RESEARCH REACTOR DHRUVA

By

N. Veeraraghavan
Reactor Operations & Maintenance Group
Bhabha Atomic Research Centre
Trombay, Bombay, India

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ABSTRACT

Dhruva, a 100 MWt research reactor located at the Bhabha Atomic Research Centre, Bombay, attained first criticality during August, 1985. The reactor is fuelled with natural uranium and is cooled, moderated and reflected by heavy water. Maximum thermal neutron flux obtained in the reactor is 1.8×10^{14} n/cm^2/sec. Some of the salient design features of the reactor are discussed in this paper. Some important features of reactor coolant system, regulation and protection systems and experimental facilities have been presented. A short account of the engineered safety features is provided. Some of the problems that were faced during commissioning and initial phase of power operation have also been dealt upon.

1. INTRODUCTION

India's fifth research reactor **DHRUVA** which became critical on August 8, 1985, is a natural uranium fuelled, heavy water moderated and cooled thermal neutron research reactor with an operating power level of 100 MWt and a maximum thermal neutron flux of 1.8×10^{14}n/cm^2/sec. The indigenously designed and built reactor is located at the Bhabha Atomic Research Centre (BARC), Trombay, close to the city of Bombay. A number of Indian industrial firms and BARC, have between them, shouldered the responsibilities of fabricating all the major components of the reactor such as reactor vessel, fuelling machine and heat exchangers. The reactor employs natural metallic uranium seven rod cluster fuel assemblies installed in zircaloy guide tubes in a stainless steel reactor vessel. Heavy water is used as the moderator, reflector and primary coolant and helium is used as cover gas. Reactor power regulation is achieved by moderator level control. Fast shutdown of the reactor is effected by nine cadmium shutoff rods with simultaneous dumping of the heavy water moderator. Heat from the primary coolant is transferred to a closed loop recirculating secondary light water system in a set of heat exchangers. The secondary coolant in turn is cooled by sea water in another set of heat exchangers. The sea water coolant is drawn from the Bombay harbour bay and flows through the heat exchangers on a once-through basis. Salient design data are given in Table I.

2. PLANT LAYOUT

Figure 1 shows the general plant layout. The reactor containment building houses the pile and storage blocks, the fuelling machine and the heavy water primary coolant pumps and heat exchangers. The service building houses the process water (secondary coolant) pumps and heat exchangers, air compressors and normal and emergency power supply equipment and air handling units. An annexe building houses the main control and instrumentation rooms. The spent fuel storage building communicates with the reactor building and houses water-filled trenches and bays for handling and storage of spent fuel. A once-through ventilation system is employed for the reactor building with air-flow maintained from lower to higher radioactive zones, the air being finally exhausted through high efficiency particulate air filters through a high stack.

3. PILE BLOCK

Figure 2 shows a schematic sectional view of the pile block. The reactor has a vertical core housed in a stainless steel vessel (or calandria) which is located inside a concrete vault filled with light water for simplifying the bulk shield design. The reactor vessel is supported at the bottom on a support structure. The vault is lined with stainless steel for providing water leak tightness. Shielding at the top is provided by an annular shield and an end shield assembly. Extension tubes are rolled into the top tube sheet of the reactor vessel and these extend the reactor vessel boundary to the top deck plate. Inside the extension tubes, zircaloy-stainless steel integral guide tubes are placed forming the reactor fuel channels extending from the inlet plenum to the tail pipes in the service space and further on to the top of the deck plate for facilitating fuel installation.

4. FUEL ASSEMBLY

4.1 Figure 3 shows a fuel assembly which consists of three sub-assemblies viz. fuel cluster sub-assembly, shield sub-assembly and seal-and-shield plug sub-assembly. The fuel cluster sub-assembly is about 3 metres in length and forms the bottom portion of the 9.3 metre long fuel assembly. It consists of 7 nos. aluminium cladded uranium fuel rods assembled inside an aluminium flow tube and is located in the zircaloy portion of the guide-tube in the core region of the fuel channel. Aluminium spacers are fixed to the central rod of the fuel cluster and are distributed evenly over the length.

