Dungeness B

AGR nuclear power station

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The Central Electricity Generating Board's advanced gas-cooled reactor (AGR) station Dungeness B in Kent, will have a net output of 1 200 000 kilowatts and will be the most powerful nuclear power station anywhere in the world.

It will be the first in Britain's second nuclear power programme (as outlined in Government White Paper 2335) and will be built by Atomic Power Constructions Ltd (A P C). The cost of electricity generated is estimated to be over 25% cheaper than that from the ninth and most powerful of the 'magnox' nuclear power stations being built at Wylfa in Anglesey and over 10% cheaper than that from the most modern coal-fired power station being built at Cottam in Nottinghamshire.

The first nuclear power programme consisted of nine stations (see TABLE I) based on the principles developed by the United Kingdom Atomic Energy Authority (UKAEA) at Calder Hall. The twin reactors at each of these stations are graphite moderated, carbon dioxide gas-cooled and use natural uranium metal fuel elements encased in mag-

TABLE I

THE FIRST NUCLEAR POWER PROGRAMME

Station	Commissioning year	Design output MW
Berkeley	1962	275
Bradwell	1962	300
*Hunterston	1964	300
Hinkley Point	1965	500
Trawsfynydd	1965	500
Dungeness 'A'	1965	550
Sizewell	1965	580
Oldbury	1966	600
Wylfa	1968	1180

* Hunterston is owned by the South of Scotland Electricity Board, all the other stations by the Central Electricity Generating Board.

nesium alloy cans. This magnesium alloy, magnox, gave its name to the reactor system.

The early magnox reactors have proved to be reliable in service. Their operating costs are low, but their capital costs are high and this has made it difficult for them to become fully economic when compared with large modern coal or oil-fired power stations.

The UKAEA have, however, developed the AGR as a successor to the magnox system, and have built a prototype at Windscale. This also uses a graphite moderator and carbon dioxide coolant but the fuel is uranium dioxide in stainless steel cans. At the expense of having to use slightly enriched uranium this allows much higher temperatures and fuel ratings than in the magnox reactor, and also permits far greater fuel irradiations; about 18 000 MW days/tonne compared with 3 000-4 000 MW days/tonne for magnox.

Overall result

The overall result is a far more compact reactor producing steam suitable for modern large high efficiency turbo-generators similar to those used in the latest coal and oil-fired power stations.

The Windscale AGR was commissioned in early 1963. The uniformly good experience from it, together with favourable results from other research and development work on the graphite needed for a commercial version, encouraged the Generating Board to issue an enquiry specification early in 1964 for a station of this type. The enquiry specification was subsequently widened to permit proven designs of water moderated reactors to be offered as well as AGR's. The station was to be built at Dungeness (Figure 6) on the English Channel alongside the nearly completed magnox station there.

On 1st February 1965 tenders were received for stations based on AGR's and on water moderated reactors. The AGR submitted by APC gave the lowest cost of generation of any tender and was chosen for Dungeness B.

Design of the station

The complete reactor, including core, gas circulators and boilers, is housed within a concrete pressure vessel, with the core at the centre, and the circulators under the boilers as shown in Figure 4. An inner pressure cylinder in the form of a bell separates the core from the boilers. The circulators deliver into the region within this cylinder, some of the flow passing downwards through the core to keep the graphite and its restraint structure close to inlet temperature. The total flow then passes upwards through the fuel channels and charge tubes, and is discharged through ports into the plenum above the pressure cylinder, whence it passes down through the boilers back to the circulator inlets.

'Hot box' unnecessary

The internal walls of the concrete pressure vessel are clad with sufficient stainless steel thermal insulation to make it unnecessary to employ a 'hot box' as in the Windscale AGR. There are shields around and above the core to prevent activation of boilers and circulators so that these can be reached and maintained: under certain conditions it is also possible to enter the space above the core.

The concrete pressure vessel is cylindrical, and is prestressed by circumferential and vertical cables in the barrel and by horizontal cables in the two end caps. Its inner boundary is sealed by a water-cooled membrane made of mild steel.

The boilers are of the once-through type with a single reheater stage. The tube ends are led out in such a way that access is available for plugging or other purposes without entry into the pressure vessel. There are four boiler sections per reactor, each operating as a unit with a gas circulator.

Each gas circulator is a centrifugal machine, the working parts of which form a cartridge unit mounted at the base of the pressure vessel wall. There is a simple sleeve valve which isolates the circulator from the main gas circuit and enables the whole cartridge unit to be removed through the wall of the vessel for maintenance after depressurisation but without filling the pressure vessel with air. If necessary, the other three circulators can be brought back to load with the fourth penetration blanked off. Each circulator is driven by a synchronous motor through a fluid coupling which allows the circulator speed to be controlled.

