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Description of the Magnox Type of Gas Cooled Reactor (MAGNOX)

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Abstract

The present report comprises a technical description of the MAGNOX type of reactor as it has been build in Great Britain. The Magnox reactor is gas cooled (CO_2) with graphite moderators. The fuel is natural uranium in metallic form, canned with a magnesium alloy called "Magnox".

The Calder Hall Magnox plant on the Lothian coastline of Scotland, 60 km east of Edinburgh, has been chosen as the reference plant and is described in some detail. Data on the other stations are given in tables with a summary of design data. Special design features are also shortly described.

Where specific data for Calder Hall Magnox has not been available, corresponding data from other Magnox plants has been used. The information presented is based on the open literature.

The report is written as a part of the NKS/RAK-2 subproject 3: "Reactors in Nordic Surroundings", which comprises a description of nuclear power plants neighbouring the Nordic countries.

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1 Introduction

A new four-year nuclear research program within the framework of NKS, Nordic Committee for Nuclear Safety Research, was started in 1994 as a follow-on to several preceding Nordic programmes. Joint research in this field is of interest for the five Nordic countries who have similar needs for maintaining their nuclear competence in the field of reactor safety and waste management, and who are exposed to the same outside risks from reactors in neighbouring countries, from nuclear powered vessels, and from risks of contamination of terrestrial and aquatic areas.

This report is written as a part of the NKS/RAK-2 subproject 3: "Reactors in Nordic Surroundings", which comprises a description of nuclear power plants neighbouring the Nordic countries.

The main objective of the project has been to investigate, collect, arrange and evaluate data of reactors in the Nordic neighbourhood to be used by the Nordic nuclear preparedness and safety authorities.

In the former NKS project, SIK-3, reactors within 150 km from the border of a Nordic country were treated, but it was decided to add a description of the British reactors, although the minimum distance to a Nordic border, the Norwegian, is about 500 km.

The present report comprises a technical description of the MAGNOX reactor. The Magnox reactor is gas cooled (CO_2) with graphite moderators. The fuel is natural uranium in metallic form, canned with a magnesium alloy called "Magnox".

The first Magnox station (Calder Hall) started operation in 1956, and over the next 15 years 10 additional stations comprising 22 reactor units started operation. Twenty reactors out of a total number of 26 reactor units are still in operation to day after 30 years of service, see Figure 1.1 and Table 1.1.

Calder Hall on the Lothian coastline of Scotland, 60 km east of Edinburgh, has been chosen as the reference plant and is described in some detail. Data on the other stations are given in tables with a summary of design data in appendix A-J. Special design features are also shortly described.

Where specific data for Calder Hall Magnox station has been unavailable, corresponding data from other Magnox plants has been used. The information presented is based on the open literature and the content of the report follows the format agreed on in the SIK-3 project, *Ref. 1*

The reactors at Calder Hall and Chapelcross were designed for dual-purpose use, producing plutonium for weapons and generating electricity as a commercial by-product.

To day the operation is optimised for power production and the power rating is upgraded from 42 MWe to 60 MWe per reactor unit for the Calder Hall station. The load factors between annual outages are between 92 % and 99 %. This upgrading was possible because the reactors were designed and build using the best standards and materials available at the time, and operated under modest conditions.

Therefore, safety is not so much depending on special safety engineered systems as is the case for light water reactors. Most of the safety upgrading is a support of inherent safety characteristics.

Figure 1.1. Location of the British Magnox stations still in operation.

After 40 years of operation the Calder Hall reactors are performing better than ever. BNFL, British Nuclear Fuel Limited, which recently has taking over the operation of all Magnox reactors in UK, now awaits a permission from the Nuclear Installation Inspectorate to extend the operating life to 50 years.

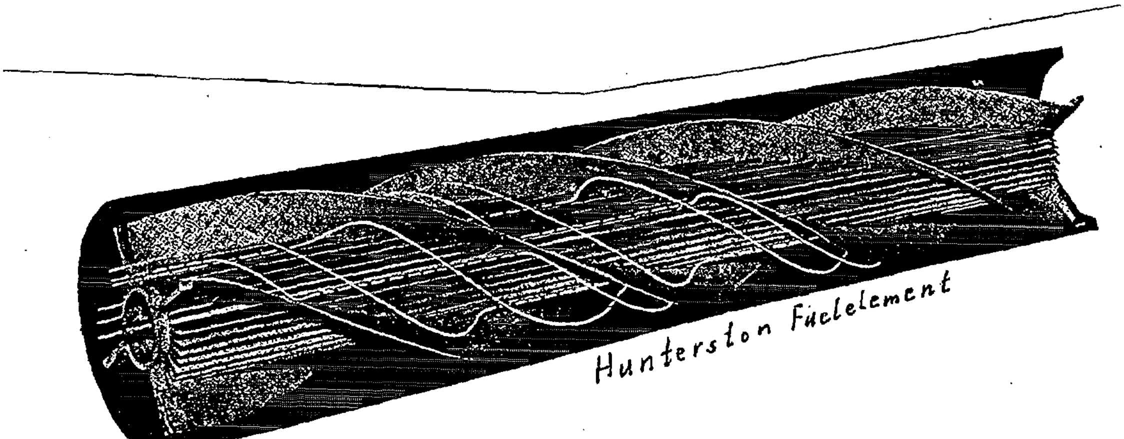
All the Magnox stations built later than the Calder Hall and Chapelcross are called the commercial stations. They are all different in construction, as it appears from appendix A through J.

Table 1.1. Magnox stations.

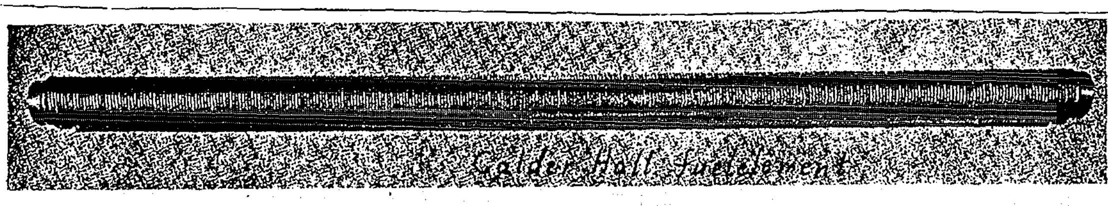
Station unit	MWe (net)	MWe (gross)	Grid connection	Status
Berkeley	138	166	1962	Shut down (1988)
Berkeley	138	166	1962	Shut down (1989)
Bradwell	123	146	1962	Operating
Bradwell	123	146	1962	Operating
Calder Hall	50	60	1957	Operating
Calder Hall	50	60	1958	Operating
Calder Hall	50	60	1959	Operating
Calder Hall	50	60	1956	Operating
Chapelcross	50	60	1959	Operating
Chapelcross	50	60	1960	Operating
Chapelcross	50	60	1959	Operating
Chapelcross	50	60	1959	Operating
Dungeness A	220	230	1965	Operating
Dungeness A	220	230	1965	Operating
Hinkley Point A	235	267	1965	Operating
Hinkley Point A	235	267	1965	Operating
Hunterston A1	150	173	1964	Shut down (1989)
Hunterston A2	150	173	1964	Shut down (1990)
Oldbury A	217	230	1964	Operating
Oldbury A	217	230	1967	Operating
Sizewell A	210	245	1966	Operating
Sizewell A	210	245	1966	Operating
Trawsfynydd	195	235	1965	Shut down (1991)
Trawsfynydd	195	235	1965	Shut down (1991)
Wylfa	475	540	1971	Operating
Wylfa	475	540	1971	Operating
Total number of build Magnox units is 26 with 22 still operating				

Much work has been done since the start of the first magnox reactor in developing fuel cannings with different kind of cooling finns, see Figure 1.2. The circumferential finning of the Calder Hall can has been replaced by helical finning and full length splitters (called the fish-bone type) to achieve better heat transfer and consequently a better fuel rating.

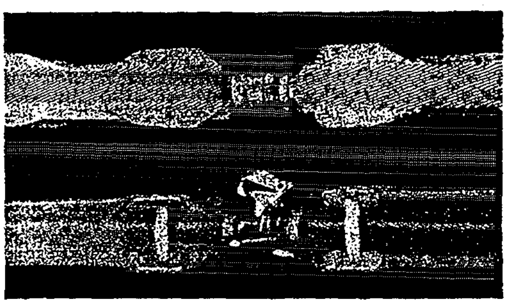
There could still be an application potential for magnox reactors in countries having an electrical system in the range of 2000 – 6000 MW capacity and interested in small highly reliable natural uranium reactors of 250 – 300 MWe output.



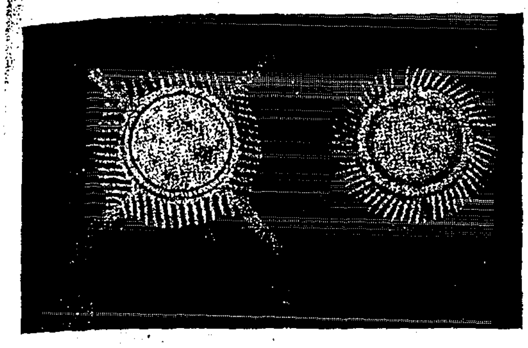
.—The Polyzonal Axial Element showing typical gas flow paths.



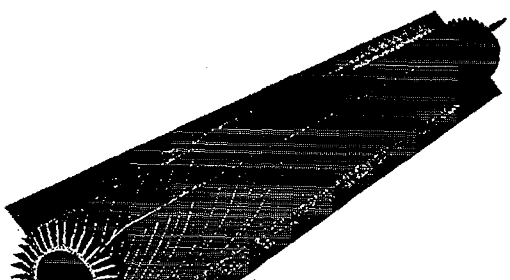
A fuel element with the end spiders removed. Enclosing a natural-uranium slug in a helium atmosphere, the magnesium alloy tube is turned from the solid with a single-start helical fin of ½-in. pitch. Transverse fins have superior heat-transfer properties under the reactor conditions than have longitudinal ones.



Fuel element end fittings on Sizewell R1 (bottom) and Wylfa.



.—Comparison of helical finning used on Sizewell R1 (right) with parallel constant angle fins on Wylfa fuel elements.



The Polyzonal Spiral Element as will be used at Bradwell

Figure 1.2. Different design of Magnox fuel elements.

2 Summary of design data

In Table 2.1 a summary of the main design data for Calder Hall Magnox nuclear power station is shown. All data applies to a single unit of the four-reactor station.

Table 2.1. Summary of design data for Calder Hall Magnox nuclear power station

Station design		
Design and construction		
Reactor type	MAGNOX	Gas Cooled
Electrical output (gross)	4 x 46	MWe
Thermal output (gross)	4 x 182	MWt
Efficiency	23	%
Number of reactors	4	
Reactor		
Moderator	Graphite	
Coolant gas	CO_2	
Number of fuel channels	1696	
Lattice pitch (square)	203	mm
Active core diameter	9.45	m
Active core height	6.4	m
Number of control rod channels	112	
Mean gas pressure	7	bar
Mean inlet gas temperature	140	°C
Mean outlet gas temperature	336	°C
Total gas flow	891	kg/s
Fuel elements		
Material	Natural uranium metal	
Type	Metal as one cast bar	
Cladding material	Magnox C	
Element length	1016	mm
Number of elements per channel	6	
Mass of uranium per reactor	120	tonnes
Average fuel rating	1.53	MWt/tU

Table 2.1 continued

Pressure vessel		
Type	Cylindrical	with domed ends
Material	Lowtem	A-kill mild steel
Internal diameter	11.28	m
Internal height	21.3	m
Plate thickness	51	mm
Design pressure	7	bar
Gas circulators		
Type	Centrifugal	blowers
Regulation	Ward-Leonard	regulation 10:1
Number circulators	4	
Power consumption per reactor	5.4	MWe
Steam generators		
Number of steam generators per reactor	4	
Turbine plant		
High pressure steam flow	180	t/h
HP-turbine inlet pressure	14	bar
HP-turbine inlet temperature	310	°C
Low pressure steam flow	53.8	t/h
LP-turbine inlet pressure	3,7	bar
LP-turbine inlet temperature	310	°C
Generator		
Number of generators	2	
Rating	23	MW
Speed	3000	rev/min
Voltage	11500	V
Generator cooling	-	

3 Site and region

3.1 Selection of the site

The Calder Hall reactors (4 units) are neighbour to the Windscale reprocessing and plutonium production plant, only separated by the river Calder. The location is on the West coast of Cumbria 130 km northwest of Manchester.

This location is a very practical choice because they are designed for dual purpose use – plutonium production and electricity generation.

Because of the heavy weight of the reactors – the weight of one reactor is about 33.000 tons – special arrangements had to be made for the foundations, because the sand stone rock is covered by a 20 – 30 meter thick layer of glacial moraine containing little silt but some clay.

In defiance of the nearby coastline and the river Calder, air cooling by cooling towers was selected. One explanation is that it was important at the time of construction that people could look at the cooling towers and find out, that the reactors were operating.

4 Safety criteria

The roots of the gas cooled power reactor go back to 1946 where much thought was given to the best type of reactor for plutonium production. The first choice law between a water-cooled graphite moderated reactor and a graphite moderated reactor cooled by gas under pressure, both with natural uranium.

The great disadvantage of the water cooled version was the hazard rising from the increased reactivity following an accidental interruption of the cooling water supply. The reactivity increase is caused by the positive void reactivity coefficient.

Against this the gas cooled version was safe and therefore could be build in "more accessible regions".

The Chernobyl accident in 1986 proved that the decision taken in 1946-47 was a very vice decision.

Figure 4.1 shows the behaviour of the Magnox reactor if all circulators fails and the trip circuits fail to trip the reactor. The excess fuel temperature is 125 ^{0}C, and the negative temperature coefficient of reactivity reduces the reactor power at once. Such a reactor system is said to be inherently safe.

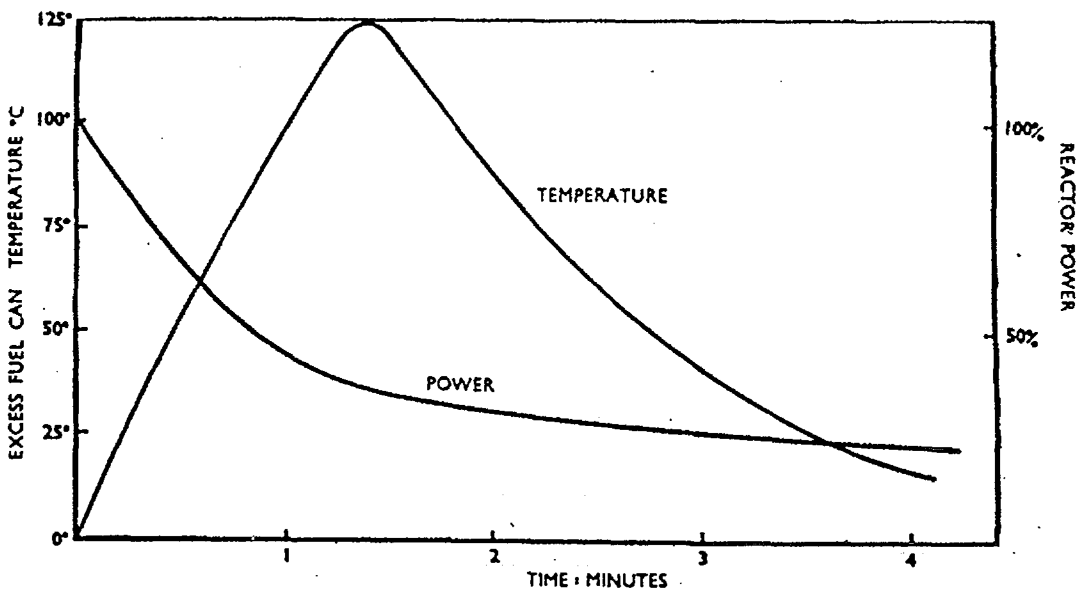


Figure 4.1 Temporary fuel temperature rise and loss in reactor power for failure of all circulators and the reactor trip circuits.

5 Tecnical description and design evaluation

5.1 Plant arrangement

In Figure 5.1 is shown a schematic layout of one unit of Calder Hall Magnox station.

The Calder Hall nuclear power plant comprises 4 reactors situated on the left bank of the river Calder, close to the Windscale reprocessing plant. Four cooling towers are present, one for each reactor. The cooling tower for reactor no 1 and the cooling tower for reactor no 2 are back-up for each other, as is the case for reactor no 3 and no 4.

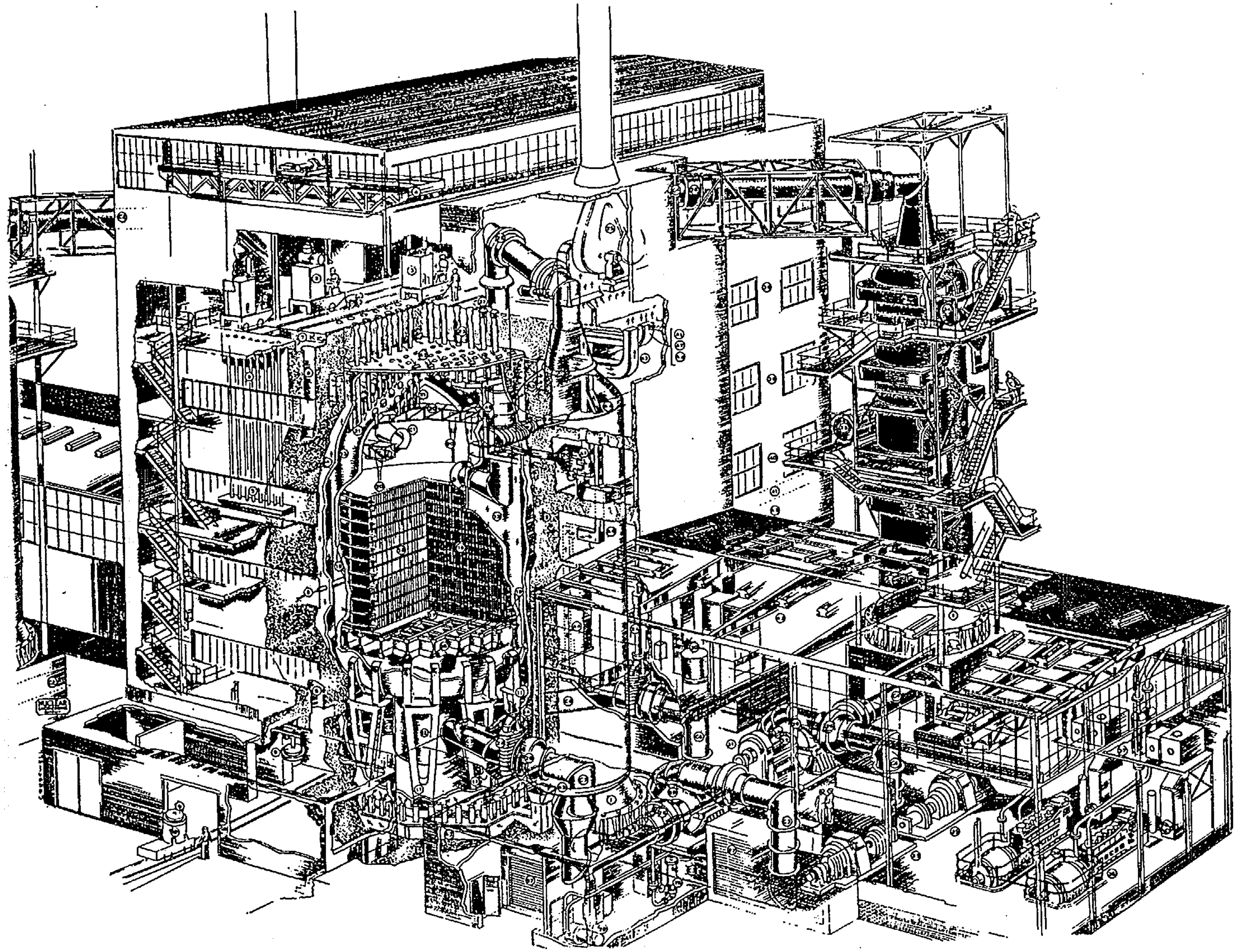


Figure 5.1. Schematic layout of one unit of Calder Hall Magnox station.