4.2 Towards ensuring that the assembly sits snugly inside the guide tube, a split-bulge is provided at the bottom of the flow-tube. The free diameter of this bulge is slightly more than the inside diameter of the fuel channel at the bottom. However, due to the split type design, the bulge collapses slightly inwards like a leaf-spring during installation and sits without any clearance inside the channel. Another split collar of a slightly different design, is provided at the top of the flow-tube for the same purpose. A solid top bulge, just below the top split-collar is provided for restricting the coolant flow bypassing the fuel rods. The shield sub-assembly and seal-and-shield plug sub-assembly form the extension of the fuel cluster sub-assembly upto the top of the reactor and provide shielding and means for locking the fuel assembly to its channel.

4.3 Refuelling is carried out by a fuelling machine which can move over the top of the pile and storage blocks. The machine has provisions to load and unload fresh and irradiated fuel into and from the core. Heavy water cooling provisions have been made in the machine to provide transit cooling to irradiated fuel assemblies, before they are discharged into the storage block or spent fuel storage bays.

5. NORMAL REACTOR COOLING

The reactor coolant circuit is shown schematically in Fig.4. The heavy water coolant enters through the inlet plenum at the bottom of the reactor vessel and then flows up through the fuel assemblies and exits through the tail pipes at the top of each fuel channel and joins into a common outlet header. From the outlet header the coolant flows through three down comers connected to the suction of three main coolant pumps. Thereon it passes through heat exchangers back to the inlet plenum, thus flowing in a closed loop recirculating circuit. A part of the coolant is diverted for cooling the upper tube sheet of the reactor vessel and other structural components, thence discharged into the moderator and finally joined at the suction of the main coolant pumps via the moderator return flow path. This feature inter-connects the moderator and coolant systems and provides cooling to the moderator also without any need for separate heat exchangers for moderator cooling. Heat transferred to the secondary light water coolant circuit is removed by circulating the secondary water through light water-sea water heat exchangers. Sea water is drawn from the Bombay harbour bay with the help of pumps located in a pump house at the end of a jetty and flows on a once-through basis. Thus the heat generated in the reactor is finally rejected to the sea. The design intent for adopting the intermediate light water circuit was to preclude any possibility of radioactive heavy water release into the sea as well as to ensure a long and reliable service life for the heavy water heat exchangers by preventing direct sea water cooling and consequent corrosion effects.

6. SHUTDOWN COOLING

Adequate provisions have been made in the design to assure uninterrupted fuel cooling to preclude any possibility of damage to the fuel. For the situation of a Class IV mains power supply failure, the reactor is automatically tripped upon loss of power to the main coolant pumps. Large flywheels installed on the main coolant pump shafts ensure a slow flow-coastdown while small auxiliary coolant pumps (operated on Class II power supply and piped in parallel with the main coolant pumps) take over and supply the required coolant flow to the core (Fig. 5). A safety feature of these pumps is the provision of a water-turbine prime-mover on the same shaft (in addition to the electrical motor prime-mover) which ensures uninterrupted operation of the pump even under a power supply black-out situation. The overhead light water storage tank ensures gravity feed of power-water to the water-turbines for several hours even without operator intervention.

7. EMERGENCY CORE COOLING

Because of the inter-connection of the heavy water coolant and moderator systems, the reactor is intrinsicaly safe against a small break loss of coolant accident (LOCA) situation. For example, for a heavy water coolant loss rate as high as 1000 litres per minute, the moderator system can supply the required coolant inventory towards uninterrupted fuel cooling for at least 30 minutes without operator action. Notwithstanding this intrinsic feature, the reactor has been provided with an emergency core cooling system (ECCS) with provisions for detecting the LOCA situation, collecting the leaking heavy water in separate tanks and recirculating the same with ECCS pumps and heat exchangers through the core. Provision also exists for injecting light water into the core through a system of valves and rupture discs, should this highly improbable situation arise.

8. REACTOR POWER REGULATION

Reactor power is regulated by control of moderator heavy water level in the reactor vessel. Level control is achieved by an independent level control circuit consisting of three level control pumps which pump heavy water into the moderator space of the reactor vessel from a dump tank below (Fig.4). Three control valves control the return flow of the moderator from the reactor vessel into the heavy water dump tank. Automatic power regulation is achieved by the power regulation system neutronic signals which adjust the valve positions for raising, maintaining or lowering the moderator level depending on the desired power level. Twelve neutron detectors (fission and boron coated ion chambers) installed in three instrument tubes in the concrete biological shield of the reactor provide log rate, linear rate, log power, linear power and over-power signals for the power regulation and safety systems.

