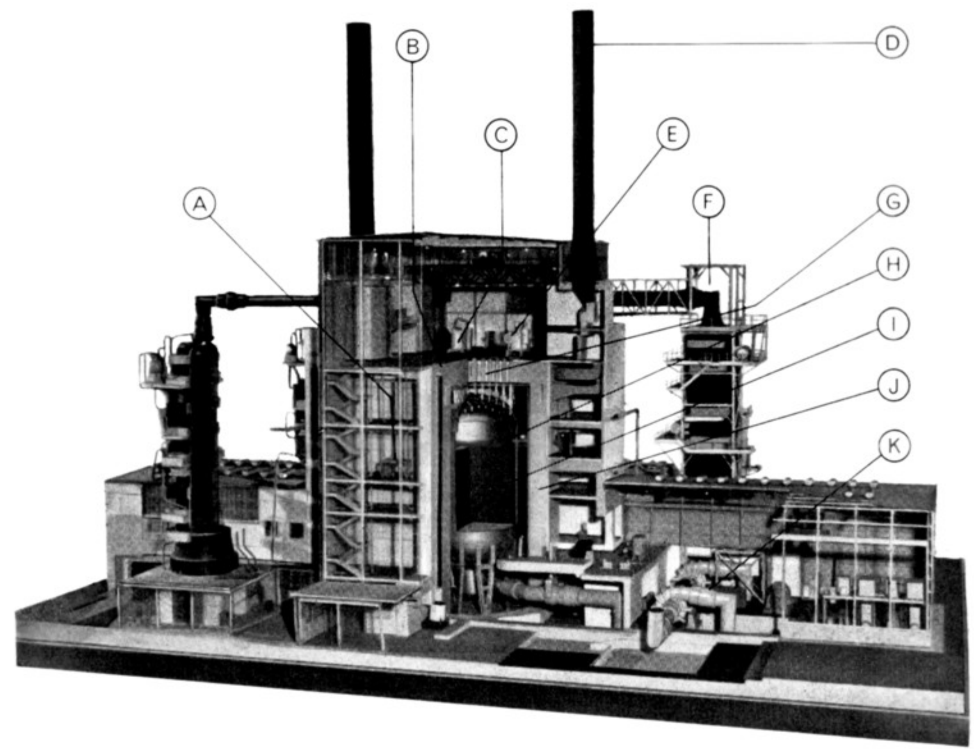
Another exercise was to examine the effects of several years of irradiation on the graphite moderator in a Calder reactor. Two methods were devised with the help of specialist industrial firms. First, a miniature T.V. camera, only 3″ in diameter, was developed to examine inside the reactor the gaps between the graphite bricks which had been left during construction to allow for graphite growth. The changes after five years measured in this way agreed with predictions. Secondly, a cutting tool, on the end of 50 feet of hose containing the pneumatic, hydraulic and electrical control circuits, was devised to cut small samples from the graphite in the reactor for examination. In addition, accurately machined 1″ cubes of graphite which had been placed in the reactor during construction have been removed during shut-downs for measurement of dimensional changes.

There is also an extensive programme concerned with the monitoring of the effects of temperature, pressure and irradiation on steel and weld metal used in the manufacture of the pressure vessels.