Improved fuel

The uranium dioxide fuel is contained in stainless steel cans as in the UKAEA prototype. These are arranged in three-ring clusters of 36 pins within graphite sleeves, to form 40 inch-long fuel elements. The multi-pin AGR fuel elements are entirely different from the fuel elements used in the magnox stations, as illustrated in Figure 3. The mean fuel rating is some three times greater than for the magnox system, and the axial shuffling of fuel elements part way through their irradiation period leads to the substantially uniform irradiation of all fuel.

Individual standpipes through the pressure vessel are used for access to every channel in the core. Eight fuel elements are made up into a stringer, which is attached to a plug unit located in the standpipe, and the whole forms a composite assembly which is handled by the fuelling machine and loaded into the reactor as one unit. The plug units incorporate motor driven gags which can be used to provide adjustment of channel flow from the control room under normal operating conditions: this is a feature which achieves maximum output while avoiding complex working on the charge face. The control rods are attached to similar plug units, containing the drive motors and mechanisms, and are interchangeable with fuel assemblies.

A single fuelling machine serves both reactors. It is mounted on a gantry which runs across the charge face and can be connected to any of the standpipes on either reactor or to the service holes in the central fuel handling block.

On-load fuelling

The fuelling machine is designed to operate with the reactor at full load, but neither grabs nor any other fuelling machine components need to penetrate the pressure envelope below charge face level for this purpose. All handling operations over the reactor are under the jurisdiction of the control room.

New and irradiated fuel handling facilities are housed in a central block located between the two reactors and this area also contains servicing facilities for the fuelling machine and the standpipe components.

660 MW sets

The two 660 MW turbo-generators operate at the same steam conditions as in modern coal-fired power stations. The turbines are based on the technology of the standard 500 MW machines which are being manufactured in large numbers for the Generating Board. The latest arrangement of pannier condensers is adopted. The generators are similar to those being designed for the 660 MW supercritical units at Drax in Yorkshire.

The electrical output from the turbo-generators is stepped up through generator transformers to give supply to the grid switch house. The works auxiliary electrical distribution follows the conventional practice of unit and station systems, the primary voltage being 11 000 volts. In the event of total loss of the external electrical connection and of the normal internal auxiliary supply system, essential supplies to maintain station safety are provided by four diesel generators, with battery back-up for guaranteed supplies.

The two reactors are housed together with all the other plant and equipment for the station in a single composite building as shown in Figures 1 and 2. This building comprises a reactor unit, housing the two reactors and the fuel handling block on the landward side, a turbine unit housing the turbo-generators and their auxiliaries on the seaward side, and a services unit containing the switchgear, instrumentation, change-rooms and other common services in between. Reinforced concrete construction is adopted below ground level and where heavy shielding is required; elsewhere the construction is steel-framed with protective metal cladding.

The operation of all major plant in the station is controlled from a single control room located centrally in the building. Extensive data processing facilities are incorporated.

The layout of the building and plant has been arranged to control contamination and to dispose of all solid active waste within the building itself, allowing all roads to be classified as clean and access to the main entrance of the building to be unrestricted. With these arrangements, radiation and contamination are adequately controlled with minimum inconvenience to operating staff or visitors.

Compactness

The most striking fact about the layout of the Dungeness B station when compared with the previous British nuclear power stations is its compactness. This is shown clearly on the site plan (Figure 6) of the Dungeness A (550 MW) and B (1200 MW) stations, and it stems from the increased fuel ratings, the improved steam conditions, the tightly integrated reactor design and the single building complex for turbo-generators and reactors. In the Dungeness B AGR design the reactor centres are only 160 feet apart compared with over 400 feet at Dungeness A, and the output per square foot of the plan area for the station is some four times greater than is general for the magnox stations.

Operating characteristics

Low fuel cycle costs

The AGR to be built at Dungeness B has many attractive features which help to keep down the cost of operation. The simple on-load refuelling arrangement using single channel access has proved very successful at Windscale. It is expected to result in good reactor availability and, together with axial shuffling of the fuel, should ensure low fuel cycle costs. The single channel access arrangement also facilitates the measurement of the gas temperature at the outlet from each channel and the provision of on-load adjustment of the flow from each channel enables output to be maintained with a minimum of variation due to the fuel cycle.

Low labour costs

The system of electric blower drive with fluid couplings for speed control was specified to give high reactor availability and together with the compact layout and extensive automatic control should result in low labour costs. Manpower requirements for refuelling will also be low since on the whole station with two reactors only two or three channels are refuelled each week and a similar number are axially shuffled.

The use of standard steam conditions for the turbine is an additional advantage.

Safety

Siting eased

The AGR has excellent safety characteristics which will enable it to be built closer to centres of population than has been the Generating Board's practice with nuclear power stations in the past. This arises partly from the use of a prestressed concrete pressure vessel to contain the complete coolant gas circuit. Such a vessel depends for its integrity on a very large number of separate high tensile steel prestressing cables and many of these would have to fail simultaneously before the vessel would show signs of distress. As a result sudden loss of coolant is inconceivable and the worst accident of this type which needs to be considered is a slow depressurisation through an auxiliary circuit which would not cause overheating of the fuel.