9. REACTOR PROTECTION SYSTEM

9.1 Nine cadmium shutoff rods are provided as primary fast-acting shutdown devices. These are parked above the core-region during power operation and are rapidly inserted into the core on a scram signal. Insertion is primarily by gravity assisted initially by an accelerating spring. Moderator dump has been provided as a slow-acting back-up shutdown system which also ensures long term shutdown safety. In addition, a fast-acting emergency shutdown (ESD) system comprising injection of a liquid poison into a set of 20 zircaloy tubes located in the central region of the core has also been provided. The ESD system is actuated in the event of failure of the shutoff rod/moderator dump system as also in the event of certain other abnormal conditions such as reactor power exceeding a pre-set limit.

9.2 Computations show no fuel damage for anticipated operational occurrences like main coolant pump trip, loss of class IV power supply and loss of reactor power regulation for a complete shutoff rod system failure due to provision of the back-up automatic heavy water dump and liquid poison reactivity shutdown mechanisms and favourable primary coolant flow coastdown characteristics.

10. EXPERIMENTAL FACILITIES

These are given below:

Type	No.	Maximum thermal neutron flux x 10^{-13} (n/cm^2/sec.)
Engineering loop (150 mm)	1	14.6
Engineering loop (100 mm)	1	16.4
Radial beam holes (100 mm)	4	3.8
Tangential beam holes (100 mm)	4	8.1
Radial beam holes (300 mm)	2	7.0
Cold neutron source (300 mm/300 mm)	1/1	13.4
Hot neutron source (300 mm/100mm)	1/2	14.3
Upper through tube (100 mm) for isotope production	1	8.1
Lower through tube (100 mm) with scatterer	1	16.3
Pneumatic carrier facility	1	18.4
Isotope tray rods (including cobalt slug rods)	4	17.7
Creep and corrosion facilities	3	11.3

11. COMMISSIONING EXPERIENCE

11.1 During commissioning and initial operating phases of the reactor, a number of problems were encountered which delayed full power regular operation till January 1988.

11.2 Considerable time and effort had to be spent during lightwater testing of the heavy water system for flushing out construction and fabrication debris like stainless steel metal turnings, stainless steel dust etc arising predominantly from inadequate cleaning of calandria after fabrication prior to site installation.

11.3 Initial design of the fuel assembly employed solid bulges at the top and bottom of the flow tube with a small radial clearance between the bulges and the inner surface of the housing guide tube. This caused large amplitude flow-induced vibrations leading to excessive wear of fuel rod aluminium cladding, especially at spacer locations, exposing the uranium to the coolant and making sustained power operation difficult due to high radioactivity in the coolant. The problem was solved by ensuring a snug fit of the fuel assembly in the guide tube by providing split bulges in place of solid bulges to act like springs bearing on the guide tube inner surface with zero radial clearance.

11.4 Aluminium turbidity appeared in the system heavy water due to the ecxcessive fuel vibration problem mentioned earlier. The turbidity was removed by purifying the heavy water through special acrylic type weak acidic magnesium-magnesium oxide loaded resins as also by employing a centrifuge-separator in the system.

11.5 The fuel assembly lock/unlock (to the channel) mechanism was not hundred percent reliable raising the concern of inadvertent ejection of the assembly during full flow operation. Back-up mechanical locks were provided for all in-core assemblies to solve this problem.

11.6 The original design of the radial bearing lubrication circuit of the heavy water primary coolant pumps had to be modified for correcting excessive oil leakage to prevent fire hazards and to enable sustained pump operation.