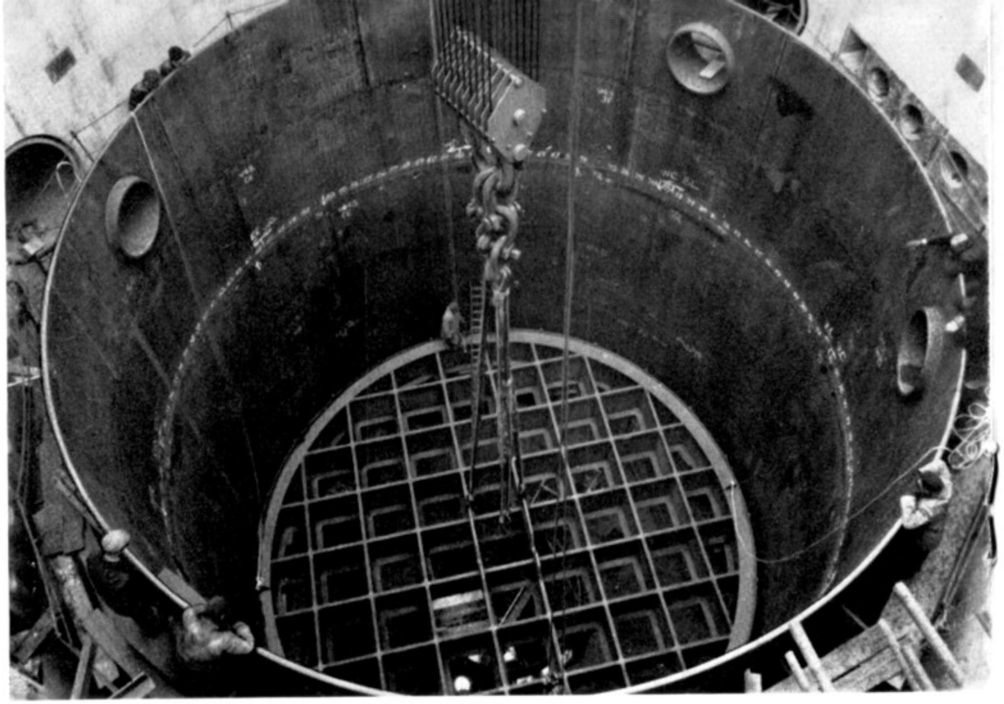
5: DEVELOPMENT FROM CALDER.

The four-reactor station operated by the U.K.A.E.A. at Chapelcross is virtually a repeat of Calder Hall and was built for the same purposes. The last of the four reactors was commissioned in May 1960. Together, the eight reactors of the two stations send out more than 2,000 million units of electricity annually.

The three stages of government policy decision on the British nuclear power programme have been first, in February 1955, the announcement of a programme to build 12 stations with a total capacity of 1,500-2,000 Megawatts by 1965 ; secondly, in March 1957, the decision to increase



A Personnel lift
B Charge face
C Discharge machine
D Ventilation chimney
E Charge machine
F Heat exchanger
G Charge tubes
H Pressure vessel
I Graphite core
J Biological Shield
K Blower house