This high integrity coolant circuit would also limit the maximum release of activity to an acceptable value if for some unforeseen reason a channel of fuel within the reactor became grossly overheated.

The safety of the reactor is also enhanced by the use of ceramic (uranium dioxide) fuel in stainless steel cans. Both these materials can stand quite severe over-temperature without distress and even at temperatures very much higher than normal are chemically inert in the carbon dioxide coolant gas.

TABLE II PRINCIPAL STATION DATA

Net electrical output	1200 MW
Gross generation	1320 MW
Number of reactors	2
Number of turbo-generators	2
Overall station efficiency	41·5%
Type of fuel	36×0·57 in pin clusters
Number of fuel elements in stringer	8
Mean fuel rating for reactor	9·5 MW/tonneU
Initial enrichment	1·47/1·76%
Feed enrichment	1·99/2·42%
Refuelling	continuous on load with axial shuffle
Lattice pitch	15·5 in
Lattice geometry	square
Active core height	27 ft
Active core diameter	31 ft
Total number of channels	465
Number of fuel channels at equilibrium	412
Channel gas inlet temperature	320°C
Channel gas outlet temperature	675°C
Peak can temperature	800°C
Circulator outlet pressure	450 lbf/in^{2}abs.
Number of circulators per reactor	4
Type of circulator	centrifugal
Circulator speed	1500 rev/min
Speed variation	fluid drive coupling
Circulator drive	synchronous motor
Circulator installed power, each	16 500 hp
Type of boiler	once through
Steam pressure	2315 lbf/in^{2}abs.
Steam temperature	565°C (1050°F)
Steam flow	3·7 M lb/h
Reheat pressure	556 lbf/in^{2}abs.
Reheat temperature	565°C (1050°F)
Condenser vacuum	28·9 inHg
Cooling water inlet temperature	14°C
Electrical power density-kW/ft^3 of pressure vessel volume	3·0
Electrical power density-kW/ft^3 of building volume	0·07

The future

The AGR represents another stage (after magnox reactors) in the development of gas-cooled reactors. As in all such developments, engineering improvements in the design of the plant can be anticipated in AGR stations constructed after Dungeness B.

Good development potential

Simultaneously with engineering developments it appears, from development work now proceeding, that it should be possible to advance the working conditions of later AGR's. An increase in coolant gas pressure to 600 pounds per square inch from the Dungeness B level of 450 and substantial advances in fuel operating parameters and in fuel management schemes are anticipated. A reduction in the cost of electricity generated approaching 10% would be the target.

If the fuel element were made up of 60×0·4″ diameter pins instead of 36×0·57″, the fuel rating could be approximately doubled. The fuel inventory could thus be markedly reduced, and the initial investment cut by around 7%. Increases in enrichment and in fuel fabrication costs could largely nullify the effect of this capital saving in generating costs. However, high fuel rating designs could be of interest if emphasis were placed on a low capital investment and could be considered for later AGR stations.

The largest single source of possible saving for later AGR's appears to be the increase of reactor size. Substantiation for the feasibility of AGR's having about double the Dungeness B output was obtained in a detailed design study carried out by the UKAEA during 1964. The target saving for a 2×1200 MW station (with four turbo-generators) would be 10% in the cost of electricity generated compared with a 2×600 MW station.

Looking further ahead, there are other possible developments in gas-cooled reactors, including the use of 'dispersed' fuels, i.e. small uranium carbide spheres embedded in highly refractory silicon carbide, instead of being canned in stainless steel.