Table 1

SALIENT DESIGN DATA

Reactor Power (thermal)	100 MW
Overhead (emergency cooling) water storage tank capacity	1.8×10^6 Litres
Reactor (pile) block	11.05 m dia x 11.94 m high
Reactor vessel (stainless steel calandria)	3.72 m dia x 3.875 m high 1.9 cm wall thickness
Annular bulk water shield thickness around calandria	1.22 m
Annular bulk concrete shield thickness	2.44 m
Number of lattice positions	146
Lattice pitch and geometry	18 cm square
Typical operational loading	
Fuel assemblies	127
Shut-off rods	9
Engineering loops	2
Creep and corrosion facilities	3
Pneumatic carrier	1
Isotope tray and slug rods	4
Fuel Assembly	
Natural uranium metal clad with 1 mm aluminium	1.27 cm dia x 303 cm long 7 rod cluster
Flow tube (aluminium)	5.23 cm ID and 1 mm thick
D_2O coolant flow rate	490 LPM
Maximum assembly power (thermal)	1125 kW
D_2O gross coolant flow rate	69000 LPM
D_2O gross coolant temp. rise	19°C
D_2O coolant exit temp.	70°C max.

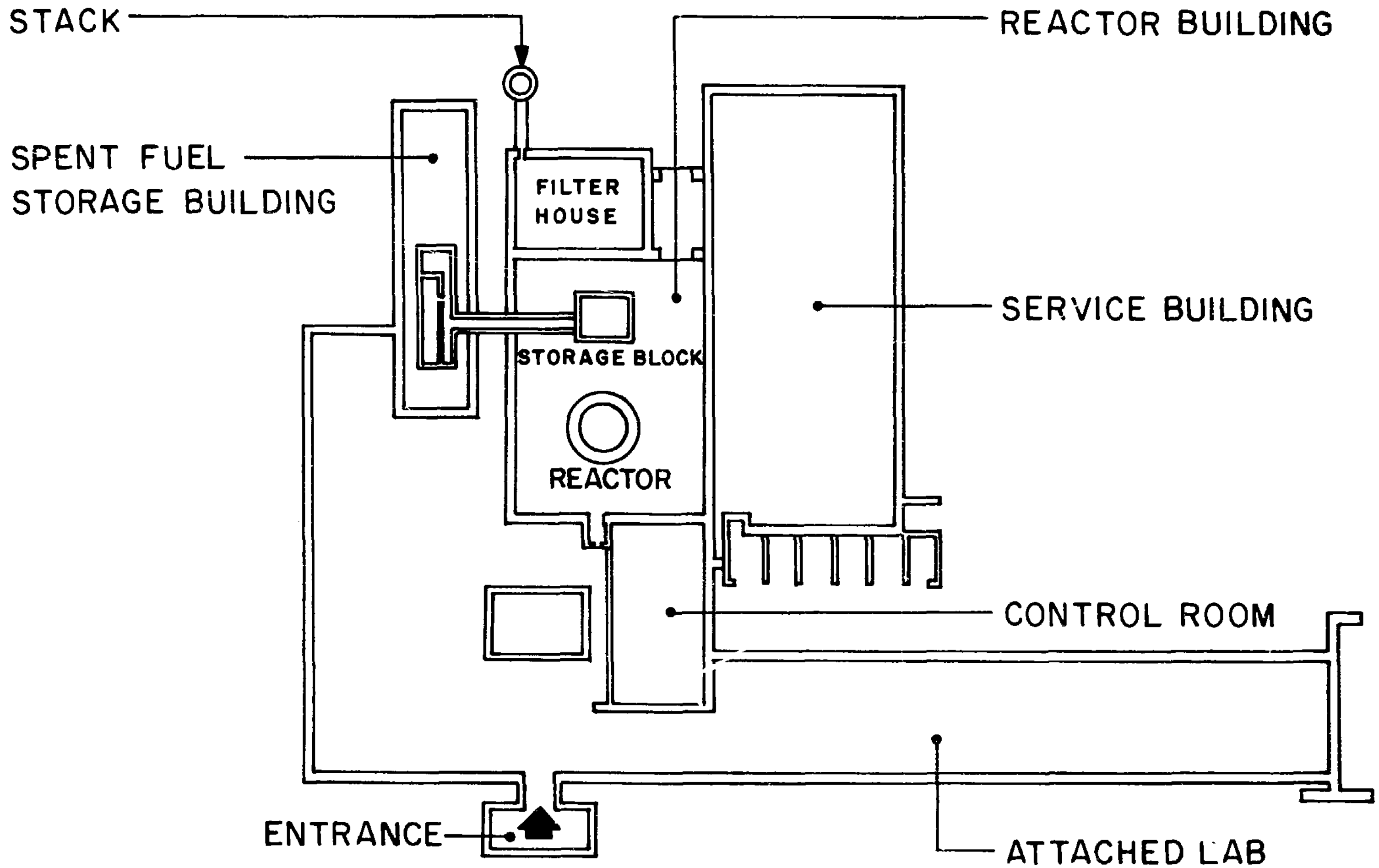

Fig. I PLANT LAYOUT

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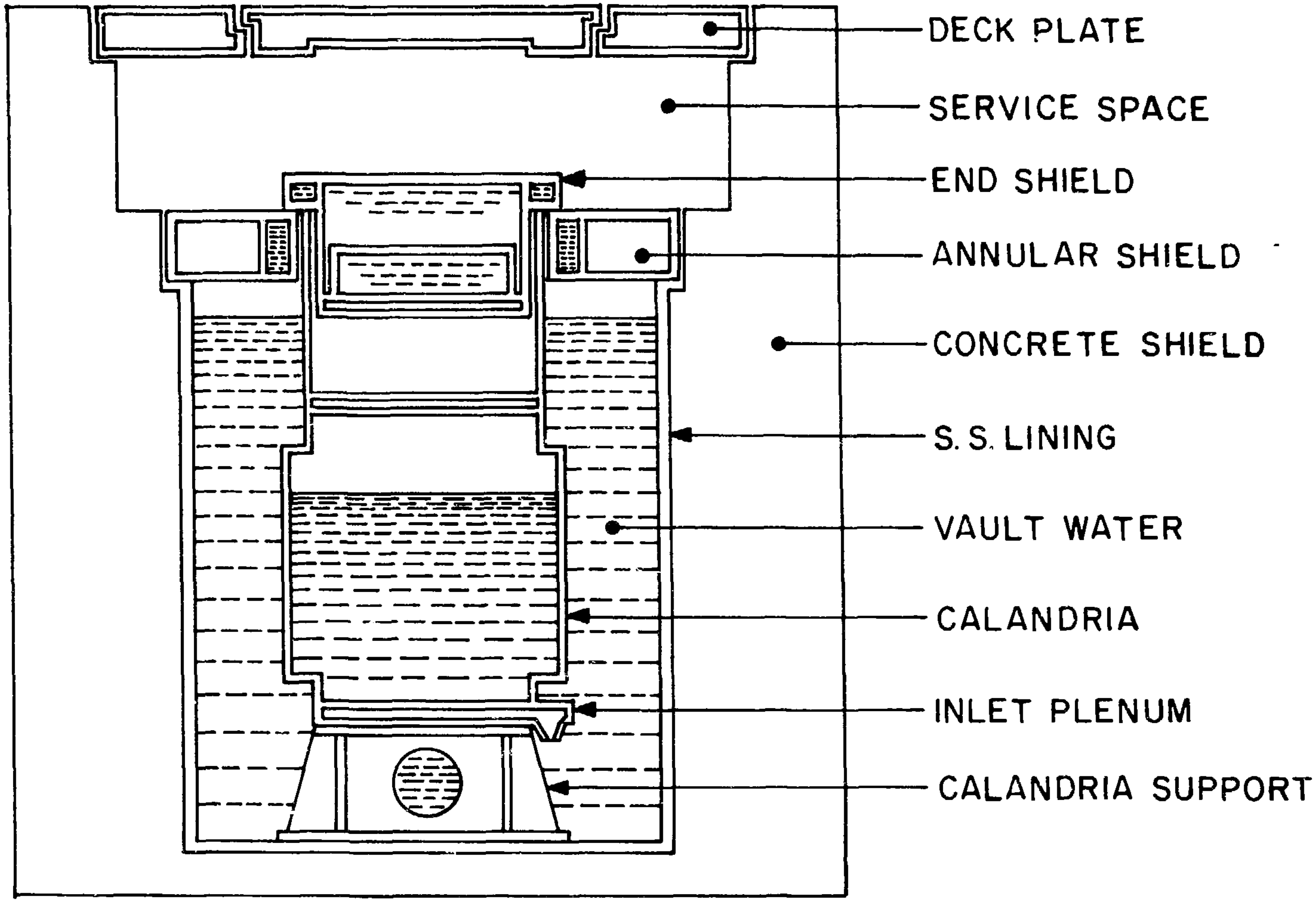

