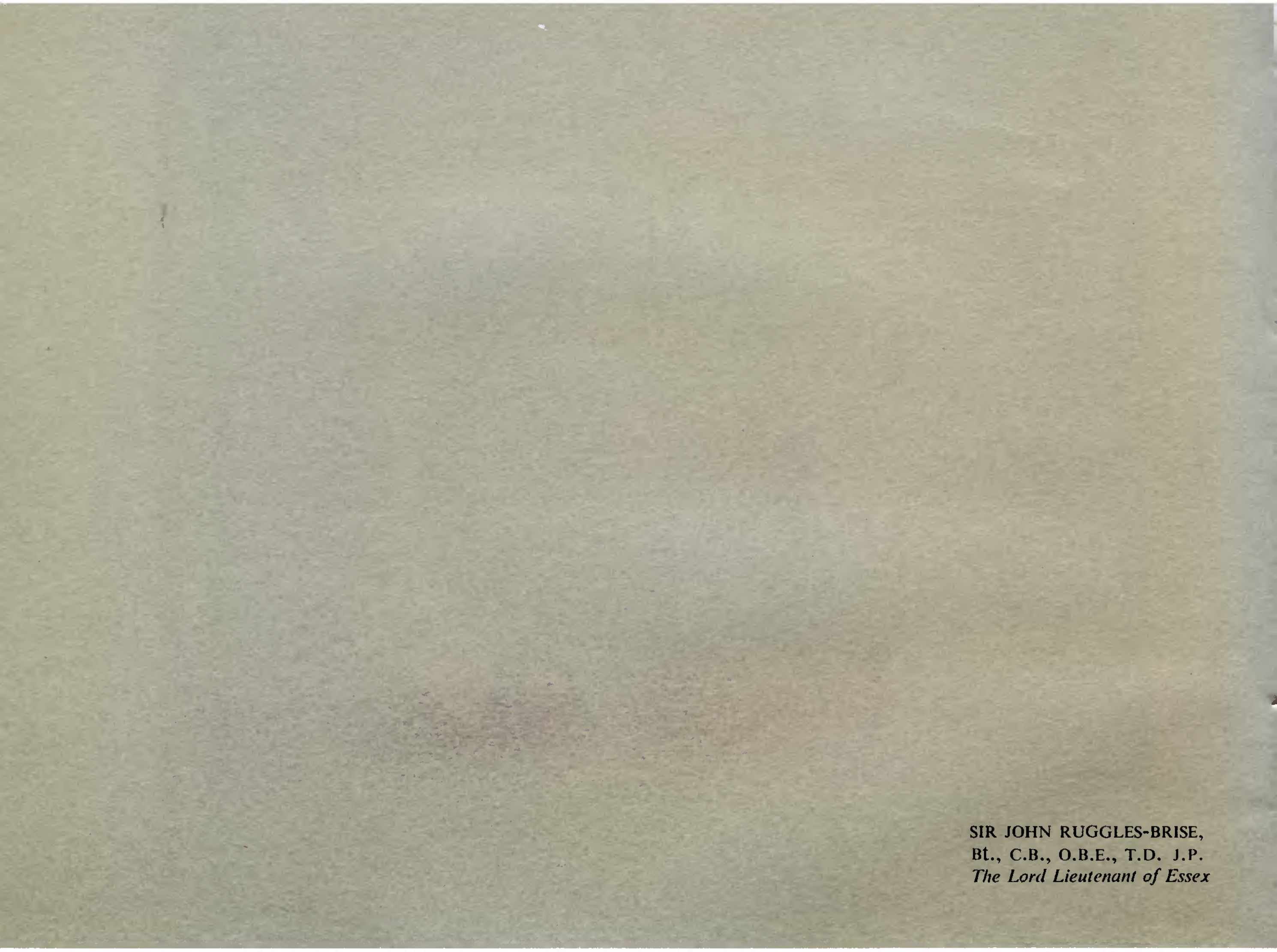
Berkeley & Bradwell

NUCLEAR POWER STATIONS

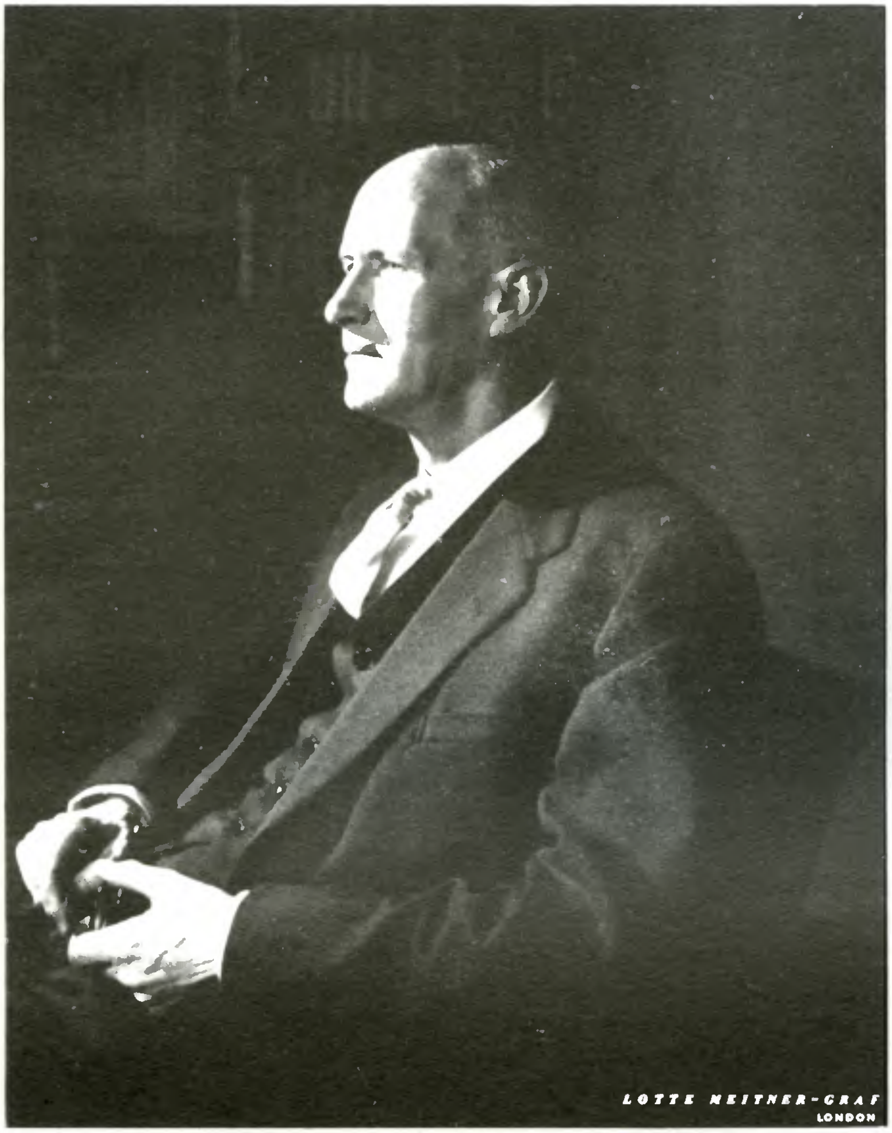
Souvenir
of the inauguration of
Berkeley Nuclear Power Station
by
His Royal Highness
The Prince Philip, Duke of Edinburgh K.G., K.T.
and of
Bradwell Nuclear Power Station
by
The Lord Lieutenant of Essex,
Sir John Ruggles-Brise Bt., C.B., O.B.E., T.D., J.P.
on the 5th day of April, 1963

HIS ROYAL HIGHNESS THE PRINCE PHILIP
DUKE OF EDINGBURGH K.G., K.T.



SIR JOHN RUGGLES-BRISE,
Bt., C.B., O.B.E., T.D. J.P.
The Lord Lieutenant of Essex

SIR CHRISTOPHER HINTON K.B.E., F.R.S.
Chairman, Central Electricity Generating Board



LOTTE MEITNER-GRAF
LONDON

Supergrid Transmission and Nuclear Development in England and Wales

All over the world the demand for electricity is steadily rising. Not only do modern industrial methods call for more and more electrically driven machinery but the rising standards of living are reflected in the domestic consumer's increasing use of the many forms of electrical labour-saving devices.

It is no surprise that the industrial and domestic demands for electricity continue their smooth and continuous rising trend. In England and Wales the slope of this increasing trend may even be getting steeper.

The undoubted success of the electricity supply industry has however brought with it serious problems. Electricity cannot be stored, so when the housewife switches on a fire or the factory worker starts up a machine, the generating plant has to be running at that instant to meet the additional load.

There must therefore be an enormous building programme to provide the power stations to meet the rapidly growing demand; the rate of growth is such that to meet it, every ten years as much additional plant has to be built as the total capacity available at the beginning of the period.

In 1953, the maximum output capacity of the system was just over 14,500 megawatts; ten years later in 1963 it was over 31,500 megawatts.

Very large sums of money have to be spent constructing this new generating capacity; £1,350 million was spent on generating plant in the ten years up to 1963, quite apart from the industry's investment in transmission and distribution facilities.

Three Fuel Economy

Electricity generation is essentially a fuel-processing industry, the refined end-product of which is electrical energy. The Generating Board's power stations are at present burning 58 million tons of coal-equivalent a year and by 1970 will burn about 100 million tons a year. But as the ceiling target output of the National Coal Board is 200 million tons a year it does not seem a wise policy to burn over half the total annual national production of coal in the country's power stations. Thus by 1975, when the Generating Board's demand for fuel is likely to have risen to 130 million tons of coal-equivalent and may still be increasing, alternative fuels must be available.

Oil supplies seem more reliable and costs are lower than some years ago. Nevertheless, while it is reasonable for power stations to burn all the heavy residual oils produced as a by-product in British refineries, it may not be desirable to increase the consumption of heavy oils to the point where importation of this by-product of overseas refineries becomes necessary.

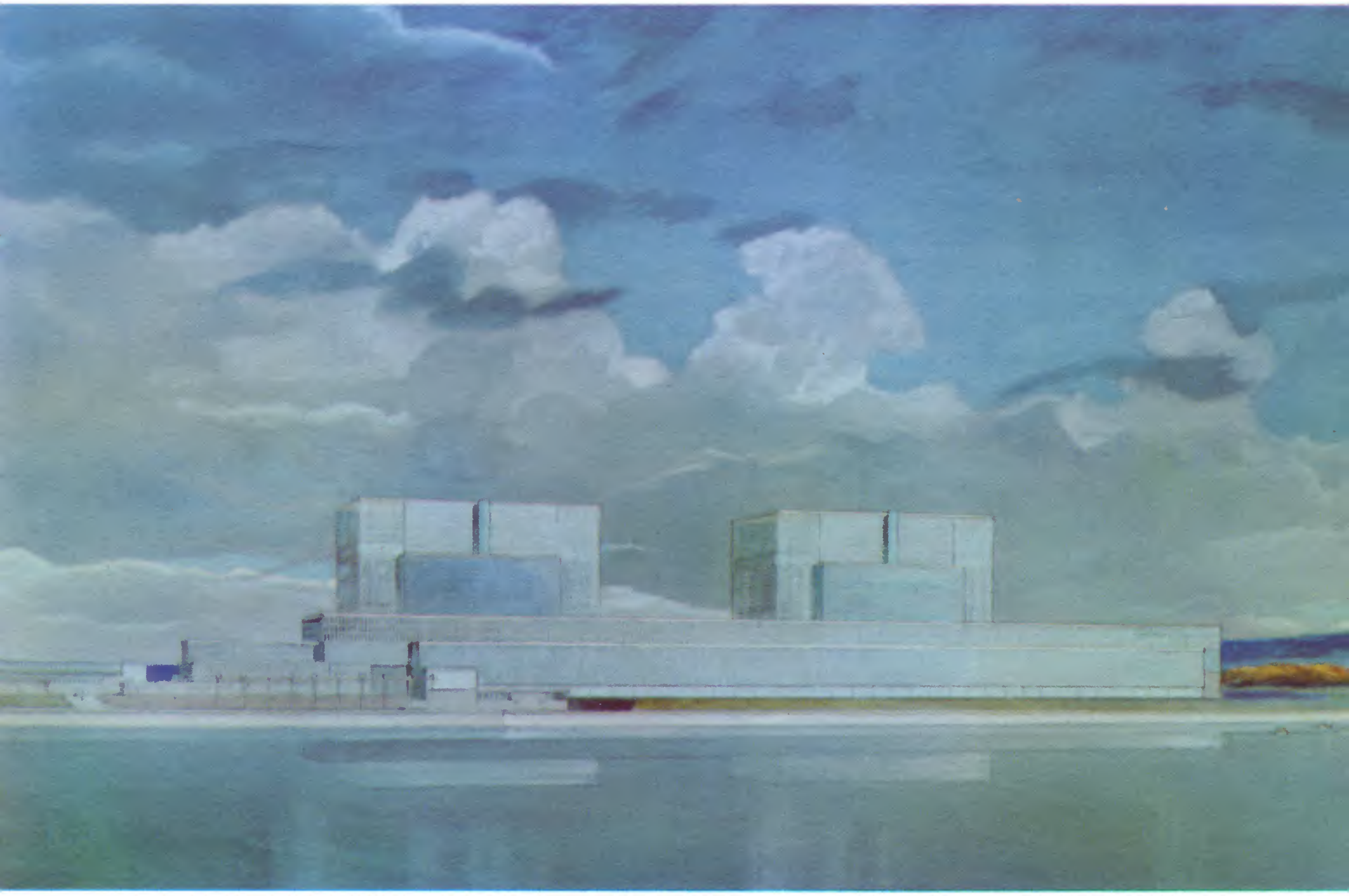
On the basis of the estimated demands for fuel alone therefore, electric power must be generated from nuclear sources by the middle 1970's. On economic grounds too, it appears that by about this time electricity from nuclear power will compete with electricity generated by burning coal or oil.

The electricity supply industry looks forward to a period starting in about 1970, in which electricity will be generated from three economically comparable fuels—coal, oil and nuclear power. The electricity supply industry should be able to manoeuvre with reasonable freedom within this "three fuel economy" to choose the proportions of these three fuels in such a way that a minimum cost for electric power is achieved.

Siting of Coalfired Stations and Grid Systems

Thirty years ago the Grid system first linked power stations in local areas so that they could help each other over difficult periods and transfer some energy when it was economical to do so. It was not until the 1939-45 war that the role of the Grid changed from an area to a national facility and electricity was first transmitted over long distances.

