The Design and Construction of HIFAR

By W. H. Roberts*

A brief description is given of the design and construction of the Australian Atomic Energy Commission's reactor HIFAR, located near Sydney at Lucas Heights. The design is based on that of the British DIDO, a high flux, heavy water moderated and cooled reactor having a maximum thermal neutron flux of 10^{14} neutrons/sq. cm/sec., and a maximum heat output of 10 megawatts.

INTRODUCTION

In April 1955 it was announced that a large research reactor was to be erected with the Commission's laboratories then being planned for a site near Sydney.

The reactor was to be virtually the same as the British DIDO, a heavy water moderated and cooled reactor, producing a maximum thermal flux of 10^{14} neutrons/sq. cm./sec., and a heat output of 10 M.W. Further data on HIFAR are listed in the appendix.

At the beginning of November 1955, a start was made on clearing the Lucas Heights site, and in June 1956 erection of the reactor itself was commenced.

Nineteen months later, on January 26, 1958, HIFAR achieved criticality.

CONSTRUCTION ARRANGEMENTS

HIFAR may be divided conveniently into two parts, namely—

(i) the reactor proper, and

(ii) the associated buildings and services.

The construction of the reactor itself has been carried out through Head Wrightson Processes of London, with International Combustion (Aust.) as their main sub-contractor.

The associated buildings were erected (mostly from drawings kindly provided by the British Ministry of Works) by Hutcherson Bros. as prime contractors to the consulting architects, Stephenson and Turner.

The whole of the work was superintended by the Commission's officers, most of whom had spent some time at Harwell.

BASIC DESIGN OF REACTOR PROPER

Throughout the text, any two numbers, thus 2:3, refer to Fig. 2, Item 3.

Introduction

HIFAR is an experimental reactor, i.e., a laboratory device erected to provide a strong neutron (and gamma) source for experimentalists and research teams engaged in various aspects of atomic energy work.

It can also be used to give experience in reactor construction and operation to design and operating personnel.

Because the object of the reactor is to produce radiation, the attendant heat generated is an embarrassment. For a given flux density, however, the heat rate can be reduced by enriching the fuel, and this course has been adopted for HIFAR. Enrichment of the fuel also reduces the physical size of the reactor core and, therefore, in general, overall costs.

The British DIDO appeared to suit our requirements, and it was decided to adopt the same design with some changes to suit our own requirements.

Later, while HIFAR itself was in course of construction, advantage was taken of operational experience obtained on DIDO to incorporate in HIFAR some modifications to the original design.

Basic design

As mentioned above, the reactor is both moderated and cooled with heavy water. The design can be understood by referring to Figures 1 and 2. An aluminium tank (1) 6ft. 7in. internal diameter, contains heavy water to a depth of 6ft. The 25 fuel elements (2), arranged vertically with a horizontal lattice pitch of 6in., are supported on a horizontal header plate (3) fixed to the tank bottom.

Because the active portion of each element is actually a box of thin vertical parallel plates 2ft. high (Figure 5), the fission heat is conveniently removed (see Figure 3) by circulating the moderator water from the header through the elements, out into the main body of the fluid, and then through overflow pipes (3:4) to external heat exchangers.

The whole of the 25 elements are contained within a horizontal plane approximately 2ft. 3in. by 2ft. 10in. (Figure 2). Because in general good moderators are good reflectors, the 2ft. (approx.) of heavy water between the elements and the tank wall will reflect back a substantial proportion of the neutrons which tend to escape from the system. Outside the tank, 2ft. of graphite (2:5) serves as a further neutron reflector, and provides a fairly large source of thermal neutrons for experimental purposes.

Those neutrons that manage to penetrate the reflectors will be mostly considerably reduced in energy, but because they have escaped from the reacting system they now become an embarrassment. The graphite is accordingly surrounded by a thin layer of an absorbing material "boral" (2:6), which is a complex of boron carbide and aluminium. Boron has a high absorption cross-section for slow neutrons without the production of hard capture gamma radiation.

Actually, the boron is studded to the interior of a steel tank (2:7) in which the graphite is stacked. The aluminium heavy water tank hangs by its top flange from the ring (2:8),

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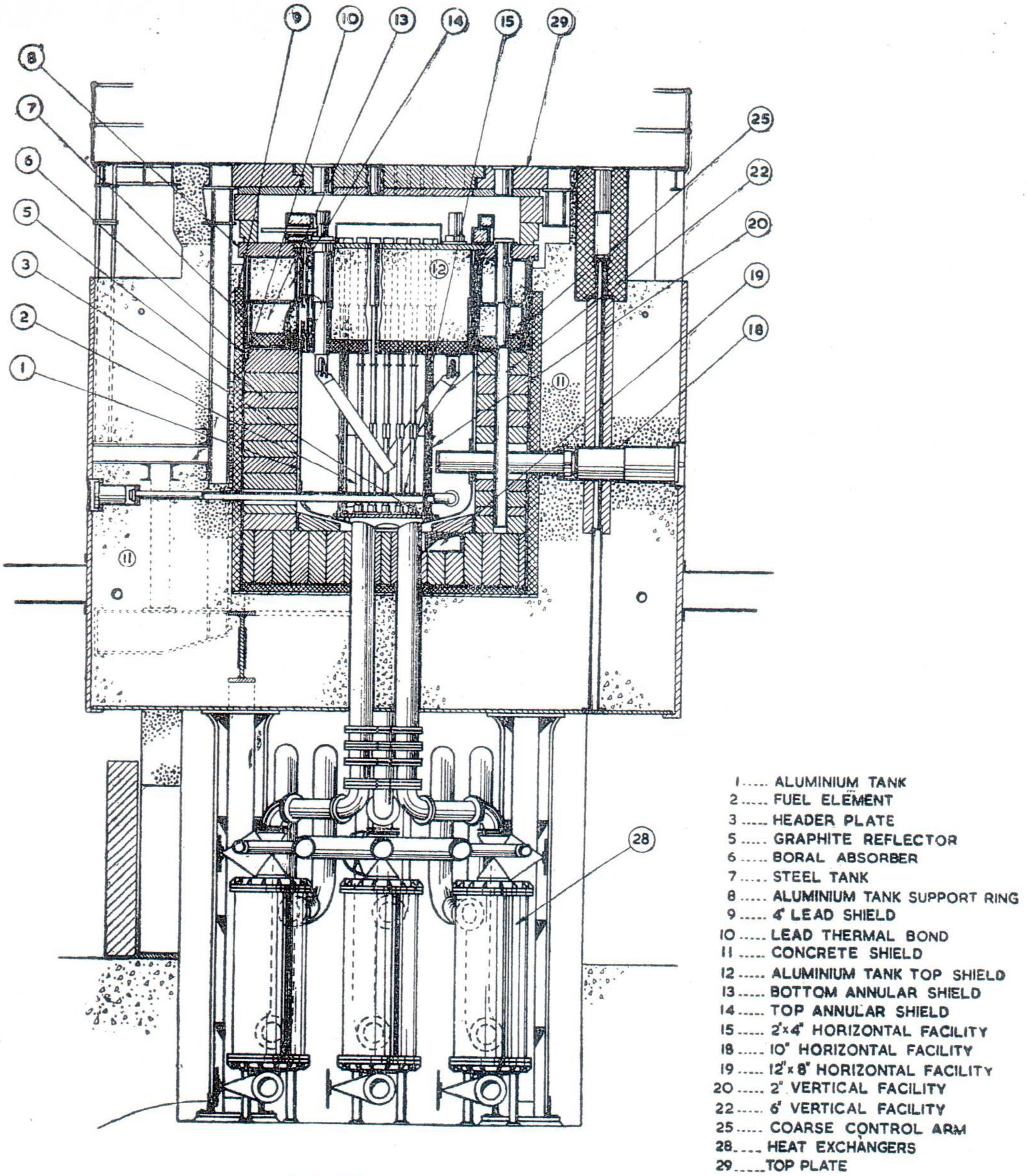


FIGURE 1:—Sectional elevation of reactor.

which itself is supported by the top of the steel tank.