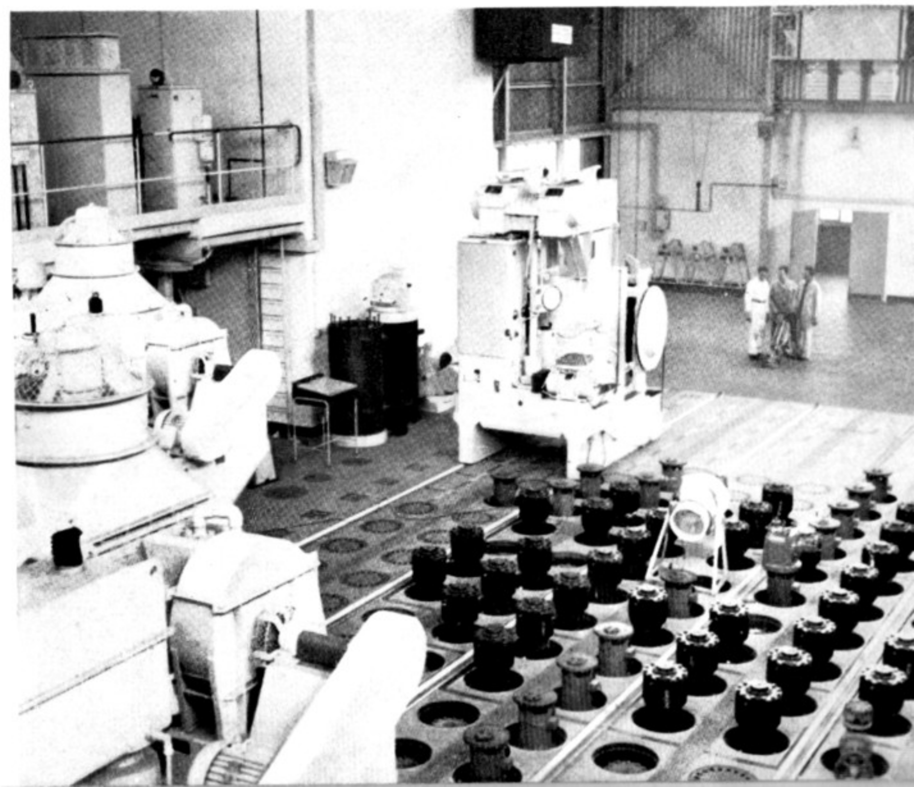


The diagrid on which the reactor core rests.

Fuel element " baskets " used for loading and unloading.

General view of the Turbine Hall.

General view of the charging deck of No. 1 reactor Calder Hall power station, showing one charging and discharging machine.



The burst slug detection gear.

The No. 1 reactor control room at Calder Hall showing the control desk and the instrumentation.

that aim to 19 stations with a total capacity of 5,000-6,000 Megawatts by 1965 ; and thirdly, in June 1960 the decision to stretch out the accelerated programme to achieve 5,000 Megawatts of capacity by 1968. The reduction in the nuclear power programme since 1957 has been one of pace rather than policy. The changes that have taken place have been primarily economic rather than technical. In place of the expected shortage of conventional fuels, prospects of supplies to meet rising demand in the present decade improved. At the same time greater improvements than were expected in the design of coal and oil-fired power stations have resulted in better thermal efficiencies and lower capital costs ; in addition the costs of the early nuclear power stations have been higher than originally expected, although later magnox stations are expected to have generating costs very near those of new conventional stations.

The Central Electricity Generating Board and the South of Scotland Electricity Board order and operate the commercial nuclear power stations. Three Consortia of industrial firms design and build them. The Authority acts as technical consultants to the Boards and collaborates with Industry, as well as being responsible for the production of fuel elements to meet the agreed design specification of the customer. The contracts for the first two stations were placed in December 1956. Before that the designs of the competing consortia had been developed into detailed tenders for the contracts for twin-reactor stations of 275 MW-300 MW capacity to be built at Bradwell and Berkeley, and commissioned about five years later.

In addition to the Electricity Boards and Consortia staff who have been trained in and attached to Authority design offices, engineers and physicists from the Boards and Consortia as well as many countries of the world have been trained in reactor operation at the Calder Operation School and on the reactors themselves. Some 60 operators for the British designed Latina nuclear power station in Italy and the Tokai Mura station in Japan, have been trained at the Operation School. Brazil, India, Argentina, Ceylon and Greece are among the thirty countries who have sent students.

The later stations in the British programme are of 550-580 MW capacity. One of the reasons for this is that the capital cost of all these gas-cooled, graphite-moderated " magnox " stations is high, but reduces in terms of capital cost per kilowatt of electricity sent out as the size and output capacity is increased. Once operating, however, the fuel replacement cost is low compared with fossil-fuelled stations. One ton of uranium fuel used in this type of station is the equivalent of 10,000 tons of coal ;

and one lorry can keep a nuclear power station in fuel, compared with the trainloads of coal required by a conventional station. It remains to be seen whether the commercial stations developed from the original Calder design will remain in dependable and safe operation for longer than the twenty years assumed in the computations of their economics ; and so make them prove cheaper in retrospect than calculated in advance. At least the better-than-expected performance of the Calder reactors to date is encouraging.

The philosophy at the outset of the 1960's is of a three-fuel economy—coal, oil and nuclear power. The prospect for nuclear power is a break-even in cost with conventional power by about the end of the decade ; and the potential for cheapening from that point by successful development of more advanced power reactor systems is very considerable. That is as well, because high capital cost nuclear stations are best used as base load (" round the clock ") stations. Many other stations must come in to meet the morning and evening peak power demands, but remain unproductive the rest of the day.