A big modern power station burns enormous quantities of coal; in full production, the furnaces of a station like High Marnham, Nottinghamshire, (completed in 1962) consume 10,000 tons a day. Economic logic requires that this huge appetite should be met from the country's most productive coalfield—the East Midlands—and stations sited as near as possible to the fuel source. But Britain's population is increasing most rapidly in the south and there is a consequent sharp rise in

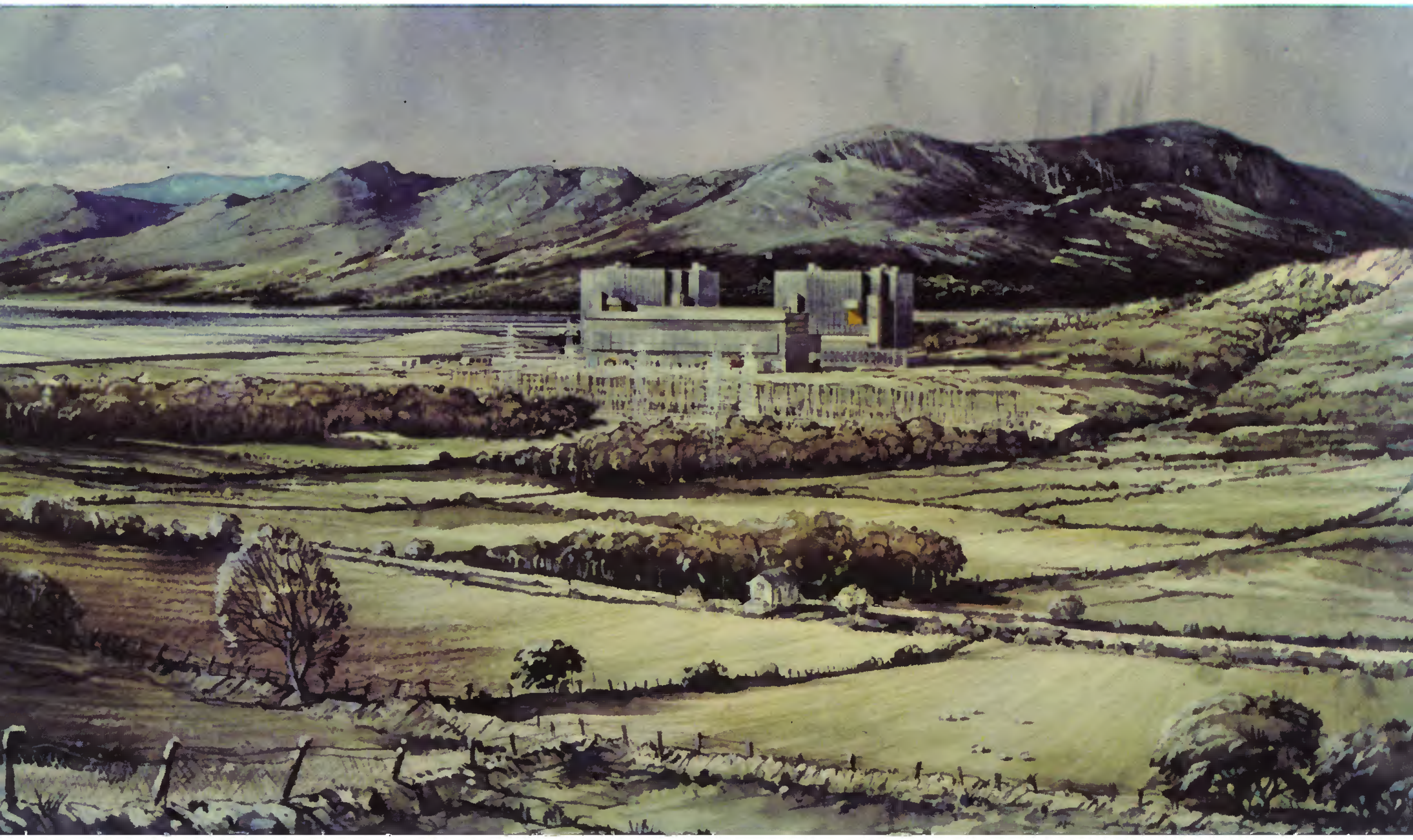


Artist's impression of
Hinkley Point nuclear power station

demand for electricity from the coal-deficient area lying south of a line drawn from the Bristol Channel to the Wash.

To date the answer has been to build stations close to the coalfield and transfer the electrical power south along overhead transmission lines. Development of this system of bulk transmission has given the East Midlands a new product—electric power. In 1948, the output of all the stations in the East Midlands was together only 780 megawatts. Since then, a whole chain of stations has been built along the River Trent and in fifteen years the East Midlands have been transformed from a power-deficient area to Britain's biggest power exporter, with a capacity of over 5,000 megawatts.

Artist's impression of Trawsfynydd nuclear power station



This advanced economic policy for electric power depends on the bulk transfer of power by the Grid and the introduction in 1953 of the 275,000 volt Supergrid was one of the most notable developments in the industry.

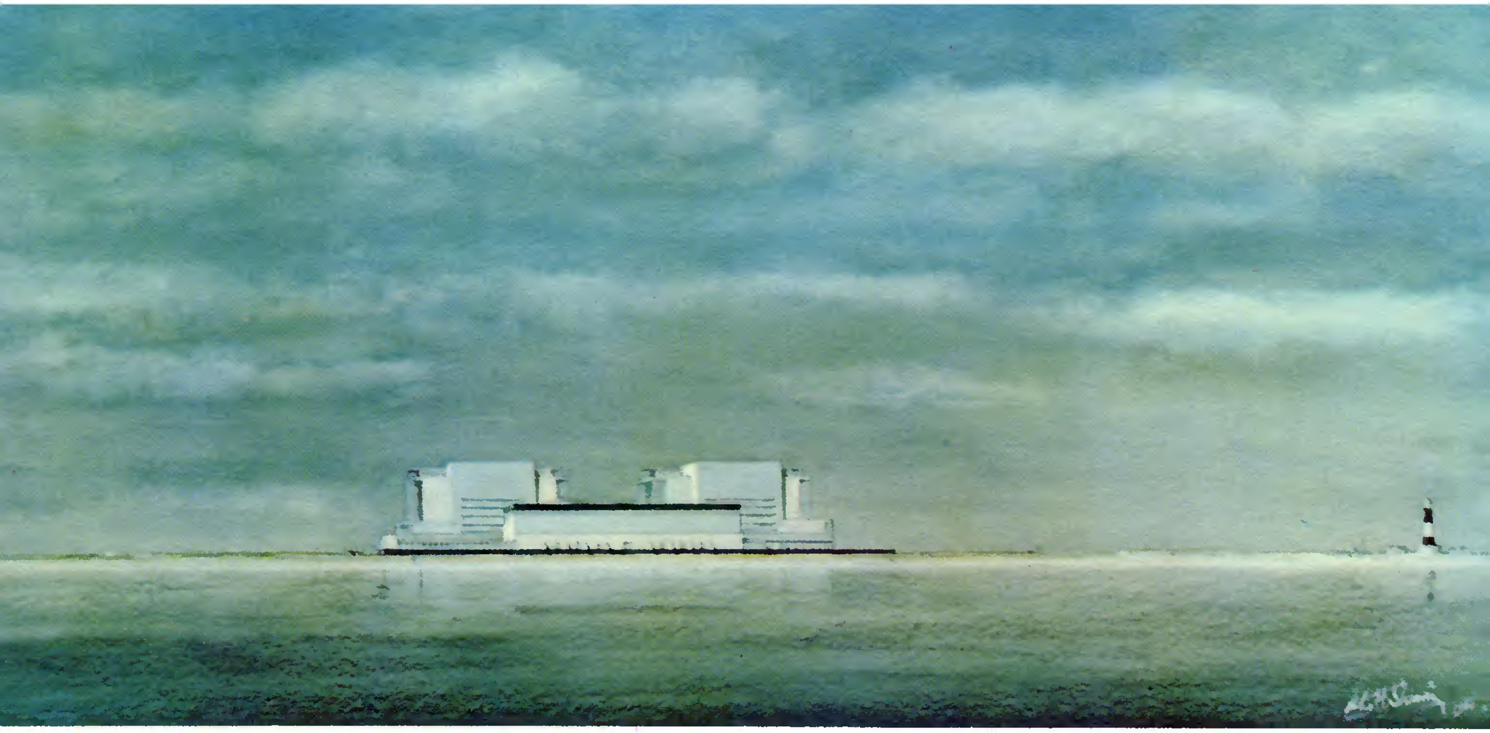
As a result of the drift of population and the build-up of industry, the rate of increase in demand for electricity in the south is nearly 50 per cent above the national average. This means there must be increasingly heavy transmission of power from the Midlands. With the future in mind, the 275,000 volt Supergrid was originally designed so that the operating voltage could be raised, and in fact the Generating Board have decided to reinsulate these lines and use them at 400,000 volts where increased transmission capacity is needed.

The adoption of the 400,000 volt system means that the carrying capacity at this voltage will be three times greater than at 275,000 volts and the amenity problem resulting from the need for an increasing number of lines and towers lessened.

Generation in the South and Siting of Nuclear Power Stations

The deficity of electricity and coal in the south-east and London areas is met by the transmission of power from the Midlands and by generating electricity in the south from heavy fuel oil, from a limited amount of coal shipped coastwise, and from nuclear power.

The total amount of power generated in the Midlands and exported to the south will ultimately be limited, not only by the amenity problem posed by the expanding Grid system but by the amount of cooling water available on the East Midlands and South Yorkshire coalfields. Even allowing for the possible use of a "dry" cooling tower system, there must eventually come a time when the siting of further power stations in this area will become impracticable.



Artist's impression of Dungeness nuclear power station

In the face of this eventual limitation, the correct siting of generating plant burning oil or using nuclear fuel becomes important. The relatively small quantities of heavy fuel oil available come from refineries in the Thames Estuary, Southampton Water and South Wales. Generation from fuel oil will evidently be most economic in the vicinity of these refineries at sites chosen to minimise the transport charges on bulk oil.

Transport charges for nuclear fuels are negligible and the siting of nuclear power stations is not governed by this economic consideration. Main factors, besides the all-important amenity consideration, affecting the choice of site are the availability of the large quantities of cooling water necessary, geological substrata which can support the very heavy station structure and plant, and a reasonable degree of remoteness, so that, in the extremely unlikely event of a mishap, the temporary evacuation of people living close to the station could be easily achieved.

The Generating Board's nuclear stations have accordingly been sited on the outer Thames Estuary, the Severn Estuary, North Wales and the east and south coasts.

Amenity considerations are of over-riding importance; if public opinion permitted the construction of nuclear power stations on any favourable site and if transmission lines could be put up wherever they were needed, it would not be difficult to meet the ever-increasing demand for electric power. But the electricity supply industry is spending more money on capital works than any other single industry in this country and this cannot be done without some effect on the countryside.

The problem of meeting the demand for greater material amenity without too great a loss of visual amenity is one of the most difficult the Generating Board have to face. The greatest possible care is taken at all stages of the Board's major construction works to ensure that power stations and transmission lines are integrated, as far as possible, with their immediate surroundings.

The Nuclear Programme

The first large-scale reactors were built in 1950 at Windscale, in Cumberland, to produce plutonium for defence purposes. They were graphite-moderated natural uranium reactors.

In these plutonium reactors, the object was not to use the heat from fission to generate power but only to remove it from the reactor as economically as possible.

Progress at the experimental nuclear power station at Calder Hall looked so promising that in 1955, the Government outlined a bold provisional programme of nuclear power production for public supply. A White Paper* stated that the main objective of the programme during the first ten years was to enable the electricity authorities and industry to obtain the practical experience in designing and building the nuclear power stations necessary for a big expansion in later years. It also stated that the programme would be subject to frequent and major changes, according to the speed of technical development and the success of the early stations.

**A Programme of Nuclear Power 1955, H.M.S.O. 1s. 3d. (Cmd 9389).*

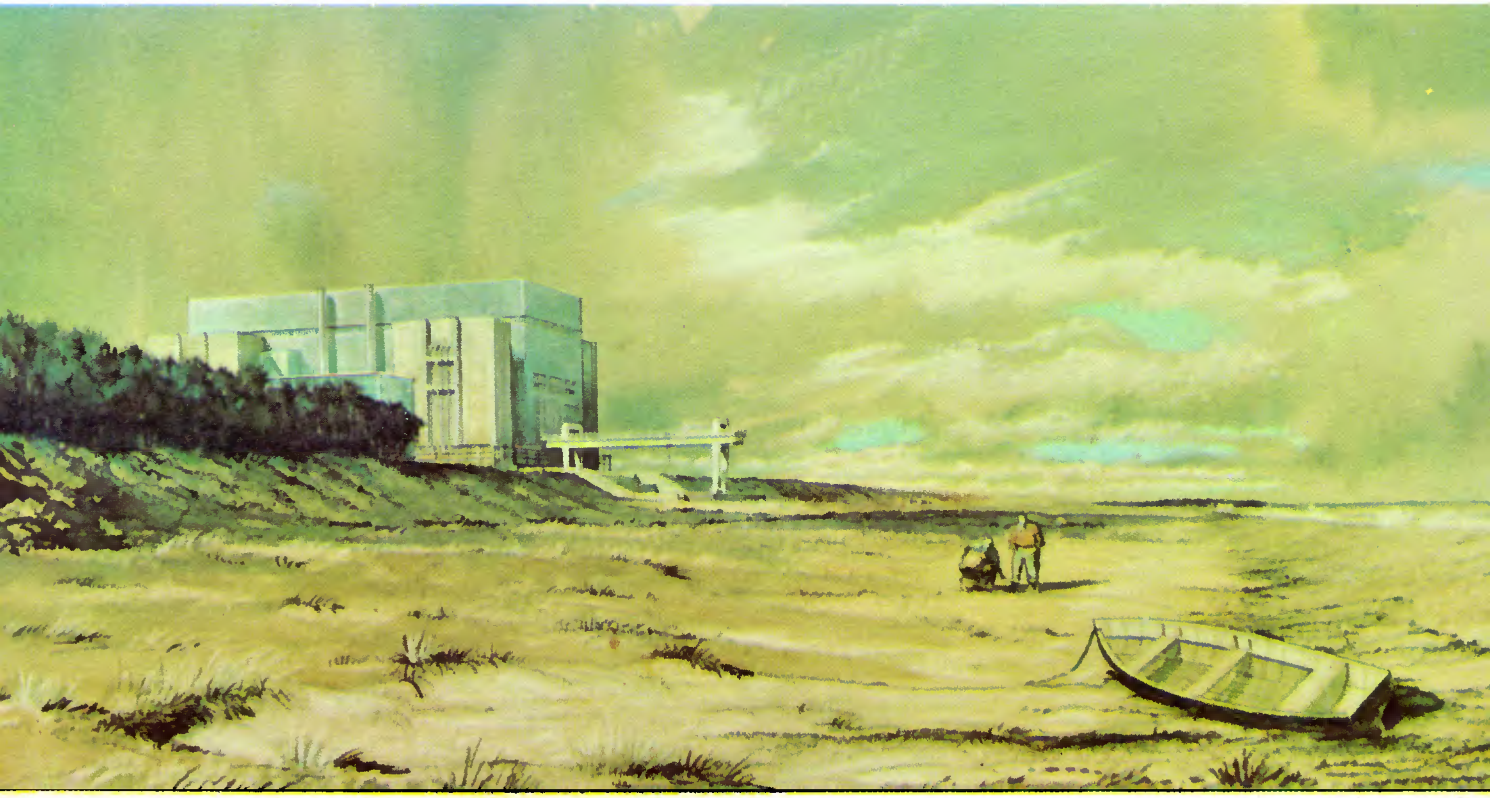
This White Paper provided that the electricity supply authorities should; by the end of 1965, have constructed 12 nuclear power stations with a total output of 1,500-2,000 megawatts. But by 1957, experience and technological progress was such that, together with a growing concern over the national energy position, it led the Government to announce an expansion of the target nuclear capacity to 5,000-6,000 megawatts by 1965—the actual number of stations to depend on the pace of technical development, the trend of capital costs, and the financial resources available. The programme has since been twice rephased. As part of the restriction on capital expenditure announced in October 1957 the target date was extended to 1966 and in 1960 it was further extended so that the target of 5,000 megawatts will now be achieved in 1968.

The Government have consequently decided that orders should be placed for nuclear power stations at the rate of roughly one a year. These modifications represent only a change of pace and not a change of policy.

There are at present under construction for the Central Electricity Generating Board nine nuclear power stations, including Berkeley in Gloucestershire and Bradwell in Essex, where construction is completed. These will bring the total nuclear generating capacity up to 3,600 megawatts by 1966. The first two stations, Berkeley and Bradwell went critical for the first time in 1961 and started feeding into the Grid in 1962.