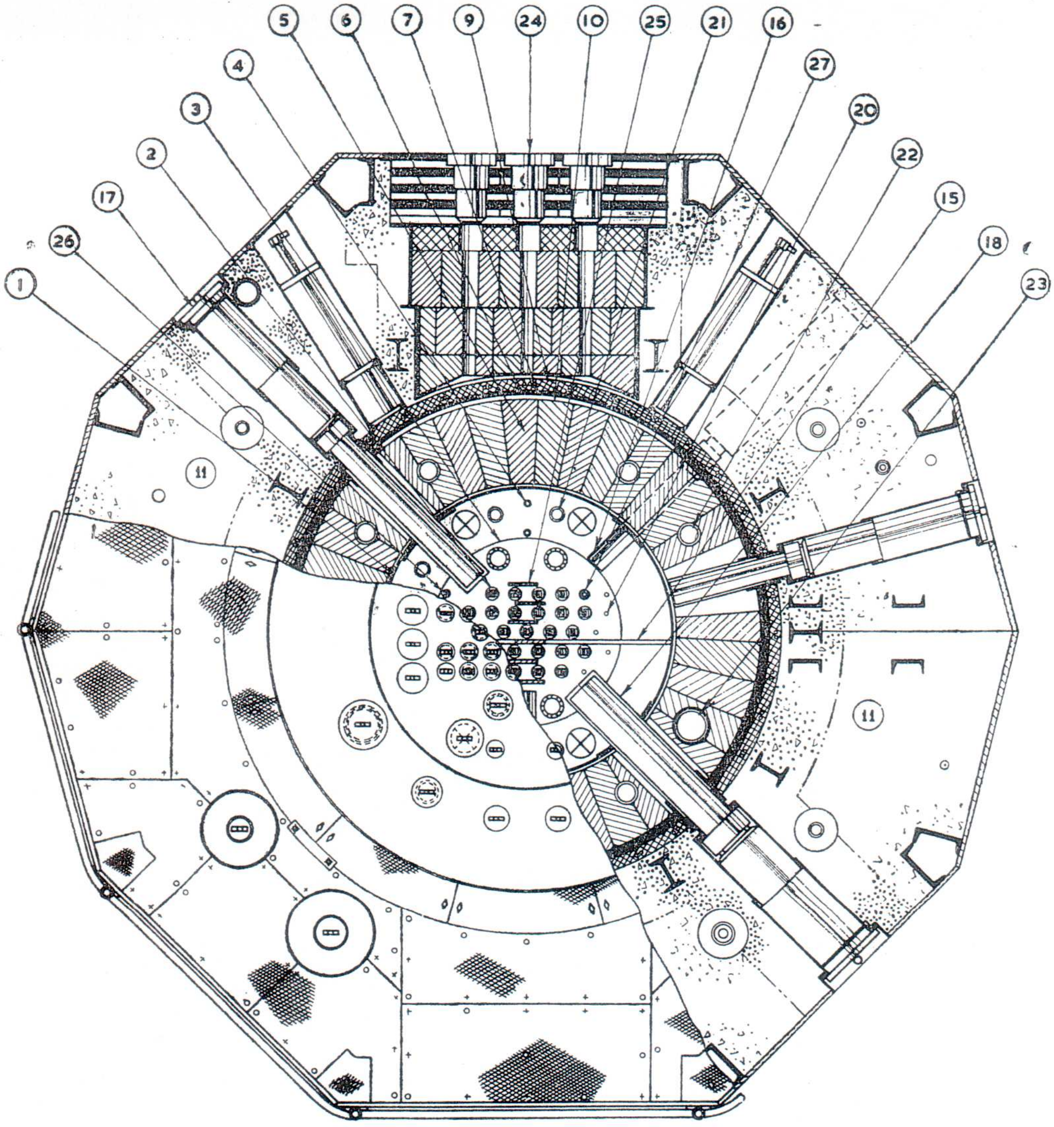
A 4in. water-cooled lead gamma shield (2:9) is fixed to the outside of the steel tank. The cooling coils in this shield cope with the heat produced in the graphite, boral and lead by the slowing down and absorption of neutrons and gamma radiation. Approximately ¾in. of lead (2:10) is poured between the graphite and boral to improve heat conduction by providing a metallic bond.

Finally, outside the lead gamma shield, a further shield of heavy concrete 5ft. thick (2:11) is erected in order to reduce the radiation intensity to about 1/10th tolerance on the outside surface.

Radiation shielding at the top of the reactor is provided by the shields (2:12), (2:13) and (2:14).

A helium atmosphere is maintained over the top of the heavy water and in the graphite space. It is necessary to use such an inert substance because irradiated air-water mixtures form nitric acid, which would corrode the aluminium tank.

Horizontal and vertical experimental facili-



1 ..... ALUMINIUM TANK
2 ..... FUEL ELEMENT
3 ..... HEADER PLATE
4 ..... D_2O OVERFLOW PIPE
5 ..... GRAPHITE REFLECTOR
6 ..... BORAL ABSORBER
7 ..... STEEL TANK
9 ..... 4" LEAD SHIELD
10 ..... LEAD THERMAL BOND
11 ..... CONCRETE SHIELD
15 ..... 2" x 4" HORIZONTAL FACILITY

16 ..... 4" HORIZONTAL FACILITY
17 ..... 6" HORIZONTAL FACILITY
18 ..... 10" HORIZONTAL FACILITY
20 ..... 2" VERTICAL FACILITY
21 ..... 4" VERTICAL FACILITY
22 ..... 6" VERTICAL FACILITY
23 ..... 10" VERTICAL FACILITY
24 ..... THERMAL COLUMN
25 ..... COARSE CONTROL ARM
26 ..... FINE CONTROL ROD
27 ..... SAFETY ROD

FIGURE 2:—Part section plan of reactor core.

ties (15-23 in Figures 1 and 2) consist of aluminium tubes of various sizes into which the materials to be irradiated can be inserted. A graphite thermal column (1:24) provides a flux of slow neutrons in the horizontal holes that penetrate it.

Control of the reactor is achieved by means of six cadmium "signal" arms (2:25) that move vertically between the elements (coarse control), together with one fine control rod (1:26). Two safety rods (1:27) are arranged to drop vertically into the reactor in case of an emergency.

COOLING WATER CIRCUITS

Heavy water circuit

The arrangement adopted for removing the 10MW of heat generated at maximum flux is shown diagrammatically in Figures 3 and 4. The moderator heavy water, operating between maximum temperature limits of about 44°C. and 51°C., is circulated in a closed circuit through the 7in. diameter pipes (3:4) (Figure 3), the pumps (3:7), the heat exchangers (3:6) and the fuel elements (3:2). Two of the three pumps and two of the three heat exchangers will cope with the heat load, so that one unit in each case is spare.

Should one of the pumps fail, the control arms are lowered rapidly to reduce the operating level (if the standby pump is not started after a given period). If both stop, as in a failure of mains power, the reactor is shut down automatically but, because a considerable amount of heat is still being generated by the fission products, continued circulation of the water is necessary. This is achieved by the immediate starting-up of one of the emergency pumps (3:8), operating from a "guaranteed" power supply, the arrangement of which will be described later. If this pump fails, the second is arranged to start, and in the remote contingency of this second pump failing, one of the main pumps can be brought back into operation from a diesel power supply, which will start automatically upon failure of mains power.

Figure 6 shows the rate of fission product heat release plotted against minutes after shutdown, following operation at 10MW for 30 days.

Apart from the ability to close the reactor down rapidly by means of control arms and safety rods, a further emergency shut-down facility exists. The valve (3:11) (Figure 3) can be opened quickly to dump the top 2ft. of the reactor heavy water into the partial dump tank (3:10). This reduces the thickness of the top reflector, thereby allowing sufficient neutrons to escape to prevent the further operation of