5.2 Buildings and structures

Each reactor is placed in its own concrete building with 2 ventilation stacks and surrounded by 4 steam generators in free air.

Between the tall reactor buildings for reactor no 1 and reactor no 2 (and the corresponding buildings for reactor no 3 and 4) is a long low building for the turbo-generator units. Each of the reactors is associated with two turbo-generator units, rated at 23MWe each.

It has not been possible to find a paper showing the position of the buildings and structures for the whole area. However, Figure 5.2 and Figure 5.3 illustrate the structures in the reactor building and the arrangement of the steam generators and the cooling gas circulation system. The fuel handling and storage building are not present at the Calder Hall plant, because fuel is transported direct to the nearly Windscale plant.

At Figure 5.3 is shown half of the gas circulation system in a horizontal view. At the top and the bottom of the figure is the connections for the two steam generators.

Figure 5.4 is a plan position view of the turbine building for two turbo-generators.

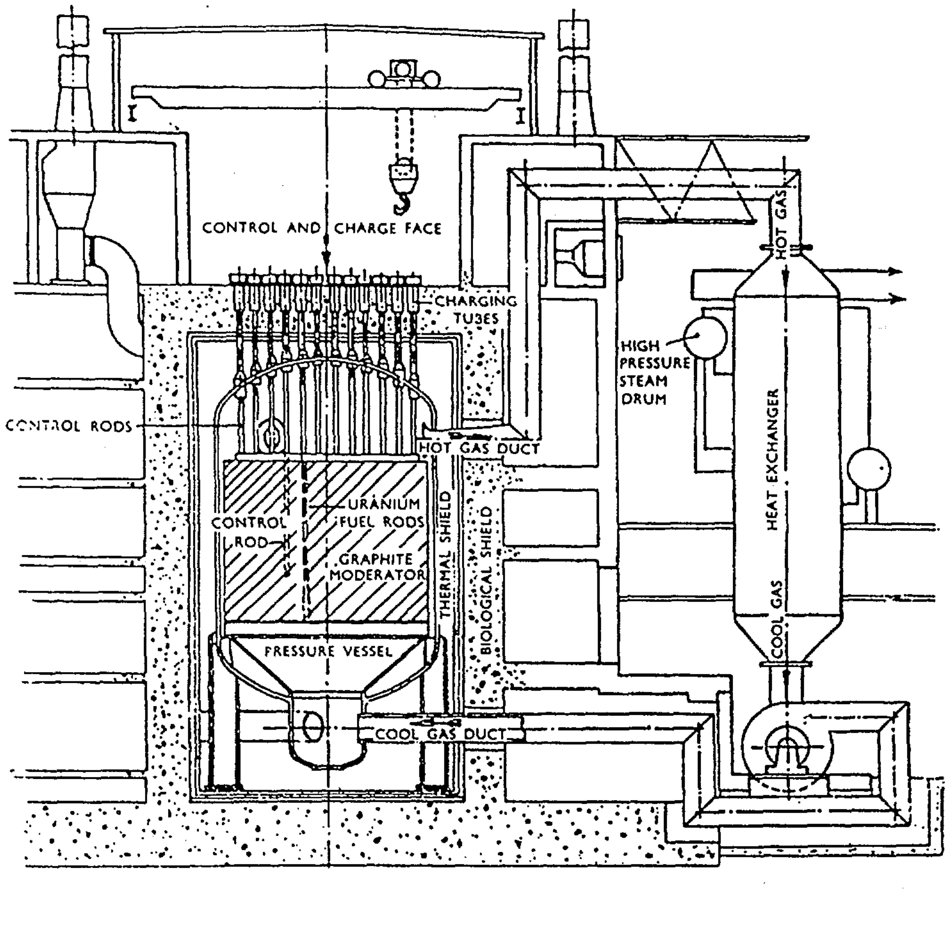


Figure 5.2. Main features of the Calder Hall plant.

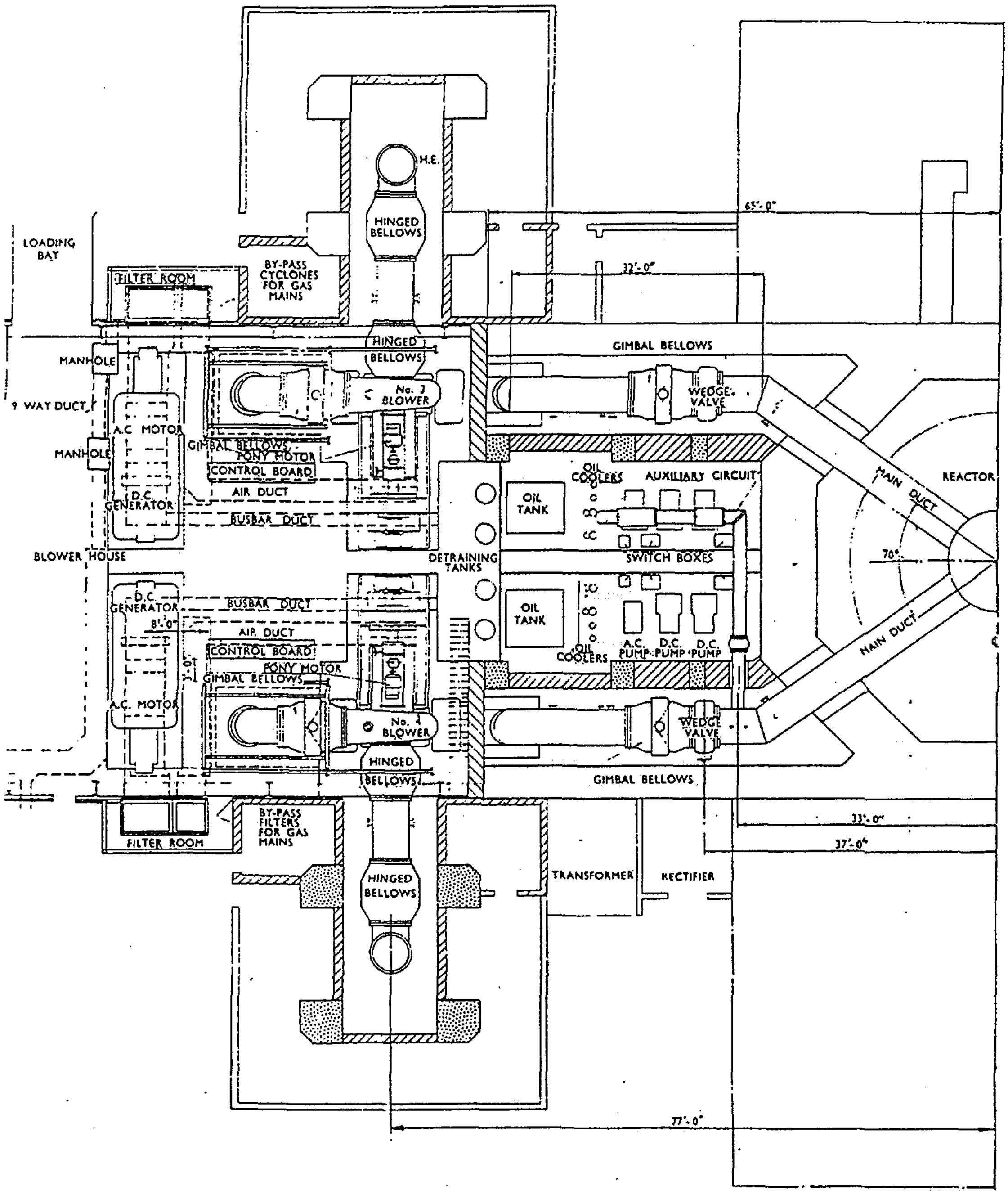


Figure 5.3. The gas circulation system lay-out (half of it).

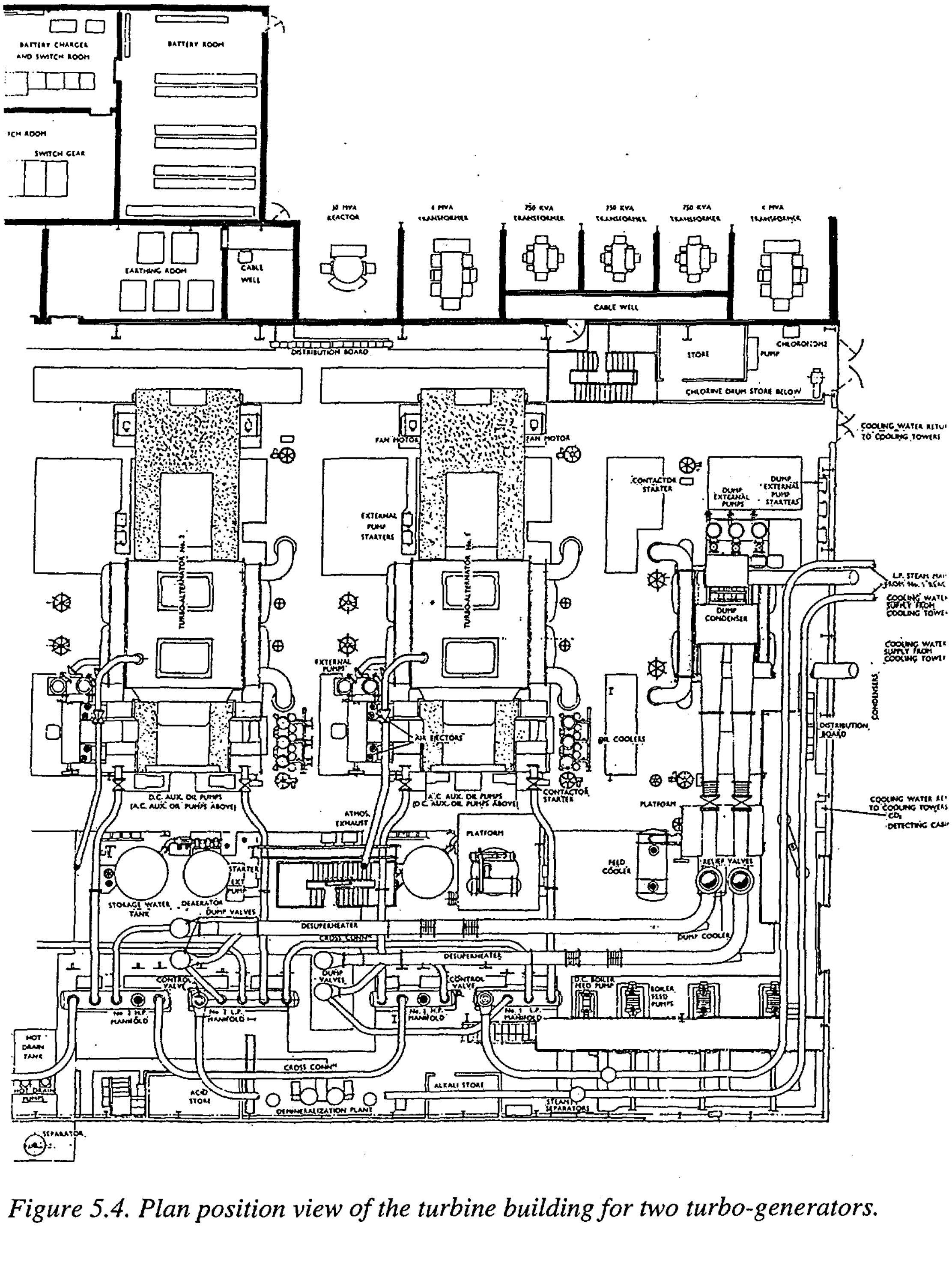


Figure 5.4. Plan position view of the turbine building for two turbo-generators.

5.3 Reactor core and other reactor vessel internals

Most of the place in the reactor vessel is filled out by a big graphite structure, formed as a 24 sided prism 823 cm high and 1077 cm across the corners. The weight is about 1150 tons. This structure is the reactor moderator and reflector. The actual core dimensions are 6,4 m high and 9,45 m diameter.

The graphite structure is build up of alternate layers of blocks and tiles keying into one another. The whole structure is held in place by 11 horizontal 24 sided restraint. The graphite structure is transported into the reactor vessel piece by piece through one of the ø 137 cm gas outlets.

1696 vertical fuel channels are placed in the graphite in a regular square, 20,3 cm pith. Provision is made for the operation of one control rod in the centre of each 16 fuel channels.

The upper face of the graphite pile is covered with heavy cast iron plates, one plate for 16 fuel channels and with a central hole to take up a control rod (or the chute locating spigot under fuel change). The plates are provided with chamfered entry holes over the fuel channels.

The chute mechanism is a selector making it possible to change fuel in 16 fuel channels through the same hole in the top dome of the vessel. Thus the number of penetrations in the top dome are reduced from 1696 to 112, making it much more easy to get sufficient mechanical strength in the dome.

Under normal operation each of the 1696 fuel channels contains 6 fuel elements, the total weight of fuel being about 120 tons.

A Calder Hall fuel element contains natural uranium as a cast bar, 29,2 mm in diameter and 1016 mm long.

The canning is a Magnesium alloy (Magnox-C) filled up with helium. The canning tube is turned from the solid with a single start helical fin to get an extended surface. This construction is chosen because transverse fins have better heat-transfer properties than longitudinal ones. The overall diameter of the fuel element is 54 mm.

The location in the centre of the fuel channel is achieved by spiders, screwed at each end of the cartridges. These spiders also provides three radial supports for the lifting grab. It is important that this grab should firmly pick up the elements and lock into place as a disconnection from the top of the reactor would allow the element to plunge vertically 50 ft.

The elements, placed vertically over one another in the channels, are located by a male cone fitting into a female cone in the top of the element below.

The whole core with 1696 fuel elements are divided into 3 zones (see Figure 5.5 and Table 5.1). The channel diameters are different, greatest in zone A (central core) and smallest in zone C (outer zone). This distributions with the greatest cooling flow in the central part of the core might give a better temperature distribution. Table 5.1 also gives the fundamental reactor physical date for the core.

The principle with different diameters of the fuel channel from zone to zone might give a problem if fuel elements should be moved from one zone to another (typical from the outer zone and closer to the centre). If fuel elements is only moved inside a zone there will be no problems with the spiders.

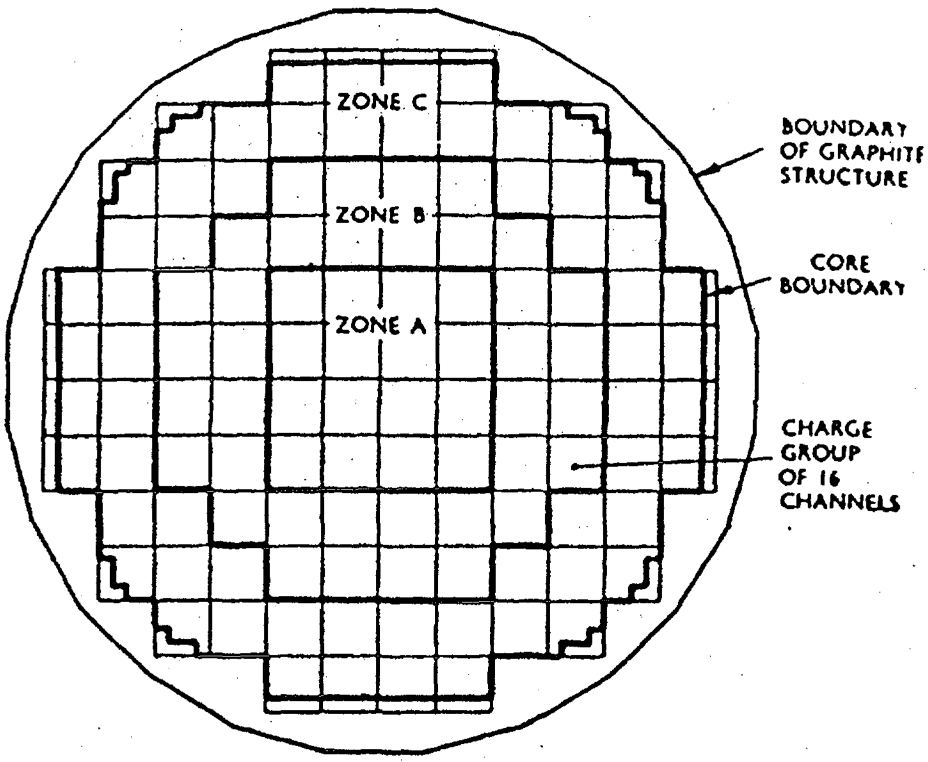


Figure 5.5. Illustration of the three core zones.

Table 5.1 Fuel specifications.

Average uranium temperature=425°C   Average graphite temperature=250°C

Constant	Zone A	Core Zone B	Zone C	Reflectors Top Reflector	Bottom Reflector	Side Reflector
Inner radius, ft.	0	6.02	10.85	3.25*	2.67*	15.49
Outer radius, ft.	6.02	10.85	15.49	—	—	18.00
Channel diameter, in. ...	4.16	3.95	3.61	—	—	—
Number of channels	256	576	864	—	—	—
Thermal utilization factor, f ...	0.93186	0.93010	0.92672	—	—	—
Resonance escape factor, p ...	0.87533	0.87861	0.88398	—	—	—
Fast fission factor, ϵ	1.02972	1.02972	1.02972	—	—	—
Thermal fission factor, η ...	1.26595	1.26595	1.26595	—	—	—
Multiplication constant, k_∞ ...	1.06330	1.06527	1.06789	—	—	—
Radial diffusion area, cm^2 ...	406.6	391.9	371.1	7,519.7	3,765.1	3,422.4
Axial diffusion area, cm^2 ...	464.6	438.9	403.6	9,340.7	4,227.4	3,422.4
Radial slowing-down area, cm^2	628.9	588.6	528.1	803.3	640.6	387.0
Axial slowing-down area, cm^2	709.5	652.7	570.6	962.1	703.2	387.0

* Thickness of reflector quoted.

5.3.1 Detection of fission gas release

The reactor is provided with a fission gas detection system.

A small stainless steel tube at the upper end of each fuel channel takes a small fraction of the gas passing through the channel.

A complex mechanical selection system and 8 scintillation chambers are monitoring the channels, grouped into fours, with a cycle of 30 minutes. Provision is made for selecting any individual channel for special attention.

The length of each of the 1696 measuring tubes is about 40 meter.

5.4 Reactivity control system

The arrangement with 16 fuel channels to each stand pipe makes it possible to operate one control rod in the centre of each 16 fuel channels, giving 112 possible control rod positions. Not all these possibilities will be used during normal operation, and a pattern of 40 rods seams to be adopted as the practical solution (Figure 5.7).

The control rod absorbers are made of boron steel in 18/8 stainless steel sheets. The weight is approximately 130 lb. The absorbers are required to travel over the full dept of the reactor core, which is 21 ft. They are suspended from the actuating mechanisms by specially developed stainless steel cables.

The actuating mechanism (Figure 5.8) comprises a synchronous motor, driving the gear train through a solenoid clutch.

A speed depending brake made up of an eddy current disc and some permanent magnets reduces the speed when the solenoid clutch is deenergized.

Position of the control rod is transmitted by a magslip. 3 phase unit, driven by a pulley running on the suspension cable. The control rods are required to operate in 2 groups, a course and a fine.

5.4.1 The course control group

The course control group consists of about 40 control units, and they are moving in and out together.

The groups are provided with 3 operational speeds. The in speeds are 127 cm/min. or 12,7 cm/min., while the out speed is only 1,27 cm/min. With all rods moving out together the change in δK is limited to 2 x 10^{-6}/sec.

Under shut off the initial acceleration is better than 61 cm/sec^2, and the maximum speed is 122 cm/sec.