The present situation is summarised as follows:

Stations	Number of reactors	Maximum electrical output (megawatts)	Date work started	Expected or actual year of completion of first reactor
Berkeley (Gloucestershire)	2	275	Jan. 1957	1962
Bradwell (Essex)	2	300	Jan. 1957	1962
Hinkley Point (Somerset)	2	500	Sept. 1957	1963
Trawsfynydd (N. Wales)	2	500	July 1959	1963
Dungeness (Kent)	2	550	July 1960	1964
Sizewell (Suffolk)	2	580	April 1961	1965
Oldbury-on-Severn (Gloucestershire)	2	560	Feb. 1962	1966
Wylfa (Anglesey)	2	1,000	June 1962	1967
Hinkley Point B (Somerset)	2	1,000	Ministerial consent obtained July 1962	1968



Artist's impression of Sizewell nuclear power station

The influences which have caused this re-phasing are essentially economic. General conditions have altered considerably since early 1957; the serious shortage of small untreated coals which was then affecting both Britain and Europe has given place to a surplus. There is also at present (1963) a world surplus of oil and its prices have been further reduced by severe competition in tanker freight rates. Added to this, the costs of electricity generated from coal and oil have continued to fall. Higher steam temperatures and larger generator units have led to significant improvements in overall efficiency.

Remembering that, for a conventional station, capital charges account for only 20 per cent of the cost of power whereas for a nuclear station they account for 67 per cent, the adverse effect of a period of high interest rates on the cost of nuclear power is evident.

This can be seen in another way by comparing the very high capital cost of nuclear power stations (£176.7 per kilowatt at Berkeley, £171.7 Bradwell falling to £106 at Sizewell) with the cost of under £40 per kilowatt for modern coal or oil fired plant.

As a result of these high interest rates and high capital charges, the cost of electricity from Berkeley and Bradwell is between 1.23 and 1.12 pence per unit, compared with the current figure of 0.55—0.70 pence per unit for conventional stations.

The cost of nuclear power is, however, coming down. The nuclear power station at Sizewell is expected to produce electricity at about 0.73 pence per unit.

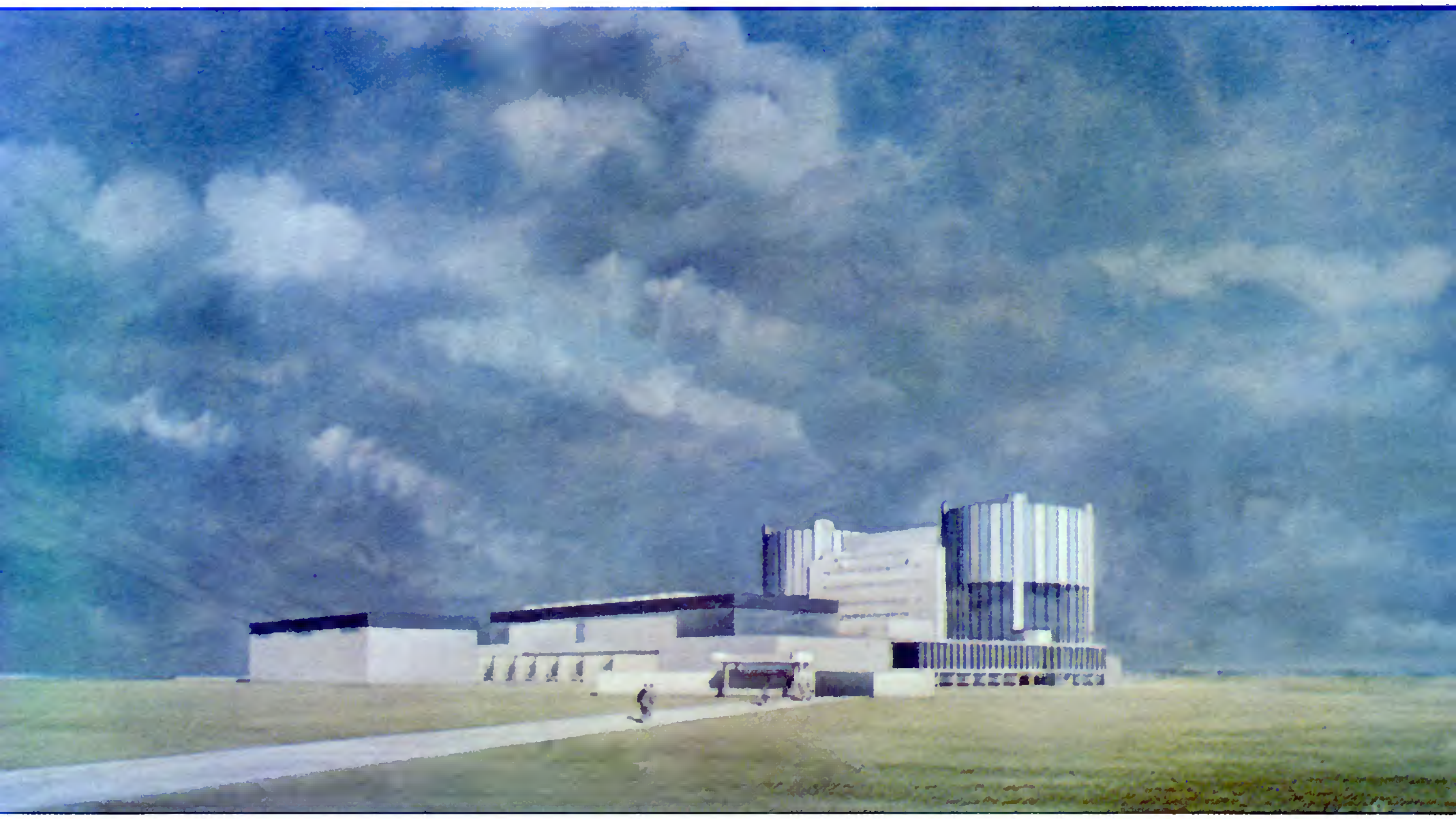
But despite this, it is clear that the long-term rate of interest in Britain, which has risen appreciably since 1955 and seems likely to remain at a fairly high level, must have the effect of postponing the date at which the cost of nuclear power is reduced to that of conventional power. This means that the development period, during which nuclear power is uneconomic is prolonged.

The Future

Considerable research effort is being put into the development of the Advanced Gas-Cooled Reactor (A.G.R.), which uses slightly enriched uranium but is basically an extension of the graphite-moderated gas-cooled systems used at Berkeley and Bradwell. The A.G.R. gives hopes of lower generating costs and a lower capital cost.

The third generation of the graphite-moderated gas-cooled systems, the high temperature gas-cooled reactor, is being developed by the U.K.A.E.A. on an experimental scale by the Dragon project sponsored by the Organisation for Economic Co-operation and Development.

The future cost of electricity from nuclear generating plant will certainly fall as a result of the introduction of more advanced types of reactors. In addition, innovations in civil engineering techniques such as the use at Oldbury of pre-



Artist's impression of Oldbury-on-Severn nuclear power station

stressed concrete pressure vessels and the housing of two reactors in one building are expected further to reduce capital costs.

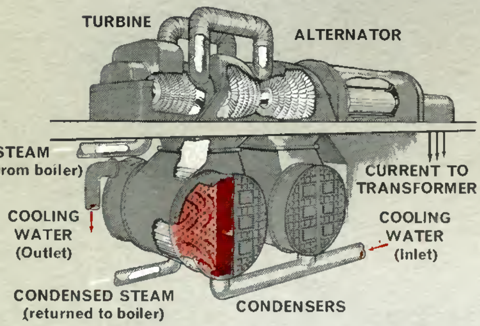
Since nuclear stations have relatively low fuel costs, they must be run as continuously as possible to justify their high initial capital cost.

Until the operating experience is actually available, all estimates of future costs must depend on assumptions. The Generating Board's stations at Berkeley and Bradwell are providing the essential experience required for planning the supply of electricity in a way which uses nuclear power to the maximum advantage.

The Generating Board have established laboratories at Berkeley in Gloucestershire to carry out research and development work arising from their nuclear power programme.

Electricity from Nuclear Energy

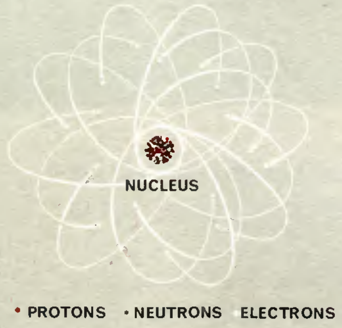
Nearly all of the electricity which the Generating Board produces is generated by turbo-alternators. For these steam is required to drive the turbines.



Nuclear power stations differ from the conventional installations in that, instead of burning coal or oil, the heat from nuclear energy is used to boil water and generate steam.

To explain what happens in a nuclear power station many words are used which some of us may not fully understand.

It is proposed to take such words in a certain order and by carefully defining them to present a fair idea of the general procedure.

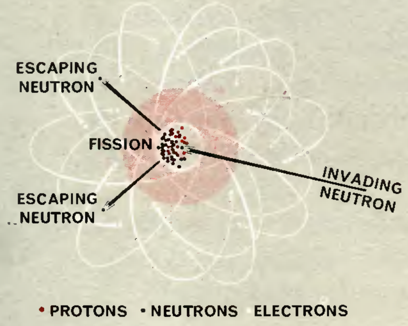


Elements are chemical substances which cannot be broken down into other substances. There are 92 natural elements.

Atoms are the smallest possible parts of an element. They are so small that in a glass of water there are sufficient to provide millions of atoms for every square inch of the earth surface of the globe.

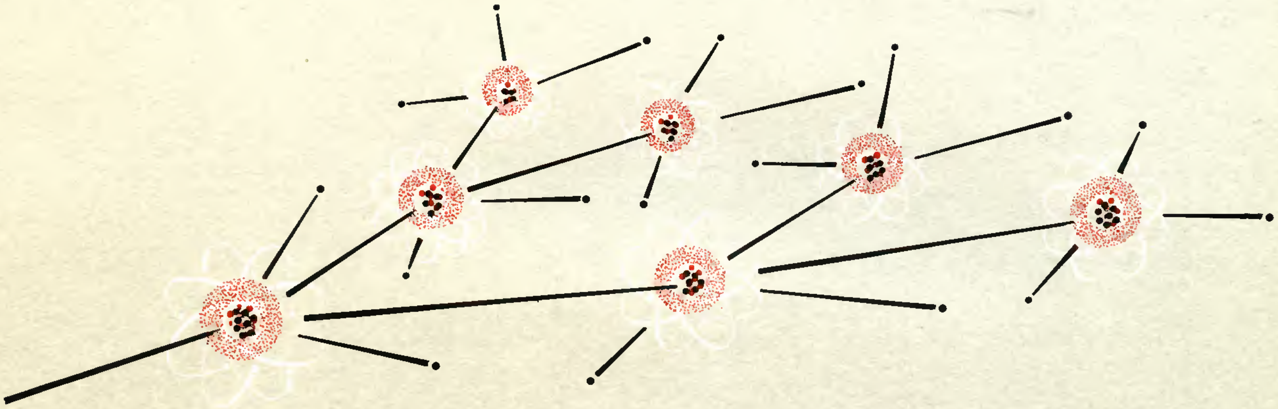
Each atom consists of PROTONS (positively charged particles) and NEUTRONS (uncharged particles), constituting the NUCLEUS which is surrounded at relatively vast distances by ELECTRONS (negatively charged particles).

Nuclear fission is the process whereby a free neutron is made to penetrate the nucleus so that it is caused to break up. This releases other neutrons and energy in the form of heat.



So great is this nuclear energy potential that the atoms in a piece of uranium the size of a pin-head could produce as much heat as the burning of 5,000 tons of coal.

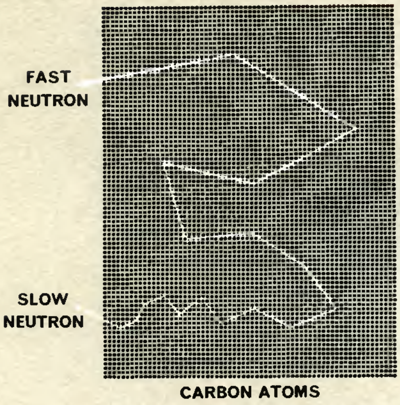
The atoms of most materials are quite stable, but the nuclei of some very heavy elements are not. If a uranium nucleus is struck by a neutron it is liable to break up, and to release two or three free neutrons. If these are slowed down some of them will be caught by other uranium nuclei, which will then break down and continue the process of chain reaction. This slowing down of the freed neutrons is accomplished by using a moderator.



This is a material which slows down neutrons without capturing them. Graphite is such a material. Uranium fuel is prepared in the form of rods about one inch in diameter. These are encased in thin metal cans, and they are inserted into holes in the graphite about eight inches apart.

It is no good being able to start nuclear reaction and to obtain great heat output unless the process can be controlled. A chain reaction can be started by bringing together a "critical" amount of uranium fuel in a graphite moderator, but there must be at hand a means to reduce the speed of reaction when necessary, and this is done by installing, as part of the reactor, rods of boron steel. Boron has a remarkable capacity to absorb neutrons. When instruments indicate that nuclear fission is proceeding too fast, the boron rods can be dropped into the reactor. They quickly soak up free neutrons, so that the frequency of fission is immediately reduced and a steady rate of operation can be resumed.

The reason for using natural uranium as a fuel is that it is the only naturally occurring material which can produce a controlled chain reaction. Because of the escape of neutrons from the moderator, this process can only take place in a reactor of a certain minimum size. This is known as the critical size. If, in a reactor, the control rods are positioned so that power is neither increasing nor decreasing, the reactor is said to be critical.

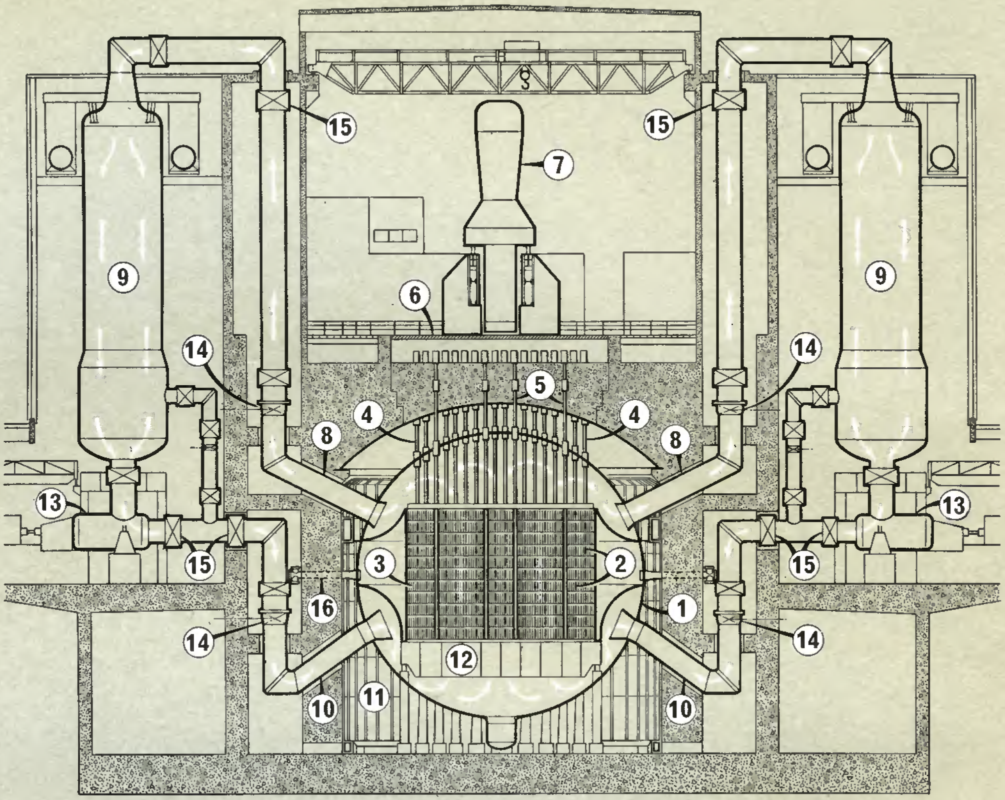


Neutrons emerge from fissioning uranium nuclei at a speed of 10,000 miles a second, at this rate their chances of hitting another nucleus are diminished, but if we can reduce the speed to about 1 mile a second, the possibility is 10,000 times improved. When we imprison the uranium fuel rods in graphite, the neutrons cannot escape. They collide with one graphite atom after another, losing speed at each collision and eventually slanting back to the fuel rod at greatly reduced momentum.