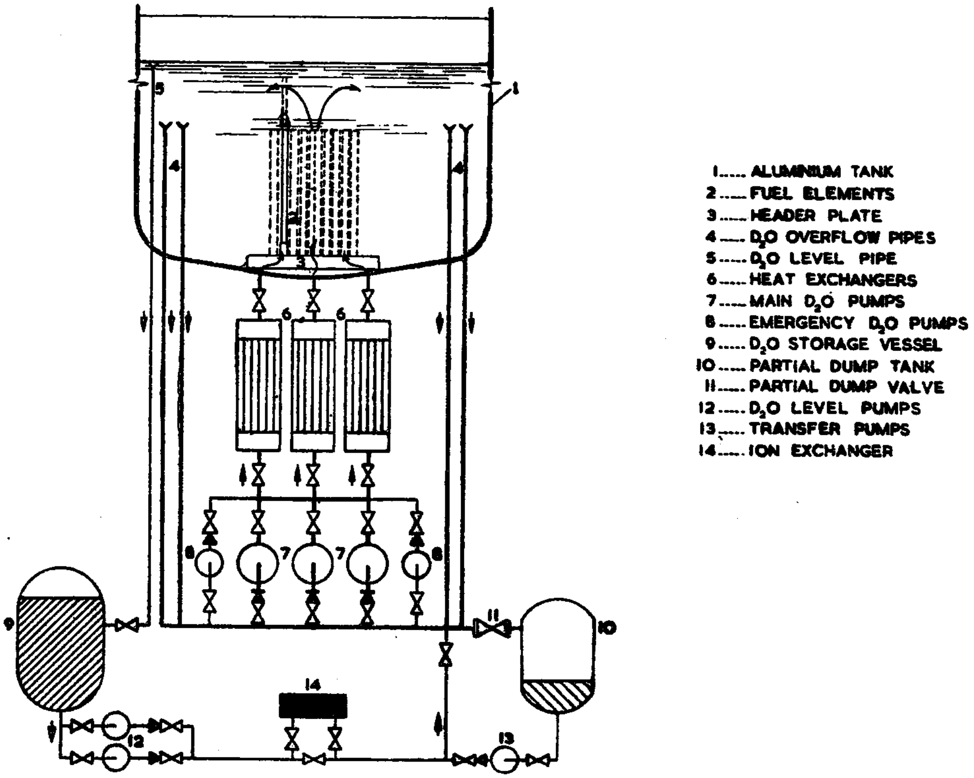


FIGURE 3:—Basic D_2O circuit.

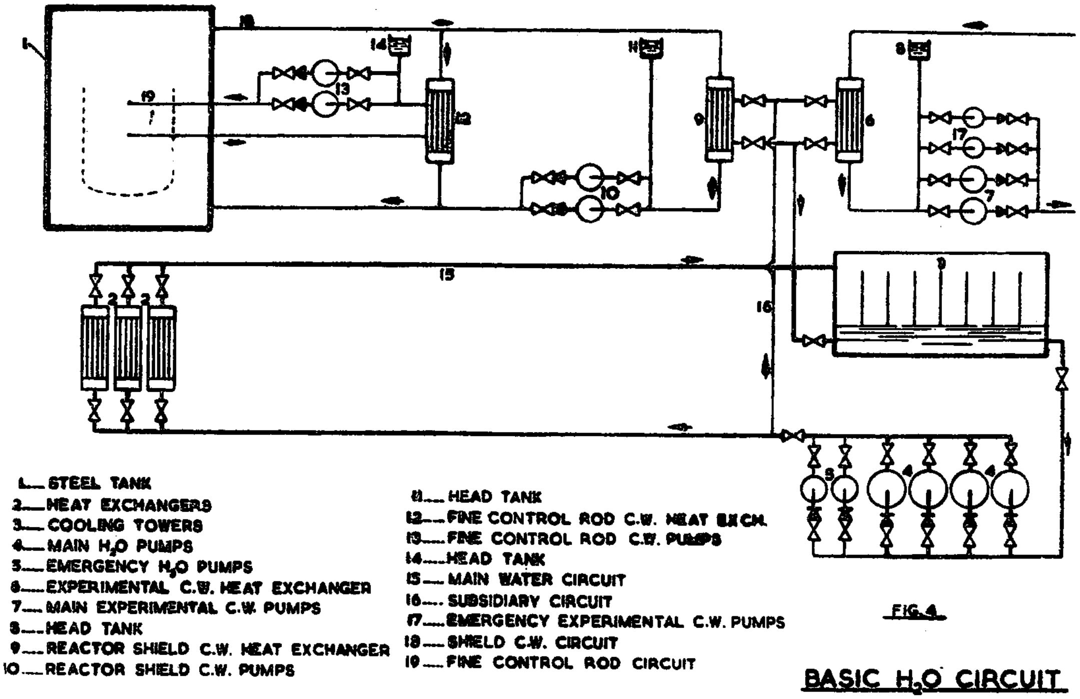


FIGURE 4:—Basic H_2O circuit.

the reactor. Heavy water leaking past the valve (3:11) during normal operation is returned to the system by the transfer pump (3:13).

In order to keep the heavy water at a constant level in the reactor, one of the level pumps (3:12) continually circulates a few gallons per minute through the pipe (3:5) and storage vessel (3:9) into the main suction header. Failure of this pump automatically starts the second pump, and failure of the latter shuts down the reactor.

The ion exchanger (3:14), arranged on a by-pass circuit, removes all impurities from the heavy water, including nitric acid arising from the irradiation of the small traces of nitrogen present. It does not, however, remove ordinary water.

The whole of the heavy water circuit outside the aluminium tank, including pipes, valves, vessels and pumps is constructed from stainless steel to reduce corrosion to a minimum. This is important, because irradiated corrosion products raise the general level of activity in the water circuits.

Moreover, to minimise the parasitic absorption of neutrons by impurities and to avoid the preferential corrosion of aluminium by the presence of such elements as copper, all surfaces wetted by the heavy water were subject to stringent cleaning procedures, and considerable care had to be exercised during construction to prevent contamination.

All welds in this circuit were radiographed to ensure that leakage of the expensive heavy water could not occur at these locations. Detectors have been fitted at all the flanged joints to give warning in the control room of heavy water leaks.

Light water circuit

The light (or ordinary) water circuits are shown diagrammatically in Figure 4. Heat brought to the heat exchangers (4:2) by the heavy water is passed on to a circuit (4:15) containing light water circulated by the pumps (4:4) to the cooling towers (4:3). These towers are designed to remove the whole of the 10MW of heat generated in the reactor, and require at this load a make-up of about 80,000 gallons per day.

Only three of the pumps (4:4) are required at maximum load. Failure of one pump runs in the control arms if the standby pump has not been started after a certain time. Failure of all three (e.g. mains failure) causes one of the two emergency pumps (4:5) to start from the guaranteed power supply. Each of the emergency pumps is large enough to remove shut-down fission product heat.

A subsidiary circuit (4:16) circulates cooling water to the two heat exchangers (4:6) and (4:9). The former extracts up to 500kW of heat from a system provided for the cooling of experiments associated with the reactor. Demineralised water is pumped through this system by one of the pumps (4:7), failure of which starts the second pump. Should the latter also fail, the reactor shuts down, and one of the emergency pumps (4:17) is automatically brought into operation from the guaranteed power supply.

The exchanger (4:9) and pumps (4:10) provide cooling for the lead gamma shield around the steel tank (referred to under "Basic design") and for a fine control rod cooling system (4:19).

The pipework of the circuits (4:15) and (4:16) is of mild steel, while that of the experimental and fine control rod circuits is of stainless steel because this water would become active from irradiation of the products of corrosion.

HELIUM CIRCUITS

As mentioned under "Basic design," a helium atmosphere is maintained over the top of the heavy water and graphite space in order to prevent the accumulation of nitric acid from irradiated nitrogen, and to avoid difficulties arising from the activation of atmospheric argon.

The arrangement of pipes and vessels may be conveniently divided into three sections.—

(i) the main expansion and displacement circuit associated with the reactor core itself,
(ii) the helium purification circuit, and
(iii) the graphite space expansion and displacement circuit.

Because the heavy water storage tank (3:9) and the partial dump tank (3:10) are connected to the reactor aluminium tank through the heavy water circuit, the air in these vessels is replaced with helium.

The pressure in the main circuit, consisting of the reactor, partial dump tank, storage tank and an expansion vessel, is maintained by a gasholder at 6in. water gauge to prevent the inward leakage of air. The expansion vessel provides sufficient volume to keep the helium pressure below 32lb./sq.in. in the event of a reactor power excursion. To prevent the gasholder from being subjected to a pressure which might damage it (e.g., during a reactor excursion), two automatic valves are set to close at 12in. water gauge.