Dungeness B will be engineered by the CEGB Southern Project Group

Main Contractors	Atomic Power Constructions Limited Associated Companies: International Combustion (Holdings) Limited The Fairey Company Limited Richardsons Westgarth and Company Limited
Architects	Howard V. Lobb and Partners
Consultants	Thomas Barrett Sons and Partners F. R. Bullen and Partners Scott Wilson Kirkpatrick and Partners
CEGB Consultant	L. G. Mouchel and Partners
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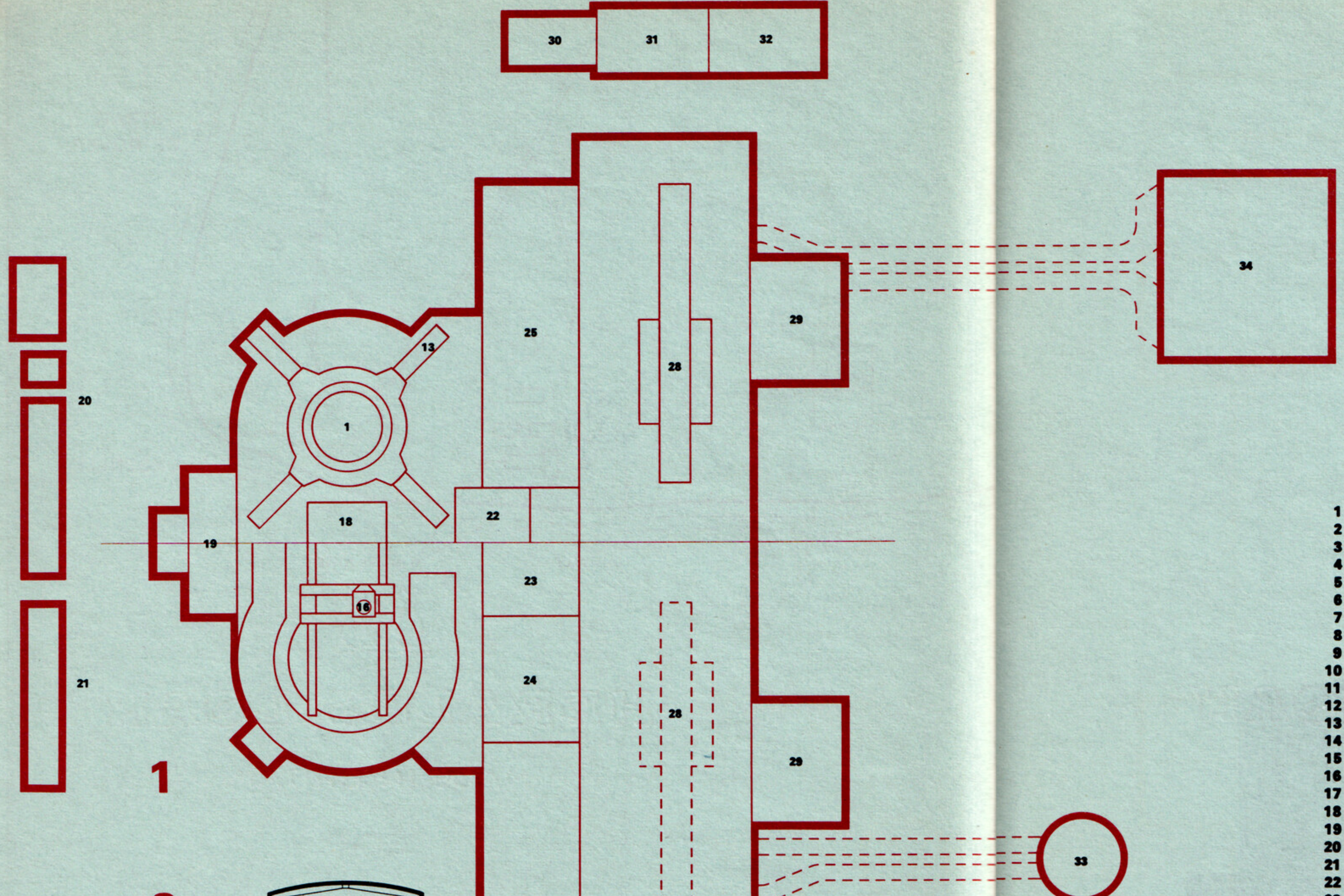

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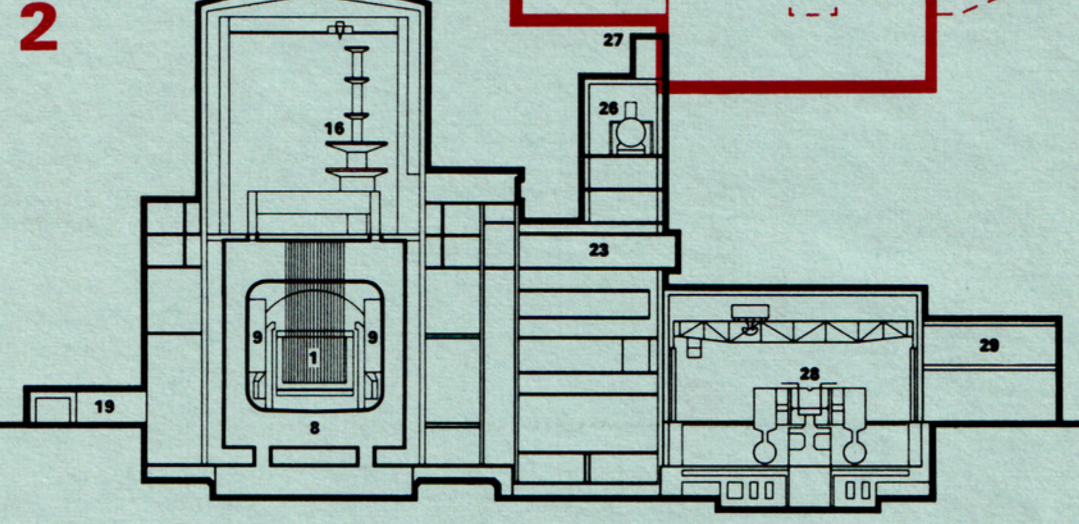