The minimum design time of travel through the centre of the core (564 cm) is 5 seconds.
A frequency converter with generates power to the course control system is excited from the station 50V DC battery.

5.4.2 The fine control group

Fine control is performed by 4 control units. They are operated by hand from two sine potentiometers (Figure 5.9).

A sine potentiometer comprises a resistor chain fed by DC and tapped to give a sinusoidal distribution of potential. The tapping points are taken up to contacts points on the front plate, from which 3 brushes pick up a three phase supply when the hand wheel is turned, because the brushes are spaced at 120° angles. Thus the three phase supply comes out with a frequency determined by the angular speed of the hand wheel.

5.4.3 Additional functions

If a solenoid clutch should fail to disengage, the corresponding motor back-run. At the same time the sine potentiometer supply is tripped, and the fine control rods makes a further shut off action.

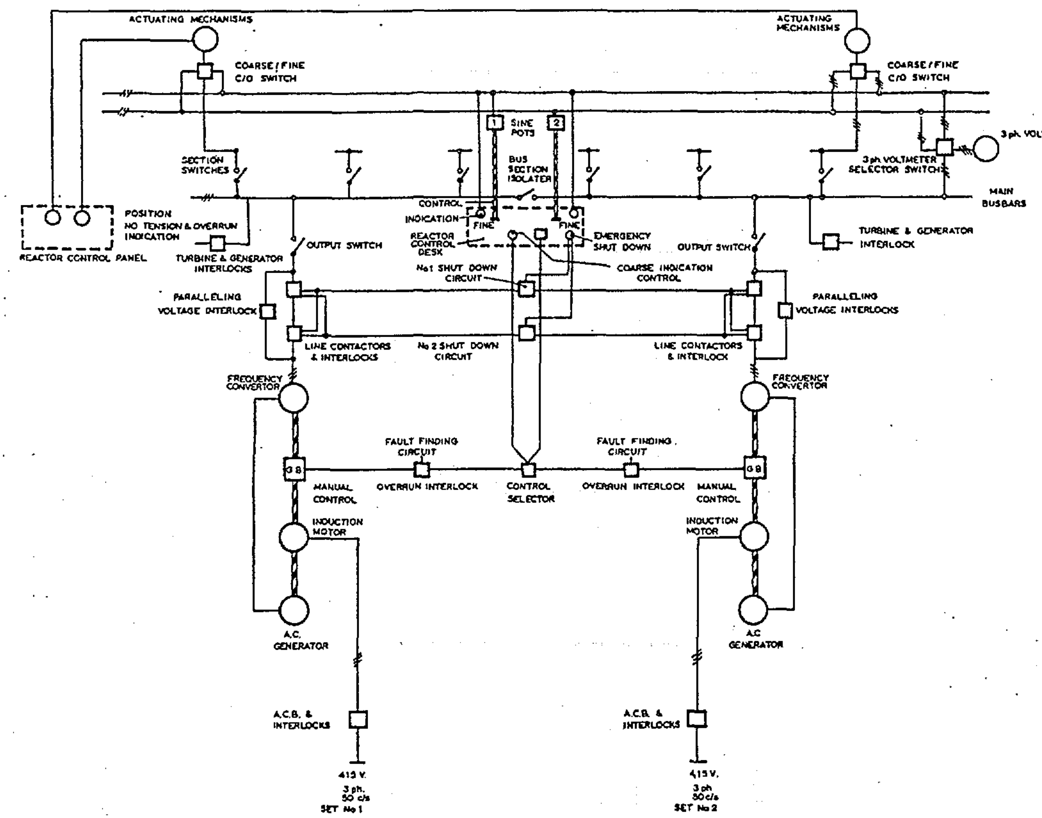
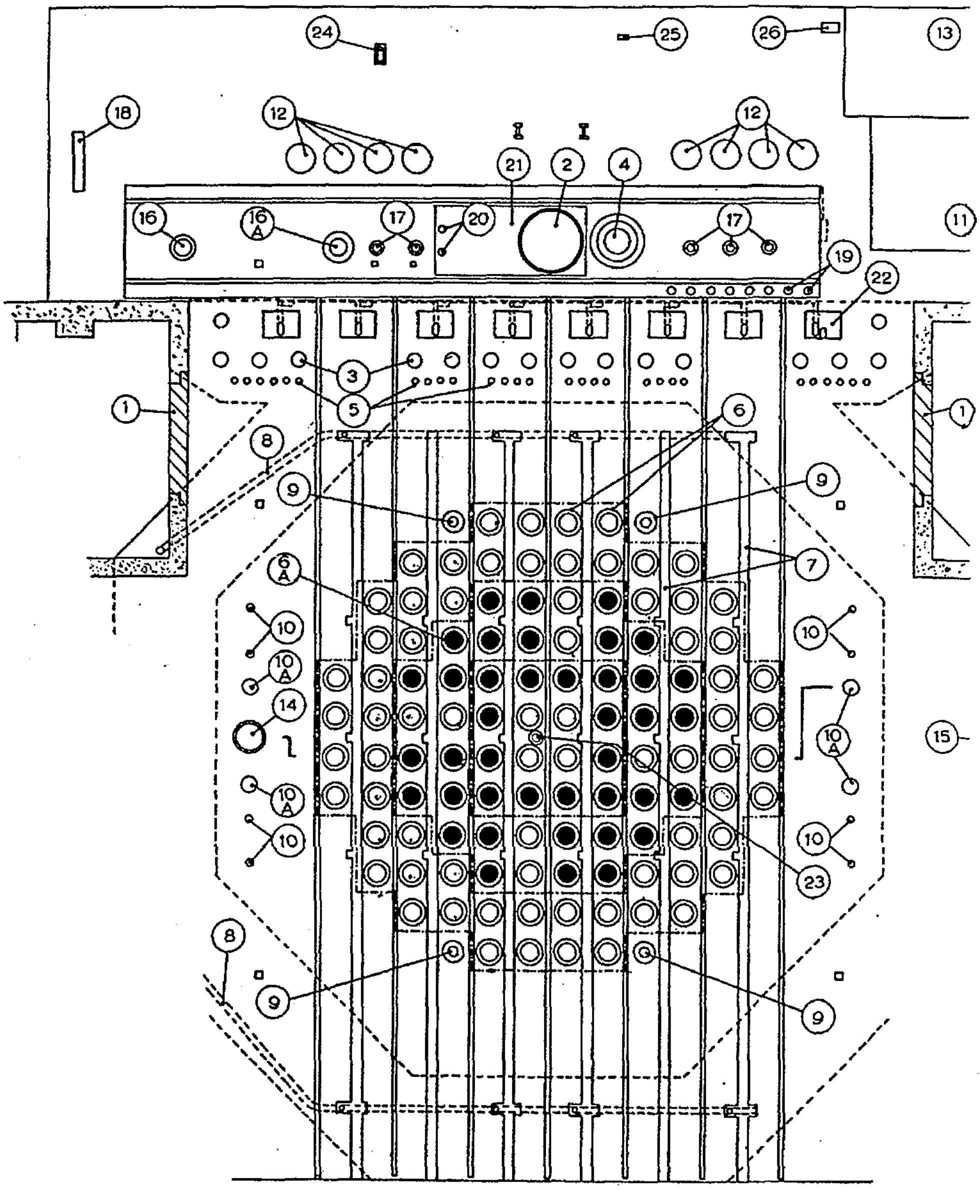


Figure 5.6 Simplified diagram of the control rod circuits.



1. Removable panel
2. Discharge well
3. Mortuary holes
4. Hydraulic cylinder
5. C.R. mortuary
6. Charge tubes
6a. C.R. positions
7. Service trenches
8. Machine purge system
9. Contamination test holes
10. Remote viewing holes
11. Hoist well
12. Charge chute stowage
13. Stairway
14. Access hole
15. Removable panel
16. C.R. test hole
17. Grab access holes
18. Ancillary CO_2 feed
19. C.R. stowage
20. Door hydraulics
21. Cross traverse
22. Charge machine contacts
23. P.V. probe
24. Oil pipes
25. Hoist footing
26. Cable slots

Figure 5.7 Plan of the charge floor. Charge tubes on a 813 mm pitch serve 16 channels. Control rod heads, shown shaded, comprise 40 in all.

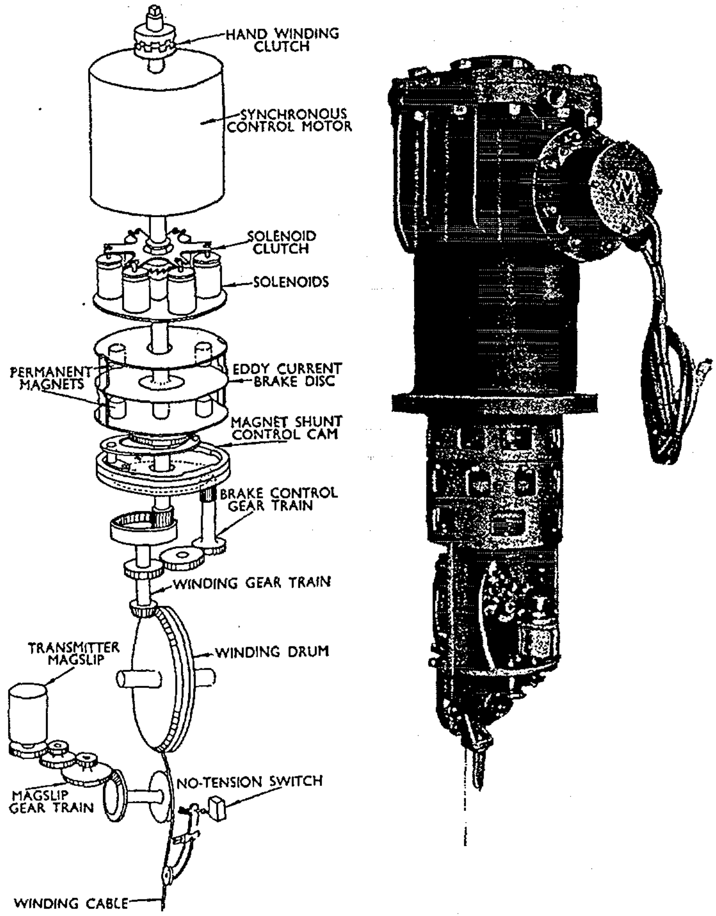


Figure 5.8 The actuating mechanism with a simplified drawing of the trains, eddy current brake and cable position and strain detectors.

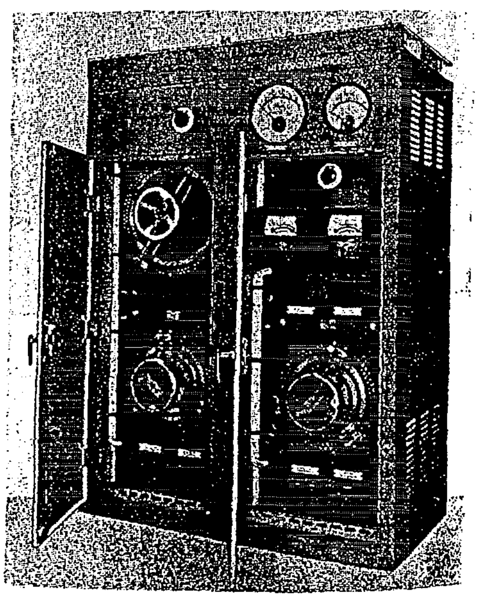


Figure 5.9 Main sine-potentiometer cubicle

5.5 Reactor main cooling system

5.5.1. System information

The main cooling system (heat transport system) is divided into four independent circuits, each comprising a gas circulator and a steam generator (Figure 5.10). CO_2 at a pressure of 100 psi is supplied to the manifold under the reactor, and circulates up through the reactor core and down through the steam generators to the gas circulators.

The steam generators (4 units) delivers superheated steam to two turbogenerator units.

The main data for the circuits are the following:

Reactor vessel inside diameter	11,28 m
Reactor vessel high	21,3 m
Temperatures at core inlet	140°C
Temperature at core outlet	336 °C
Mass flow through the core	891 kg/sec.
Mass flow through the core, maximum	980 kg/sec.
Mean coolant velocity in the cold ducts	15 m/sec.
Mean coolant velocity in the hot ducts	22,55 m/sec.
Working pressure	7,031 kg/cm^2

Turbine system (2 units per reactor):

High-pressure steam pressure at TSV[1]	14 kg/ cm^2
High-pressure steam temperature at TSV	310 °C
High-pressure steam per set (77% total)	90.000 kg/hr.
Low-pressure steam pressure at TSV	3,7 kg/ cm^2
Low-pressure steam per set (23% total)	26.9000 kg/hr.

[1] TSV is the turbine stop valve.

Cooling towers:

2 towers are serving two reactors.	
Tower high above sill	88,4 m
Tower diameter at ring beam	61 m
Throat diameter	31,7 m
Half-basin capacity	2.600 m^3
Cooling range	30,5°C to 21,1 °C

5.5.2. Reactor Vessel and Primary Cooling System

The reactor vessel is a cylindrical vessel with an inside diameter of 11,28 m and 21,3 m high. It has domed ends of ellipsoidal form. The lower dome has an auxiliary smaller dome, about 3,66 m in diameter (Figure 5.11) which acts as an inlet manifold for the coolant gas.

The vessel is welded on site. This dictated a maximum plate thickness of 50 mm and ductile mild steel with a good notch value at low temperatures. The finally choice was a aluminium-killed high manganese steel, named "Low term".

If a hole should be present in the upper dome of the pressure vessel opposite to each fuel channel it would require 1696 holes, and the pitch would be only 8 in. (20,3 cm). It would have been extremely difficult to ensure enough mechanical strength between the holes. The practical solution was to provide only one hole in the pressure vessel head to every 16 fuel channels.

The charging machine is provided with a chute so that any fuel channel in the group can be served through this one hole. The same hole also gives access to the control rods.

10 vertical legs of "A" frame, equally spaced around the periphery, supports the vessel. The legs allows radial movement during expansion and contraction maintaining the center line fixed.

The internal load of the reactor core (fuel and graphite) is about 1260 tons. This load is supported by a circular grid construction resting at the periphery on brackets, welded to the shell exactly opposite to the "A" frame brackets, so that the weight do not add to the pressure stresses in the vessel.

5.5.3. Reactor Coolant Piping

The main flow of the coolant gas is shown at Figure 5.10. The gas ducts are of mild steel and the diameter is 122 cm.

Each steam generator (called heat exchanger at Figure 5.10) and the associated gas circulator can be isolated from the rest of the plant by isolation valves.

The expansion in the circuits has been taken care of, partly by expansion loops, partly by bellows.

5.5.4. Reactor Gas Circulators

The reactor operates with 4 single stage centrifugal blowers, one in each steam generator circuits.

The mass flow in a circulator is 227 kg/sec. (250 kg/sec. maximum), and the circuit pressure drop is 0,388 kg/cm^2.

The circulators, operated from Ward Leonard motor generators, have a speed variation of 1:10. The total power requirement for four circulators is 5,44 MW.

In an emergency operation very low speeds is possible by use of pony-motors at 10/100 hp. The pony-motor is coupled to the main circulator through a Sinclair clutch, to prevent the pony-motor being run at overspeed by the main motor.

5.5.1 Steam generator

Each Calder Hall reactor has four independent steam generators and two turbo generators. The steam generator (Figure 5.13) were designed and constructed by Babcock and Wilcox Ltd., and the main problems was to choose a thermodynamic cycle giving maximum overall efficiency in both power production and plutonium production.

This is a problem because the plutonium production is proportional to the thermal output, while the electrical output is very much depending on the temperatures involved.

Extensive studies were carried out on a dual pressure cycle, and the result is represented at Figure 5.12.

77% of the steam is generated as high pressure steam, and 23% as low pressure steam. Steam for the low pressure turbine is partly taken directly from the low pressure boiler, partly from the exhaust of the high pressure turbine (Figure 5.14).

The gas temperature is much lower than the corresponding "gas" temperature in a coal- or oil fired power plant. Extended heating surfaces is only a minor compensation for this.

The distribution of the heating surfaces are the following:

HP superheater	437 m^2
LP superheater	73 m^2
HP evaporator	2930 m^2
LP evaporator	2930 m^2
Economizer	2930 m^2

The finally conditions for the Calder Hall reactors were a dual steam cycle with an electrical output of about 40 MW per reactor with an inlet gas temperature of 336°C and a steam pressure of 14 kg/cm^2. The corresponding outlet temperature and pressure are 140 °C and 3,5 kg/cm^2 respectively.

The steam generators for the first generation of magnox reactors (Calder Hall and Chapple Cross) is placed outdoor. Later magnox reactors have a green house around the steam generators.

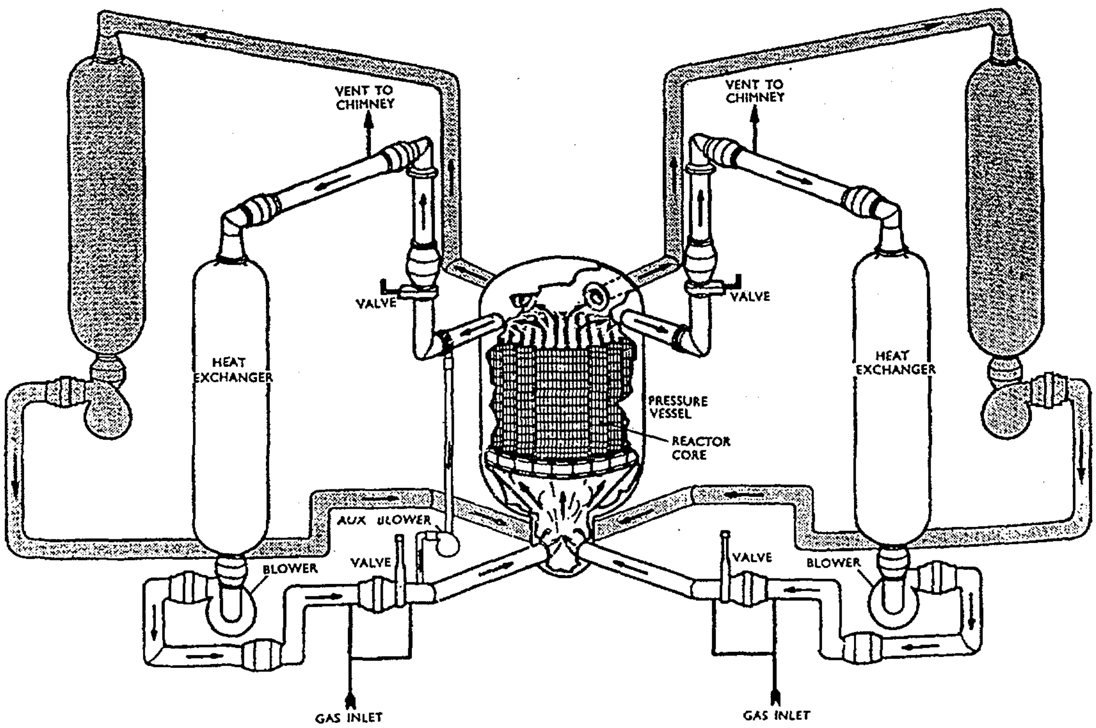


Figure 5.10 Simplified schematic diagram of primary coolant circuit.