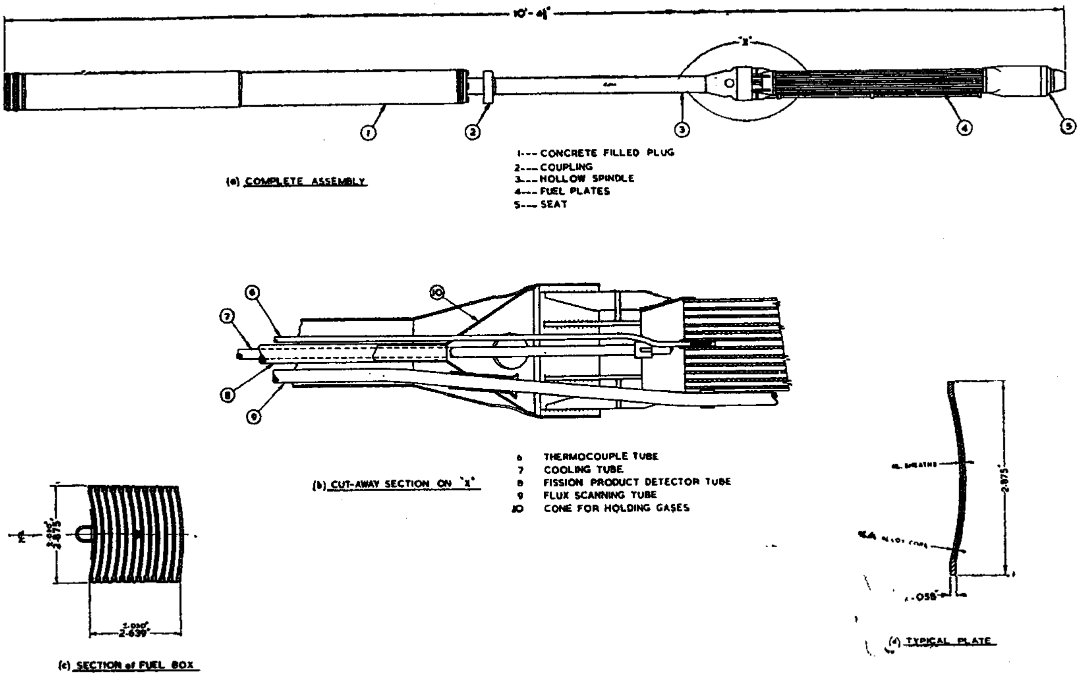
The helium purification unit has two functions:—

(i) to recombine any oxygen and deuterium that becomes dissociated due to the irradiation of the heavy water in the reactor, and
(ii) to remove gaseous impurities and heavy water vapour which collects during operation in a drier-adsorber unit.

The recombination unit operates whenever the reactor is operating, although it is customary to run the adsorber when the reactor is shut down. This latter apparatus first condenses the heavy water vapour content of the helium in a freezer, and then adsorbs the gaseous impurities by allowing the helium to pass over an activated carbon bed cooled with liquid nitrogen.

The graphite space is pressurised with helium from a separate gasholder. There is, of course, no need for the presence of an elaborate purification apparatus in this circuit.

All piping and vessels in the helium circuits are constructed from stainless steel, and the same stringent cleaning procedures as for the heavy water circuits were adopted during construction to prevent contamination.



(a) COMPLETE ASSEMBLY

(b) CUT-AWAY SECTION ON "X"

(c) SECTION of FUEL BOX

(d) TYPICAL PLATE

FIGURE 5:—Fuel element.

REACTOR SHIELD AND REFLECTOR

Shielding

The shielding of a reactor is substantially determined by the nature of the gamma and neutron flux. In general, heavy substances prove to be good gamma shields, and light substances good neutron shields. An all-round material suitable for both purposes is ordinary concrete. However, although this provides perhaps the cheapest form of shield, it has proved more economic to surround the reactor with more expensive denser concretes, because this decreases the thickness required and reduces the diameter of the surrounding building for a given clearance between it and the reactor face.

Two types of concrete were used—one in which the aggregate of ordinary concrete is replaced with barytes and the other in which the aggregate is replaced with steel shot. Approximately, the thickness of a gamma shield for the kinds of reactor gamma energies expected is inversely proportional to the density and the densities of these two concretes are:—

Barytes concrete—3.5.
Steel shot concrete—5.6.
(Ordinary concrete—2.4.)

Proceeding from the reactor core outwards in a radial direction, the reflecting and shielding arrangements consist of (Figures 1 and 2):—

Heavy water—24in.
Graphite—24in.
Lead—¾in.
Boral—¼in.
Steel—½in.
Lead—4in.
Steel—½in.
Steel shot concrete—18in.
Barytes concrete—42in.
Steel—½in.

This combination of materials results in a radiation tolerance on the outer face of the reactor of about 1/10 of the maximum permissible level. This produces a suitable background for both personnel and instrumentation.

A slightly different scheme holds above the reactor core. No graphite reflector is used. A layer of cadmium inside the bottom of the aluminium tank top shield (1:12) and the bottom annular shield (1:13) is followed by 4in. lead and then steel shot concrete only.

The cadmium is used as an absorber of neutrons in preference to boral beneath the aluminium tank shield, because it was felt that the neutron flux density was sufficiently high to make the rate of production of helium from the B (n, α) Li reaction a significant factor in the disintegration of the boral. The 14in. thick mild steel reactor top plate (1:29) completes the vertical shielding arrangements.

Graphite reflector

The graphite reflector around and under the aluminium tank was built up from over 800 separate blocks, each machined to close tolerances to ensure correct fitting around the network of experimental facilities that penetrate the graphite.

Particular care had to be taken with the bottom layer to ensure that irregularities of the bottom of the steel tank, upon which this layer sat, were not transferred upward. Accurate measurements of the contour of the tank bottom were therefore made, and the amount and angle of cut on each block determined to ensure that the tops of the blocks all lay in a horizontal plane.

During stacking of the graphite, considerable care was exercised to keep it as clean as possible, because extraneous material absorbs neutrons, and this is obviously not desirous at this location. In particular, boron from welding fluxes could become an embarrassment. A canopy was accordingly erected above the reactor space and personnel working inside the steel tank provided with special clothing.

Graphite block clearances in the vicinity of the core had to be suitably proportioned to allow for Wigner growth, i.e., increase in the volume of the graphite due to fast neutron bombardment.

EXPERIMENTAL FACILITIES

General

The facilities provided in the reactor for the irradiation of materials consist for the most part of blind-ended vertical and horizontal hollow tubes with internal diameters varying from 2in. to 10in. (Figures 1 and 2), into which the experiments are placed.

These facilities may be grouped conveniently as follow:

Thus some 58 holes (28 vertical) are available for experimental purposes.

An idea of the variation of neutron flux can be obtained from Figures 7 and 8. These show the approximate estimated thermal and fast distribution over one vertical plane through the centre of the reactor. The distribution over any other vertical plane through the centre will be substantially the same.

Construction of facilities

The method of construction of an experimental facility is illustrated by Figure 9, which shows a typical cross-section suitable for a

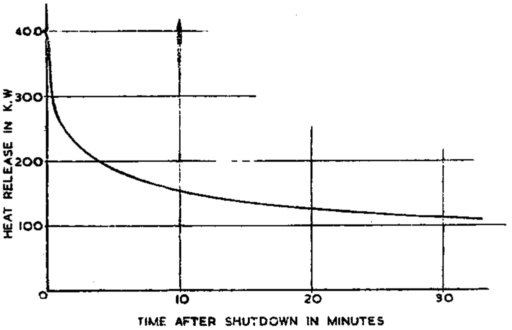


FIGURE 6:—Approximate fission product heat release rates after operation at 10 MW for 30 days.

		Max. Thermal Flux n/sq. cm/sec (x 10^{14})	Max. Fast Flux n/sq. cm/sec (x 10^{14})
1. PENETRATING D_2O			
Vertical—	2in. dia. holes (9 off)	0.6—0.8	0.1—0.5
	4in. dia. holes (5 off)	0.3	0.01
	6in. dia. holes (4 off)	0.7	0.2
Horizontal—	3.35in. by 0.85in. hole (1 off) (passes completely through reactor)	0.9	0.4
	4in. dia. holes (6 off)	0.5—0.8	0.03—0.4
	6in. dia. holes (1 off)	0.8	0.6
	10in. dia. holes (1 off)	0.7	0.2
2. PENETRATING GRAPHITE ONLY			
Vertical—	4in. dia. holes (2 off)	0.03	0.0002
	6in. dia. holes (6 off)	0.03	0.0002
	10in. dia. holes (2 off)	0.03	0.0002
Horizontal—	6in. dia. holes (10 off)	0.09—0.1	(0.007-
	12in. by 8in. holes (2 off)	0.07	(0.002
	(pass from one side to other underneath steel tank)		0.002
3. THERMAL COLUMN			
Horizontal—	4in. by 4in. holes (9 off)	0.0007	0.00004

horizontal hole such as (2:17).

An aluminium thimble (9:14) is clamped against the end (9:6) of the fixed liner (9:4) by means of the bayonet fitting (9:8). The experiment to be irradiated is placed in this thimble, which is made removable to cope with accidental contamination of its interior.

To protect personnel from radiation, a concrete and iron plug (9:15) is inserted in the liner (9:4), a gas-tight joint being then made by the ring (9:20) and the plate (9:19)). The end of the plug is fitted with a boral plate (9:16), which acts as an absorber of thermal neutrons.