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1	core and reflector
2	top shield
3	side shield
4	support structure
5	pressure cylinder
6	thermal insulation
7	fuelling and control standpipes
8	concrete pressure vessel
9	boiler
10	steam outlet
11	feed water inlet
12	plenum chamber
13	circulator
14	circulator drive
15	charge face
16	fuelling machine
17	charge face crane
18	IFD block
19	new fuel store
20	gas storage
21	reservoir
22	cooling pond
23	control room
24	safety/instrument rooms
25	main change room
26	de-aerator
27	exhaust stack
28	generators
29	generator transformer
30	diesel fuel store
31	reserve feed water tanks
32	fire fighting water storage tanks
33	syphon recovery chamber
34	cooling water pump house

figure 1 plan of station*
2 section through station*
3 magnox and A G R fuel elements
4 section through reactor
5 model of station*
6 site plan

*as submitted to the Royal Fine Art Commission

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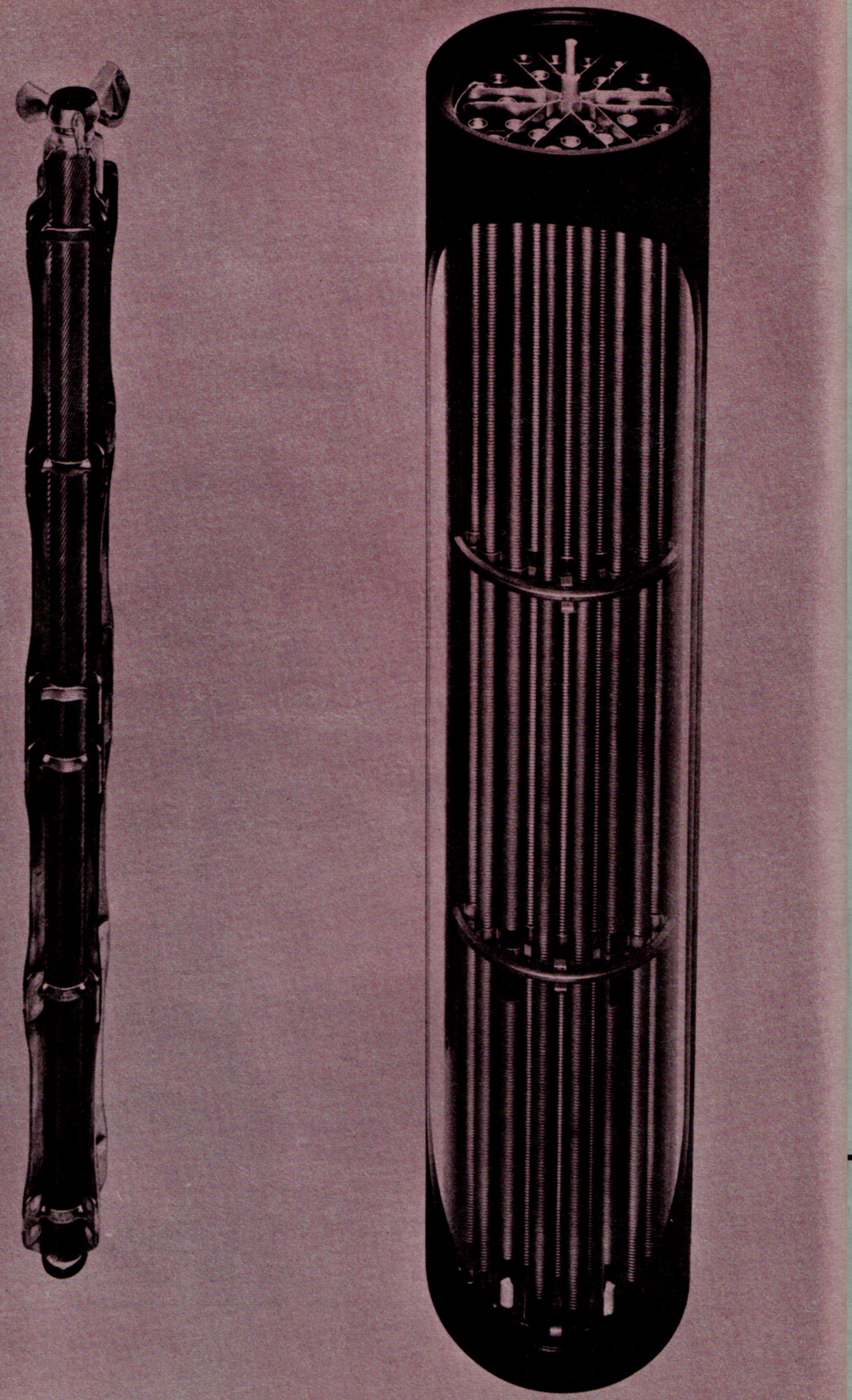