It is the duty of the Authority to pioneer new power reactor systems. Development and design effort are concentrated on an Advanced Gas-Cooled reactor system ; on the Fast Breeder reactor ; on the High Temperature Gas-Cooled reactor system and on the Steam Generating Heavy Water reactor system in collaboration with Canada.

Each stage of progress from Calder power reactors poses increasingly advanced problems of many kinds, particularly investigation of properties and compatibility of materials and development of methods of fabrication. For example, the 2″ steel pressure vessel plates at Calder were followed by 3″ and then 4″ in later magnox stations ; and the implications of stainless steel and beryllium instead of magnox as a fuel cladding and of sodium instead of carbon dioxide as a coolant, are under investigation and development respectively for the A.G.R. and Fast Reactor systems. The essence of the task is to push up operating limits (temperature, pressure, etc.) safely, so as to reduce the capital cost per unit of output and to obtain better fuel utilisation.

6: A TOUR OF A REACTOR AND TURBINE HALL.

Approaching Calder.

The Windscale and Calder Works are on the West Cumberland coast, just north of Seascale, between Whitehaven and Barrow. The site is approached by road by turning off the A.595 at Calderbridge : and by rail by alighting at Sellafield Station close to the Works. By either

approach, the visitor is impressed by the tall chimneys and great bulk of the disused Windscales piles and the 200 ft. chimney on top of the 10 storey 200 ft. high chemical separation plant for processing irradiated reactor fuel elements. Newer and neater is the pear-shaped dome of the compact experimental A.G.R. installation.

The Calder reactors lie to the south and east, just across the River Calder : and with Lake District Fells in the background. Calder A and Calder B each consists of a pair of reactors with a turbine hall between them and a pair of cooling towers at either extremity of the layout. The visitor will notice the bright and cheerful colour scheme for the four heat exchangers per reactor : and, as he or she goes round a reactor, the high standard of cleanliness.

Fuel Element Preparation Room.

One floor below the pile cap in the reactor building is the fuel element preparation room, to which you go first, by lift. The fuel elements arrive from the U.K.A.E.A's. Springfields factory in steel cases like ammunition boxes. Each fuel element is individually wrapped in polythene. After unpacking and final examination, they are stacked in charge baskets, each of which holds 24 fuel elements. At this stage they are quite safe to handle. Each fuel element is 40 inches long and weighs 28 lbs. The loaded basket is hoisted to the charge machine on the pile cap for loading into the reactor.

Charge Floor (or Pile Cap).

This is over the top of the reactor. On entering, you will notice two fuel element charging machines and two much heavier discharging machines. These run on rails straddling the charge tubes or entrance holes into the reactor. The reactor under you will be working, so these tubes are sealed off with flanges or protruding heads containing control rod mechanism (blue) or measuring equipment (red). You may also see T.V. cameras or other special equipment for inspecting the inside of the reactor many feet below.

To re-fuel the reactor, the control rods are inserted to shut down the reaction, the gas pressure inside the reactor is run down and the heads and concrete shield plugs are removed from the charge tubes. A chute is then inserted to the top of a group of 16 fuel channels and the heavily shielded discharge machine withdraws one irradiated fuel element at a time by means of a grab, and places it in a stainless steel basket inside the machine. The hinged chute is swivelled like a pair of compasses to connect to each channel of the group in turn. When full of highly radioactive fuel elements the basket inside the machine is located over a shielded well, or shaft, running the full depth of the building to the ground floor. The basket is lowered down this well into a heavily shielded steel container. When full, the container is transported by a special low loader to the Windscale cooling ponds, for radioactivity to decay before the fuel elements are processed.

To re-charge the reactor, the smaller charge machine lowers the new fuel elements one by one into each fuel channel—six on top of one another in 1,696 channels. Fuel elements may go on fissioning and producing heat in the reactor day and night for years on end.

Burst Cartridge Detection Room.

One of the reasons for sealing the uranium fuel rods in magnox cans is to prevent corrosion of the uranium by the carbon dioxide gas coolant. Corrosion would lead to radioactive contamination of the whole gas system including the blowers and heat exchangers. The object of the burst cartridge detection gear is to give automatic notice of the onset of the slightest leak of radioactivity into the gas stream of each fuel channel separately.