A thermocouple tube (9.22) is provided for temperature measurement of the inner end of the plug, and cooling water pipes (9:23) are included to maintain this liner end at any desired temperature.

Air can be purged from the facility through the line (9:21), which is connected to the reactor building extract ventilation system, and carbon dioxide may be introduced through a similar connection. The formation of radioactive argon and nitric acid from irradiated nitrogen can thus be kept to a minimum.

The thermal column, shown in Figures 1 and 2, supplies a comparatively weak source of thermal neutrons for special experiments. It consists of stacked graphite blocks penetrated by nine 4in. by 4in. holes, shielding being provided by a composite door formed from lead, steel and a hydrogenous material, "jabroc." The metal casing of the column is lined with boral sheeting to absorb escaping neutrons, and cooling coils are provided in the adjacent concrete of the biological shield to remove any heat generated.

Experimental handling

Experiments are introduced into or withdrawn from the reactor when the latter is shut down. Nevertheless, there may still be, even under these conditions, considerable fission product gamma radiation that must be allowed for when the shielding plug is removed from an experimental facility. Moreover, an irradiated experiment may itself possess considerable gamma activity.

A method of removing experiments from horizontal facilities is shown diagrammatically in Figure 10. A 20-ton cast-iron hollow flask (10:6) (whose walls may be up to about 20in. thick) contains an electromagnet (10:7) which may be moved along the hollow barrel by the screws (10:12) operated through gearing from the hand-wheel (10:10). Two gear ratios are available by sliding the hand-wheel spindle in a longitudinal direction.

The flask has a removable section (10:5) in which slides a lead door (10:4). When an experiment and its plug are to be removed, the flask is offered up to the outer face of the reactor, the door (10:4) and door (4a) in the flask body itself are raised, and the plug and experiment withdrawn into the barrel by means of the electromagnet. The lead doors are then lowered to cover the face of the facility, the removable section (10:5) is detached from the flask and left on the face of the reactor, while the flask and contents are transferred to a shielded storage block, where the experiment and plug are left until suitable arrangements have been set up to work on them.

The reverse procedure is adopted when replacing the plug.

For vertical facilities, a similar arrangement

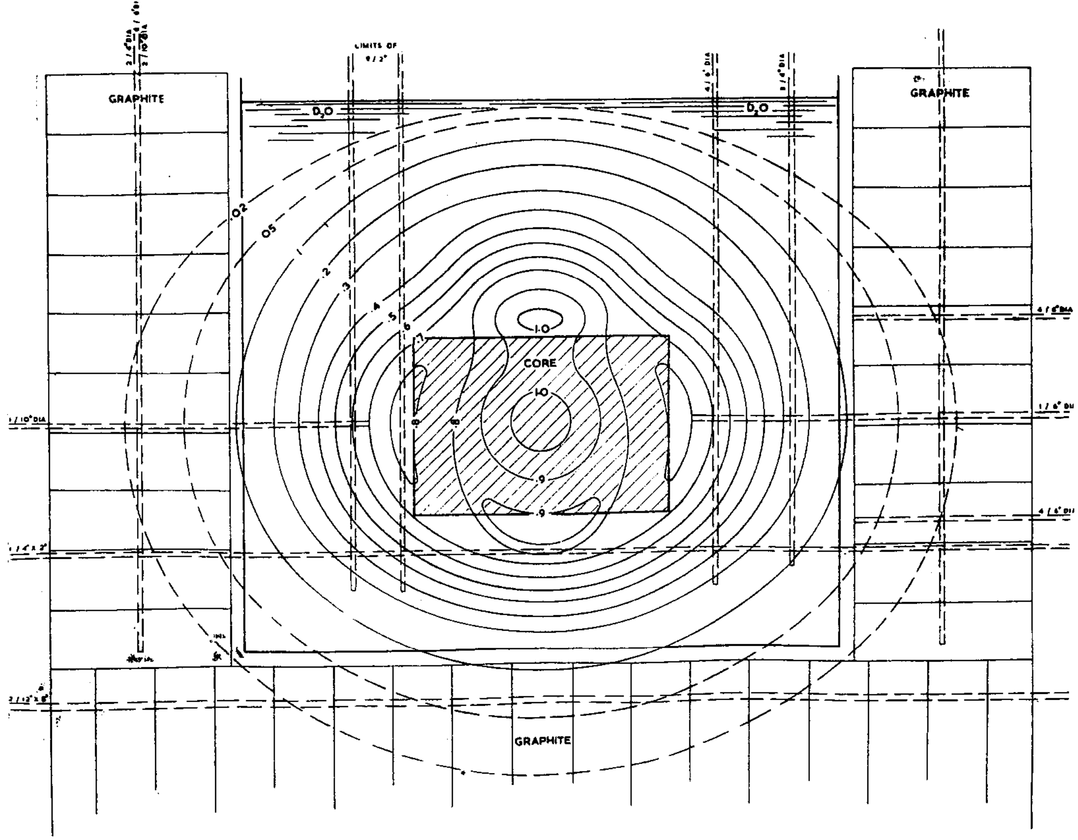


FIGURE 7:—Approximate estimated undisturbed thermal neutron distribution over a vertical plane through centre of reactor (neutrons/sq.cm/sec. x 10^{14}).

is adopted, except that the electromagnet is replaced with a hook or eye-bolt.

FUEL ELEMENTS

The general design of the fuel elements is shown in Figure 5. The complete assembly (Figure 5a) is some 10ft. 4⅝in. long, and consists of a stainless steel tubular shielding plug fitted with steel shot concrete (5:1), joined at the coupling (5:2) to a hollow aluminium tube (5:3). This aluminium tube forms a welded unit with the fuel element proper (5:4) and the seat (5:5).

The active section (5:4) is built up from 10 plates (Figure 5d) into the form of a box (Figure 5c), the gaps between the plates being used as passages for the circulation of heavy water and consequent heat removal, as described earlier. Each plate contains approximately 10 grams of enriched uranium in the form of UAl_4 in a matrix of aluminium. This alloy is "canned" between two aluminium plates to prevent contamination of the heavy water by fission products. The plates in each box are all slightly curved in the one direction to prevent any significant irregularities of the gap between plates arising from expansion or contraction of the metal.

Four tubes are brought from the top of the shield plug down to the fuel element proper. One contains a thermocouple lead (5:6) to measure the temperature of the fuel plates. Another (5:7) is a special cooling tube, through which heavy water may be sprayed over the fuel plates should the element during removal from the reactor become stuck in a location where there is no alternative method of removing fission product heat—a condition which could result in melting of the fuel plates.

A third tube (5:8) is connected to the top of a cone (5:10) which is located just above the heavy water level. Gaseous fission products tend to collect in the cone, and samples may be taken through (5:8) for analysis. Finally, the tube (5:9) is arranged to pass through the cone, and is fastened to the outside of the fuel element box. It contains leads from a neutron flux measuring device attached to the fuel element.

CONTROL AND INSTRUMENTATION

A description of the reactor control and instrumentation will not be given here, because it forms the subject of another paper being presented at this symposium by Mr. G. Page.