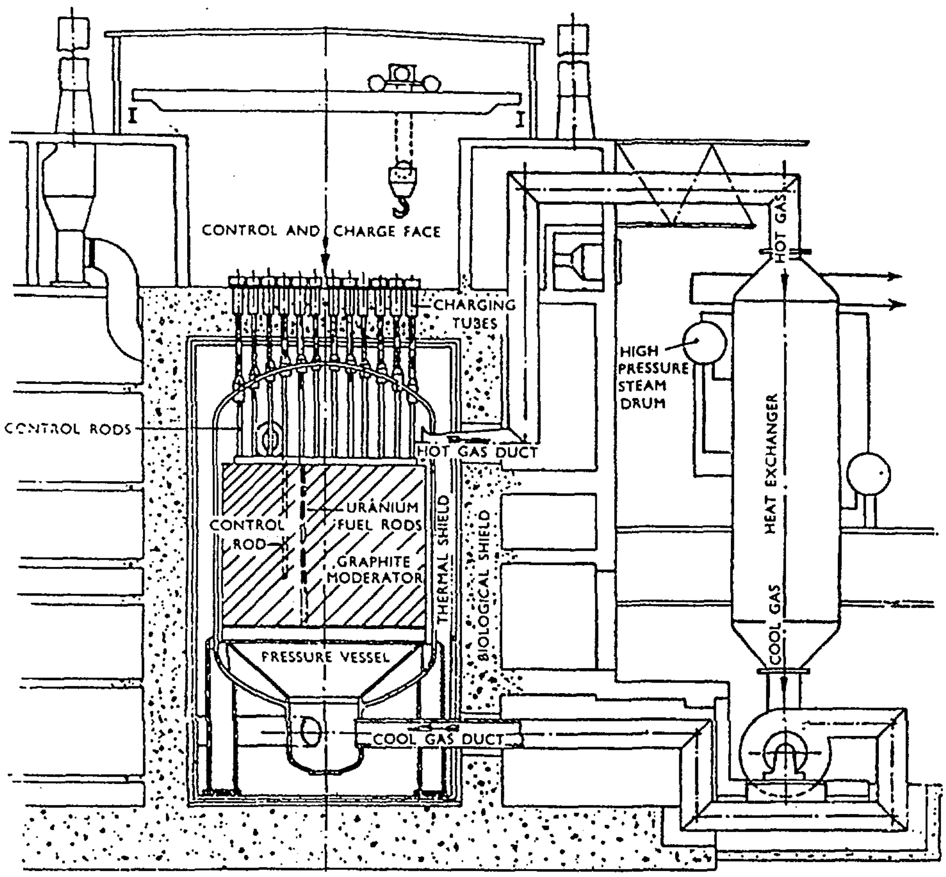


Figure 5.11. Vertical arrangement of fuel channels, control rods and pressure vessel and one of the primary coolant circuit.

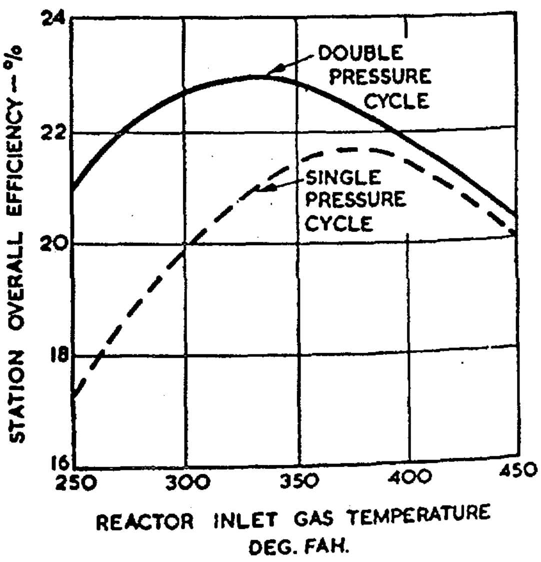


Figure 5.12. Comparative efficiencies of double and single steam cycles.

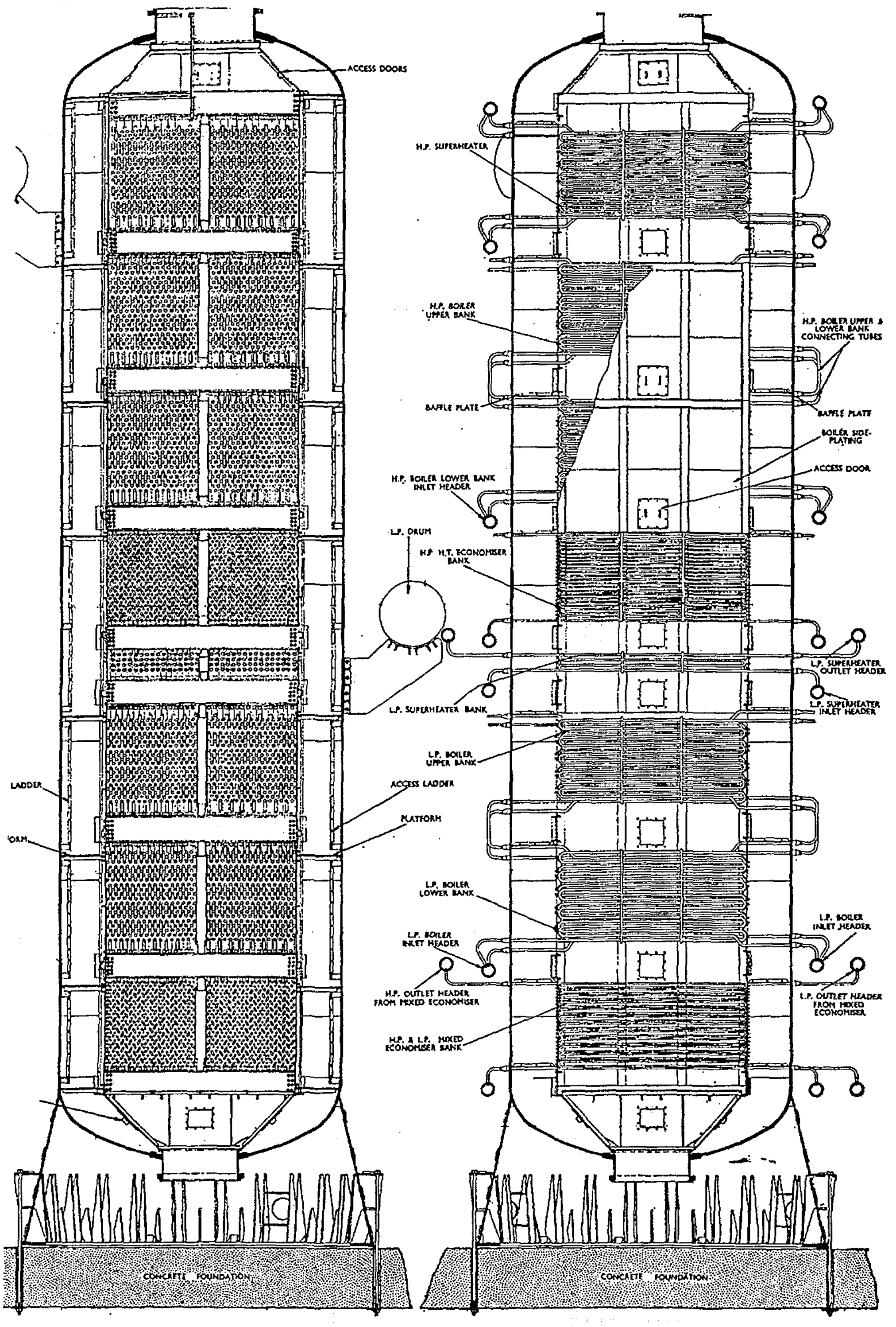


Figure 5.13. Part sectional elevations of steam generator – left part turned 90°.

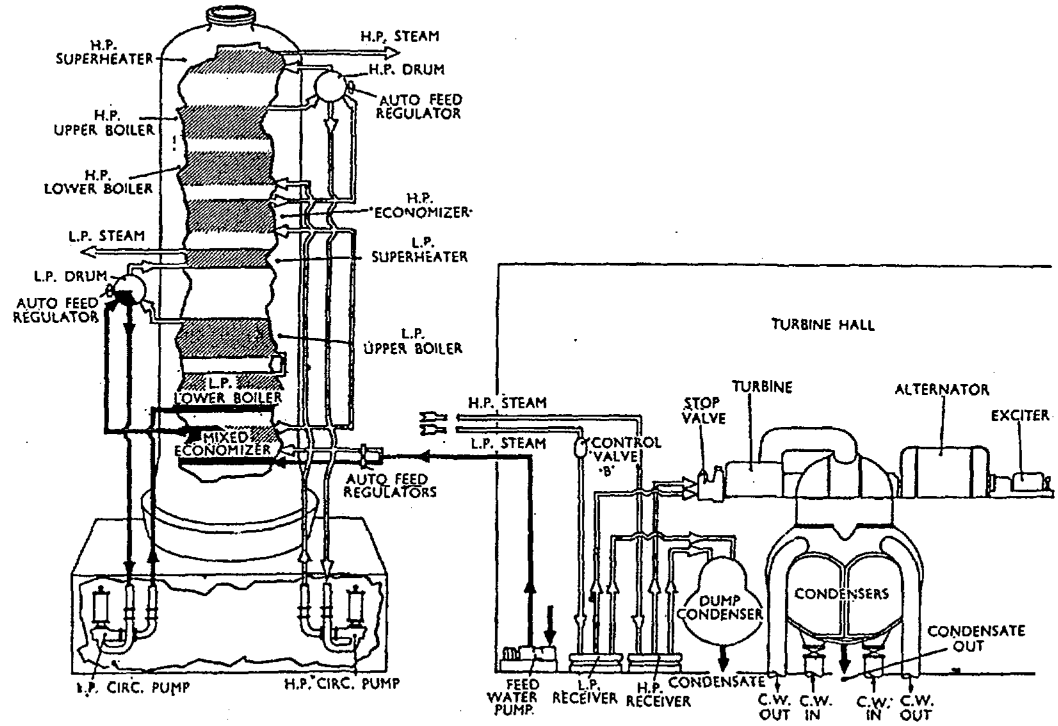


Figure 5.14. Simplified schematic diagram of steam lines.

5.6 Residual heat removal systems

The decay heat of the reactor following a shut down is removed by the main cooling system.

A desired temperature run-down is obtained by reducing the speed of the circulators.

Remote control gear in the control room for the Ward Leonard motor generators allows speed changes to be carried out simultaneously on all four circulators

5.7 Emergency core cooling system

From the very beginning the graphite moderated gas cooled type of reactor was looked upon as a safe reactor, and could consequently be build in "more accessible regions". The negative temperature reactivity coefficient contributes very much to a safe reactor, see chapter 4. Therefore, safety is not much depending upon special safety circuits.

The lack of void and two-phase flow is an important safety feature. The reactor core cannot be drained for the cooling media, as it is the case in water-cooled reactors. This, together with natural circulation and the large heat capacity of the graphite moderator makes it almost impossible to loose the necessary emergency cooling. Consequently, natural circulation was looked upon as sufficient for emergency core cooling.

For an emergency situation each of the main blowers can be operated at very low speeds by use of pony-motors rated at 10 hp/100 hp. In all cases the heat is dissipated through the steam generators.

Later Magnox stations have elevated steam generators to improve the conditions for natural circulation.

Also heavy flywheels added to the blower shafts is seen (f. inst. at the Hunterston station). In this way the transient in a shut down situation is very much reduced.

5.8 Containment systems

5.8.1 Overall system information

The first generation of Magnox reactors – Calder Hall and Chapel Cross – with the steam generators in free air – are designed with three barriers to prevent the release of radioactivity into the atmosphere:

1) The fuel matrix
2) The fuel cladding
3) The primary circuit (including reactor vessel, primary tubing, circulators and steam generators).

This seems to be a barrier less when compared with light water reactors.

However, the conditions are very much different. The lack of void or two-phase flow provides a significant safety advantage. Further, the graphite moderator represents a large heat sink, and this together with natural circulation makes it almost impossible to loose the cooling.

This means that some problems about emergency cooling of LWR reactors do not exist when the talk is about gas cooled reactors. Most important is:

1) Void in the cooling media – it do not exist
2) The core becoming uncovered – is not possible
3) Complete loss of coolant – is not possible
4) Phase change as a result of a sudden temperature increase – is not possible.

In the later Magnox stations (the commercial stations) the steam generators are placed in "green houses", and thus protected against the weather. The "green houses" could be a further barrier preventing release of radioactivity to the surrounding.

5.8.2 Containment Structure

The structure consists of the pressure vessel and four steam generator circuits.

The pressure vessel and the containment vessel are the same unit. The test pressure is 9,5 kg/cm^2 and the normal operating pressure is 7 kg/cm^2.

A possible leak in a steam generator circuit should be handled by isolation of the circuit in question.

5.8.3 Containment penetrations

The top of the pressure vessel is penetrated by 112 studs, each containing a control rod, an ionchamber, or giving access to 16 fuel channels.

No horizontal penetration is present.

5.9 Steam and power conversion system

Described under section 5.5.5.

5.10 Fuel handling and storage system

The original idea was that fuel charge and discharge should be possible with the reactor operating at full power, just as it should be possible for maximum efficiency to move fuel elements from part of the reactor with low reactivity towards the centre where reactivity is greater.

Early in the project it was decided that time did not permit the development of charge and discharge machines that would fulfil these specifications.

Consequently the charge and discharge machines have been designed to operate only in shut down and with the reactor depressurised.

It is a complication that 40 out of 112 positions for the charge and discharge machines (and with it the access to 640 fuel channels) are occupied by control rods and their operating mechanisms and additional positions are occupied by ionchambers (Figure 5.16).

The fuel shift takes place by two different machines, a charge machine and a discharge machine. They are basically similar in design, both with an annular magazine with 24 sockets (positions).

The discharge machine require heavy shielding, about 30 tons, to protect the operator, making total weight 60 tons. The weight of the charge machine is only 12 tons.

Under discharge operations the full magazine is lowered through the discharge well into the water-cooled coffin at floor level. The coffin is transported to the nearby Windscale reprocessing plant (Figure 5.15).

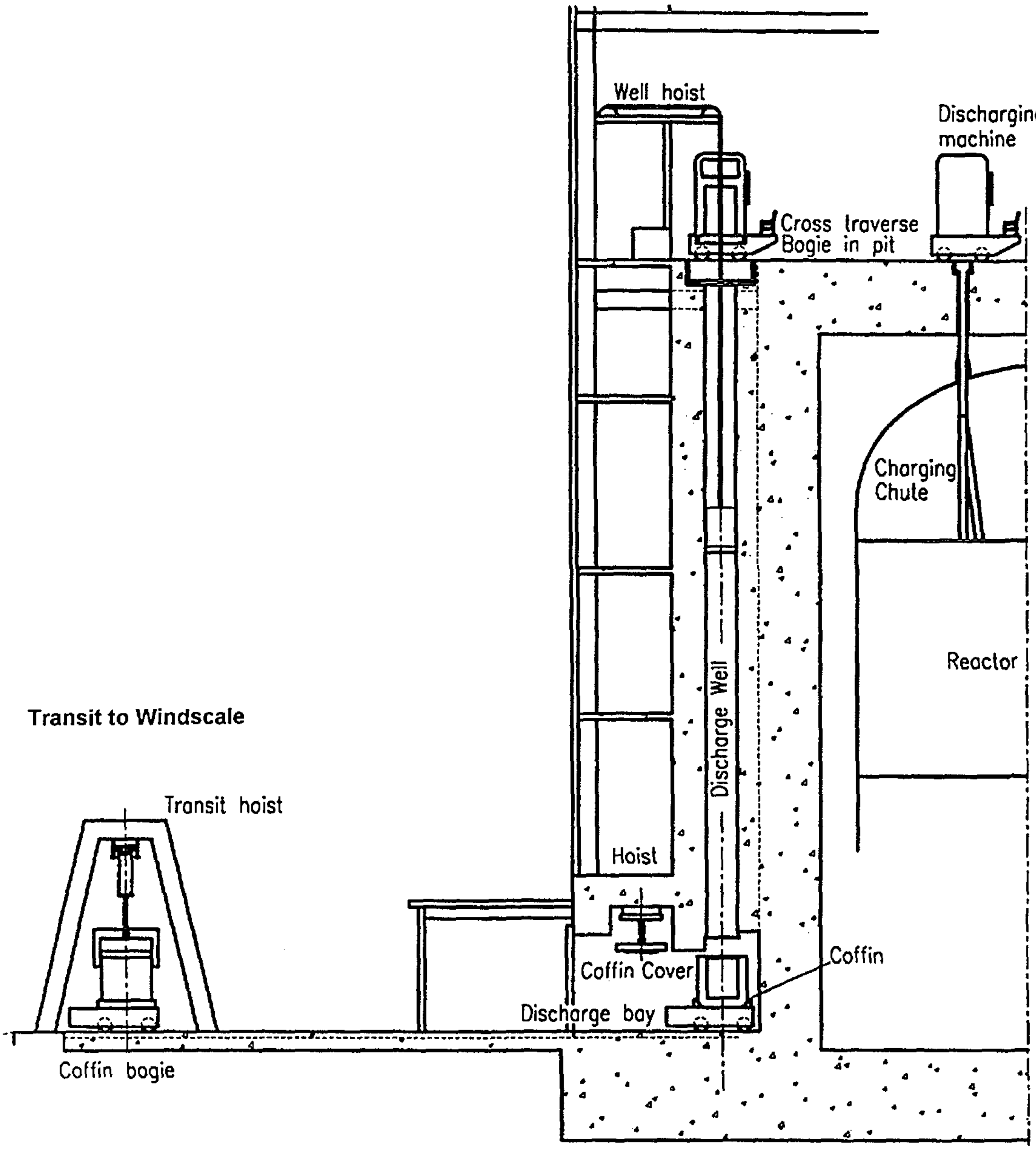
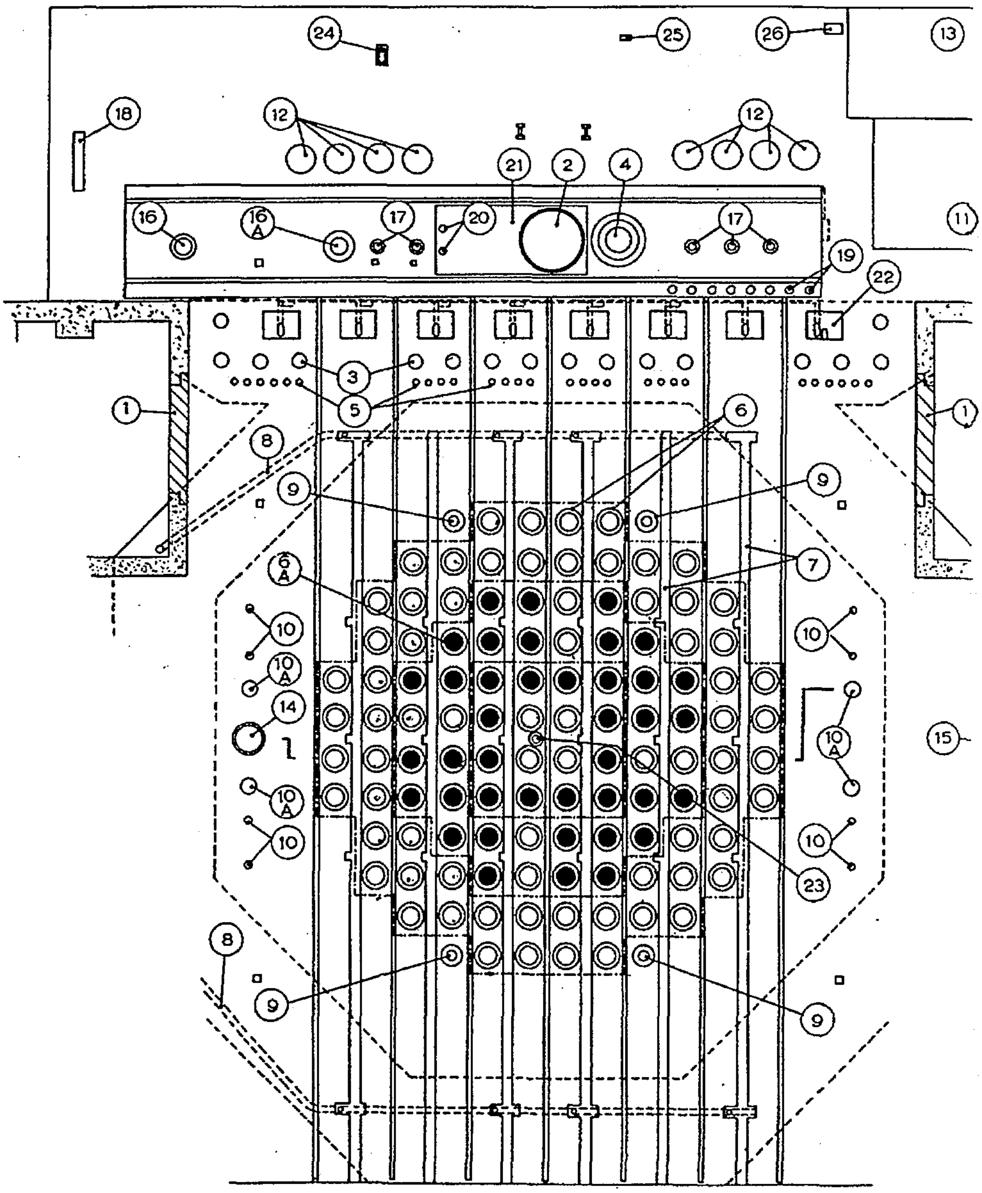


Figure 5.15. General arrangement of discharge facilities. Full magazine is lowered into water-cooled coffin for transfer to Windscale ponds.