In a room on the next floor down, eleven blue cylindrical pressure vessels or precipitators are connected by a mass of pipework to the reactor fuel channels. Samples of gas are taken from each group of fuel channels every twenty minutes and passed through the precipitators. Radioactive particles in the gas are attracted to wire charged with a high voltage. The amount of radioactivity thus deposited on the wire from the gas over a period of half a minute is measured by instrument and relayed to the control room below. A high reading can only be caused by a leaking fuel element can in the reactor channel from which the gas came. The progress of the " burst " (which is in fact usually a minute pin-hole not even visible to the naked eye) can be watched in this way to determine whether the reactor should be shut down to change the offending fuel element.

The burst cartridge detection, or " sniffer ", system incorporates over 40 miles of stainless steel tubes.

Reactor Control Room.

Again one floor down, is the reactor control room. The reactor controller's control console is in the middle of the room. He can shut the reactor down at the touch of a button. From time to time he adjusts the speed of the blower motors or the position of the control rods to keep the reactor running steadily. The dials and recorders round the side of the room give him all the data he requires. On the left hand wall are the burst

cartridge detection recorders. On the centre wall is a mimic diagram indicating steam flows and pressure and showing whether the main isolating valves are open or shut. Other panels light up and a bell rings to indicate a fault. The light remains on and the bell ringing until the fault is rectified. Further to the right, the position of each of the control rods in the reactor is shown : and on the extreme right are the relays which operate the automatic safety system. If a fault develops the current holding a relay switch closed fails : the switch is thrown open as a result, and the reactor " trips ".

The Blower Houses.

There are four blowers per reactor—two in each blower house on either side of the reactor building. Each 2,200 h.p. blower blows coolant gas received from the heat exchangers back into the reactor core at the rate of a quarter of a ton of gas per second. To guard against overheating in the reactor resulting from failure of the electricity supply to the blower, there are a pair of stand-by diesel generators and a bank of storage batteries.

The Heat Exchangers.

The heat exchangers are outside the reactor containment building—one at each of the four corners. Water is pumped up the water tubes. Hot gas from the reactor comes down the gas tubes. The steam produced is taken off at two levels—high pressure steam at about 200 pounds per square inch : and low pressure steam at about 60 pounds per square inch. It is fed via a pipe bridge to the turbine hall.

The Turbine Hall and Cooling Towers.

On the upper floor are four sets of turbo-alternators serving two reactors. Each set consists of a turbine driven by steam from the heat exchangers, linked by a shaft to drive its alternator or electricity generator. Each set was originally designed to produce 21 MW but reblading of the turbines has increased this to 27 MW.

The steam used by the turbines is converted back to water in condensers underneath the turbo-alternators. This water is then taken to the cooling towers where it is sprayed down to the pond at the bottom and cooled in the process by the upcurrent of air in the tower. The plumes from the cooling towers and the vapour deposition from them are pure steam or water. From the pond, the cooled water is pumped for re-circulation through the condensers.

CONCLUSION.

Silently, invisibly, inside their shielding walls, the nuclear reactors provide the heat which the steam engineers need. You have seen how the reactor is controlled, how fuel is put in and taken out and you have seen the stringent safety precautions that must be applied. This is the first of the commercial-size nuclear power stations, and the principles you have seen apply also to the new stations being built.

TECHNICAL DATA

CALDER HALL A AND B

CIVIL ENGINEERING

FOUNDATIONS

Sandstone rocks at 60 ft. to 100 ft. overlain with glacial moraine with clay lenses at intervals. Pressure on substrata: 2¾ tons/ft.^{2} from each 33,000 ton reactor.

RAFT (*Carrying Reactor and Biological Shield*)

Material	Reinforced Concrete
Weight	10,000 tons
Dimensions	130 ft. × 104 ft. × 11 ft.
Reinforcing rods	273 tons of ⅞ to 1⅜ steel rods

BIOLOGICAL SHIELD

Shape	Octagonal plan
Dimension	Height 90 ft. Across parallel faces outside 60 ft. Wall thickness 7 ft. Roof thickness 8 ft.
Material	Concrete
Density	Average : 154 lb./ft.^{3}
Weight	9,000 tons approx.