Fig. 2 **PILE BLOCK SCHEMATIC**

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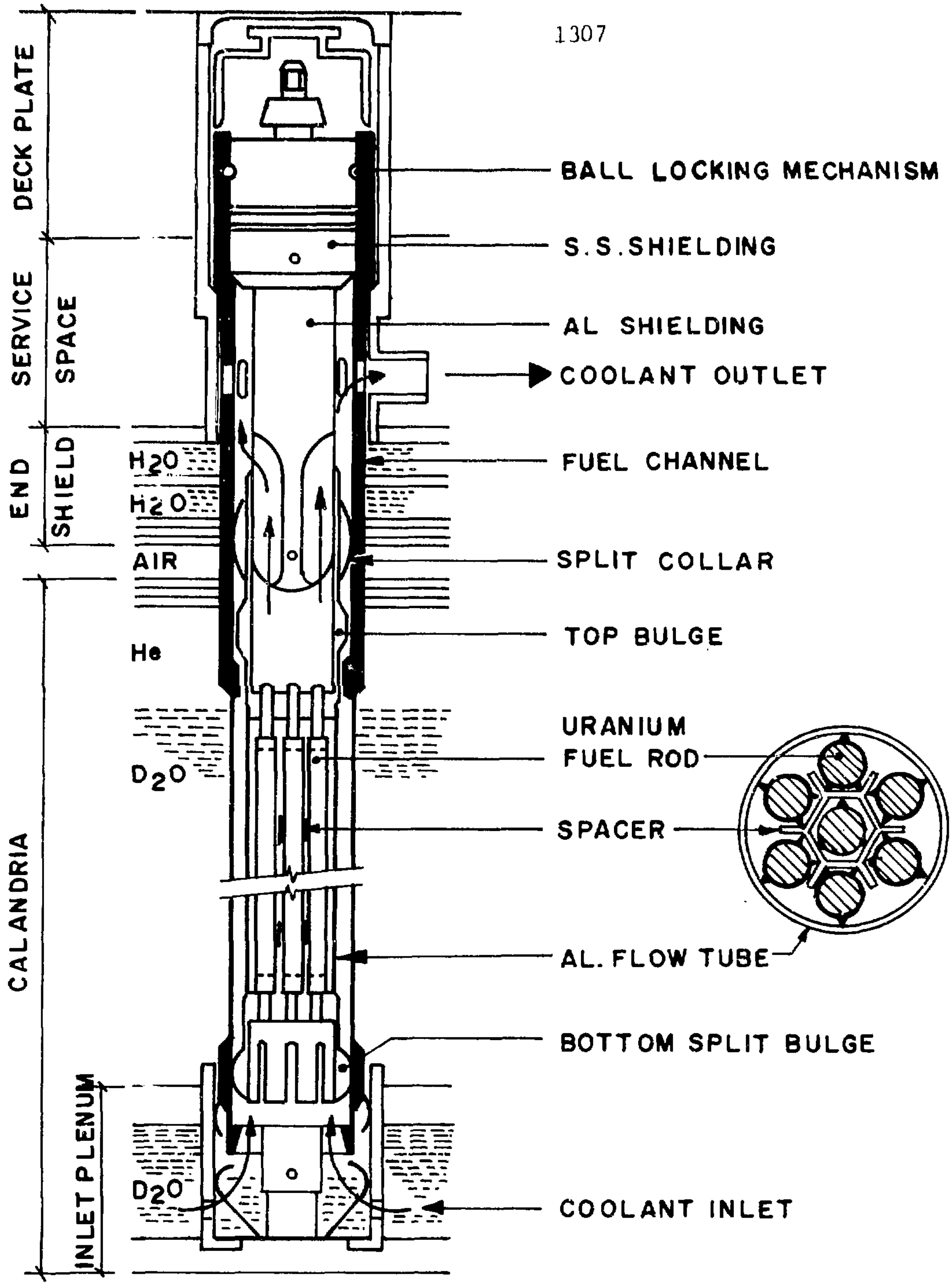