1. Removable panel
2. Discharge well
3. Mortuary holes
4. Hydraulic cylinder
5. C.R. mortuary
6. Charge tubes
6a. C.R. positions
7. Service trenches
8. Machine purge system
9. Contamination test holes
10. Remote viewing holes
11. Hoist well
12. Charge chute stowage
13. Stairway
14. Access hole
15. Removable panel
16. C.R. test hole
17. Grab access holes
18. Ancillary CO_2 feed
19. C.R. stowage
20. Door hydraulics
21. Cross traverse
22. Charge machine contacts
23. P.V. probe
24. Oil pipes
25. Hoist footing
26. Cable slots

Figure 5.16 Plan of the charge floor. Charge tubes on a 813 mm pitch serve 16 channels. Control rod heads, shown shaded, comprise 40 in all.

6 Wigner Energy

After the Wigner Energy release in the Windscale Pile No. 1 in 1952 and after the Windscale incident in October 1957 the UKAEA recommended that the temperatures of the graphite in the C.E.G.B. power reactors should be increased to a level that prevent an accumulation of stored energy over the lifetime of the reactors.

This recommendation resulted in the inclusion of removable sleeves in the fuel channels of Chapel-cross No. 2, 3 and 4.

The inclusion of sleeves create a thermal gradient, raising the temperature of the graphite particularly in the lower (inlet) part of the core. The increased temperature by isolating the fuel channels from the cooling gas, comes from gamma and neutron heating.

The C.E.G.B. stations Berkeley and Bradwell (and also Calder Hall) were designed to release Wigner energy at intervals under reactor shut down.

This solution was found unsatisfactory for the Bradwell and the Berkeley stations, and it was decided to sleeve the lower part of the fuel channels.

After a fast research and development work experiments showed that the effectiveness of sleeving is questionable, depending upon gas leakage's at the joint and pores in the graphite.

Also studies by the AEA in 1959 about stored energy showed more optimistic results than before, makes the use of sleeves unnecessary. Most of the graphite blocks for Bradwell No. 1 had been machined to take up sleeves, but it was decided to scrap them.

The Hunterston magnox station used fuel elements in graphite sleeves. In this design each canned fuel rod is supported separately in a graphite sleeve, and the weight of the complete stack is transferred to the grid plate through the sleeves. This means that the sleeves are changed out together with the fuel rods.

In the Trawsfynydd plant sleeves in the fuel channels are eliminated because the graphite temperatures should be sufficient to prevent unsafe accumulation of stored energy.

This is also the situation in magnox stations of later construction.

The elimination of sleeves means that large quantities of irradiated graphite for disposal is avoided.

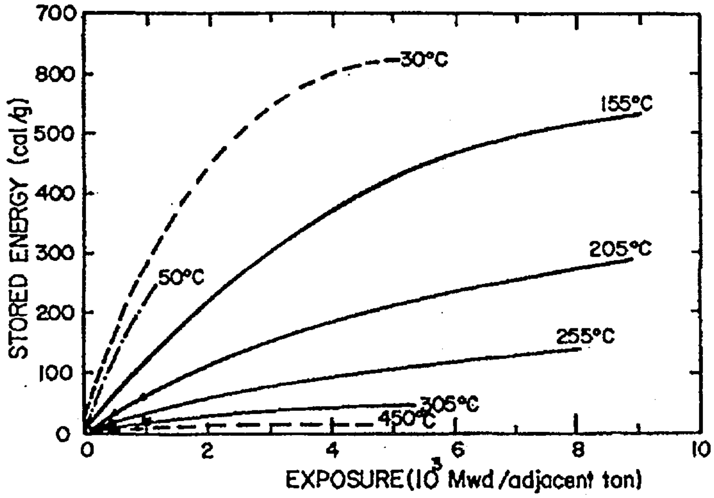


Figure 6.1. Accumualation of stored energy in graphite at different temperatures.

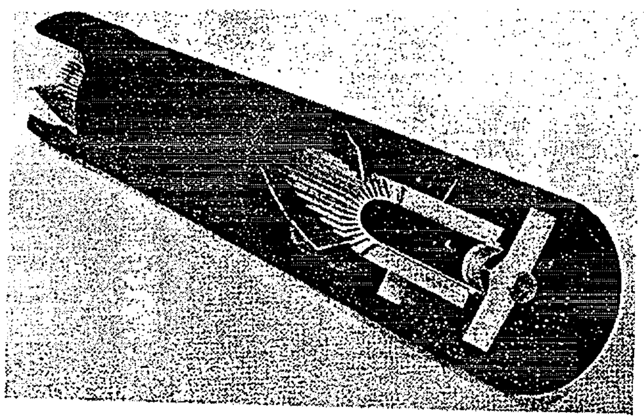


Figure 6.2. Cut-away view of fuel element in graphite sleeve.

7 References

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Ref. 2 *Description of the Advanced Gas Cooled Type of Reactor (AGR).* Nonbøl, E., NKS/RAK2(96)TR-C2, 1996.

Ref. 3 *Status and Prospects for Gas Cooled Reactors.* Technical Report Series No235, IAEA 1984.

Ref. 4 *Nuclear Engineering International, 1956-1970.* Sutton, England.

Ref. 5 *Nuclear Power Reactors in the World. IAEA Reference Data Series No 2.* April 1997.

Ref. 6 *Nuclear Engineering International, 1970-1997.* Sutton, England.

Ref. 7 *Personal notes from visit at Hunterston A and B.* July 9-10, 1990.

Ref. 8 *Stored Energy in Graphite of Power Producing Reactors.* Physical Transactions, Royal Society London, A254, 1962.

Appendix A: Chapel Cross Magnox Power Station

Location: The Chapel Cross reactors are located in Scotland, near Annan, Dumfriesshire, 110 km south-east of Glasgow

The Chapel Cross power station is a sister station to the Calder Hall. Information about design data is found in the Calder Hall description.

There are, however, a few important changes in design. The most important is the inclusion of removable graphite sleeves in the fuel channels of Chapel Cross no. 2, 3 and 4. The idea is to minimize the effect of Wigner growth by creating a thermal gradient, and thus raising the temperature of the graphite. In this way the graphite moderator is inherently self-annealing.

Another difference compared to Calder Hall is that Chapel Cross is provided with its own cooling pond for spent fuel, necessitated by the distance to Windscale.

Appendix B: Berkeley Magnox Power Station

Location: The Berkeley reactors in Gloucestershire is located 30 km north of Bristol at the bank of the river Severn.

Berkeley nuclear power station is the first commercial magnox power station. The main purpose for the station was production of electricity. (The main purpose for the Calder Hall and Chapel Cross reactors was production of plutonium).

Reactor no. 1 started operation mid 1960, and no. 2 early 1961.

The pressure vessel is a dome-ended cylindrical construction.

The steam generators are situated completely outside the reactor building, as it is the case at Calder Hall, but they are placed in "green houses".

Cooling water is taken from the river Severn.

The reactors were finally shut down late 1988 and about spring 1989, respectively.

Table 7.1. Summary of design data for Berkeley Magnox nuclear power station

Station design		
Design and construction	AEI John Thompson Nuclear Energy Co	
Reactor type	MAGNOX Gas Cooled	
Electrical output (gross)	2 x 138	MWe
Thermal output (gross)	2 x 560	MWt
Efficiency	25	%
Number of reactors	2	
Reactor		
Moderator	Graphite	
Coolant gas	CO_2	
Number of fuel channels	3265	
Lattice pitch (square)	203	mm
Active core diameter	13.1	m
Active core height	7.47	m
Number of control rod channels	132	
Mean gas pressure	8.5	bar
Mean inlet gas temperature	160	°C
Mean outlet gas temperature	350	°C
Total gas flow	2819	kg/s
Fuel elements		
Material	Natural uranium metal	
Type	Polyzonal spiral fin with splitters	
Cladding material	Magnox A12	
Element length	574	mm
Number of elements per channel	13	
Mass of uranium per reactor	231	tonnes
Average fuel rating	2.42	MWt/tU

Table 7.1 continued

Pressure vessel		
Type	Cylindrical	with domed ends
Material	Mild steel	JTA 101
Internal diameter	15.24	m
Internal height	24.17	m
Plate thickness	76	mm
Design pressure	8.5	bar
Gas circulators		
Type	Single stage	axial blowers
Number circulators per reactor	8	
Power consumption per reactor	17	MWe
Regulation	2900 rpm	Induction motors, hydraulic couplings
Steam generators		
Number of steam generators	8	
Turbine plant		
High pressure steam flow	507	t/h
HP-turbine inlet pressure	21.8	bar
HP-turbine inlet temperature	319	°C
Low pressure steam flow	235	t/h
LP-turbine inlet pressure	5.1	bar
LP-turbine inlet temperature	316	°C
Generator:		
Number of generators per reactor	2	
Rating	85	MW
Speed	3000	rev/min
Voltage	11800	V
Cooling	Hydrogen	

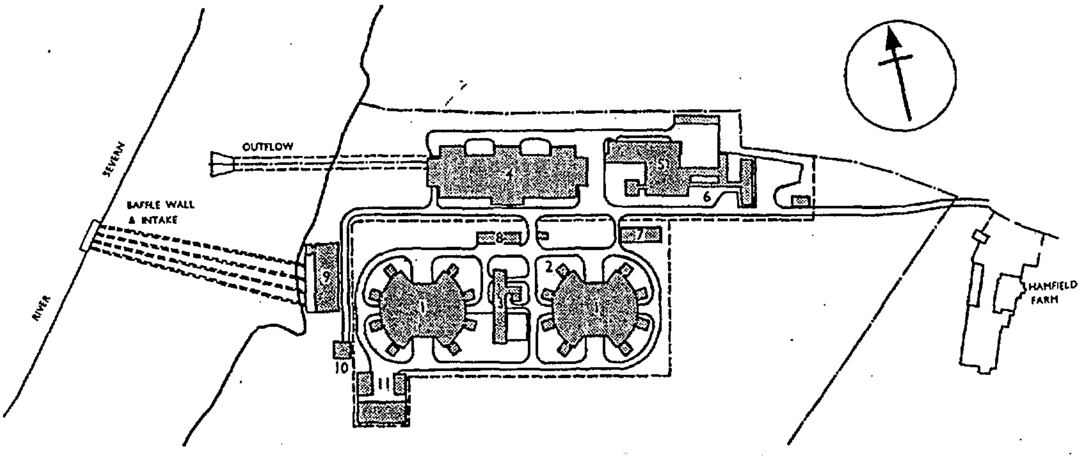


Figure 7.1 Site plan of the Berkeley station.

1. Reactor
2. Heat exchangers
3. Cooling pond
4. Turbine hall
5. Workshop
6. Canteen
7. Fuel element storage
8. Carbon dioxide store
9. Cooling water pump house
10. Sewage works
11. Active waste treatment

Appendix C: Bradwell Magnox Power Station

Location: The Bradwell plant is located at the south-east extremity of the Blackwater estuary in Essex, 75 km east-north-east of London.

The Bradwell reactors started operation in July 1962 and November 1962, respectively, and they are still in operation.

They are the first Magnox reactors with spherical pressure vessels, Figure 7.2.

The steam generators are situated close up to the reactor buildings, and in "green houses". The "green houses" could be a zero-pressure containment, but is it the case?

Cooling water is taken from the nearby sea.

Table 7.2. Summary of design data for Bradwell Magnox nuclear power station

Station design		
Design and construction	TNPG, Thompson Nuclear Power Group	
Reactor type	MAGNOX Gas Cooled	
Electrical output (gross)	2 x 150	MWe
Thermal output (gross)	2 x 538	MWt
Efficiency	28	%
Number of reactors	2	
Reactor		
Moderator	Graphite	
Coolant gas	CO_2	
Number of fuel channels	2606	
Lattice pitch (square)	203	mm
Active core diameter	12.2	m
Active core height	7.87	m
Number of control rod channels	158	
Mean gas pressure	9	bar
Mean inlet gas temperature	180	°C
Mean outlet gas temperature	390	°C
Total gas flow	2434	kg/s
Fuel elements		
Material	Natural uranium metal	
Type	Polyzonal spiral fin with splitters	
Cladding material	Magnox A12	
Element length	912	mm
Number of elements per channel	8	
Mass of uranium per reactor	239	tonnes
Average fuel rating	2.25	MWt/tU

Table 7.2 continued

Pressure vessel		
Type	Spherical	
Material	Conlo 2	and Hitem
Internal diameter	20.35	m
Internal height	20.35	m
Plate thickness	76- 102	mm
Design pressure	10	bar
Gas circulators		
Type	Single stage	axial blowers
Number circulators per reactor	6	
Power consumption per reactor	20.5	MWe
Regulation	Variabel frequency, induction motors 600/3300 rpm	
Steam generators		
Number of steam generators	6	
Turbine plant		
High pressure steam flow	465	t/h
HP-turbine inlet pressure	52.4	bar
HP-turbine inlet temperature	371	°C
Low pressure steam flow	286	t/h
LP-turbine inlet pressure	13.7	bar
LP-turbine inlet temperature	371	°C
Generator:		
Number of generators per reactor	3	
Rating	52	MW
Speed	3000	rev/min
Voltage	11800	V
Cooling	-	

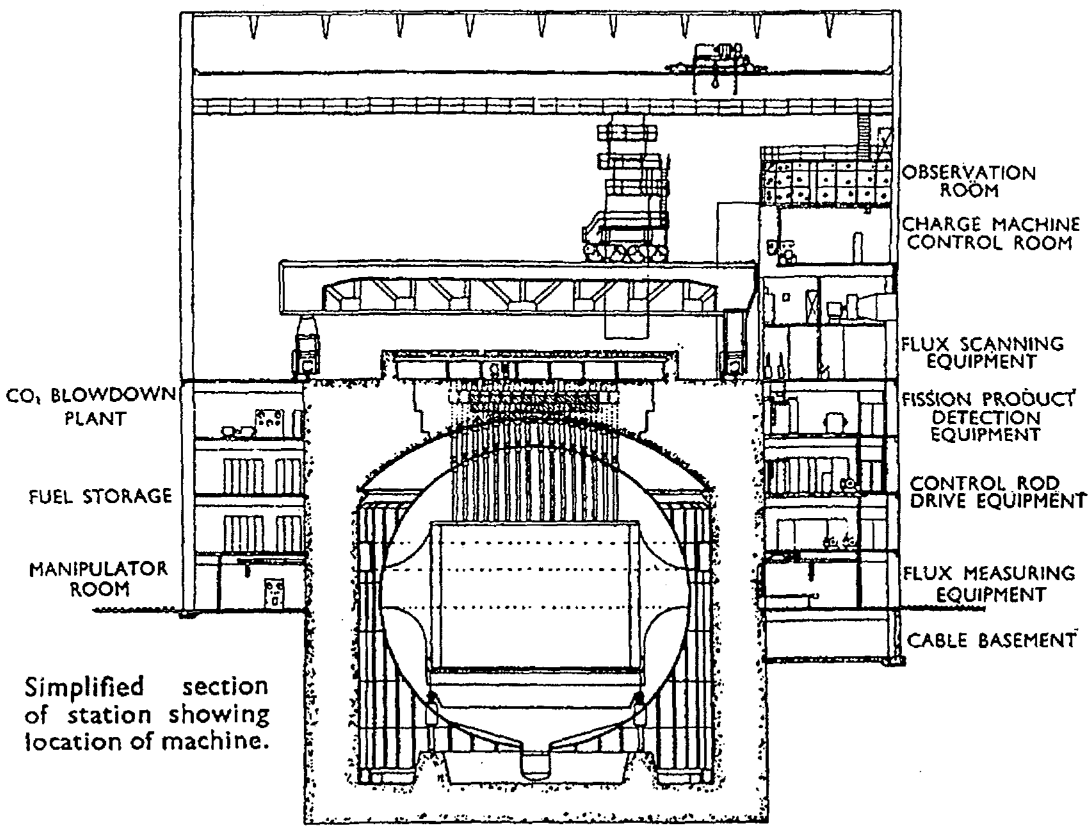


Figure 7.2. Bradwell Magnox Power Station.

Appendix D: Hunterston Magnox Power Station

Location: The Hunterston Magnox reactors are located in the Stratchclyde Region in Scotland, 60 km west-south-west of Glasgow.

The construction work started in October 1957, and the reactors were connected to the grid in February 1964 (A1) and June 1964 (A2).

The Hunterston reactors are different from other magnox reactors, because refuelling operations takes place from below. One standpipe serves 36 fuel channels, selected by the chute at the top of the charge machine, Figure 7.3 and Figure 7.4.

A magazine tube in the charge machine takes up half the stack of fuel elements, and the magazine is rotated until a second empty tube can take the rest of the stack. Refuelling from below is more complicated than normal refuelling from the top.

Safety aspects:
When the Hunterston reactors were designed it was not a requirement that they should be able to withstand a major failure in the cooling system.

The remedy for this weakness was to connect the isolating valves for the main cooling circuits electrically, so that if more than two (out of four) circuits are isolated with the reactor on power, it is tripped automatically. When the reactor is pressurised the natural circulation alone is sufficient for removing the decay heat.

The Hunterston magnox reactors were finally shut down in December 1989 and March 1990.