CROSS SECTION THROUGH NUCLEAR REACTOR

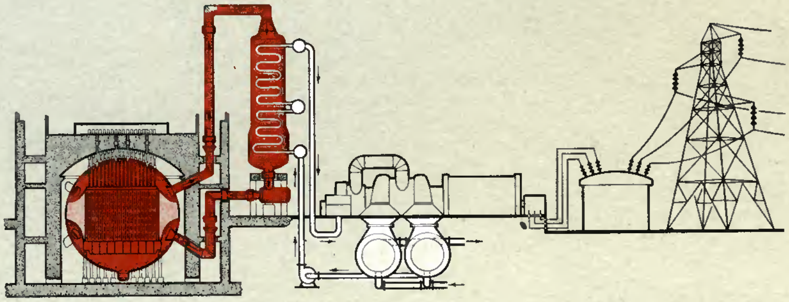
KEY

1. REACTOR PRESSURE VESSEL
2. FUEL ELEMENTS
3. GRAPHITE—MODERATOR
4. CHARGE TUBES
5. CONTROL ROD STANDPIPES
6. CHARGE FLOOR
7. CHARGE/DISCHARGE MACHINE
8. HOT GAS OUTLETS FROM REACTOR
9. BOILERS (SIX PER REACTOR)
10. COOL GAS INLETS TO REACTOR
11. THERMAL SHIELD
12. DIAGRID
13. MAIN CIRCULATORS
14. GAS ISOLATING VALVES
15. HINGED EXPANSION BELLOWS
16. CAN-FAILURE DETECTION STANDPIPES



ARROWS SHOW THE FLOW OF CARBON DIOXIDE THROUGH REACTOR AND BOILERS

During operation carbon dioxide gas is blown through the moderator holes at high pressure. This transfers the heat of fission from the uranium, through the can into the gas. The hot gas is then blown over thousands of tubes containing water in boilers, where the water is turned into superheated steam for driving ordinary turbo-alternators.



Berkeley

NUCLEAR POWER STATION

Berkeley Nuclear Power Station

Berkeley nuclear power station lies on the eastern bank of the Severn Estuary, rougly midway between Gloucester and Bristol. The river at this point is over a mile wide and is strongly tidal.

The construction site occupied some 96 acres, but the final area contained by the station security fence is approximately 43 acres.

The construction of the station was initiated by the Nuclear Power Branch of the Central Electricity Generating Board and later responsibility for the project passed to the Southern Project Group of the Generating Board. The station was built for the Generating Board by the Nuclear Power Group. Before work started on the site, the Gloucestershire County Council, on behalf of the Generating Board, built a new 22 feet wide roadway from Berkeley town to the site.

Access was given to the site on the 7th January, 1957 and the station commenced supplying electricity to the national Grid system on the 12th June, 1962.

The station has a net output of 275,000 kilowatts, the plant consisting of two natural uranium carbon dioxide gas-cooled graphite-moderated reactors, supplying heat to sixteen boiler units, eight boilers being associated with each reactor. The boilers supply steam to four dual pressure turbo-generators, each of 83,000 kilowatts capacity.

Each reactor core comprises a vertical cylinder 48 feet in diameter by 30 feet high, built up from graphite blocks and containing 3275 vertical channels. 3265 channels contain uranium fuel and the other 10 channels contain graphite samples. The core is contained in a cylindrical steel pressure vessel three inches thick which is surrounded by a concrete biological shield having a thickness of 8 feet 6 inches.

The fuel elements are natural uranium rods 1.1 inches in diameter and 19 inches long sheathed in magnesium alloy. There are 13 fuel elements in each channel.

Carbon dioxide gas at a pressure of 125 lb. per square inch transfers the heat produced in the reactor to its eight associated boiler units through five feet diameter ducts. Eight blowers, each connected to the outlet of a boiler, circulate the gas back into the reactor vessel.

Turbine hall, No. 1. turbo-generator

CIVIL WORKS

Beneath the top soil of the site, the principal materials found were marl and clay, banded with layers of claystone and sandstone. Deeper excavation exposed the Old Red sandstone series.

Preliminary investigation also revealed there was a great deal of ground water particularly in the sandstone bands. It was, therefore, decided to keep excavations dry by lowering the ground water levels with a system of deep well pumping instead of using expensive sheet piling to form cofferdams. The wells, ringing each excavation area, were driven well below the depth of the lowest excavation point and a submersible pump inserted in each.

One of the first tasks was to construct roads and raise the general level of the site. Roads were constructed by the importation of some 400,000 tons of stone and the site level was raised by placing excavated material on the lower ground areas.

The civil works for the reactors comprise two circular reinforced concrete rafts each 150 feet in diameter and 14 feet thick. For this work two excavations 300 feet in diameter and 30 feet deep were necessary, the stiff marl providing suitable load-bearing properties at this depth. The walls of the biological shields of the two reactors are 80 feet high and 8 feet 6 inches thick, and the roofs consist of concrete 12 feet thick.

For condensing purposes, six circulating water pumps, with a total capacity of 21 million gallons per hour, are installed in the circulating water pump house. The cooling water is drawn from the River Severn 650 feet off shore into two vertical shafts leading to two 1,000 feet long horizontal water tunnels, each of 9 feet 6 inches diameter. These tunnels are lined with pre-cast concrete segments and finished with a cement/sand lining. A third tunnel seven feet in diameter provides access for personnel to the intake structure.

After passing through the condensers the cooling water is discharged back into the river through four outlet culverts, one serving each turbo-generator. A baffle wall has been constructed in the estuary to prevent recirculation of the cooling water.

Owing to the tidal variation the circulating water pump house had to be placed well below ground and here the deepest excavation on the site of 65 feet was required. The circulating water tunnels connecting the pump house to the intakes penetrate 100 feet below ground level.

The Generating Board arranged with the local authority to lay a nine inch diameter water main which can supply the station with 250,000 gallons a day.

REACTORS AND BOILERS

The pressure vessel which contains the reactor core is cylindrical with domed ends. It is 80 feet high and 50 feet in diameter and was fabricated on site from three inch thick steel plates. Some pre-fabrication of the smaller plates was carried out but most of the plates were lifted singly into position. The heaviest single lift was 15 tons.

The lower domed end of No. 1 reactor vessel was, however, pre-fabricated on site to allow speedier construction of the first pressure vessel, the bowl section being completely assembled and then moved to its final foundation over temporary rail tracks.

To facilitate welding on site it was necessary for all plates, pressed and cut to size in the manufacturer's works, to be accurate to one-sixteenth of an inch, and to attain this accuracy templates were employed. These templates which were of sheet steel were, in turn, accurate to one-sixtyfourth of an inch.

After pressing to shape, the plate edges were prepared for welding by a special flame planing technique. This process left the correct weld preparation angles on the curved edges of the plates without need of machining or further work.

All welding was carried out to Lloyds Class 1 standard which called for 100 per cent radiographic examination of all welds.

The boilers, or heat exchangers, are cylindrical pressure vessels 70 feet high and 17 feet 6 inches in diameter. They were fabricated from steel plate made up of five cylindrical sections forming the body of the vessel and a domed section at top and bottom. Each of the seven sections was completed as far as possible at the manufacturer's works and transported to the site for assembly. The whole of the welding was to Class 1 requirements and the complete vessel was stress relieved and hydraulically tested after welding. Each cylindrical body section was made from two curved steel plates, 1⅛ inches thick, roll-formed cold to shape and machine welded to form a complete ring.

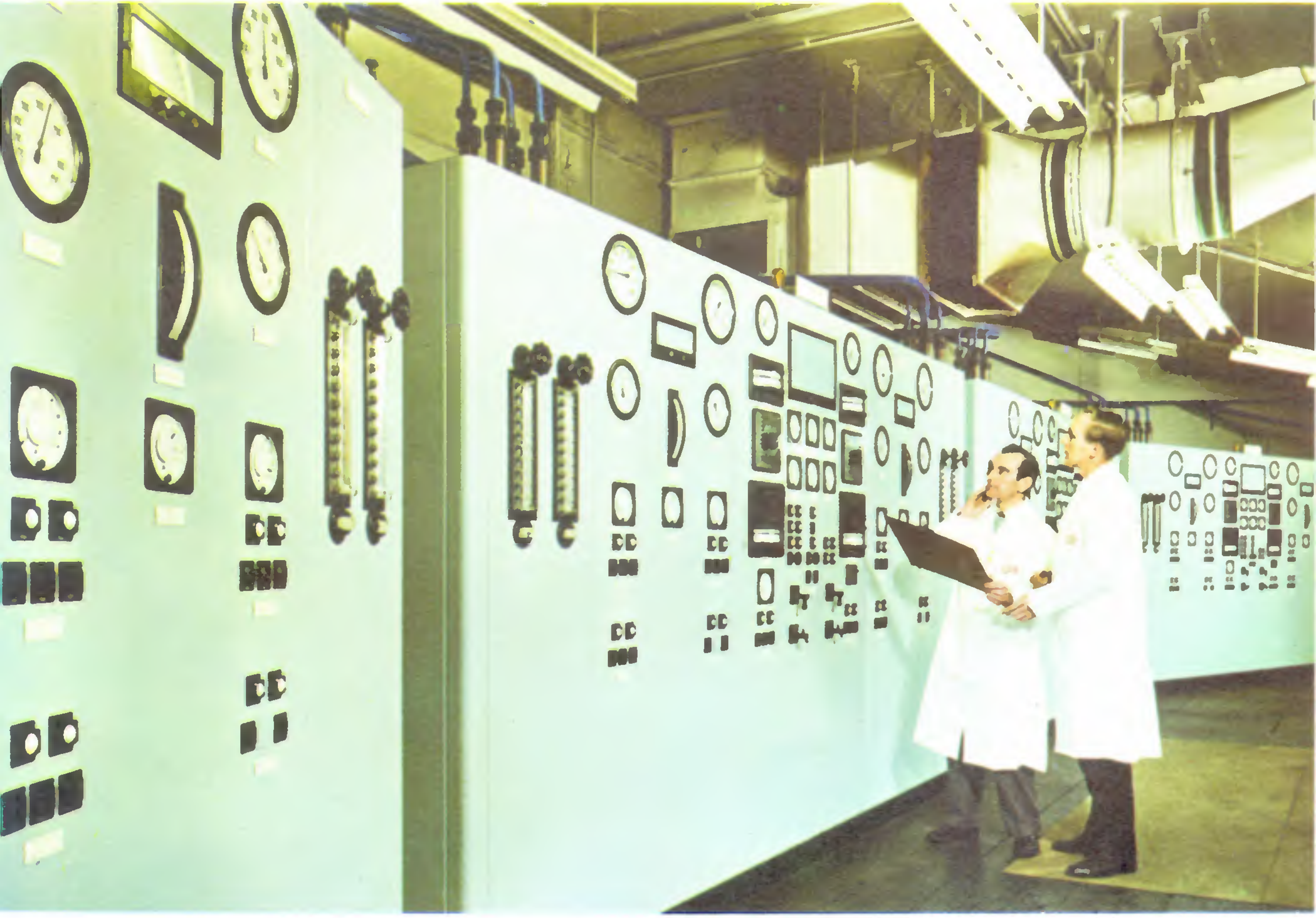
Each boiler produces 204,000 lb of steam per hour at two pressures—306 lb per square inch and 62 lb per square inch at a temperature of 322 degrees Centigrade.