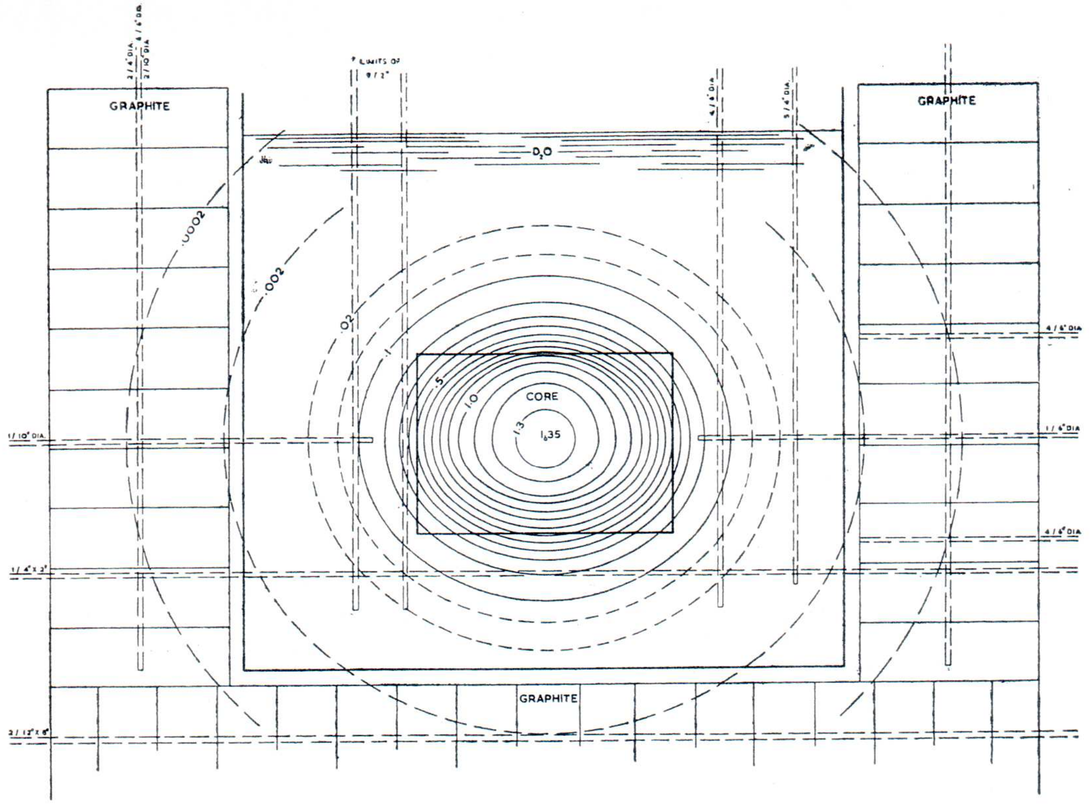
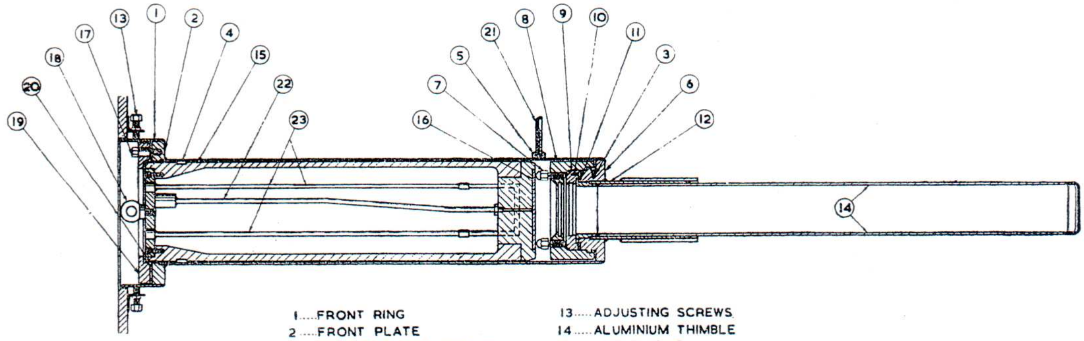


FIGURE 8 (above):—Approximate estimated undisturbed FAST neutron distribution over a vertical plane through centre of reactor (neutrons/sq. cm/sec. × 10^{14}).

FIGURE 9 below):—Typical horizontal experimental facility.



1.....FRONT RING
2.....FRONT PLATE
3.....STOP SECURING SCREWS
4.....PLUG LINER
5.....PURGING LINE CONNECTION
6.....MALE BAYONET
7.....CLAMPING SET SCREWS
8.....FEMALE BAYONET
9.....THIMBLE LOCATING RING
10.....THIMBLE SECURING SCREWS
11.....THIMBLE SECURING RING
12.....THIMBLE LINER
13.....ADJUSTING SCREWS
14.....ALUMINIUM THIMBLE
15.....SHIELD PLUG
16.....BORAL PLATE
17.....OUTER SEALING PLATE SCREWS
18.....EYE BOLT
19.....OUTER SEALING PLATE
20.....SEALING RING
21.....PURGING LINE
22.....THERMOCOUPLE TUBE
23.....COOLING WATER TUBES

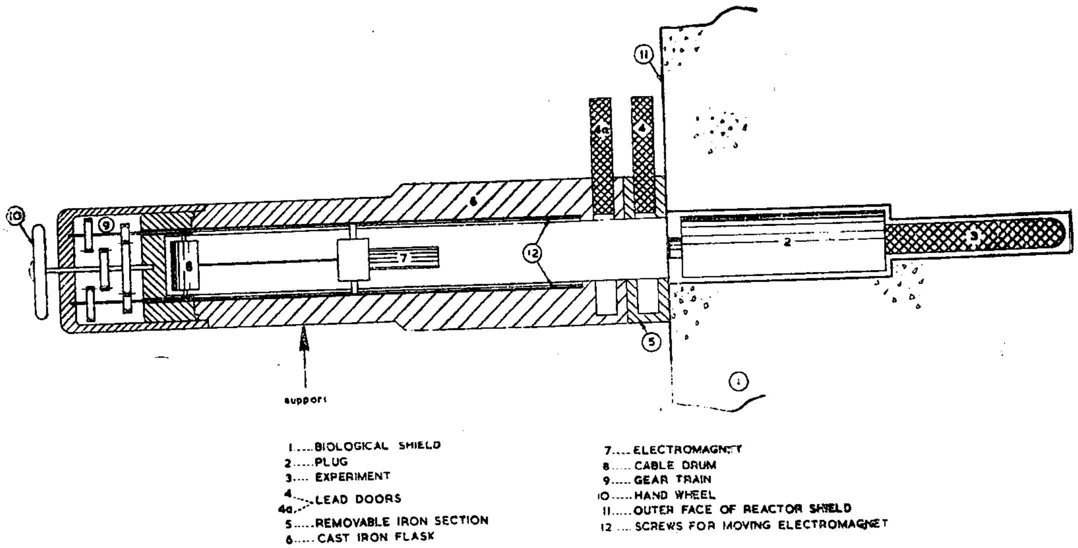


FIGURE 10:—Handling of horizontal experiments—diagrammatic arrangement.

REACTOR BUILDING

Structure

It was decided to house the reactor in the same type of structure as was used for DIDO—a cylindrical steel building 70ft. in diameter and 70 ft. high, completely sealed from the outside except for three personnel and one vehicle access locks. The object of this arrangement is to contain any radioactive gases or particles that might accidentally escape from the reactor or its experimental rigs.

Figure 12 shows an east-west diagrammatic vertical section through the building. Ten sets of columns (12:10) form, together with a continuously welded internal steel shell (12:14) a structure of sufficient strength to withstand the load from a 20-ton circular crane (12:9) and the internal-external pressure differential due to barometric variations or accidental gas release.

The shell itself consists of specially selected mild steel plates varying in thickness from 13/16in. at the bottom to 9/16in. at the top. The plates were butt-welded, and all welds radiographed. In order to prevent gases from passing through the concrete floor of the building a continuous steel diaphragm (12:15) was embedded in the concrete and welded to the main shell.

The capacity of the 20-ton circular crane was decided by the weight of the container ("flask") into which the spent fuel elements are withdrawn from the reactor. Because the elements are highly radio-active, heavy shielding is needed around the flask.