COOLING TOWERS

Number	Four
Dimensions	Height 300 ft. dia., at base 190 ft. dia., at throat 104 ft.
Capacity (*per tower*)	3×10^6 gallons/hour

REACTOR ENGINEERING

PRESSURE VESSEL

Material	Aluminium - killed, high - manganese steel (" *Lowtem* ")
Overall height	71 ft. 6 ins.
Height of vertical wall	36.0 ft.
Inside diameter	37.0 ft.
Thickness of cylindrical shell	2.0 ins.
Thickness of domed ends	2.0 ins. to 4½ ins.
Max. internal pressure	100 p.s.i.

THERMAL SHIELD

Material	500 plates of 6 in. thick mild steel, each weighing about 3 tons. (The plates are not joined, but merely rest on top of each other, supported by vertical soldiers.)

MODERATOR

Material	Graphite, specially manufactured for purity and low neutron absorption
Core height including reflector	27 ft.
Core diameter (*across corners*)	36 ft.
Core weight	About 1,200 tons
Number of blocks	58,000 all interlocking and held in position by 11 restraint rings consisting of 24 steel pieces articulated by knuckle joints

FUEL

Number of fuel channels	1,696 (*per reactor*)
Total charge	130 tonnes
Stacking	Vertically, 6 per channel
Material	Natural uranium
Rod length	40 in.
Rod diameter	1.15 in.
Weight of rod	28 lbs.

CANS FOR FUEL ELEMENTS

Material	" Magnox " magnesium alloy

CHARGE/DISCHARGE GEAR

Charge machine

Weight	12 tons
Capacity	24 elements

DISCHARGE MACHINE

Weight	60 tons
Magazine	CO_2 cooled, demountable, capacity 24 elements
Shielding	30-ton casting surrounding basket

CONTROL RODS

Material	Stainless steel tube lined with 3% boron steel sleeve and 4% boron steel core
Weight per rod	120 lb.
Number (*per reactor*)	48
Suspension	Multi-strand flexible stainless steel cable
Max. speed (*for shut-off*)	4 ft./sec.
Min. speed	0.5 in./min.
Travel	21 ft.
Coarse control	46 rods ganged together
Fine control	2 rods independently operated
Winch mechanism	Synchronous motor of variable type, driving through a solenoid clutch, and an eddy current brake

COOLANT

Gas	Carbon dioxide
Pressure	100 lb. p.s.i.
Flow	9 million lb. per hour
Inlet temperature	140°C.
Outlet temperature	333°C.
Filtering	2% of the mass flow is by-passed through an auxiliary circuit and filtered for graphite dust and iron oxide
Weight	26 tons in pressure circuit
Storage	In liquid form in 5-ton tanks under pressure

BURST-CARTRIDGE DETECTION

Material of tubes	Stainless steel
Number of tubes	1,696 (*one to each fuel channel in eight groups of 212*)
Diameter of tubes	½ in.
Precipitation chambers	Total of 11, designed to operate at gas pressure of 100 p.s.i. Precipitation equipment consists of motor-driven Tufnol pulleys carrying a wire of 0.005 in. diameter, kept at a potential of 4 kV.

MECHANICAL ENGINEERING

BLOWERS

Number	4 per reactor, i.e., one per heat exchanger circuit
Total capacity of all four	2,480 lb./sec. at 284°F. (140°C.) and 100 lb. p.s.i.
Power absorbed	7 MW per reactor

HEAT EXCHANGERS

Four heat exchangers per reactor, each exchanger generating high and low pressure steam simultaneously.