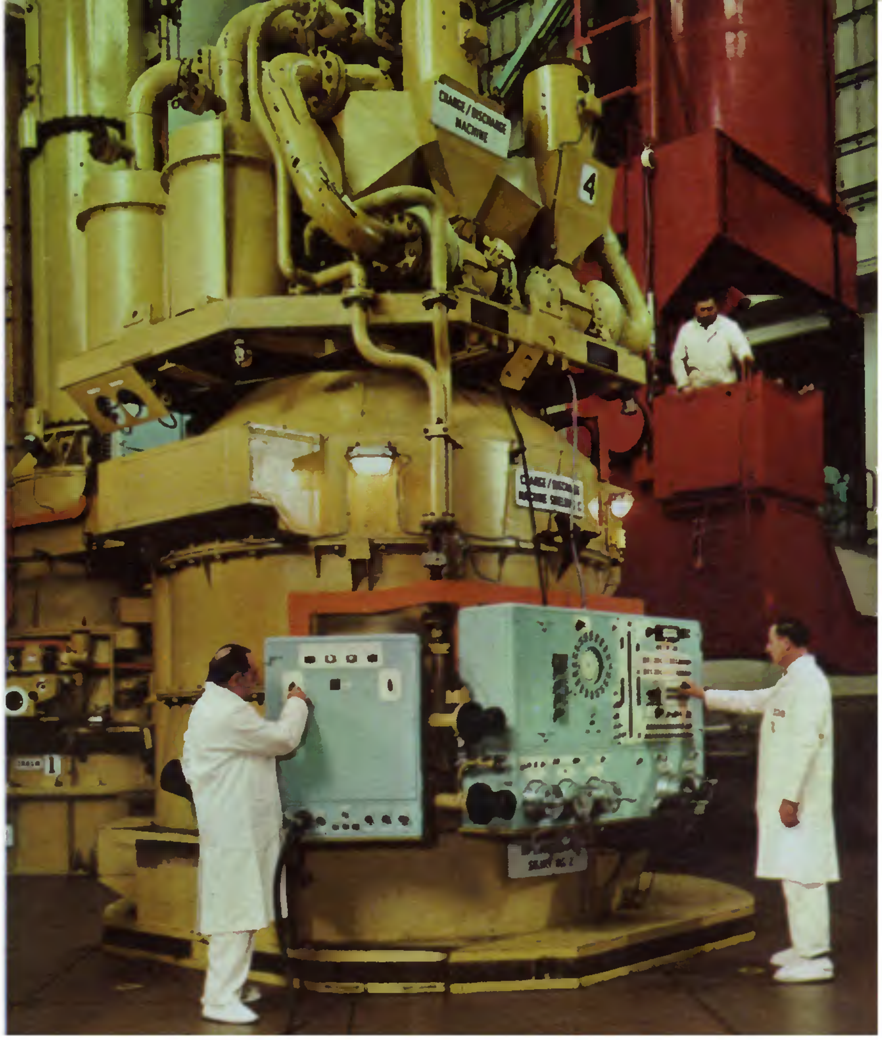
TURBO-GENERATORS

There are four turbo-generators each of 83,000 kilowatts

Nos. 1, 2 and 3 circulating water pumps

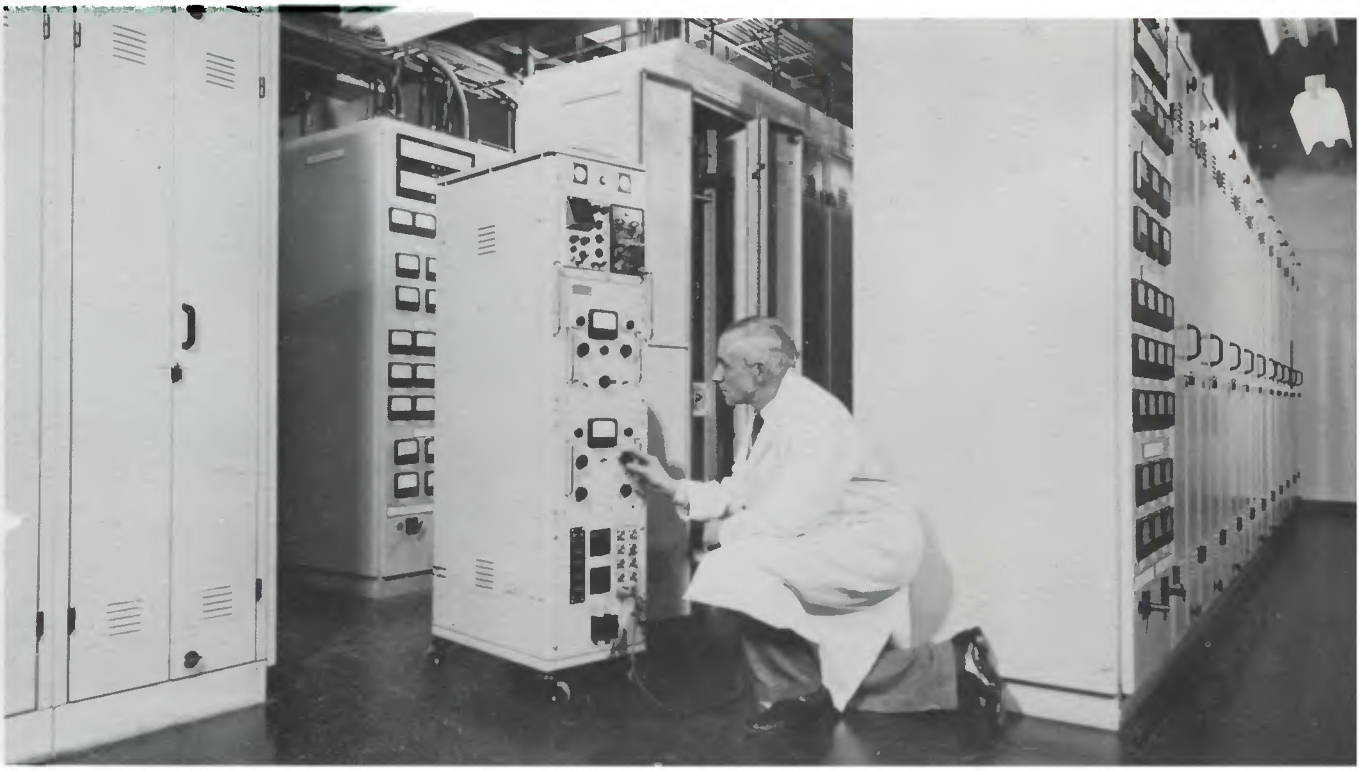
Boiler/blower control panel





Charge/ discharge machine No. 4 in operation

Safety line panels and test trolley in central control room annexe



capacity. The turbine is of the horizontal, close coupled, tandem compound, mixed pressure, impulse type.

High pressure steam enters the front, or mixed pressure, cylinder and after expansion this steam meets the low pressure steam which is admitted further along the cylinder. Expansion of the mixed steam takes place and then the flow divides, one third continuing forward through the front low pressure stages and two thirds passing through the overhead cross-over ducts to the double flow low pressure cylinder. Steam is exhausted from the turbine to three radial flow condensers.

The generator, which is direct driven at 3000 revolutions per minute through a semi-flexible coupling, employs hydrogen cooling at a pressure of 30 lb per square inch and supplies current at 11,800 volts.

FUEL HANDLING AND CONTROL

The station is equipped for on-load fuel changing, the fuel channels being replenished progressively, a few at a time. The general conception of fuel handling has been to use separate functional machines rather than one or two multi-purpose machines. Access to the 3265 fuel channels is by means of 60 charge standpipes led through the top of the biological shield. Movement of the fuelling machines on the charge face is by means of a rigid mast crane of 100 tons capacity.

The ancillary buildings attached to the station include a cooling pond in which irradiated fuel elements discharged from the reactors can be stored for several months to allow the high intensity radiation to die down before they are transported to the United Kingdom Atomic Energy Authority's chemical factory for processing. Other facilities include changing rooms through which all personnel entering and leaving the reactor area must pass; comprehensive active effluent treatment plant which reduces all effluent to an acceptable level before discharging; laundry equipment for dealing with contaminated clothing; and extensive laboratory and medical services for providing full monitoring and checking facilities. These are in addition to the normal administrative and welfare services provided in the Generating Board's power stations.

Control of the station is from a central control room where the main switchgear controls, main running controls for blower speed, control rod position, turbine throttle setting and all important indicating, recording and alarm instrumentation are located.

STATION COMMISSIONING

Proposals for commissioning the station were drawn up and approved by the Berkeley Commissioning Committee. This Committee under the Chairmanship of the Station Superintendent included representatives of the Nuclear Power Group, C.E.G.B. Southern Project Group, Nuclear Plant Design Department, Nuclear Operations Department, Nuclear Health and Safety Department and the United Kingdom Atomic Energy Authority. The station was commissioned jointly by the staffs of the Contractors and the Generating Board.

The Commissioning Programme was divided into three main stages:—

Stage A: Functional tests on sections of the plant to ensure fitness of equipment before fuel loading.

Stage B: Tests from the acceptance of the reactor for fuel loading to the time the section of the station was ready for the raising of the reactor to power.

Stage C: Procedures for power raising, normal operation and emergency and controlled shut down.

COMMISSIONING DATES

Reactor No. 1
Commencement of fuel loading, 12th August, 1961.
Attainment of nominal full power, 30th July, 1962.

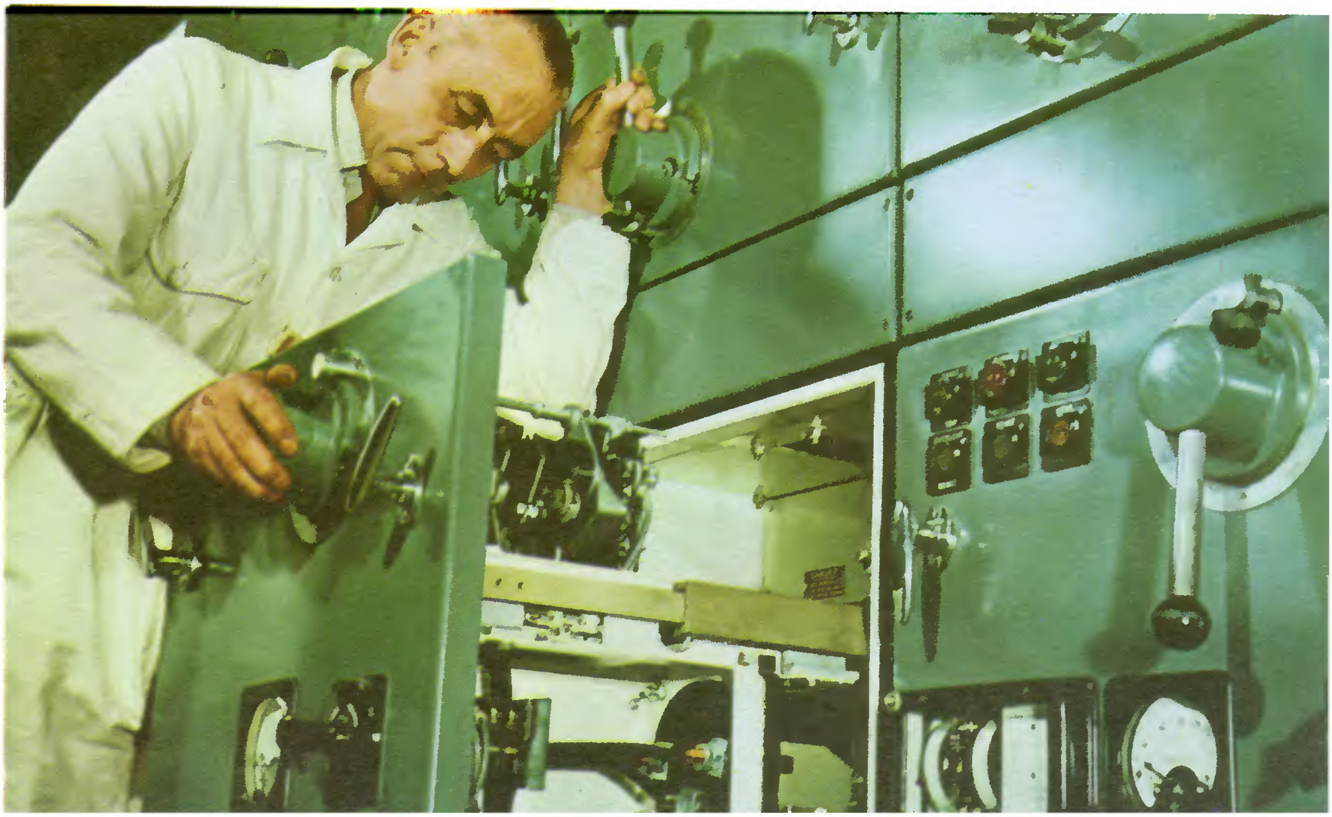
Reactor No. 2
Commencement of fuel loading, 19th February, 1962.
Attainment of nominal full power, 2nd November, 1962.

Turbo-Generators
No. 1 synchronised, 12th June, 1962.
No. 2 synchronised, 15th June, 1962.
No. 3 synchronised, 25th June, 1962.
No. 4 synchronised, 12th July, 1962.

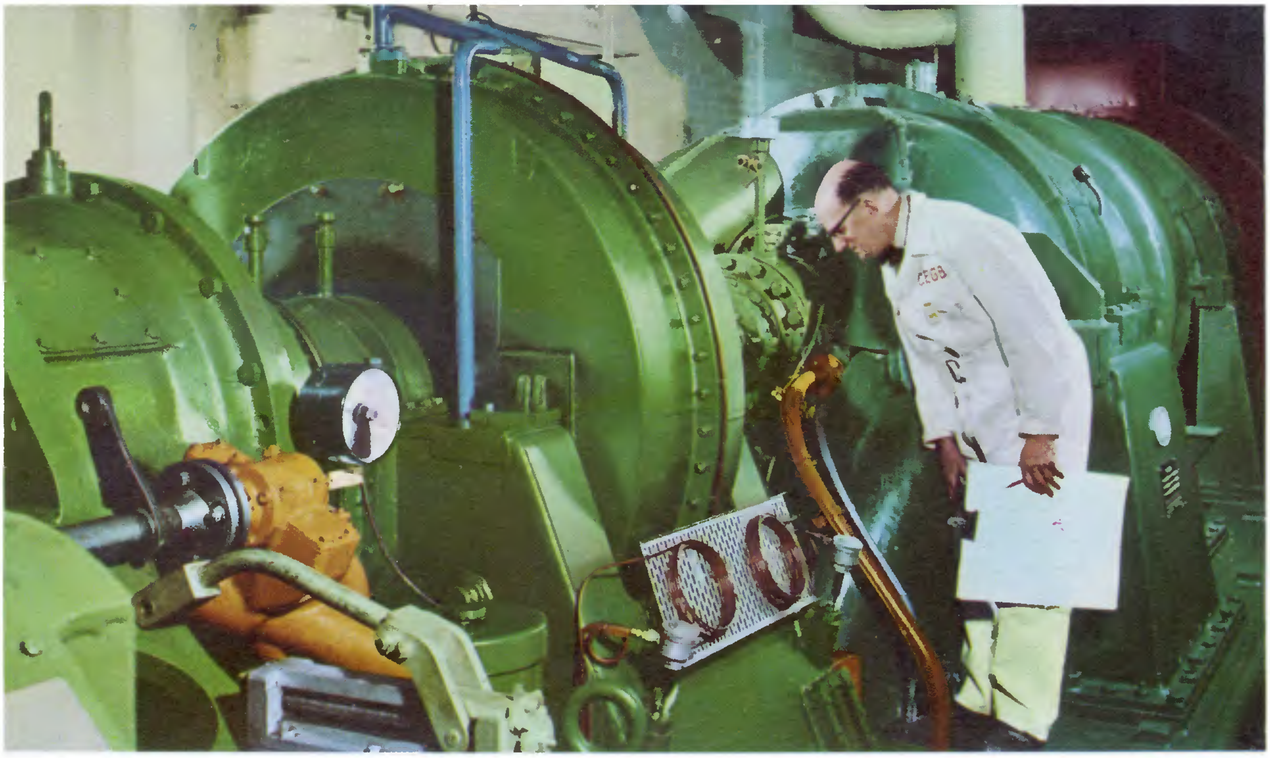
AMENITY AT BERKELEY

Originally there were some objections to Berkeley nuclear power station because of fears that it would spoil the view from Berkeley Castle, which dates back to the twelfth century. Careful siting has ensured that it can only be seen from very few places, and it is in fact now listed in the Castle brochure together with the Severn Wild Fowl Trust as a further tourist attraction.

Captain Berkeley, descendent of the first Lord Berkeley, requested that the 18th Century gazebo on the river bank of the site should be retained. Special precautions were taken, and in spite of the very heavy construction which has taken place in the close vicinity for five years, the gazebo remains intact.

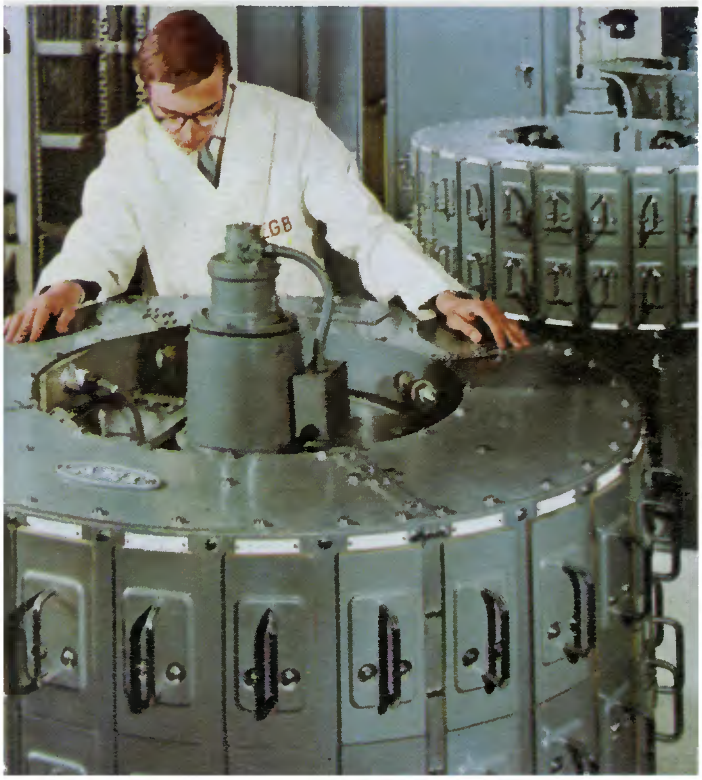


Station auxiliary board 415 Volt air circuit breaker truck



Gas blower showing fluid drive coupling

Control rod rotary selector switches



Control rod actuator power unit panels and test trolley

Bradwell

NUCLEAR POWER STATION

Bradwell Nuclear Power Station

The nuclear power station at Bradwell-on-Sea, Essex is situated about one-and-a-half miles from the village which has a population of 680. It is located on the south-east extremity of the Blackwater estuary.