Table 7.3. Summary of design data for Hunterston Magnox nuclear power station

Station design		
Design and construction	GEC and Simon Carves Atomic Energy Group	
Reactor type	MAGNOX Gas Cooled	
Electrical output (gross)	2 x 160	MWe
Thermal output (gross)	2 x 538	MWt
Efficiency	30	%
Number of reactors	2	
Reactor		
Moderator	Graphite	
Coolant gas	CO_2	
Number of fuel channels	3288	
Lattice pitch (square)	210	mm
Active core diameter	13.6	m
Active core height	7.0	m
Number of control rod channels	208	
Mean gas pressure	10.6	bar
Mean inlet gas temperature	204	°C
Mean outlet gas temperature	396	°C
Total gas flow	2560	kg/s
Fuel elements		
Material	Natural uranium metal	
Type	-	
Cladding material	Magnox A12	
Element length	-	mm
Number of elements per channel	10	
Mass of uranium per reactor	251	tonnes
Average fuel rating	2.11	MWt/tU

Table 7.3 continued

Pressure vessel		
Type	Spherical	
Material	Coltuf 28	
Internal diameter	21.34	m
Internal height	-	m
Plate thickness	73	mm
Design pressure	10.6	bar
Gas circulators		
Type	Vertical shaft	centrifugal blowers
Number circulators per reactor	8	
Power consumption per reactor	12.6	MWe
Regulation	DC-motors supplied from controlled rectifiers	
Steam generators		
Number of steam generators per reactor	8	
Turbine plant		
High pressure steam flow	519	t/h
HP-turbine inlet pressure	39	bar
HP-turbine inlet temperature	366	°C
Low pressure steam flow	252	t/h
LP-turbine inlet pressure	9.5	bar
LP-turbine inlet temperature	349	°C
Generator:		
Number of generators per reactor	3	
Rating	60	MW
Speed	3000	rev/min
Voltage	11800	V
Cooling	Hydrogen	
Cos φ	0.8	

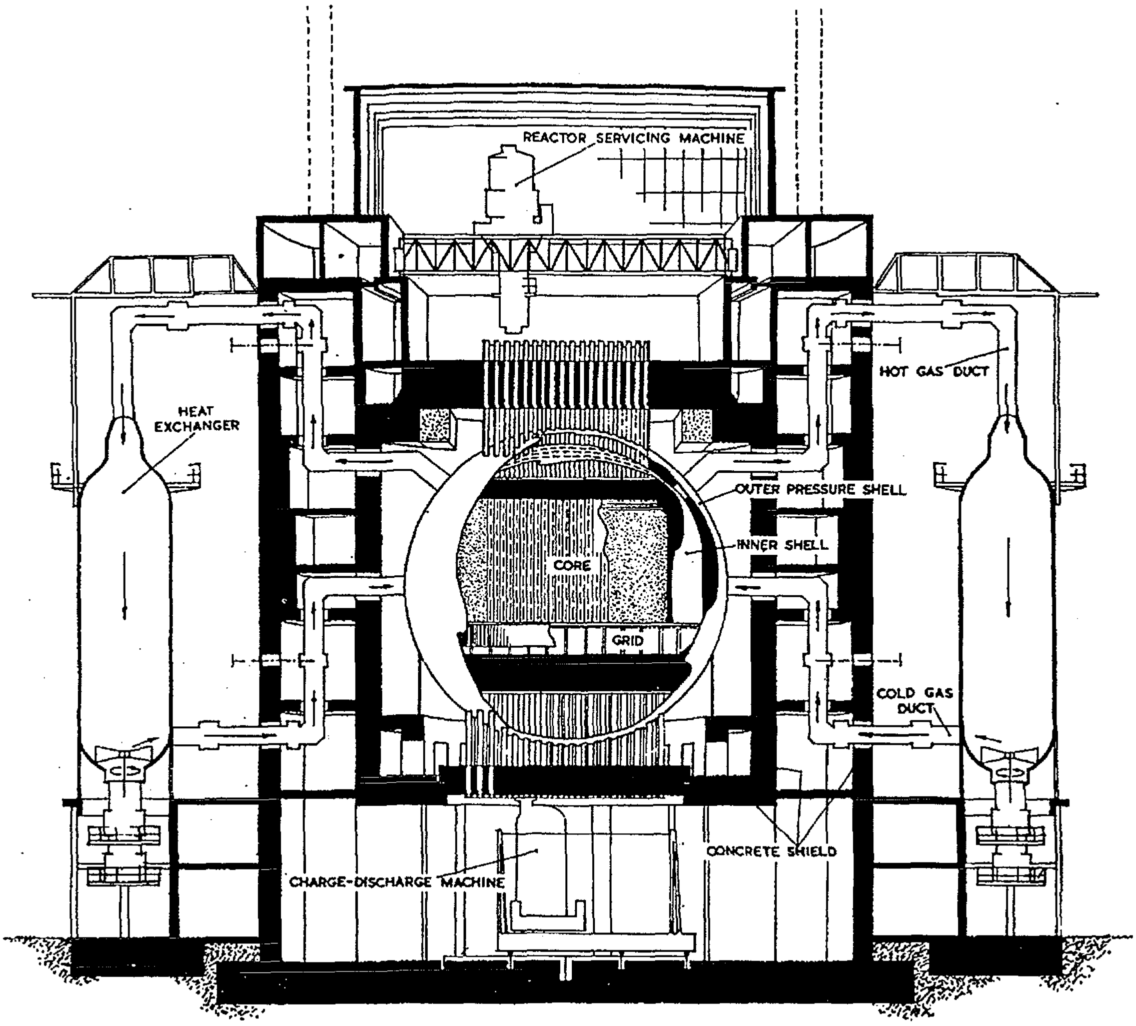


Figure 7.3. Hunterston Magnox Station, most notable departure from existing practice is the bottom charge and discharge facility.

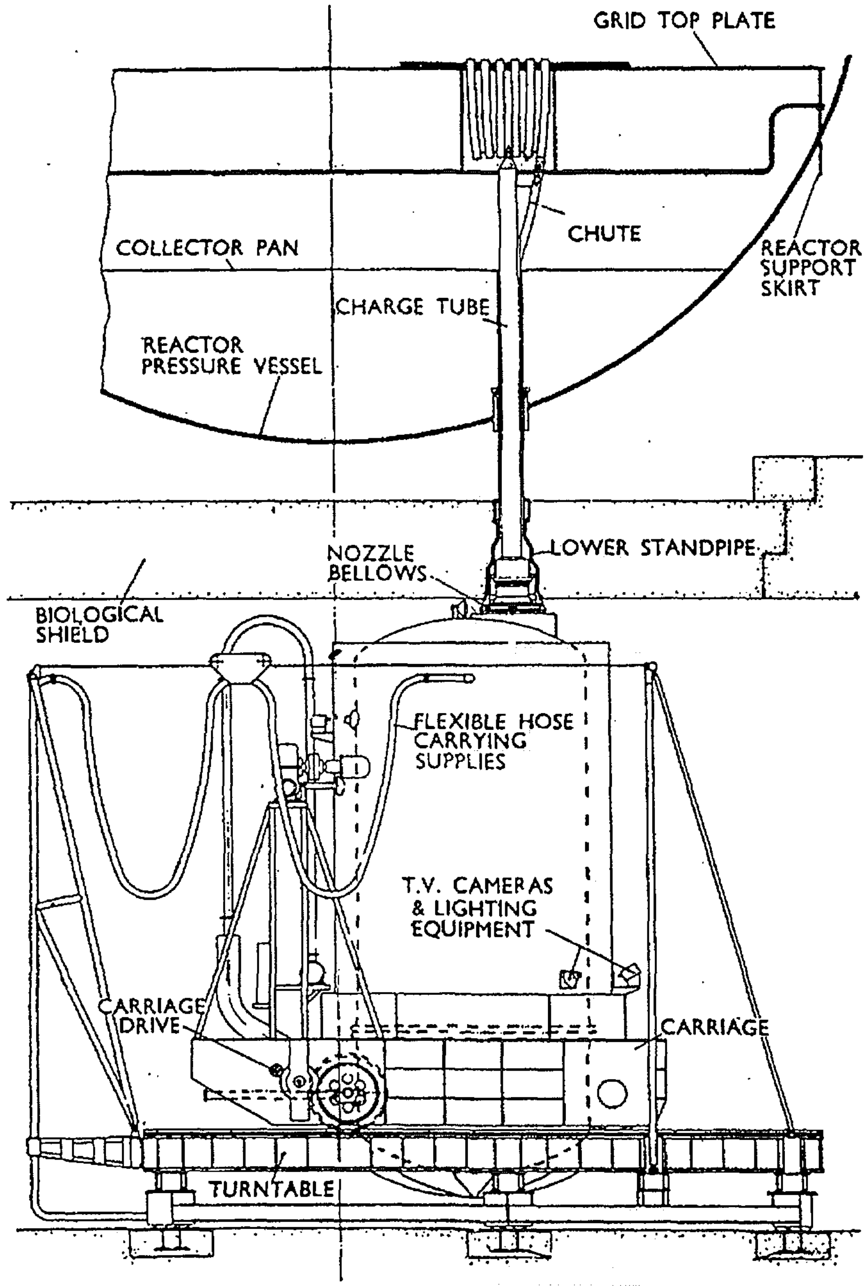


Figure 7.4. Arrangement of bottom-charging machine for Hunterston.

Appendix E: Dungeness Magnox Reactors

Location: The Dungeness Magnox reactors are located at the coast of the British Channel, 100 km south-east of London.

Construction work started mid 1960. Commercial operation started in September 1965 and November 1965, respectively.

The advance in thermodynamic efficiency has been pushed up to 32,9%. This is believed to represent the highest efficiency to be obtained by Magnox fuel cladding.

The main circulators are operated by small steam turbines driven by the high-pressure steam.

Safety aspects:
Operation of the main circulators by steam turbines directly has important advantages from the safety point of view.

The pony motors that takes over the shut down cooling also assists under start up conditions.

The Dungeness Magnox reactors are still in operation.

Table 7.4. Summary of design data for Dungenes Magnox nuclear power station

Station design		
Design and construction	TNPG The Nuclear Power Group	
Reactor type	MAGNOX Gas Cooled	
Electrical output (gross)	2 x 275	MWe
Thermal output (gross)	2 x 835	MWt
Efficiency	33	%
Number of reactors	2	
Reactor		
Moderator	Graphite	
Coolant gas	CO_2	
Number of fuel channels	3876	
Lattice pitch (square)	197	mm
Active core diameter	13.8	m
Active core height	7.3	m
Number of control rod channels	-	
Mean gas pressure	18.2	bar
Mean inlet gas temperature	250	°C
Mean outlet gas temperature	410	°C
Total gas flow	-	kg/s
Fuel elements		
Material	Natural uranium metal	
Type	-	
Cladding material	Magnox	
Element length	1060	mm
Number of elements per channel	7	
Mass of uranium per reactor	298	tonnes
Average fuel rating	2.8	MWt/tU

Table 7.4 continued

Pressure vessel		
Type	Spherical	
Material	Carbon steel	
Internal diameter	19.05	m
Internal height	-	m
Plate thickness	101,6	mm
Design pressure	18.2	bar
Gas circulators		
Type	Blowers coupled directly to back pressure turbines	
Number circulators per reactor	4	
Power consumption per reactor	28	MW
Regulation		-
Steam generators		
Number of steam generators per reactor	4	
Turbine plant		
High pressure steam flow	-	t/h
HP-turbine inlet pressure	99	bar
HP-turbine inlet temperature	392	°C
Low pressure steam flow	-	t/h
LP-turbine inlet pressure	38.7	bar
LP-turbine inlet temperature	391	°C
Generator:		
Number of generators per reactor	2	
Rating per generator	143	MW
Speed	1500	rev/min
Voltage	13800	V
Cooling	-	
Cos φ	-	

Appendix F: Hinkley Point Magnox Reactors

Location: At the coast of Bristol Channel 50 km south-west of Bristol and 210 km west of London.

Construction started late 1957. Commercial operation started in March 1965 and May 1965.

Hinkley Point A is a conventional Magnox Plant with spherical pressure vessels. Each reactor has 6 steamgenerators.

Safety aspects:
The position of the steam generators is such to obtain the maximum possible chimney effect for natural circulation of gas in the event of blower failures.

The Hinkley Point Magnox reactors are still in operation.

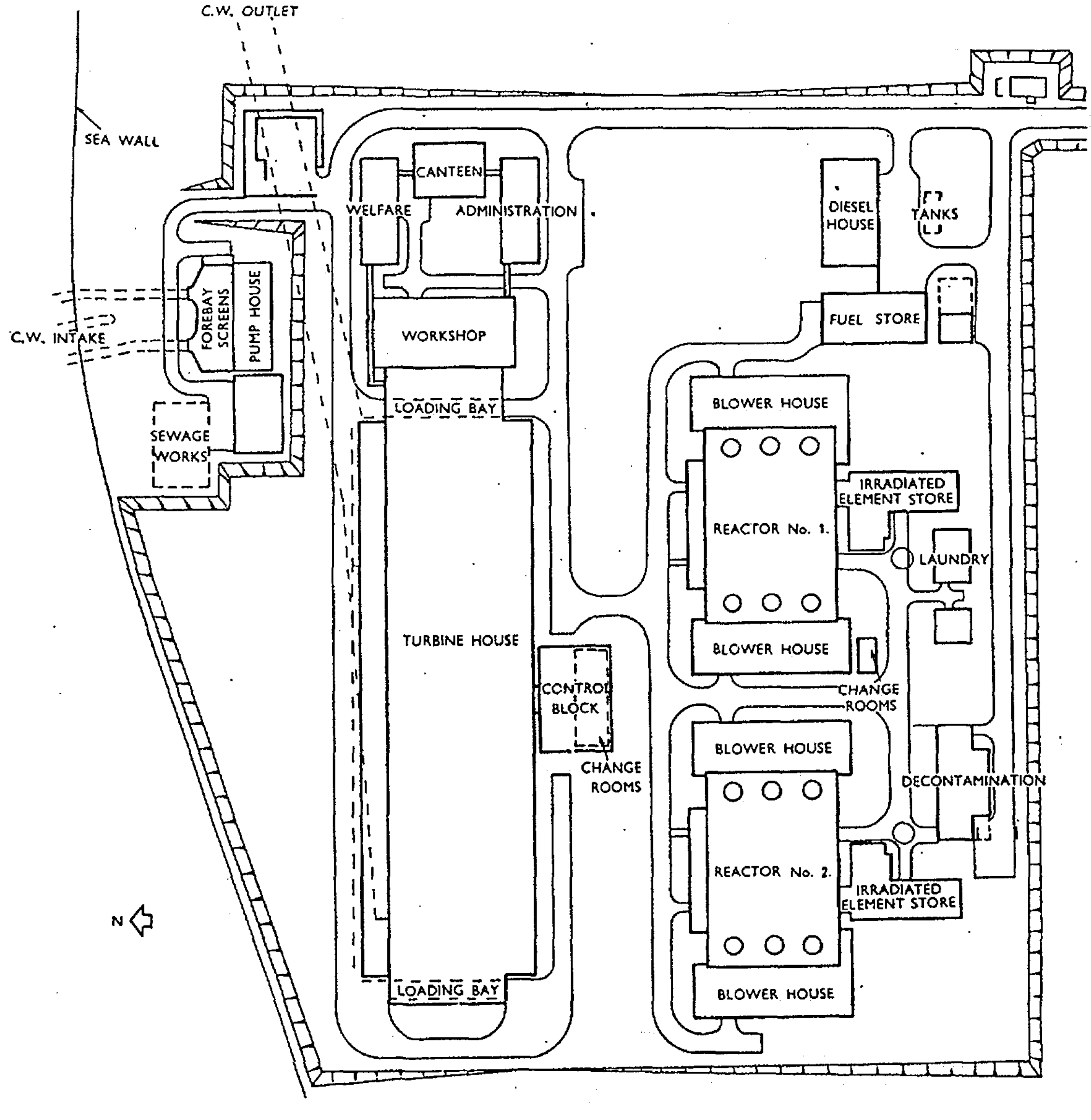


Figure 7.5. Site plan of Hinkley Point Magnox Station.

Table 7.5. Summary of design data for Hinkley Point Magnox nuclear power station

Station design		
Design and construction	English Electric Babcock and Wilcox-Taylor Woodrow Atomic Power Group	
Reactor type	MAGNOX Gas Cooled	
Electrical output (gross)	2 x 250	MWe
Thermal output (gross)	2 x 980	MWt
Efficiency	26	%
Number of reactors	2	
Reactor		
Moderator	Graphite	
Coolant gas	CO_2	
Number of fuel channels	4500	
Lattice pitch (square)	197	mm
Active core diameter	14.9	m
Active core height	7.6	m
Number of control rod channels	113+14	
Mean gas pressure	12.2	bar
Mean inlet gas temperature	180	°C
Mean outlet gas temperature	375	°C
Total gas flow	4536	kg/s
Fuel elements		
Material	Natural uranium metal	
Type	-	
Cladding material	Magnox	
Element length	914,4	mm
Number of elements per channel	8	
Mass of uranium per reactor	370	tonnes
Average fuel rating	2.65	MWt/tU

Table 7.5 continued

Pressure vessel		
Type	Spherical	
Material	Steel 28/32	Si-killed
Internal diameter	20.42	m
Internal height	-	m
Plate thickness	76,2	mm
Design pressure	13.6	bar
Gas circulators		
Type	Single stage, axial	
Number circulators per reactor	6	
Power consumption per reactor	-	MWe
Regulation	Variable frequency motors	
Steam generators		
Number of steam generators per reactor	6	
Turbine plant		
High pressure steam flow	-	t/h
HP-turbine inlet pressure	45.7	bar
HP-turbine inlet temperature	363	°C
Low pressure steam flow	-	t/h
LP-turbine inlet pressure	12.7	bar
LP-turbine inlet temperature	354	°C
Generator:		
Number of generators per reactor	3	
Rating per generator	93,5	MW
Speed	-	rev/min
Voltage	13800	V
Cooling	Hydrogen	
Cos φ	-	

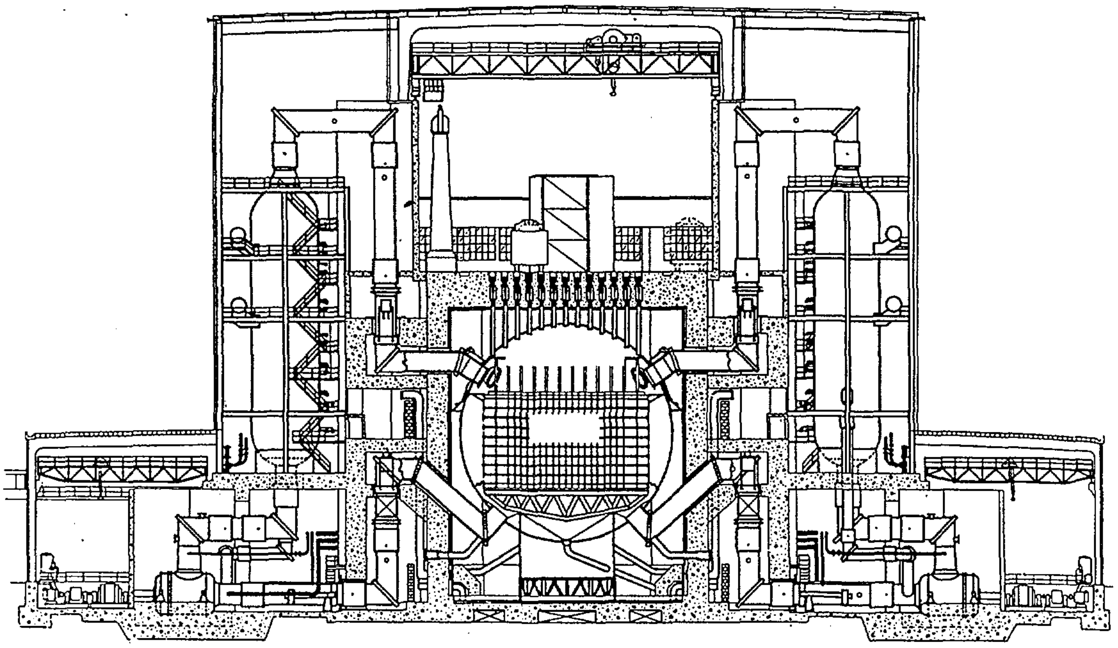


Figure 7.6. Hinkley Point Magnox Station.

Appendix G: Trawsfynydd Magnox Reactors

Location: The Trawsfynydd reactor plant is located in North Wales at the shore of Lake Trawsfynydd, 130 km west-south-west of Manchester and 80 km south-west of Liverpool

Construction work started in the summer 1957. Commercial operation started early in the year 1965.

Trawsfynydd is no. 5 of commercial magnox stations.

The plant do not represent any big construction news, but a great deal of improvements have been made since the construction of Hinkley Point.

The charge machine is designed to handle fuel with the reactor on load.

The Trawsfynydd reactors were finally shut down early 1991.