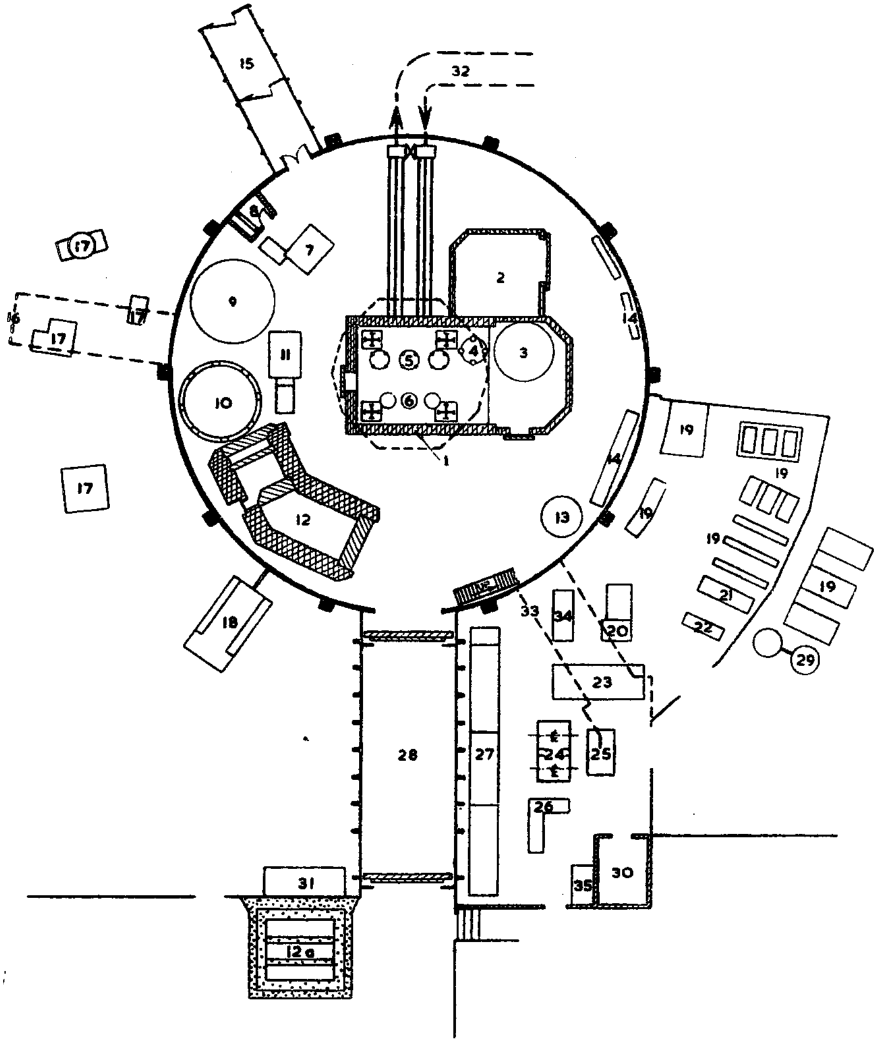
The reactor stands in the pit (12:2), which is of sufficient capacity to hold the whole of the heavy water in the event of a major leak from the reactor or its piping and vessels. In order also to prevent the water in such an event from soaking into the concrete, probably taking with it radio-active material, which might require the removal of the concrete to reduce the radio-activity to acceptable levels, the floor and walls of the pit were sprayed with liquid envelope (p.v.c.) to a thickness of 0.015in.-0.030in. In fact, all concrete at or about ground floor level has been covered with the same material, which can be readily stripped off if necessary.

Reference to Figure 11 shows that the pit and some of the adjacent space have been surrounded with steel shot concrete walls. These are 9in. to 18in. thick, and enclose the whole of the heavy water circuits and equipment. Such shielding is mainly necessary because of the hard gamma radiation (6.1 MeV) produced from the disintegration of radio-active N^{16} formed during operation. However, because this has a half life of only 7.3 secs., it is possible to enter the space a short time after reactor shut-down without undue hazard.

The exterior of the building was painted with a special type of white paint capable of reflecting 80 per cent. to 90 per cent. of incident solar energy of all wavelengths. The heat flow into the building (or from the building in cold weather) is also reduced by a layer of poly-urethane 2in. thick glued to the inside of the shell and protected from mechanical damage by an outer covering of tempered hardboard. Joints between the hardboard were covered with a standard type of expansion tape and the whole of the surface was sprayed with liquid envelope, which can be stripped off if required.

The operating floor (12:16) is 15ft. above ground level, and upon this will be collected most or all of the experimental equipment. The control room (12:8) is situated also at this level.

As mentioned above, there are four locks through which access can be obtained to the building. One of these permits the entry of vehicles, and consists merely of a tunnel with



1----SHOT CONCRETEWALLS OF D_2O PLANT ROOM
2----EXPERIMENTAL PLANT ROOM
3-----D_2O STORAGE VESSEL
4-----PARTIAL DUMP TANK
5----HEAT EXCHANGERS
6----MAIN D_2O PUMPS
7----He ABSORBER UNIT
8-----STORE ETC.
9----He EXPANSION VESSEL
10-----He GASHOLDER
11----He FANS
12-----FUEL ELEMENT STORAGE BLOCK No. 1
12a---FUEL ELEMENT STORAGE BLOCK No. 2
13-----He GASHOLDER FOR GRAPHITE SPACE
14-----SWITCHBOARDS
15-----EMERGENCY LOCK
16-----PERSONNEL LOCK (at 15' level)
17 ...EXTRACT VENTILATION EQUIPMENT
18.....STORAGE BLOCK No. 1 HEAT EXCHANGERS
19.....INLET VENTILATION EQUIPMENT
20.....MERCURY ARC RECTIFIER
21.....MAIN AIR COMPRESSORS
22.....INSTRUMENT AIR COMPRESSORS
23.....STAND-BY DIESEL GENERATOR
24-----MOTOR GENERATOR SETS
25.....SWITCHBOARD
26.....EQUIPMENT FOR OPERATING VEHICLE LOCK DOOR
27.....MAIN ELECTRIC SWITCHBOARDS
28.....VEHICLE LOCK
29.....AIR RECEIVERS
30.....BATTERY ROOM
31.....FANS FOR STORAGE BLOCK No. 2
32.....LIGHT WATER COOLING PIPES
33.....PERSONNEL LOCK (at 12' level)
34.....D.C. SWITCHBOARD
35.....SELENIUM RECTIFIER

FIGURE 11:—Ground floor plan of reactor equipment.

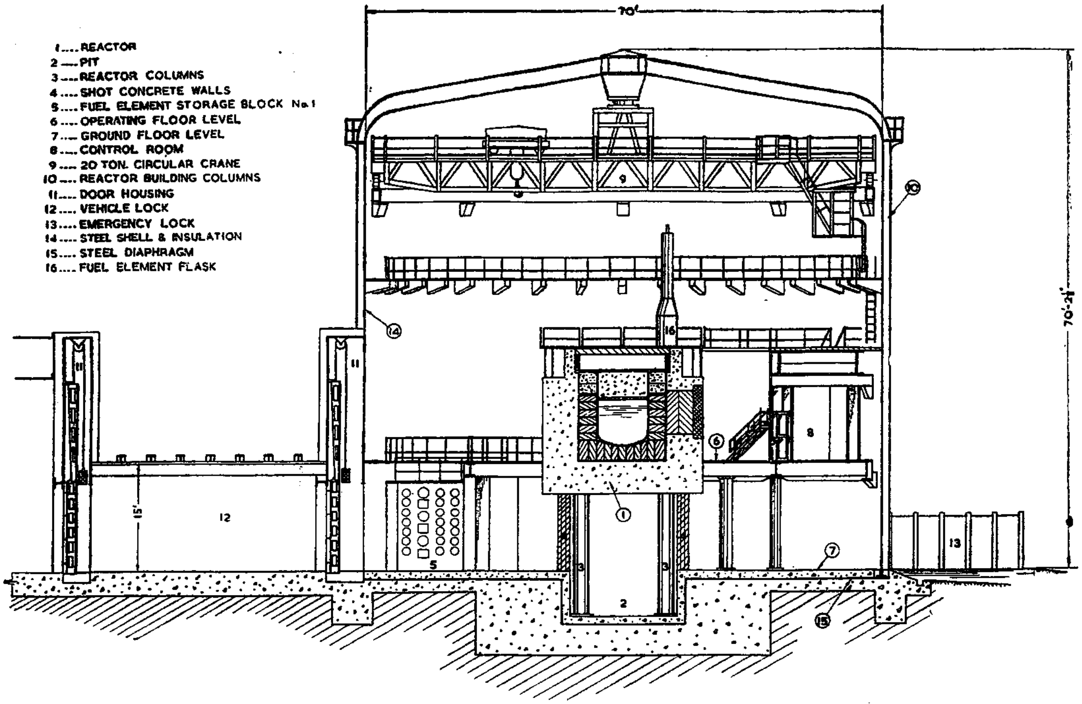


FIGURE 12:—East-west section through reactor building.

a power-operated vertically sliding door at each end.

The three personnel locks (see Figure 11) have a similar arrangement, except that the doors are operated by hand.

VENTILATION

Normal air conditioning and ventilation of the reactor building (Figure 13) is by a conditioned air supply from the conditioners (13:7). It is delivered to the building at the rate of about 4,500 cu.ft. per minute, and removed from various locations by one of the fans (13:22).

There are, in addition, six space conditioners evenly spaced around the circumference of the building. These automatically remove or supply heat, depending on external weather conditions and the amount of heat radiated from the reactor and experimental equipment.

The "water seals" (13:1) and (13:2) are merely vertical U-bends in the air ducting and, of course, normally do not contain water. In the event of an incident necessitating temporary evacuation of the building, these U-bends are flooded by means of a push-button in the control room, and thus prevent escape of gases through the ventilation system should the pressure in the building rise above atmospheric. The dampers (13:9) and (13:10) back up these seals and are operated remotely, but this aspect will be discussed under "Emergency Control Room."