The construction site occupies some 75 acres, or about one-eighth of a square mile, but the final area contained by the station security fence is about a quarter of this.

Access to the site is by road, the nearest railhead being eight miles from the site, and the Central Electricity Generating Board has spent £250,000 on road improvements. Adjacent to the site is a war-time airfield, the perimeter track of which provides an acess road to the site of the power station.

The construction of this power station was initiated by the Nuclear Power Branch of the Central Electricity Generating Board, and later, responsibility for the project was passed to the Southern Project Group of the Generating Board. The station was built for the Generating Board by the Nuclear Power Group.

Access to the site was given on 1st January, 1957, and construction work on the first half of the station was completed early in 1961.

The first reactor became critical on 19th August, 1961, and was put on load 1st July, 1962. The second reactor became critical on 14th April, 1962, and was put on load 12th November, 1962.

The station has a guaranteed net output of 300,000 kilowatts, the plant comprising two natural uranium, carbon-dioxide gas-cooled, graphite-moderated reactors, supplying heat to twelve boiler units. Six boilers are associated with each reactor, and are placed in two groups of three on opposite sides of the reactor to form one complete unit. There are six turbo-alternators each of 52,000 kilowatts capacity.

Each reactor core comprises a vertical cylinder approximately 45 feet in diameter by 31 feet high, built up from graphite blocks and containing about 2,600 fuel channels. The core is contained in a spherical steel pressure vessel which, in turn, is surrounded by a concrete biological shield having a varying thickness of 8 feet to 10 feet.

The fuel elements are uranium rods, approximately 1 inch in diameter and sheathed in magnesium alloy. Carbon dioxide gas at a pressure of 130 lb per square inch transfers the heat produced in each reactor to its six associated boiler units via 5 feet diameter ducts. Six gas circulators driven by induction motors each connected to the outlet of a boiler, circulate the gas through the reactor core and boilers.

Three 20,000 kilowatt turbo-alternators having a variable speed of between 600 and 3300 revolutions per minute (a total of 90,000 horsepower) are used for supplying power to these gas circulators.

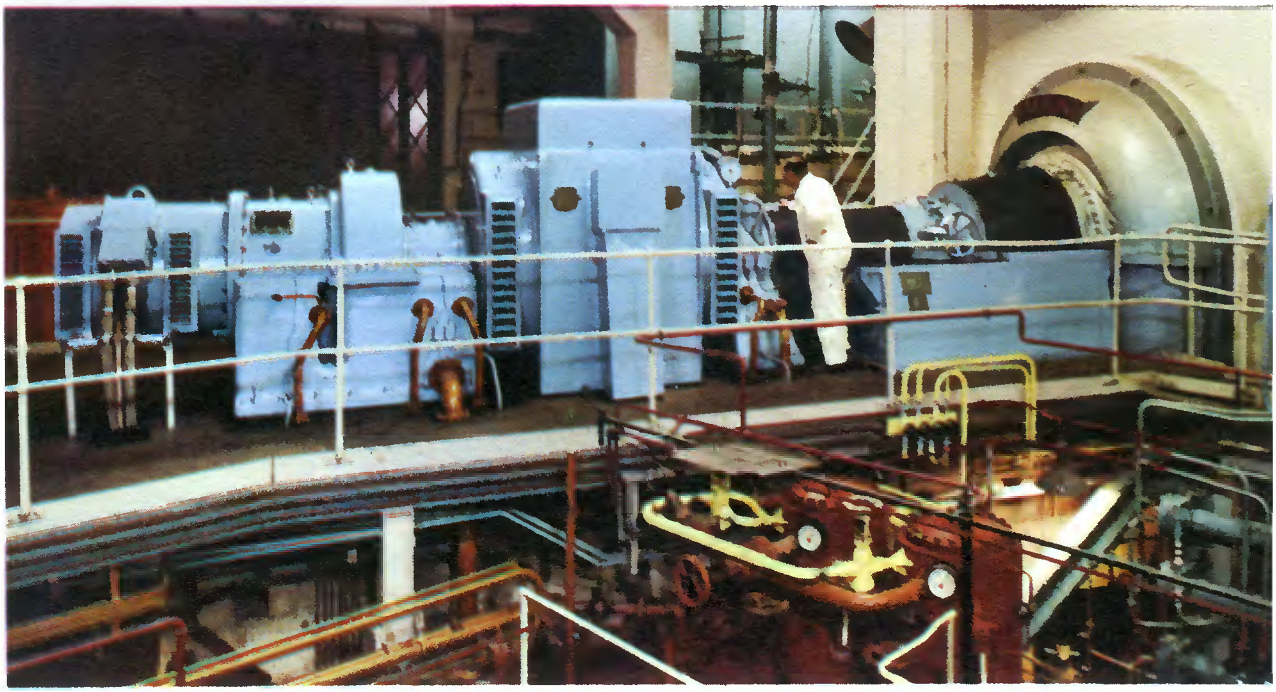
The reactors will be re-fuelled on load, the fuel channels being replenished progressively, a few at a time.

CIVIL WORKS

The site was originally a marsh, below the high tide level, and all land in the vicinity of the main buildings has been raised to a level 3½ feet above the maximum recorded flood level.

An investigation into the soil and ground conditions showed the main features to be "London blue clay", extending to a depth of at least 150 feet and overlaid by some 20-30 feet of stiff brown clay with a thin layer of top soil. The bearing properties of the clay improved with depth and all foundations have been carried down into the London clay. The actual maximum bearing pressures for the design are of the order of nearly

No. 6 gas circulator, Reactor No. 1.



4 tons per square foot for the reactor building and 2-2½ tons per square foot for the turbine house. Exposure of the London clay causes rapid deterioration of the bearing properties and special techniques had to be used to enable the clay to be sealed immediately after excavation depth had been reached.

The civil works for each reactor comprise a heavily reinforced concrete raft 9 feet thick and extending 200 feet by 100 feet. On this raft, which is 45 feet below finished ground level, is constructed a series of reinforced concrete "box" structures to take the load of the three boilers at each end of the reactor, together with the gas circulators and associated plant. The centre bay comprises the reactor vault, 77 feet in internal diameter and 81 feet 6 inches high, enclosed by the concrete biological shield 8 feet to 10 feet thick. All plant and machinery are supported by the main concrete raft.

For condensing purposes, 21 million gallons of cooling water per hour are required. The water is drawn from the estuary at a point some 450 yards off-shore into two vertical shafts, each formed by a cofferdam 32 feet in diameter, of standard sheet steel piles each 94 feet in length, in which is constructed a reinforced concrete shaft to a depth of 66 feet below sea level. Water is admitted into the shafts through coarse mesh screens below minimum tide level. The two shafts connect to the circulating water pump-house through 9 feet diameter tunnels each 1,500 feet long, driven through the clay and lined with concrete segments. After passing through the condensor, the water is discharged to two syphon recovery chambers located on each side of the pumphouse. From thence the water flows by gravity through two tunnels to two outfall shafts similar to and adjacent to the intake shafts.

The flow in the estuary is tidal and, to avoid re-circulation of the water, the intake and outfall shafts are separated by a barrier wall of sheet steel piling 805 feet in length, the wall being formed by a vertical driven pile and an angled pile at high water level.

To ensure adequate mains water supplies to the station, the Generating Board have provided £135,000 for the reinforcement of the water supply system in the whole area.

REACTORS AND BOILERS

The pressure vessel containing the reactor core is a sphere of 66 feet 9 inches diameter and was fabricated on site from 3-inch and 4-inch thick steel plates. The plates were pressed and cut to size at the manufacturer's works, and then delivered to site where they were welded in the site workshops by automatic welding machines into four-plate sections. The sections were then assembled to form horizontal rings and hand-welded together. These ring sections were then transferred to the biological shield of the reactor building by means of a Goliath crane, which was capable of lifting 200-ton loads and completely spanned the reactor building. The ring sections were finally manually welded inside the shield to form the complete sphere.

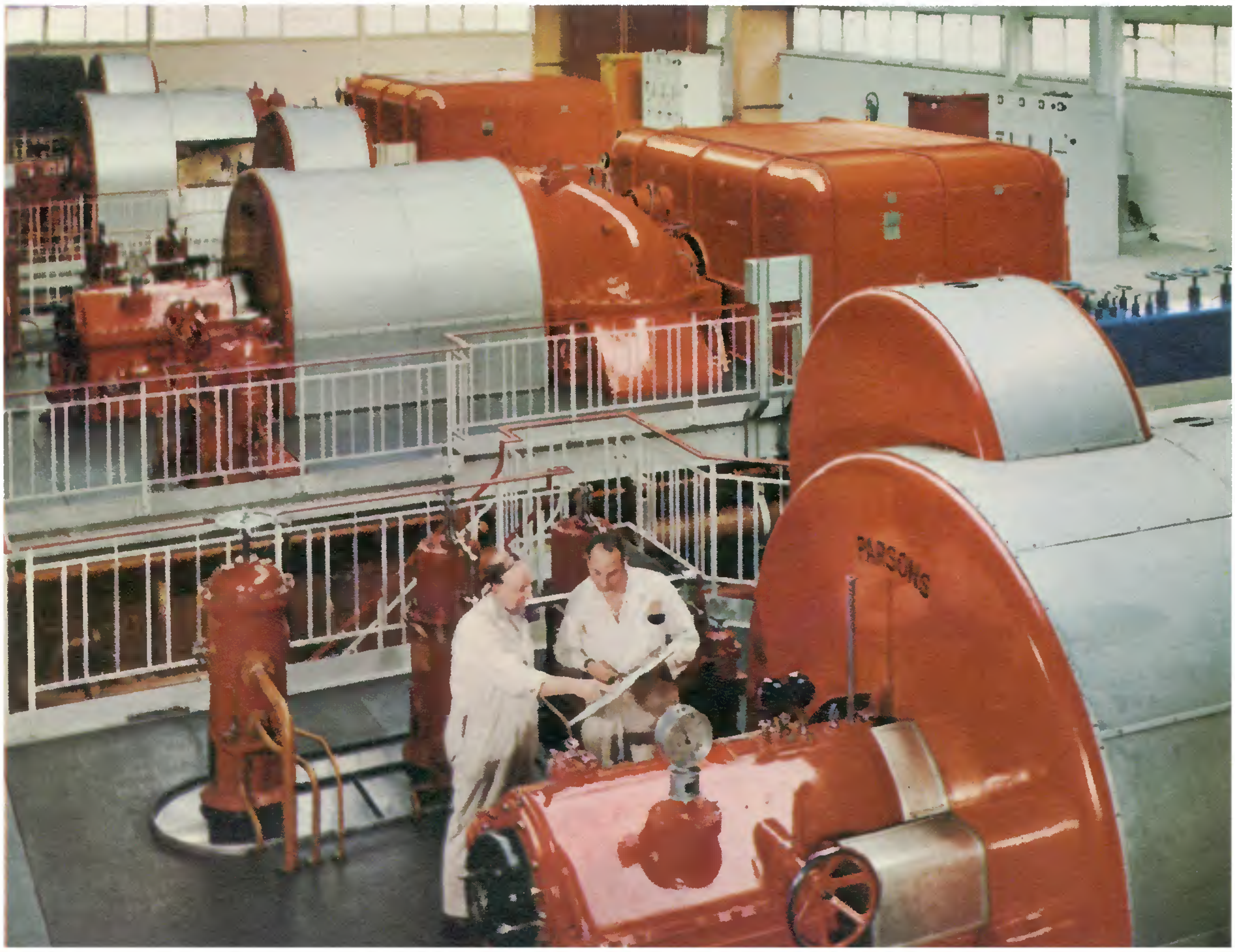
All welding is carried out to Lloyds Class "A" standard, which calls for 100 per cent radiological examination of weld metal.

The completed vessel was then stress relieved by means of internally installed electric heaters with a capacity of some 2,750 kilowatts. Following this, a pneumatic pressure test was carried out to one-and-a-half times the design pressure. The The vessel is supported by twenty-four columns on an annular reinforced concrete plinth on the main raft of the foundations, these supports being carried through the shell and supporting the reactor core.

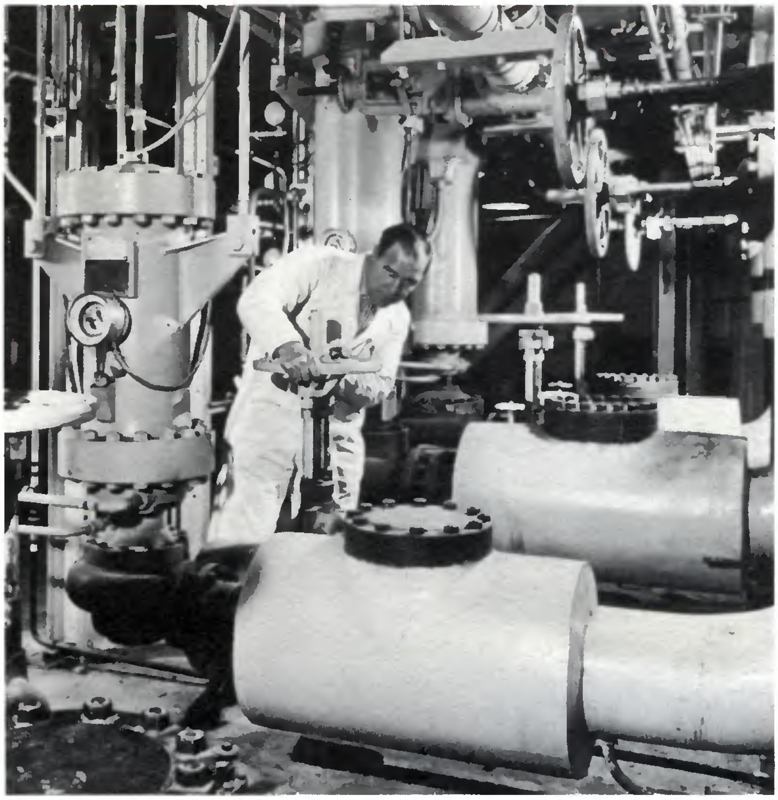
The boilers are cylindrical pressure vessels 92 feet high and 19 feet in diameter, constructed complete at the manufacturer's works and then towed down to the site by sea. After landing at Bradwell waterside they were transported by road to the station and lifted into position around the reactor by the Goliath crane, after which internal tubing was undertaken. Each boiler produces approximately 250,000 lb of steam per hour to the turbine at two pressures, 171 k.lb/hr. at 763 lb per square inch gauge and 87·5 k.lb/hr. at 199 lb per square inch gauge both at a temperature of 704 degrees Fahrenheit.

TURBO-GENERATORS

The main turbines are double admission twin cylinder machines with a combined double exhaust to twin condensers. Included in the main steam system are two dump condensers capable of dealing with approximately 10 per cent of the load output to the reactors. The main generators are hydrogen-cooled each of 52,000 kilowatts capacity at 3,000 revolutions per minute, and have a generated voltage of 11·8 kilovolts. Direct-connected transformers step this voltage up to 132 kilovolts, and connect the machines to the national Grid system. The main switchgear is of an air-blast type with a breaking capacity of 3,500 megavolt amps at 132 kilovolts, located in an outdoor switch station adjacent to the station site.