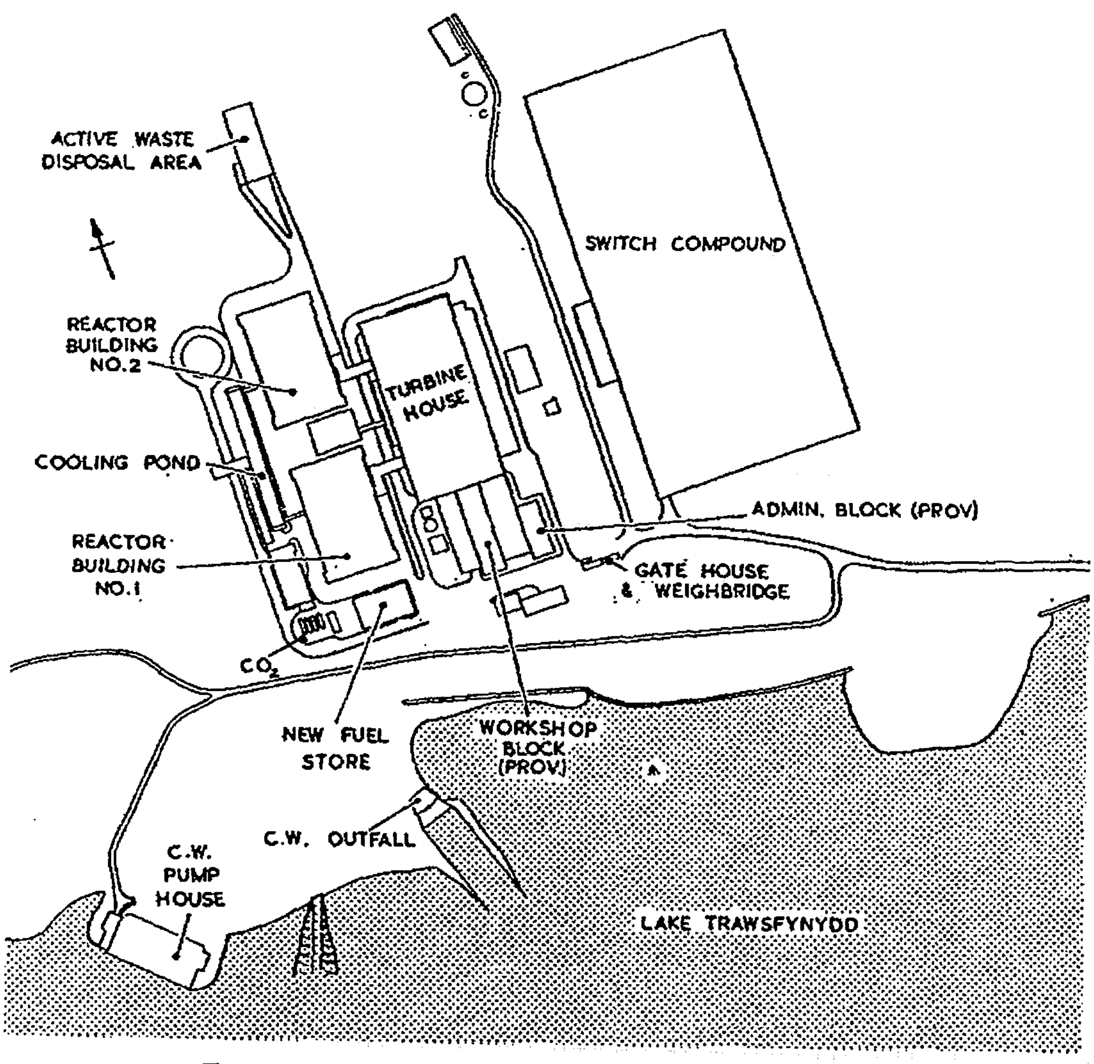


Figure 7.7. Site plan of Trawsfynydd Magnox Station.

Table 7.6. Summary of design data for Trawsfynydd Magnox nuclear power station

Station design		
Design and construction	Atomic Power Constructions	
Reactor type	MAGNOX Gas Cooled	
Electrical output (gross)	2 x 250	MWe
Thermal output (gross)	2 x 870	MWt
Efficiency	29	%
Number of reactors	2	
Reactor		
Moderator	Graphite	
Coolant gas	CO_2	
Number of fuel channels	3720	
Lattice pitch (square)	197	mm
Active core diameter	14.9	m
Active core height	8.4	m
Number of control rod channels	-	
Mean gas pressure	16.9	bar
Mean inlet gas temperature	200	°C
Mean outlet gas temperature	400	°C
Total gas flow	4082	kg/s
Fuel elements		
Material	Natural uranium metal	
Type	Spiral fins and 4 longitudinal splitters	
Cladding material	Magnox	
Element length	-	mm
Number of elements per channel	9	
Mass of uranium per reactor	280	tonnes
Average fuel rating	3.1	MWt/tU

Table 7.6 continued

Pressure vessel		
Type	Spherical	
Material	JT 101	
Internal diameter	18.6	m
Internal height	-	m
Plate thickness	89	mm
Design pressure	16.9	bar
Gas circulators		
Type	Single stage, axial constant speed squirrel cage motors	
Number circulators per reactor	6	
Power consumption per reactor	26,5	MWe
Regulation		None
Steam generators		
Number of steam generators per reactor	6	
Turbine plant		
High pressure steam flow	789	t/h
HP-turbine inlet pressure	65.1	bar
HP-turbine inlet temperature	379	°C
Low pressure steam flow	422	t/h
LP-turbine inlet pressure	20.4	bar
LP-turbine inlet temperature	363	°C
Generator:		
Number of generators per reactor	2	
Rating per generator	145	MW
Speed	-	rev/min
Voltage	-	V
Cooling	Water cooled stator	
Cos φ	-	

Appendix H: Sizewell Magnox Reactors

Location: The Sizewell reactors are located on the Suffolk coast a few miles south of Dunwick. This location is about 145 km north-east of London.

Construction work started in April 1961. Commercial operation started in September 1966 and March 1966, respectively.

The Sizewell magnox station is the seventh of the commercial stations.

The most important improvements, compared with the Hinkley Point station, are simplicity in the steam circuit.

The station use only two turbines, each rated at 325 MW (one to each reactor), compared with 6 turbines for Hinkley Point.

The number of steam generators is reduced from 12 to 8 for the whole station.

The Sizewell Magnox reactors are still in operation.

Table 7.7. Summary of design data for Sizewell Magnox nuclear power station

Station design		
Design and construction	English Electric Babcock and Wilcox-Taylor Woodrow Atomic Power Group	
Reactor type	MAGNOX Gas Cooled	
Electrical output (gross)	2 x 290	MWe
Thermal output (gross)	2 x 950	MWt
Efficiency	31	%
Number of reactors	2	
Reactor		
Moderator	Graphite	
Coolant gas	CO_2	
Number of fuel channels	3800	
Lattice pitch (square)	197	mm
Active core diameter	13.7	m
Active core height	7.9	m
Number of control rod channels	99+8	
Mean gas pressure	17.9	bar
Mean inlet gas temperature	214	°C
Mean outlet gas temperature	410	°C
Total gas flow	4470	kg/s
Fuel elements		
Material	Natural uranium metal	
Type	Herring bone	
Cladding material	Magnox	
Element length	-	mm
Number of elements per channel	7	
Mass of uranium per reactor	321	tonnes
Average fuel rating	2.95	MWt/tU

Table 7.7 continued

Pressure vessel	
Type	Spherical
Material	Steel JT 101 28/32
Internal diameter	19.4 m
Internal height	- m
Plate thickness	106 mm
Design pressure	17.9 bar
Gas circulators	
Type	Single stage, axial
Number circulators per reactor	4
Power consumption per reactor	- MWe
Regulation	Variable inlet guide vanes
Steam generators	
Number of steam generators per reactor	4
Turbine plant	
High pressure steam flow	980 t/h
HP-turbine inlet pressure	47.6 bar
HP-turbine inlet temperature	389 °C
Low pressure steam flow	335 t/h
LP-turbine inlet pressure	18.8 bar
LP-turbine inlet temperature	389 °C
Generator:	
Number of generators per reactor	1
Rating per generator	325 MW
Speed	- rev/min
Voltage	- V
Cooling	-
Cos φ	-

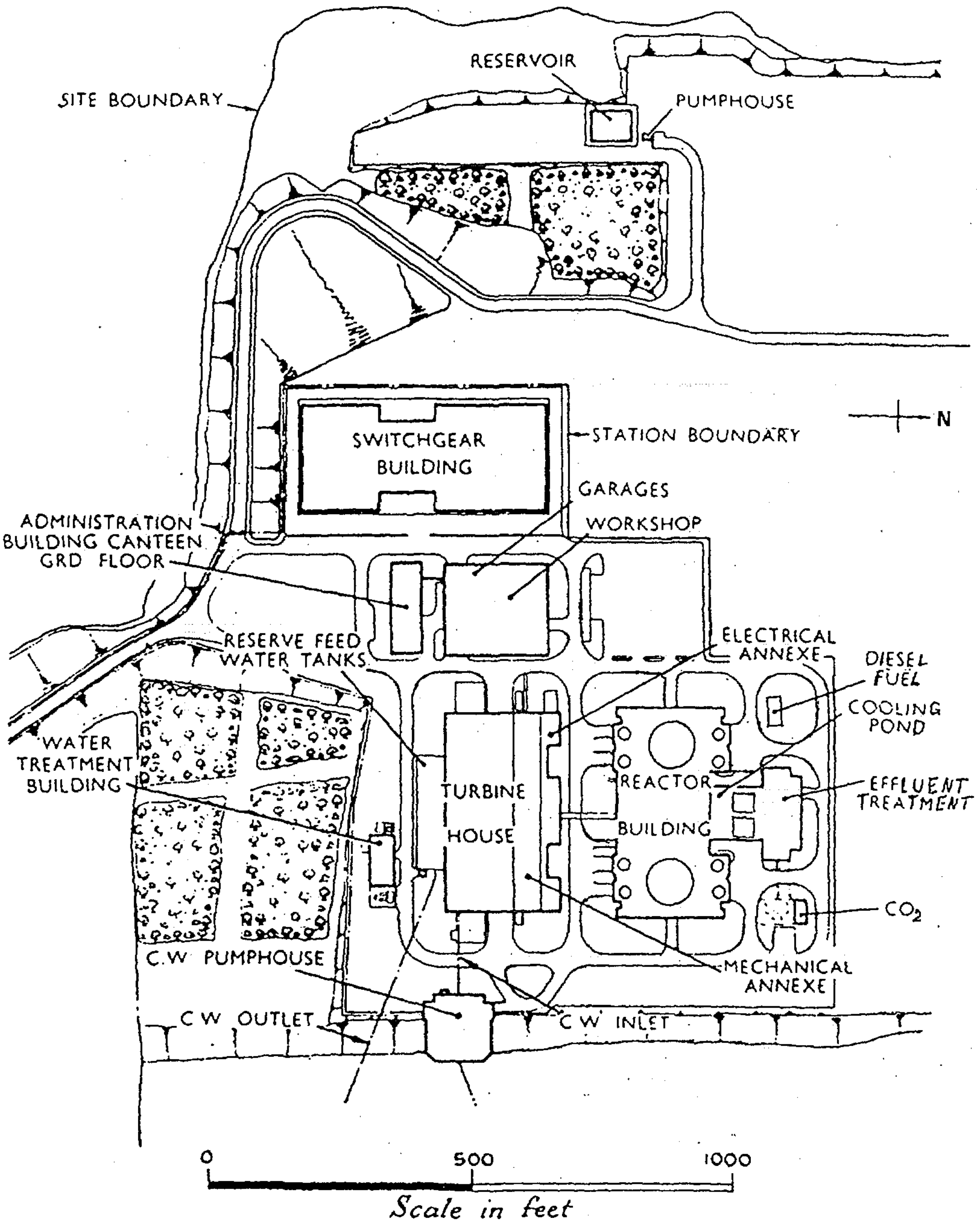


Figure 7.8. Site plan of Sizewell Magnox Station..

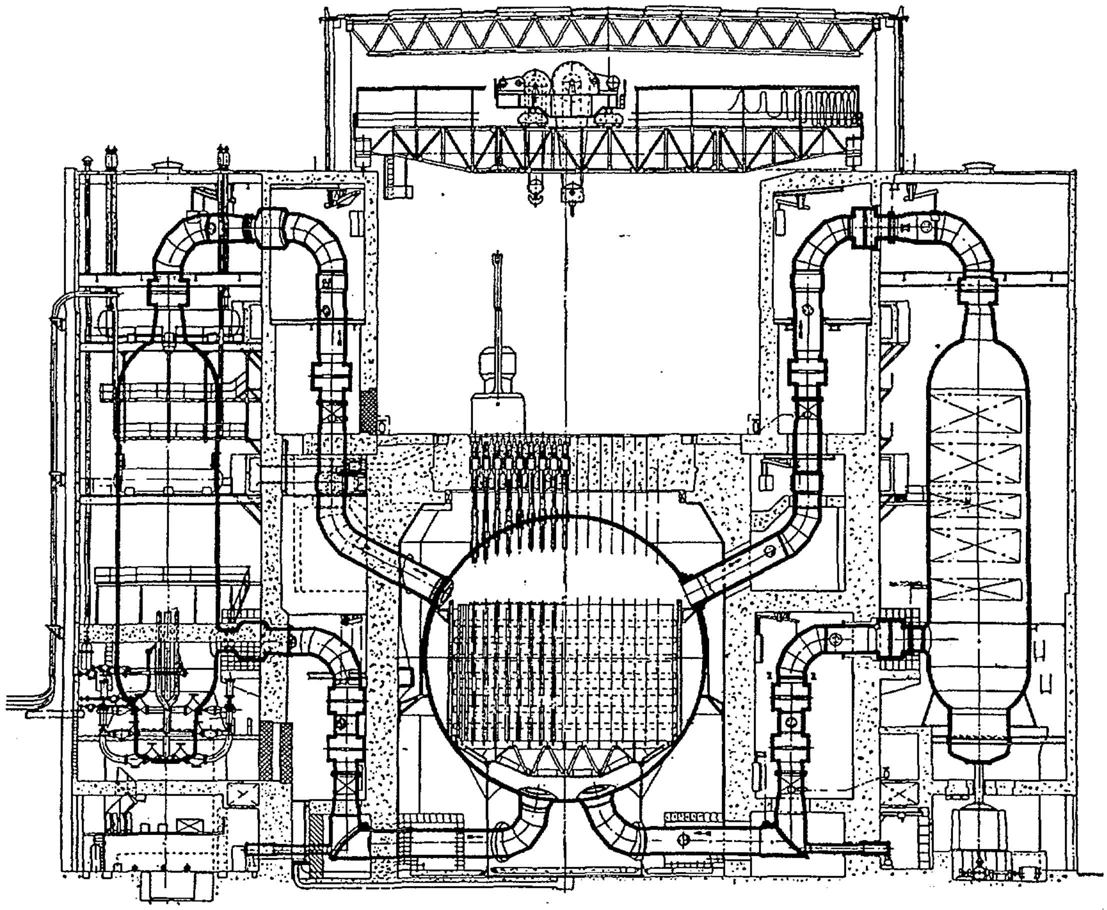


Figure 7.9. Coolant circuit of one of the Sizewell Magnox reactors. The coolant circuit has been simplified by mounting the blowers in the boilers.

Appendix I: Oldbury Magnox Reactors

Location: 150-km west of London.

Oldbury is Britains first concrete vessel nuclear power station, and it is no. 8 in the series of commercial size in the UK.

Each reactor is contained within a pressure vessel of pre-stressed high strength concrete. The concrete is made from normal Portland Cement.

Also the steam generators are inside the concrete vessel.

The vessel is a flat-topped cylindrical construction with a liner of 12,7 mm mild steel.

Safety aspects:
The use of a concrete vessel is an important increase in safety margins. The catastrophic failure that can be postulated with brittle fracture in steel circuits can be ruled out entirely, as simultaneous failure of all pre-stressing cables would be absurd.

It is important that the cables can be changed out, a feature that should guarantee a long life of the vessel.

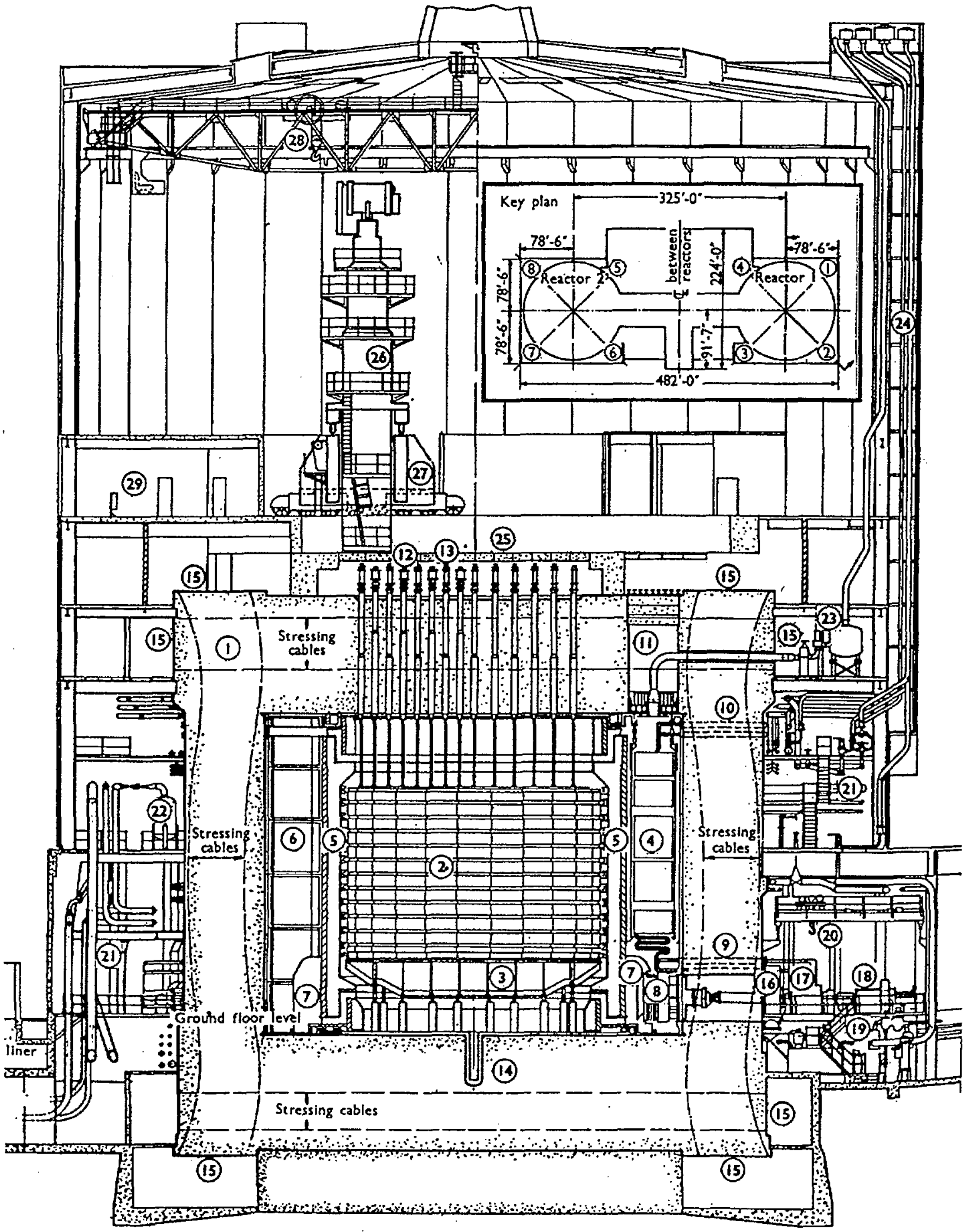
The Oldbury Magnox reactors are still in operation.