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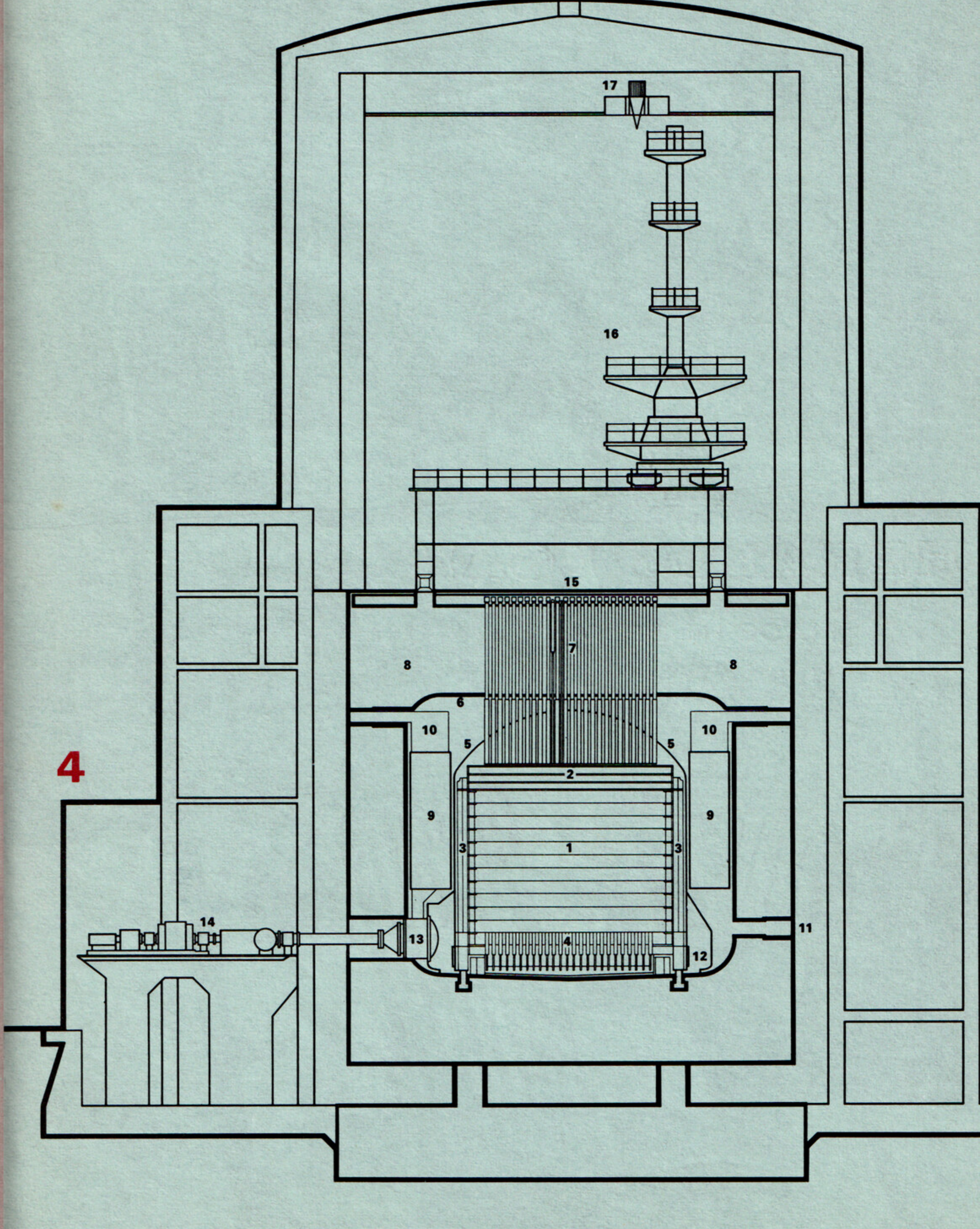