Shell	1 5/16 in. steel plate
Height	80 ft.
Diameter	17 ft. 6 in.
Gas pressure	100 p.s.i.
Weight (*empty*)	200 tons
Tubing	2 in. overall dia. mild steel tubes. There are about 11 miles of tubing to each heat exchanger
Studs	Eleven million studs to each heat exchanger quadruple the effective heat transfer surface

TURBO-ALTERNATORS

Number of sets (*2 per reactor*)	8
Reactor power	225 MW (Th)
Gross electrical generation per reactor	54 MW (E)
Net electrical generation	45 MW (E)
Speed	3,000 r.p.m.
Generator voltage	11,500 V.3 phase 50 c/S.

CALDER HALL TYPE
TWIN REACTOR POWER STATIONS

Nuclear power stations now being built for or authorised by the Central Electricity Generating Board and the South of Scotland Electricity Board are listed below :—

Name	*For*	*Capacity*	*Start-up Date*
Berkeley	C.E.G.B.	275 MW	1961
Bradwell	,,	300 MW	1961
Hinkley Point	,,	500 MW	1962
Hunterston	S.S.E.B.	320 MW	1962
Trawsfyndd	C.E.G.B.	500 MW	1964
Dungeness	,,	550 MW	1964
Sizewell	,,	580 MW	1966
Oldbury-on-Severn	,,	550 MW	
		3,575 MW	

This total represents about one-tenth of the generating capacity already installed in the United Kingdom.

In addition Calder Hall type reactors are being installed at overseas power stations at :—

Name	*Country*	*Capacity*	*Start-up Date*
Latina	Italy	200 MW (one reactor)	1962
Tokai Mura	Japan	150 MW (one reactor)	1965