A separate "cleansing system" has also been provided for removing gaseous and solid impurities from the building atmosphere, should this ever become necessary. It does not normally operate, the dampers (13:11) and (13:12) being usually closed and the seals (13:3) flooded. When required, air is drawn through the damper (13:12) and the water scrubber (13:27) (in which the impurities are removed) and returned to the building through the damper (13:11). If expedient, air can be discharged to atmosphere through the filters (13:20a) and fan (13:25).

ELECTRICITY SUPPLY

Supply of electricity to the reactor is complicated by the fact that a continuous supply must be provided to certain apparatus at all times. For example, emergency heavy and light water cooling pumps, reactor liquid level pumps, control room services, emergency lights, and some experiments require a guaranteed source of power.

The arrangement adopted is shown diagrammatically in Figure 14. This is basically the same as the DIDO system, although there is some difference in detail.

Duplicate 415V feeders from the reactor substation are brought to one of three interconnected switchboards in the auxiliary plant room (11:27).

Number 2 Board (in Figure 14) is concerned exclusively with the provision of a guaranteed supply, and normally operates with the circuit breaker C/B 2 closed and C/B 3 open, thus deriving the power from one of the substation feeders. Under these conditions, one of the

(iv) remove heat at a suitable rate to prevent a build-up of pressure inside the reactor building, and

(v) provide some means of cleansing the building air from outside the building.

When evacuation of the building is necessary, the "Scram" button is pressed in the control room. This button operates circuits which—

(i) run in the fine and coarse control arms and drop the safety rods, and

(ii) flood the ventilation building seals by operating D.C. driven flooding pumps, and stop the input and extract ventilation fans.

The first shuts the reactor down and the second ensures that gas escape to the outside atmosphere is prevented.

Certain of the reactor operating staff proceed to an emergency control room, which is a shielded compartment located near the reactor building, and from which the air-tight dampers (13:9) and (13:10) may be operated remotely.

The building is now completely sealed off, and the state of all ventilating equipment can be determined from a recording panel in the emergency control room. Here also are located instruments indicating the reactor building air pressure and level of heavy water in the reactor, and a diagram similar to Figure 14, showing the relationships of the various power circuits.

Power supply to the building is complicated by the fact that it may be necessary to isolate some circuits, but at the same time provide a guaranteed supply to cooling water pumps in order to remove reactor fission product heat irrespective of whether mains power is available or not.

As a result of this, it was found that some circuit-breakers must be remotely controlled from the emergency control room, because there is a possibility of gamma radiation from the reactor building, rendering uninhabitable the plant room which contains the main switchboards (Figure 11).

The removal of heat at a suitable rate to prevent an unduly high pressure in the reactor building, is expected to be met by the operation of the six space conditioners referred to earlier, because these are very conservatively rated for normal operation.

At a convenient time after the incident, the ventilation cleansing system (Figure 13) briefly described earlier can be operated to remove suspended matter, active or otherwise, from the building atmosphere. When tests indicate that the activity in the building has been reduced to a suitably low level, the air can be discharged to atmosphere through the filters (13:12a) and (13:20a) and the fan (13:25). When the internal pressure falls to approximately atmospheric pressure, the input system can be started and the building slowly purged.

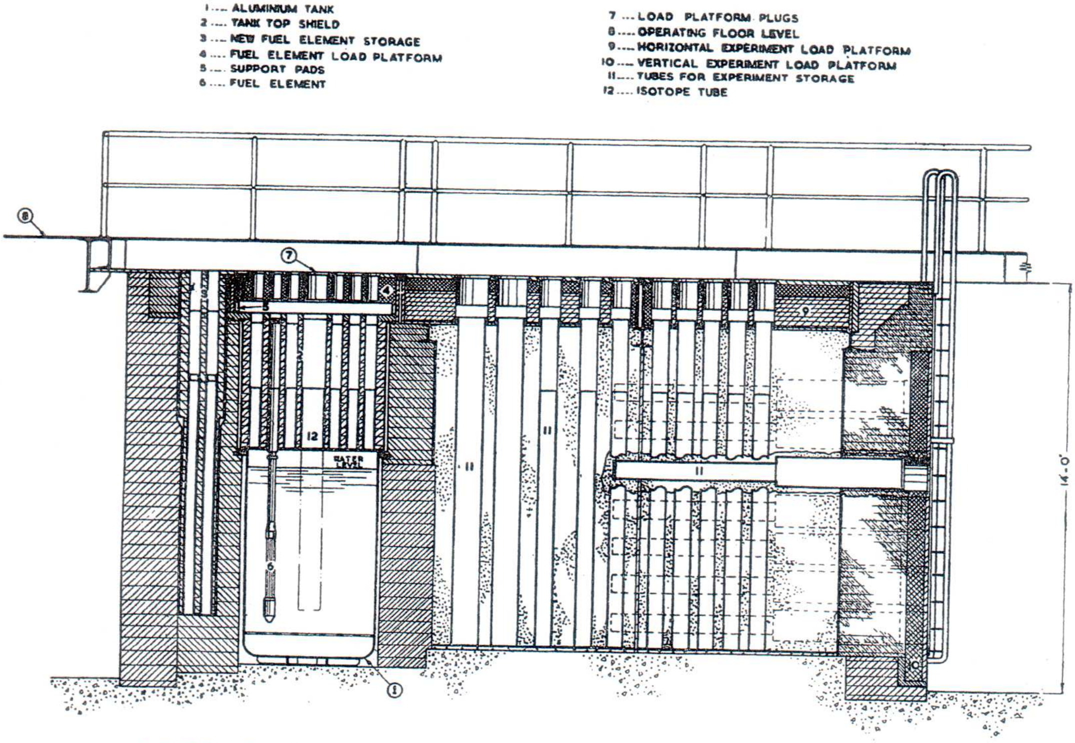


FIGURE 15:—Diagrammatic vertical section through storage block No. 1.

FINAL REMARKS

The author has endeavoured to keep this description of HIFAR within reasonable limits but, unfortunately, quite a large amount of interesting detail has had to be omitted.

It is hoped, however, that sufficient information has been presented to give a clear picture of the reactor.

ACKNOWLEDGEMENTS

This reactor could not have been built without the willing co-operation of the United Kingdom Atomic Energy Authority, and the British Ministry of Works and their various sub-contractors.

The author, who was intimately connected with the project, would like to express his appreciation of the way in which the personnel of these organisations assisted the Commission's officers in bringing the project to a successful conclusion.

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APPENDIX

SOME REACTOR DATA

STEEL BUILDING HOUSING REACTOR

Diameter	— 70ft.
Height	— 70ft.
M.S. plate	— 9/16in. to 13/16in.
No. Personnel locks	— 3
No. vehicle locks	— 1
Operating floor level above ground	— 15ft.
Mass concrete in foundations	— Approx. 3,000 tons.

REACTOR DIMENSIONS AND WEIGHTS

Outside "diameter"	— approx. 22ft.
Thickness concrete shield	— 5ft.
Material shield	
(a) Barytes concrete	— 500 tons
(b) Shot concrete	— 100 tons
Height reactor proper	— 21ft.
Height reactor top above ground	— 36ft. 6in.
Total weight reactor on its 4 columns	— 1,400 tons
Weight steel tank	— 64 tons
Size steel tank	— 13ft. high x 11ft. inside diameter
Size aluminium tank	— 11ft. high x 6ft. 7in. inside diameter.
Total heavy water	— 10 tons
Weight graphite in reflector and thermal column	— 31 tons

REACTOR RATINGS

Maximum heat production	— 10 MW
Maximum thermal flux	— 1 x 10^{14}n/sq cm-sec.
Av. rating U235 in centre fuel element	— 4,800 w/gm.
Total power generated by centre element	— 480 KW
Heavy water temp. into tank	— 44°C
Heavy water temp. out of tank	— 51°C
Heavy water flow rate	— 285,000 gals./hr.
Light water flow rate	— 306,000 gals./hr.
Water evaporated in cooling towers at 10MW	— 80,000 gals./day
Normal rate of power consumption	— 550 KVA

FUEL ELEMENTS

No. elements	— 25
Total weight U235	— 5½lb.
No. plates per element	— 10
Length element proper	— 24in.
Pitch	— 6in.
Rate removal elements at 10MW	— 1/3 total per 2 weeks

CONTROL

No. coarse control arms	— 6
No. fine control rods	— 1
No. safety rods	— 2

EXPERIMENTAL FACILITIES

No. horizontal holes	— 30
No. vertical holes	— 28