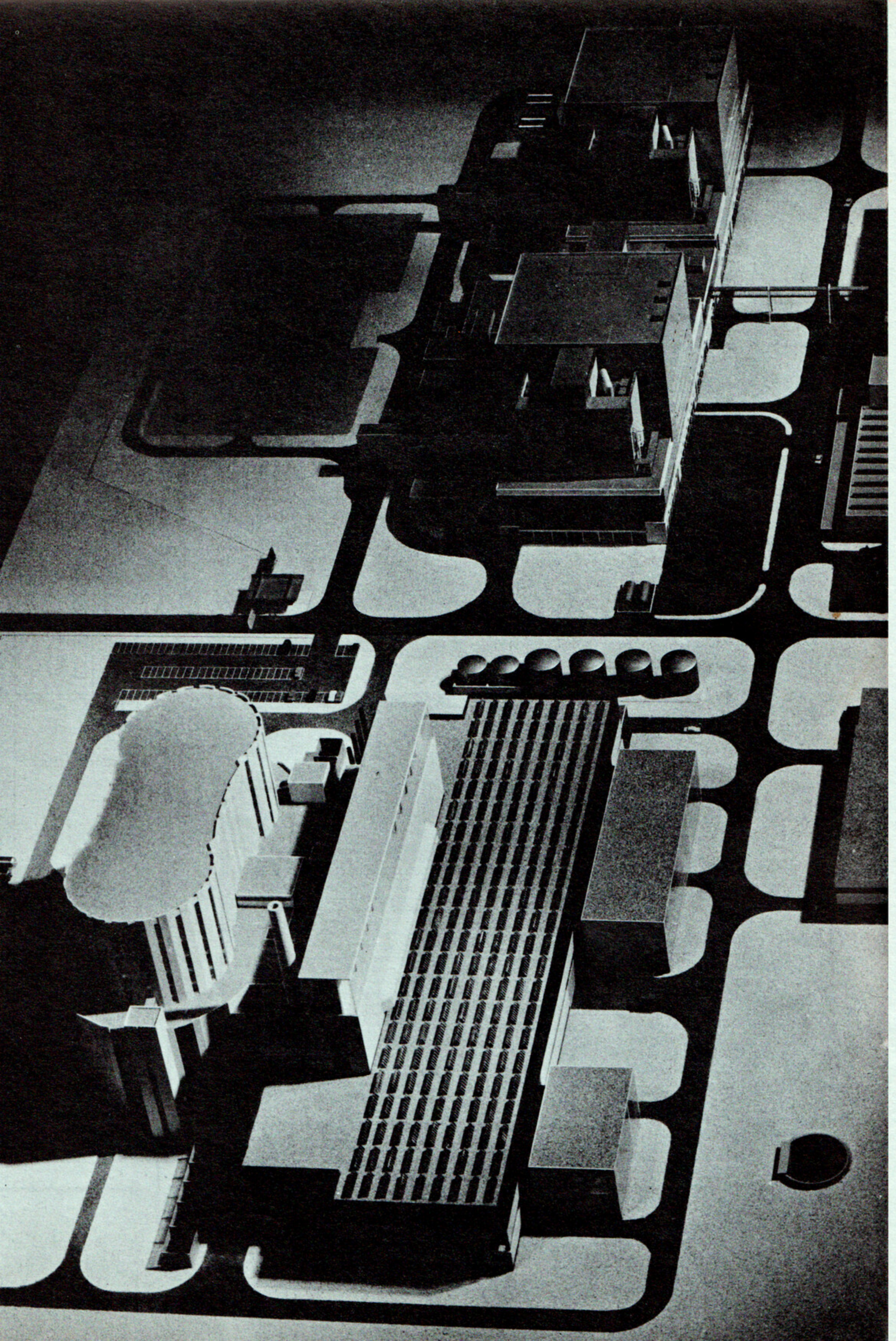

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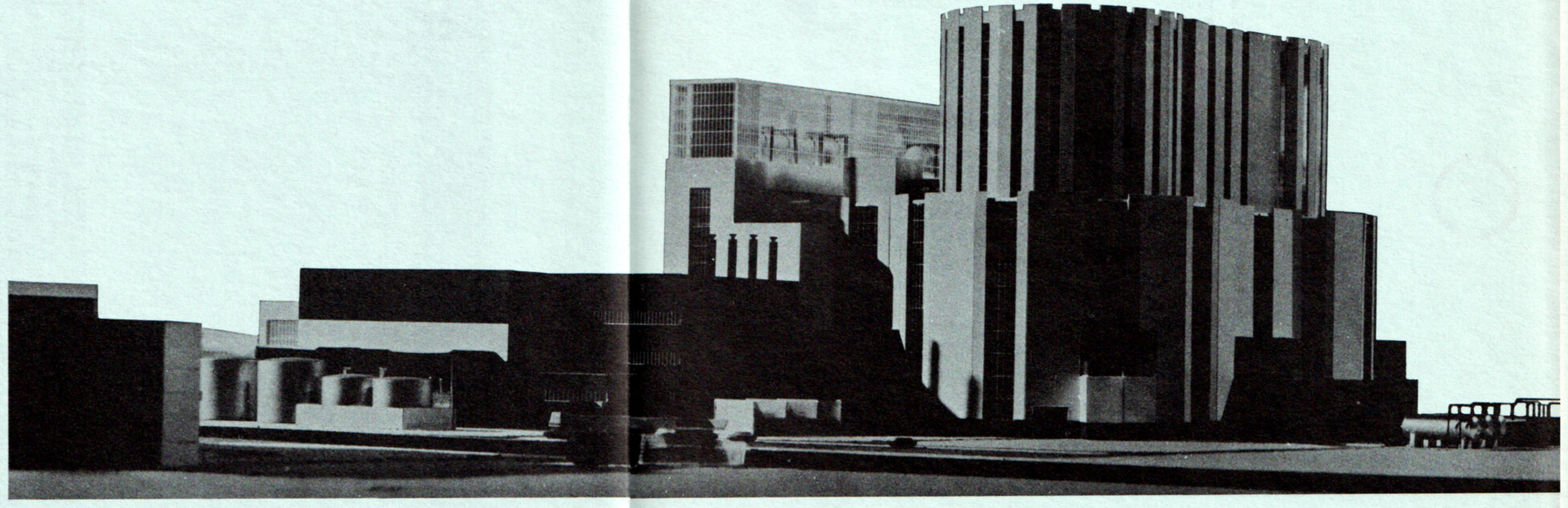