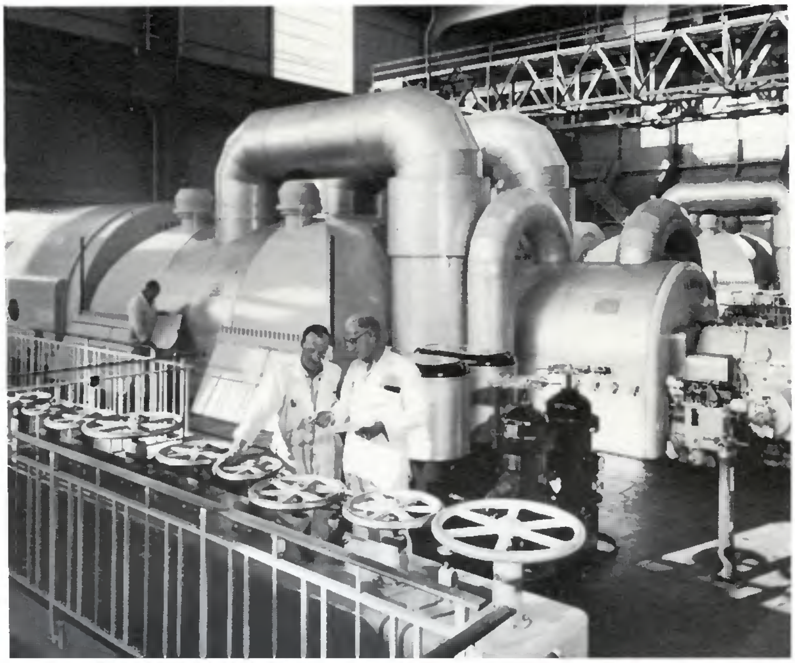


No. 9 auxiliary turbo-generator



No. 1 circulator hall, operation of boiler L.P. circulating pump

No. 2. Main turbo-generator



Main turbine hall

FUEL HANDLING AND CONTROL

The station is controlled from a central control room which contains the controls for the reactors and boilers, turbo-generators and electrical switching operations. From this point it is possible to monitor the whole of the plant and effect essential operations.

The loading of new fuel and the discharge of spent fuel into and out of the core is carried out with the reactor at power by one dual purpose machine. This machine is essentially a cylindrical pressure vessel, built of high density concrete rings sheathed in steel plate and having storage facilities for both new and spent fuel. The structure is some 60 feet high and is fitted with bogies which traverse a movable gantry. Accurate positioning can thus be achieved over any of the 80 standpipes through which access into the reactor core may be made to carry out fuelling operations. The complete weight of the machine and gantry is some 400 tons. Special hoisting equipment is fitted on the top of the machine and control is carried out from a control room overlooking the pile cap.

The reactor contains 21,000 fuel elements which will be changed by the machine over a period of 4 years. The cost of a full change of fuel is £5,000,000.

The ancillary buildings attached to the station include a cooling pond, in which discharged fuel elements can be stored for several months to allow the high intensity radiation to die down before they are transported to the United Kingdom Atomic Energy Authority's chemical factory for processing; changing room facilities, through which all personnel entering and leaving the reactor area must pass and be monitored; comprehensive active effluent treatment plant, which reduces all effluent to an acceptable level before discharging; laundry facilities for dealing with contaminated clothing; and extensive laboratory and medical services for providing full monitoring and checking facilities. These are in addition to the normal administration and welfare facilities provided for the Generating Board's power stations.

The staff of the power station are not housed within the immediate vicinity of Bradwell. New houses have been built in three villages within a radius of 10 miles.

STATION COMMISSIONING

Proposals for the commissioning of the station were drawn up and approved by the Bradwell Commissioning Committee.

This Committee under the Chairmanship of the Station Superintendent included representatives of the Nuclear Power Group, C.E.G.B. Southern Project Group, Nuclear Plant Design Department, Nuclear Operations Department, Nuclear Health & Safety Department and the United Kingdom Atomic Energy Authority. The station was commissioned jointly by the staffs of the Contractors and the Generating Board.

The commissioning programme was divided into three main stages:—

Stage A: Functional tests on sections of the plant to ensure fitness of equipment before fuel loading.

Stage B: Tests from the acceptance of the reactor for fuel loading to the time the section of the station was ready for the raising of the reactor to power.

Stage C: Procedures for power raising, normal operation and emergency and controlled shut down.

COMMISSIONING DATES

Reactor No. 1

Commencement of fuel loading, 15th August, 1961
Attainment of nominal full power, 4th August, 1962

Reactor No. 2

Commencement of fuel loading, 7th April, 1962
Attainment of nominal full power, 10th December, 1962

Turbo-Generators

No. 1 synchronised, 6th July, 1962
No. 2 synchronised, 1st July, 1962
No. 3 synchronised, 2nd July, 1962

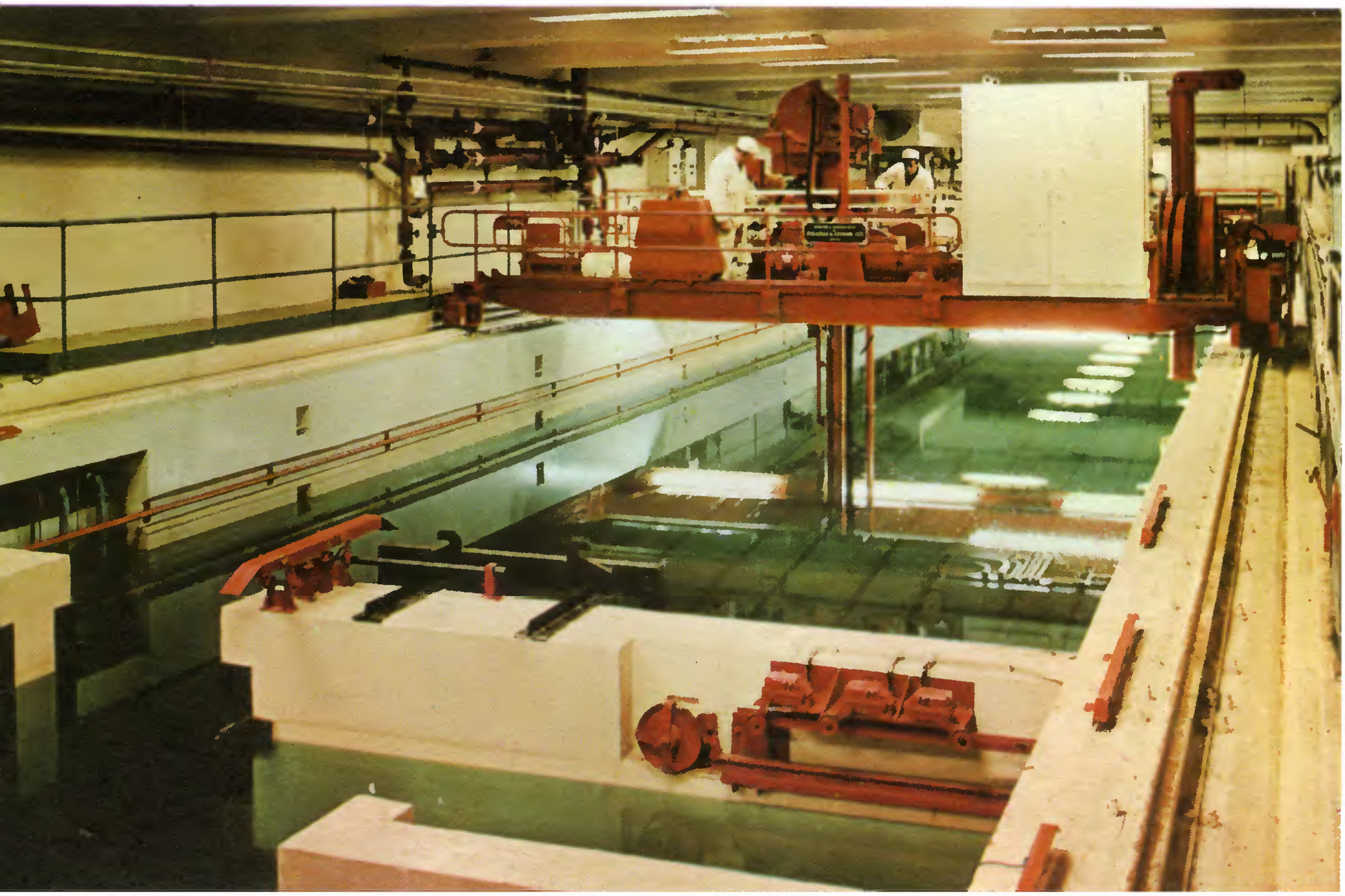
No. 4 synchronised, 8th December, 1962
No. 5 synchronised, 18th September, 1962
No. 6 synchronised, 6th July, 1962

Reactor No. 2. Positioning chute headbox on standpipe

Main control room

Essential supplies room, reactor No. 1.

Irradiated fuel cooling pond



AMENITY AT BRADWELL

At the public inquiry into the proposed development of Bradwell power station many fears were expressed of the possible effects it might have on the neighbourhood. It is interesting to see how events have turned out.

The wild and lonely character of the Dengie Peninsular has not been dominated by the power station and, due to the skilled design of the architect, and the landscaping and tree-planting schemes drawn up by the landscape architect, the building blends with the local landscape. Far from the station becoming the spearhead of industrial development, the implementation of the Government policy that nuclear stations must be in sparsely populated areas has reinforced the town and country planning proposals in locating new developments, and has materially helped to preserve the locality.

The migrant Brent Geese who frequent the Blackwater Estuary have not been driven away by the construction and operation of the power station—their numbers have increased in recent years.

The oyster fishery interest's experts suggested that the estuary would become a dead sea. The Ministry of Agriculture, Fisheries and Food, in collaboration with the Generating Board, are engaged in a continuing survey of marine conditions. To date no detrimental effects of the warmed circulating water discharges have been found.

BERKELEY NUCLEAR POWER STATION

TECHNICAL DETAILS

Capacity

Maximum continuous electrical rating (installed capacity) from two reactors and four turbo-alternator sets:	322 MW
Electrical output ("sent out" capacity):	275 MW
Reactor heat rating:	560 MW

Boilers

(John Thompson)

Number	Eight per reactor
Shell size	17ft. 6ins. dia. by 70ft. high (82ft. high with skirt)
Shell material	Mild steel 1⅛ins. thick
H.P. steam temperature	322°C.
H.P. steam pressure	306 p.s.i.g.
H.P. steam flow	1,100,000 lb/hr.
L.P. steam temperature	322°C.
L.P. steam pressure	62 p.s.i.g.
L.P. steam flow	520,000 lb/hr.
Feed temperature	77°C.

TURBO-ALTERNATORS

(A.E.I. Manchester)

Turbines

Four 2-cylinder, close coupled, mixed pressure impulse turbines driving alternators with rated output of 83 MW at 0.8 power factor.

Alternators

Four direct-driven alternators generating at 11,800 volts at 0.8 power factor 3 phase, 50 cycle, hydrogen cooled at 30 p.s.i.g. Transmission voltage 132 kV.

Condensing Plant

Three two pass condenser shells per turbo-alternator.

Feed Heating Plant

Two stages of L.P. fed heating giving feed temp. of 77°C.

C.W. System

Intake to pumps through 9ft. 6ins. dia. tunnels located 100ft. below site level.

BRADWELL NUCLEAR POWER STATION

TECHNICAL DETAILS

Capacity

Maximum continuous electrical rating (installed capacity) from two reactors and six main turbo-alternator sets and 2 auxiliary turbo-alternator sets		347·4 MW
Electrical output ("sent out" capacity)		300 MW
Reactor heat rating	each	537·6 MW (H)

Boilers

(Head Wrightson/Clarke, Chapman)

Number	Six per reactor
Shell size	20 ft. 0 ins. diameter by 80 ft. high (92 ft. 4 ins. overall)
Shell material	Mild steel $1\frac{9}{16}$ in. thick
H.P. Steam temperature	372°C.
H.P. Steam pressure	755 p.s.i.g.
H.P. Steam flow	1,026,000 lb/hr.
L.P. Steam temperature	372°C.
L.P. Steam pressure	195 p.s.i.g.
L.P. Steam flow	528,000 lb/hr.
Feed temperature	87·8°C.

TURBO-ALTERNATORS

C. A. Parsons (Newcastle-on-Tyne)

Turbines

Six 2-cylinder, close coupled, mixed pressure, reaction turbines driving alternators with rated output of 52 MW at 0·8 power factor.

Alternators

Six direct-driven alternators generating at 11,800 volts at 0·8 power factor, 3 phase, 50 cycle, hydrogen cooled at 15 p.s.i.g. Transmission voltage 132 kV.

Condensing Plant

Two double pass condenser shells per turbo-alternator

Feed Heating Plant

Two stages of L.P. feed heating giving feed temp. of 87·8°C.

C. W. System

Intake to pumps through 9 ft. 0 ins. dia. tunnels located 66 ft. below sea level

BERKELEY NUCLEAR POWER STATION

C. W. System

Pumps	Six vertical spindle centrifugal, driven by 900 h.p. motors.
Total flow	21,000,000 g.p.h.
Temperature rise	8°F.

Civil and General

Construction site area	96 acres

Area inside station security fence 43 acres.

Excavation

Turbine house	95,000 cu. yds.
Reactor 1	78,000 cu. yds.
Reactor 2	75,000 cu. yds.
C.W. pumphouse	35,000 cu. yds.

Geology

Kauper Marl with horizontal bands of Claystone and Green Sandstone for about 40ft. from surface. Below this is Old Red Sandstone series.

Bearing Pressure	2½ tons per square foot

REACTORS

Fuel

Natural uranium as rods (99·3% U.238, 0·7% U.235).

Size of rods	19 ins. long by 1·1 ins. dia.
Number of rods per channel	13
Number of channels	3265 (plus 10 graphite sample channels)
Total number of rods	42445
Total weight of fuel	228 tons
Canning material	Magnox A.12 (Magnesium alloy)
Nominal max. can temperature	435°C.

Moderator

Graphite as blocks and tiles (approx. 100,000 pieces).

Overall size	48 ft. dia. by 30 ft. high
Core size	42 ft. dia. by 24 ft. high
Total weight of moderator	2,100 tons
Lattice pitch	8·16 in.

BRADWELL NUCLEAR POWER STATION

C.W. System

Pumps	Six vertical spindle centrifugal, driven by 950 h.p. motors
Total flow	32,700,000 g.p.h.
Temp. rise	8·3°C.

Civil and General

Construction site area	75 acres
Area inside station security fence	20 acres

Excavation

Turbine house	120,000 cu. yds.
Reactor 1	75,000 cu. yds.
Reactor 2	75,000 cu. yds.
C. W. Pumphouse	30,000 cu. yds.

Geology

"London Blue Clay" for 150 ft. with overlay of 20-30 ft. of stiff brown clay.

Bearing pressure	2½ tons per square foot

REACTORS

Fuel

Natural uranium as rods (99·3% U.238, 0·7% U.235)

Size of rods	36 ins. long by 1·155 ins. dia.
Number of rods per channel	8
Number of channels	2837
Total number of rods	20,970
Total weight of fuel	241 tonnes
Canning material	Magnox A.12 (Magnesium alloy)
Nominal max. can temperature	440°C.

Moderator

Graphite as blocks and tiles (approx. 100,000 pieces)

Core size	40 ft 1 in. dia. by 25 ft. 10 ins. high
Total weight of moderator	1,931 tons
Lattice pitch	8 ins.