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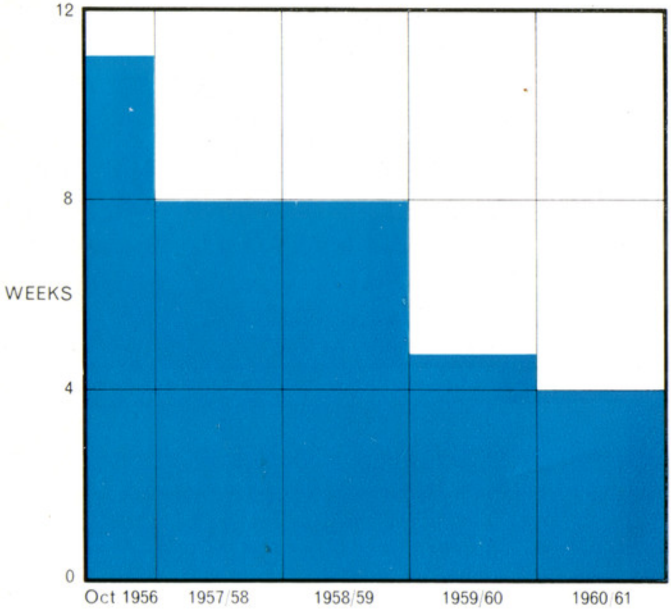
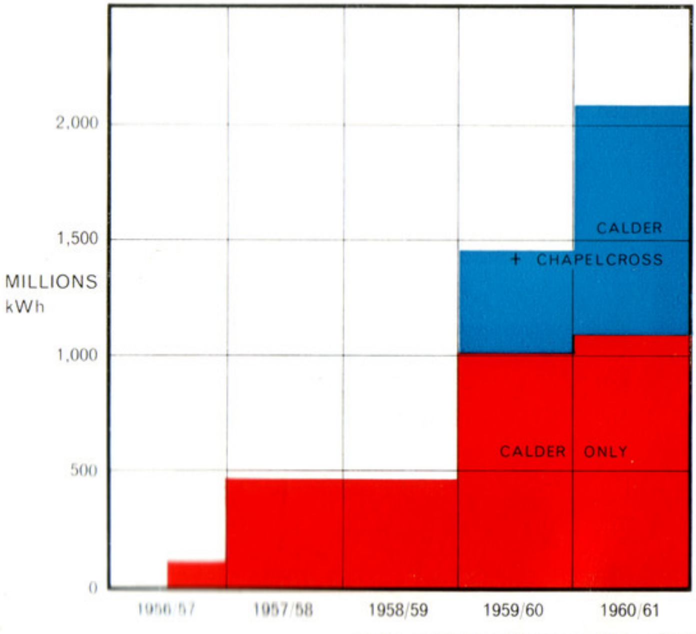
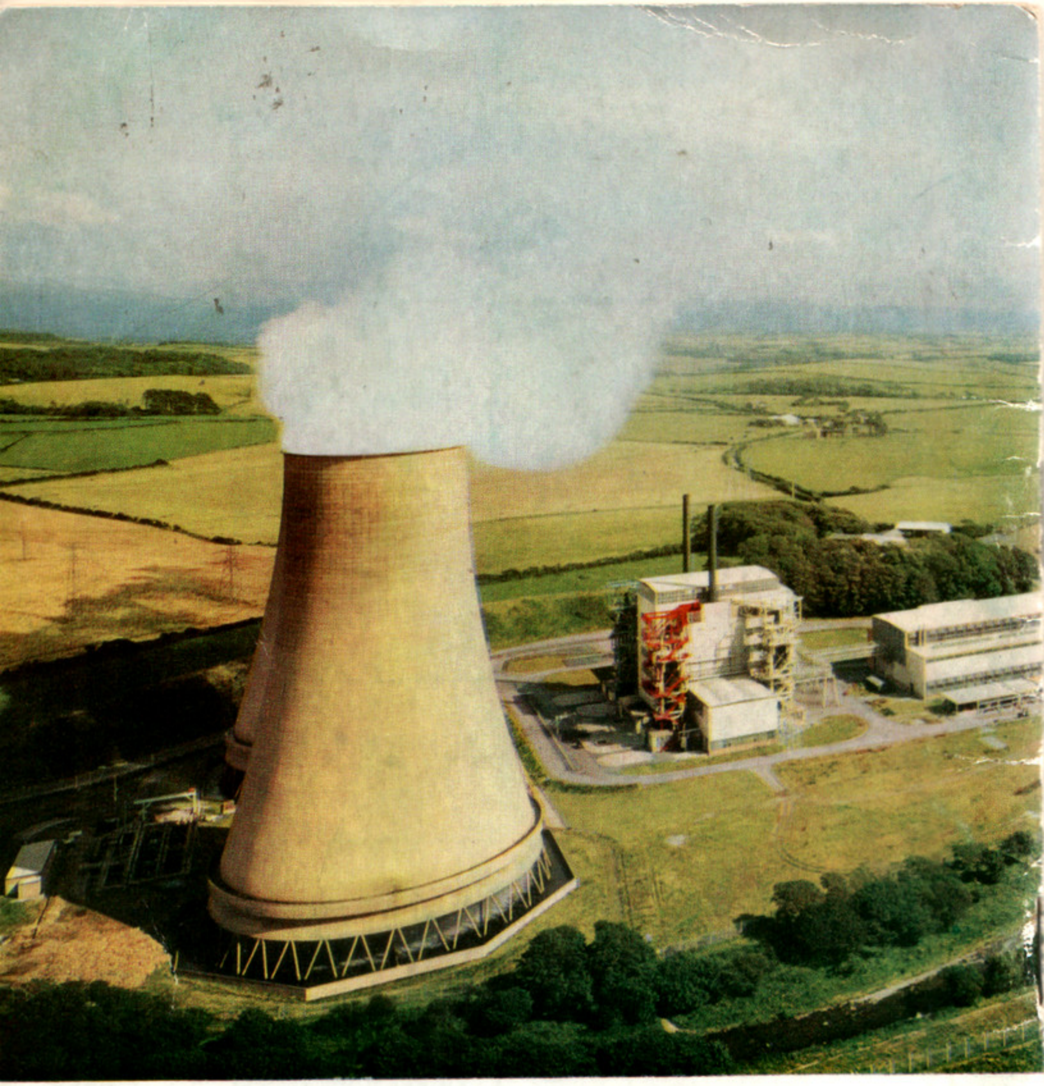


Average time taken to complete the scheduled refuelling and maintenance of Calder reactors.



Total annual nett generation of electricity at Calder and Chapelcross works.



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