Table 7.8. Summary of design data for Oldbury Magnox nuclear power station

Station design		
Design and construction	TNPG The Nuclear Power Group	
Reactor type	MAGNOX Gas Cooled	
Electrical output (gross)	2 x 280	MWe
Thermal output (gross)	2 x 835	MWt
Efficiency	34	%
Number of reactors	2	
Reactor		
Moderator	Graphite	
Coolant gas	CO_2	
Number of fuel channels	3320	
Lattice pitch (square)	197	mm
Active core diameter	12.8	m
Active core height	8.5	m
Number of control rod channels	101	
Mean gas pressure	25.6	bar
Mean inlet gas temperature	245	°C
Mean outlet gas temperature	410	°C
Total gas flow	4627	kg/s
Fuel elements		
Material	Natural uranium metal	
Type	Fins with 4 radial splitters	
Cladding material	Magnox	A12
Element length	-	mm
Number of elements per channel	8	
Mass of uranium per reactor	293	tonnes
Average fuel rating	2.85	MWt/tU

Table 7.8 continued

Pressure vessel		
Type	Cylindrical	
Material	Pre-stressed concrete	
Internal diameter	23.5	m
Internal height	18.3	m
Concrete thickness	Walls 4.6 m thick, top and bottom 6.7 m	
Steel liner temperature	65	^0C
Design pressure	26.1	bar
Gas circulators		
Type	-	
Number circulators per reactor	4	
Power consumption per reactor	20.8	MWe
Regulation		-
Steam generators		
Number of steam generators per reactor	4	
Turbine plant		
High pressure steam flow	691	t/h
HP-turbine inlet pressure	97	bar
HP-turbine inlet temperature	393	^oC
Low pressure steam flow	457	t/h
LP-turbine inlet pressure	49.6	bar
LP-turbine inlet temperature	393	^oC
Generator:		
Number of generators per reactor	1	
Rating per generator	292	MW
Speed	-	rev/min
Voltage	-	V
Cooling	-	
Cos φ	-	



Key: **1.** Pre-stressed concrete pressure vessel. **2.** Graphite core. **3.** Core support grid. **4.** Boiler. **5.** Boiler shield wall. **5.** Boiler end piece. **7.** Gas circulator outlet duct. **8.** Gas circulator. **9.** Boiler feed penetrations. **10.** H P & L P steam penetrations. **11.** Boiler loading slot. **12.** Charge standpipe. **13.** Control standpipe. **14.** Debris mortuary tube. **15.** Pressure vessel stressing galleries. **16.** Gas circulator shield doors. **17.** Gas circulator pony motor. **18.** Gas circulator turbine. **19.** Gas circulator auxiliaries. **20.** Gas circulator crane, 25 ton. **21.** Steam & feed pipe work. **22.** Boiler start-up vessels. **23.** Reactor safety valves & filters. **24.** Relief valve pipes to atmosphere. **25.** Charge floor. **26.** Charge/discharge machine. **27.** Charge/discharge machine gantry. **28.** Charge hall crane, 25 ton. **29.** B F E D room. **30.** Transformers.

Figure 7.10. Sectional view of an Oldbury Magnox reactor.

Appendix J: Wylfa Magnox Reactors

Location: The northern tip of the Isle Angesey, 150 km west of Manchester and 100 km west of Liverpool.

Wylfa nuclear power station is the most advanced power station developed from the Calder Hall reactors, and it is the second station with the reactors and the steam generators contained in a pre-stressed concrete construction.

The most important improvements in design appears from Figure 7.12, Figure 7.13 and Figure 7.14.

The development of the gas circuit from Hinkley to Wylfa is seen at Figure 7.12.

Perhaps the most important simplification is within the steam circuit. As it appears from Figure 7.13 the once through steam generators can be divided in an economiser part, an evaporator part and a superheater part.

Compared to the predecessor (Sizewell) the gas pressure is increased from 19,6 kg/cm^2 to 28 kg/cm^2, which improves the operational efficiency.

Safety aspects:
The use of a concrete vessel is an important increase in safety margins. The catastrophic failure that can be postulated with brittle fracture in steel circuits can be ruled out entirely, as simultaneous failure of all pre-stressing cables would be absurd.
Quite sure the magnox stations with pre-stressed concrete vessels have been a model for the AGR constructions.

The gas blower design has undergo revision caused by operation troubles.

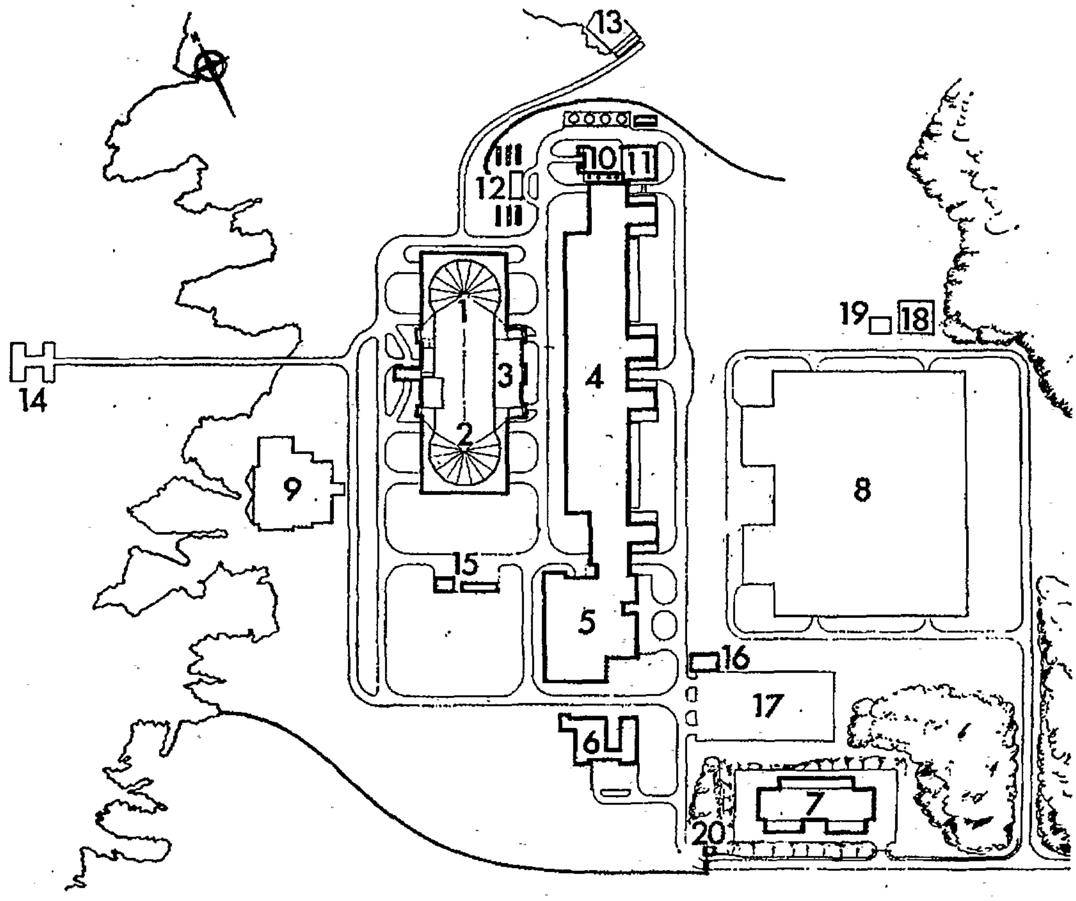
The troubles came from pressure pulses, radiated from high speed single stage blowers with few blades.

Table 7.9. Summary of design data for Wylfa Magnox nuclear power station

Station design		
Design and construction	English Electric Babcock and Wilcox-Taylor Woodrow Atomic Power Group	
Reactor type	MAGNOX Gas Cooled	
Electrical output (gross)	2 x 590	MWe
Thermal output (gross)	2 x 1875	MWt
Efficiency	33	%
Number of reactors	2	
Reactor		
Moderator	Graphite	
Coolant gas	CO_2	
Number of fuel channels	6150	
Lattice pitch (square)	197	mm
Active core diameter	17.4	m
Active core height	9.2	m
Number of control rod channels	167+18	
Mean gas pressure	26.2	bar
Mean inlet gas temperature	247	°C
Mean outlet gas temperature	414	°C
Total gas flow	10254	kg/s
Fuel elements		
Material	Natural uranium metal	
Type	Herring bone finned	
Cladding material	Magnox	AL 80
Element length	-	mm
Number of elements per channel	8	
Mass of uranium per reactor	595	tonnes
Average fuel rating	3.15	MWt/tU

Table 7.9 continued

Pressure vessel		
Type	Spherical	
Material	Pre-stressed concrete	
Internal diameter	29.3	m
Internal height	-	m
Concrete thickness	3.35	m
Steel liner temperature	65	^0C
Design pressure	26,2	bar
Gas circulators		
Type	Single stage, axial with squirrel cage induction motors	
Number circulators per reactor	4	
Power consumption per reactor	55.9	MWe
Regulation	Inlet guide vanes	
Steam generators		
Number of steam generators per reactor	1	
Turbine plant		
High pressure steam flow	2600	t/h
HP-turbine inlet pressure	46	bar
HP-turbine inlet temperature	401	^oC
Low pressure steam flow	-	t/h
LP-turbine inlet pressure	-	bar
LP-turbine inlet temperature	-	^oC
Generator:		
Number of generators per reactor	2	
Rating per generator	334	MW
Speed	-	rev/min
Voltage	-	V
Cooling	-	
Cos φ	-	



Layout of the Wylfa Station. 1, Reactor building No. 1; 2, Reactor building No. 2; 3, Reactor equipment building and shielded facilities; 4, Turbine house; 5, Workshop and welfare block; 6, Canteen and administration; 7, 132 kV Switch house; 8, 400 kV Switch house; 9, C.W. Pumphouse; 10, Gas turbine house; 11, Water treatment plant; 12, CO_2 Store; 13, C.W. outfall; 14, C.W. intake; 15, Garages; 16, Cycle store; 17, Car park; 18, Reservoir; 19, Pumphouse for reservoir; 20, Gatehouse and main entrance.

Figure 7.11. Site plan of Wylfa Magnox Station.

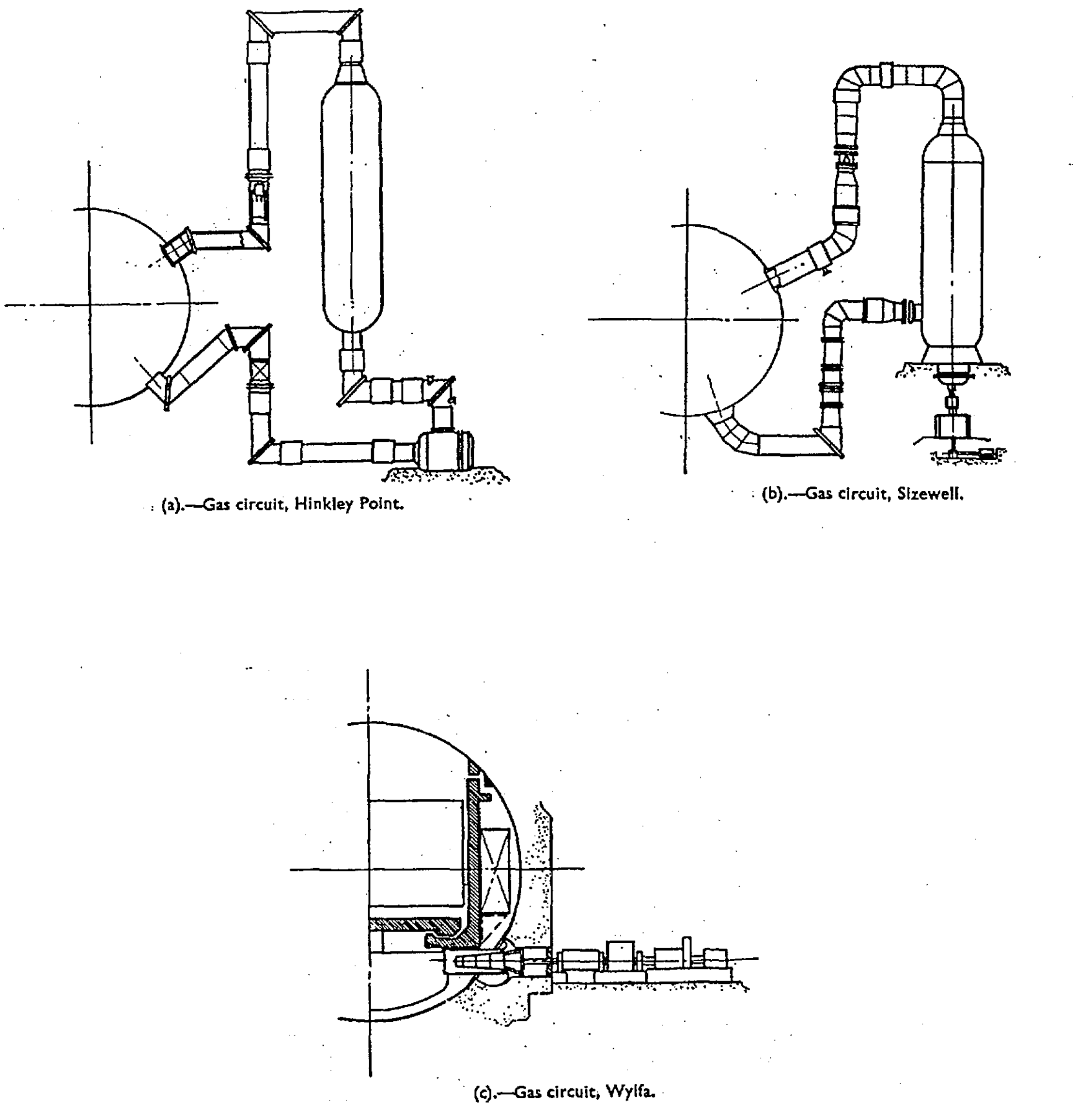


Figure 7.12. The development of the gas circuit from Hinkley Point over Sizewell to Wylfa.

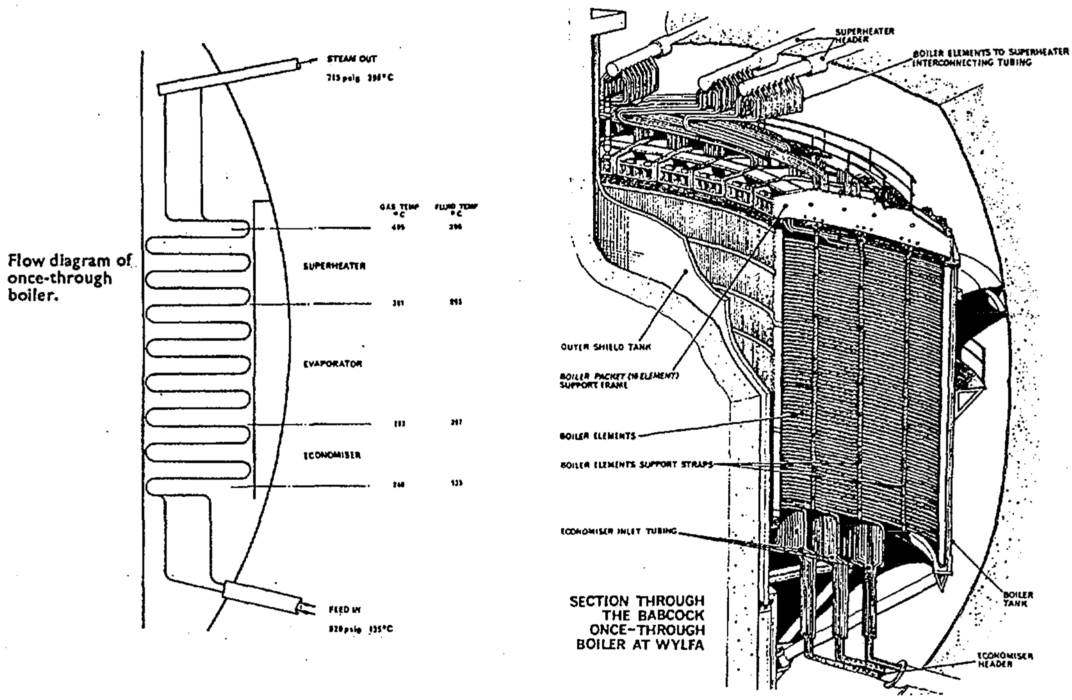


Figure 7.13. Once through steam generator of Wylfa Magnox reactor contained in a pre-stressed concrete construction.

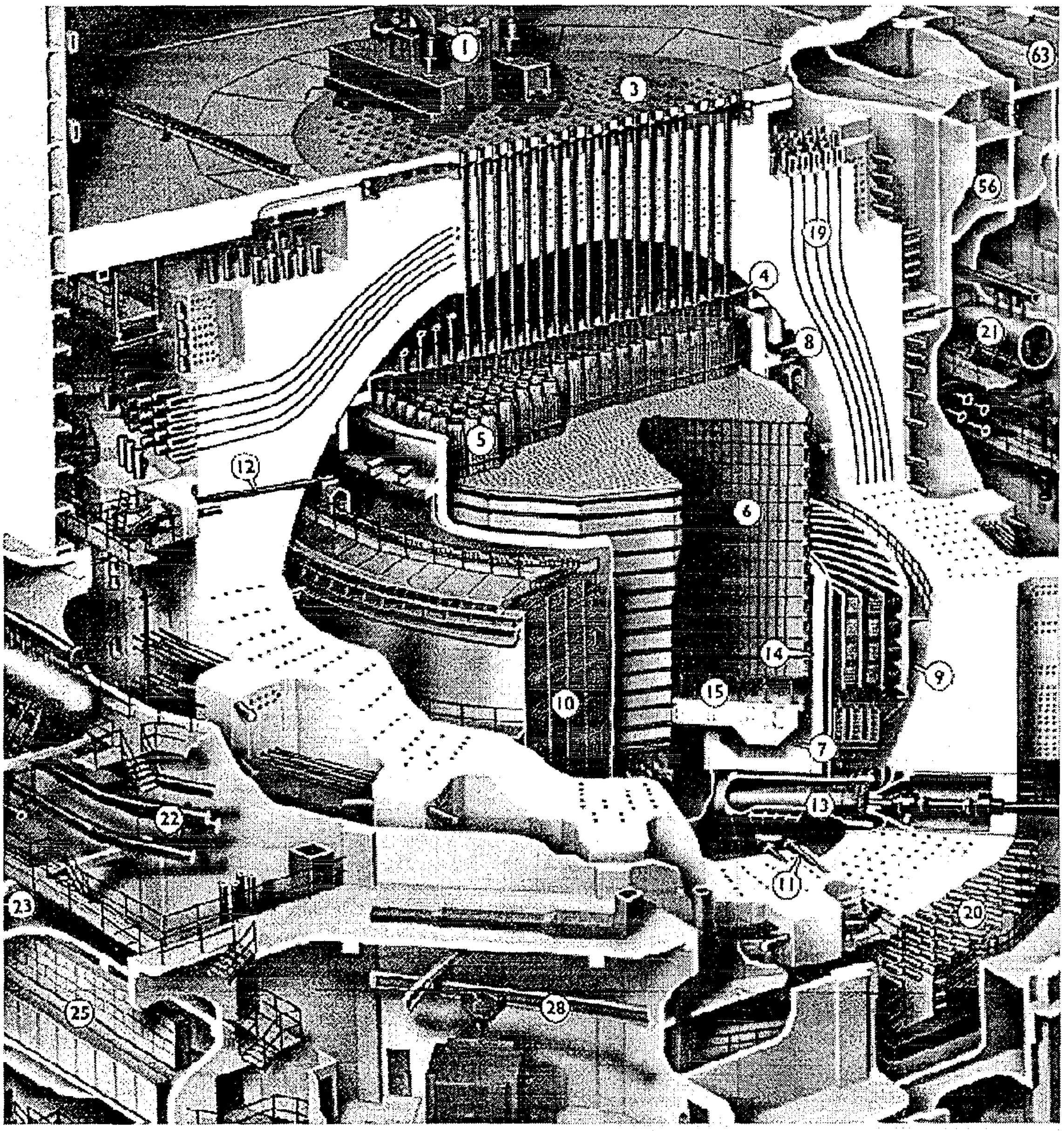


Figure 7.14. Spherical, pre-stressed concrete vessel of Wylfa Magnox reactor. The pre-stressing cables are shown very clear.

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