BERKELEY NUCLEAR POWER STATION

Control rods	Material	4·25% boron steel
	Number	132
	Size	27 ft.—11 ins. by 2 ins. diameter
	Drive	Synchronous motor
Pressure Vessel	**(John Thompson)**	
	Shape	Cylinder with hemispherical ends
	Dimensions	80 ft. high by 50 ft. dia. by 3 ins. thick
	Material	Silicon killed mild steel
	Max. temperature	300°C.
	Operating pressure	125 p.s.i.g.
Coolant	(Blowers—B.T.H. Ducts—John Thompson)	
	Carbon Dioxide	
	Pressure	125 p.s.i.g.
	Mass flow	6500 lb/sec.
	Inlet temperature	160°C.
	Outlet temperature	345°C.
	Ducting size	5 ft.
	Blowers (or circulators)	Eight single-stage axial flow per reactor
	Blower drive	3,800 h.p. a.c. squirrel cage induction motor running at 2,900 r.p.m.
	Blower speed control	Vulcan-Sinclair scoop control fluid couplings
Shielding	Thermal—Bottom	4 in. thick steel plate
	Sides	Two ½ in. thick plates with 1½ ins. air gap between
	Top	Two 2½ in. steel plates
	Biological—Bottom (incl. raft)	15 ft. thick concrete
	Side	8 ft. 6 ins. thick concrete
	Top	12 ft. thick concrete
	Shielding concrete	
	Composition	¾ in. crushed limestone 3·91 Ball Mill Sand 2·59 Portland Cement 1·00 Water 0·60
	Density (Dry)	141-144 lb/cu. ft.

BRADWELL NUCLEAR POWER STATION

Control Rods	Material	7·4% boron steel
	Number	119
	Size	27 ft. $3\frac{1}{2}$ ins. by $2\frac{1}{2}$ ins. dia.
	Drive	Low frequency A.C. variable speed
Pressure Vessel (Whessoe)	Shape	Spherical
	Dimensions	66 ft. 9 ins. dia.
	Material	Silicon killed mild steel
	Max. temperature	386°C.
	Operating pressure	132·2 p.s.i.g.
Coolant	(Blowers—C. A. Parsons, Ducts—C.A. Parsons)	
	Carbon Dioxide	
	Pressure	132·3 p.s.i.g.
	Mass flow	5,332 lb./sec.
	Inlet temperature	180°C.
	Outlet temperature	390°C.
	Ducting size	5 ft. 0 ins.
	Blowers (or circulators)	Six single-stage axial flow per reactor
	Blower drive	4,400 h.p. a.c. squirrel cage induction, variable speed
	Blower speed control	Variable speed auxiliary turbo-alternators
Shielding	Thermal	$\frac{3}{16}$ in. thick steel sheet
	Biological—Bottom (incl. raft)	9 ft. 0 ins. thick concrete
	Side	8 ft. 6 ins. thick and 10 ft. 0 ins. thick concrete
	Top	8 ft. 6 ins. thick and 10 ft. 0 ins. thick concrete
	Shielding concrete:	
	Max. density of concrete	
	Ordinary	140 lb./cu. ft.
	Barytes	200 lb./cu. ft.

Berkeley nuclear power station
was designed and constructed for
The Central Electricity Generating Board
by The Nuclear Power Group

MAIN CONTRACTORS

A.E.I. — John Thompson Nuclear Energy Company Limited

Member Companies:
Associated Electrical Industries Limited
John Thompson Limited

Civil Engineers:
John Laing and Son Limited
Balfour Beatty & Company Limited

Consultants — Civil:
W. S. Atkins and Partners

Full acknowledgment is made also to the thousands of sub-contractors, both great and small, in Great Britain, who contributed to the building of Berkeley.

Bradwell nuclear power station
was designed and constructed for
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The Nuclear Power Plant Company Limited

Member Companies:

C. A. Parsons & Company Limited
A. Reyrolle & Company Limited
Head, Wrightson & Company Limited
Sir Robert McAlpine & Sons Limited
Whessoe Limited
Strachan & Henshaw Limited
Alex, Findley & Company Limited
Clarke, Chapman & Company Limited
Parolle Electrical Plant Company Limited

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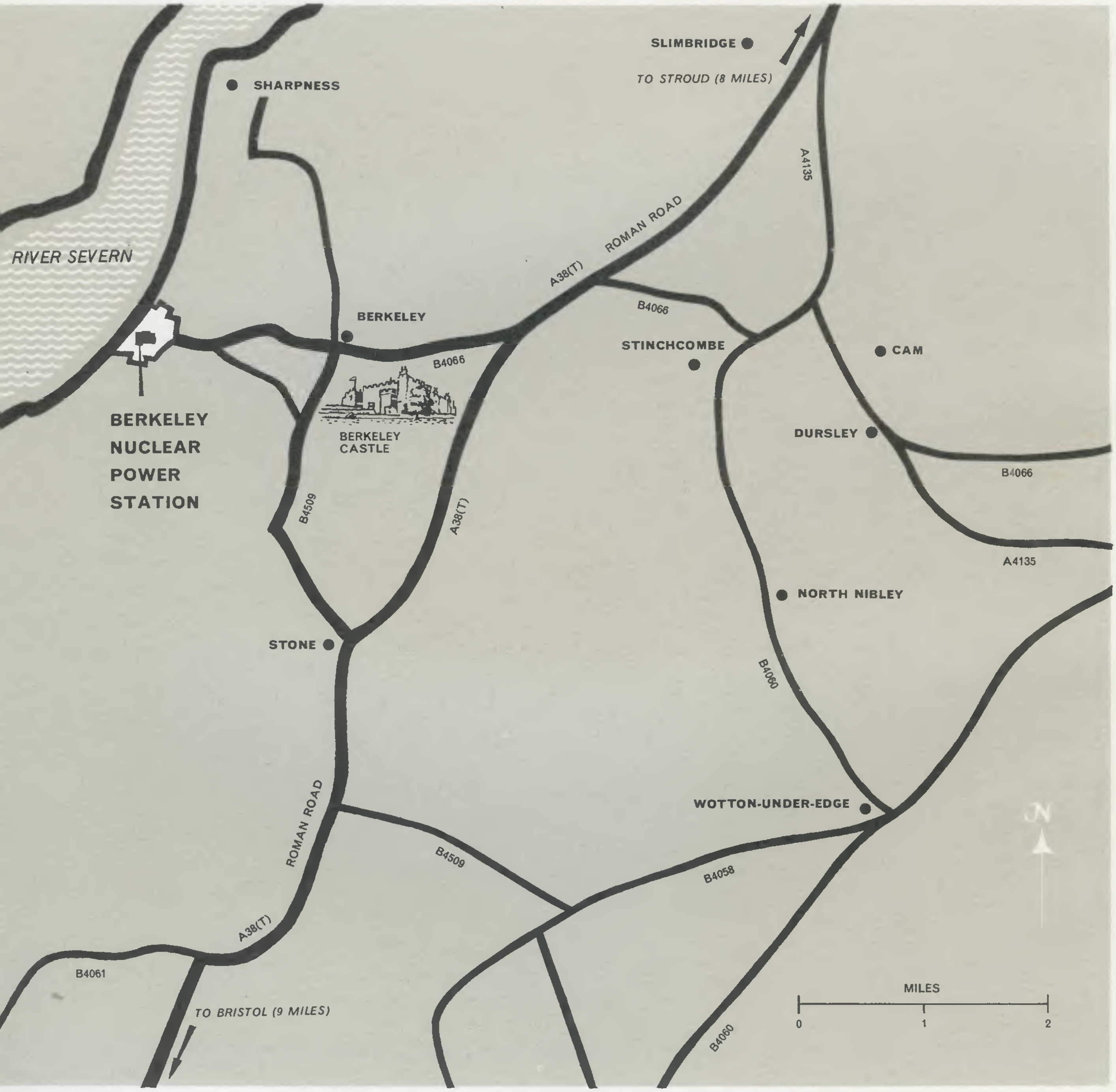
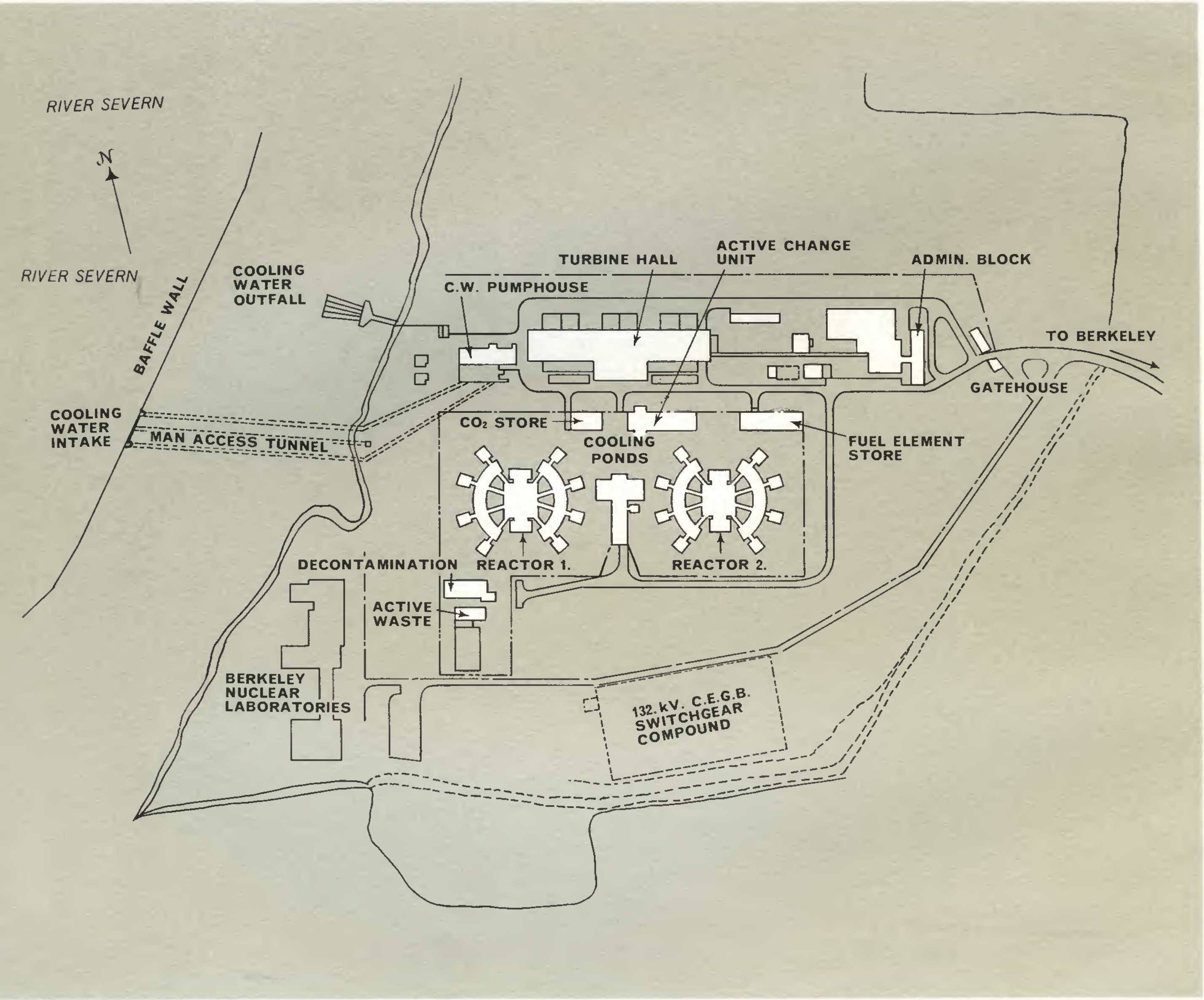
Location Map – Berkeley

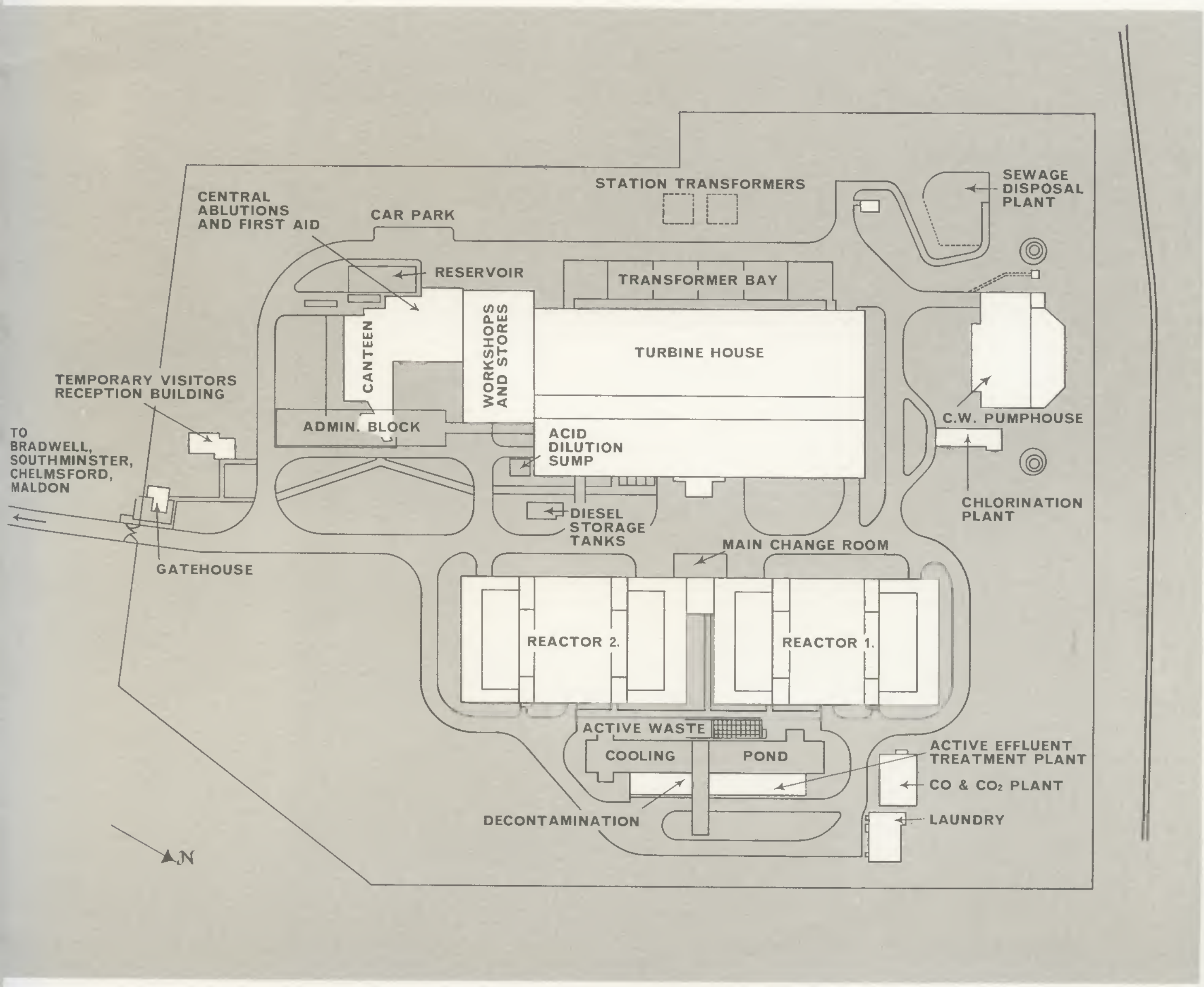


Location Map – Bradwell

Berkeley Site Plan



Bradwell Site Plan



Scanned October 2016 www.coaley.net

Ray Wilson

Hon. Sec. Gloucestershire Society for Industrial Archaeology

Joined CEGB at BNL on 3 January 1972, Retired 7 May 2007
Continued part-time under Post-Retirement contracts until 30 June 2012

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