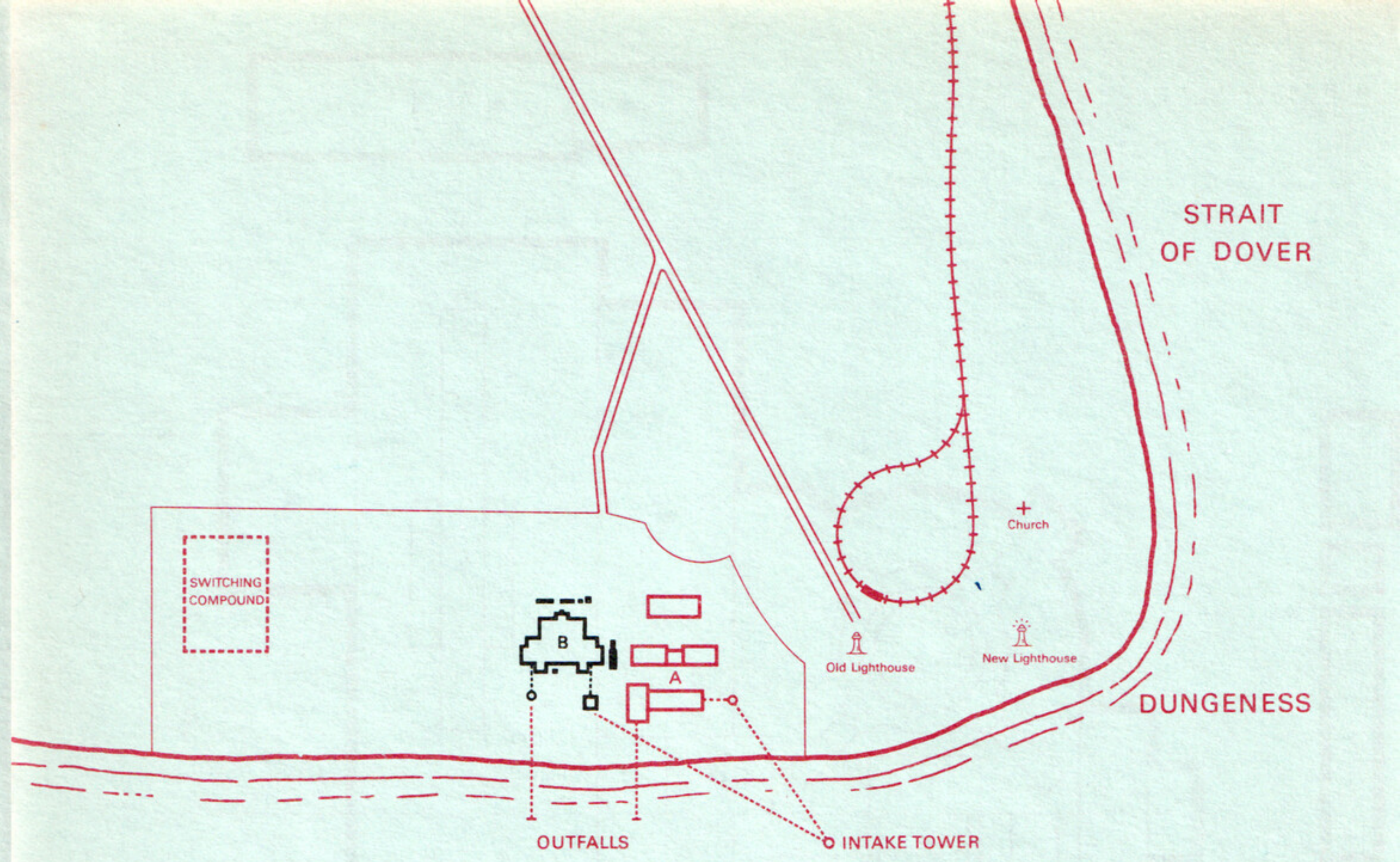
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New Lighthouse
DUNGENESS
OUTFALLS
INTAKE TOWER

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