Fig. 3 FUEL ASSEMBLY

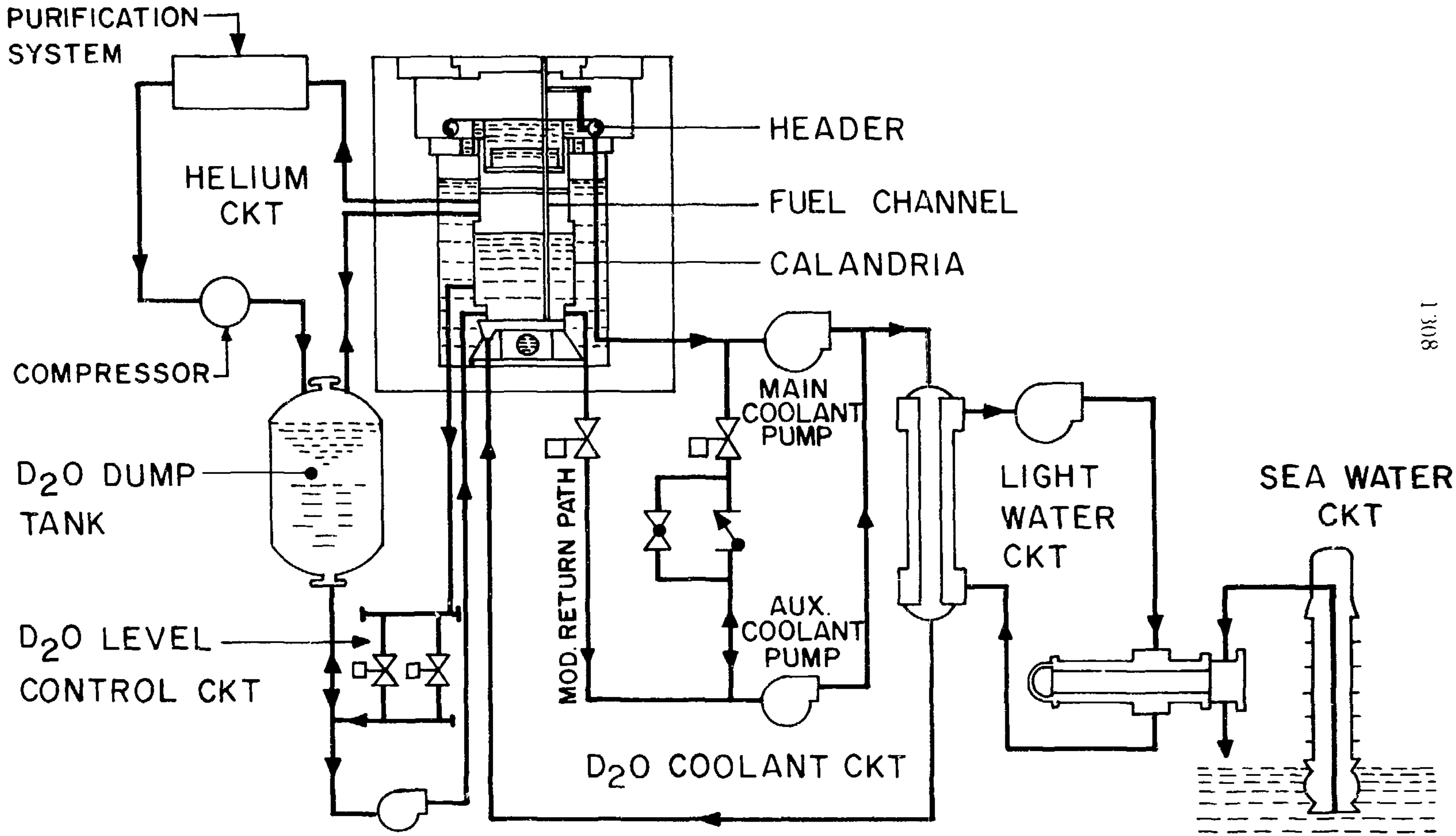

Fig. 4 NORMAL COOLING SCHEMATIC

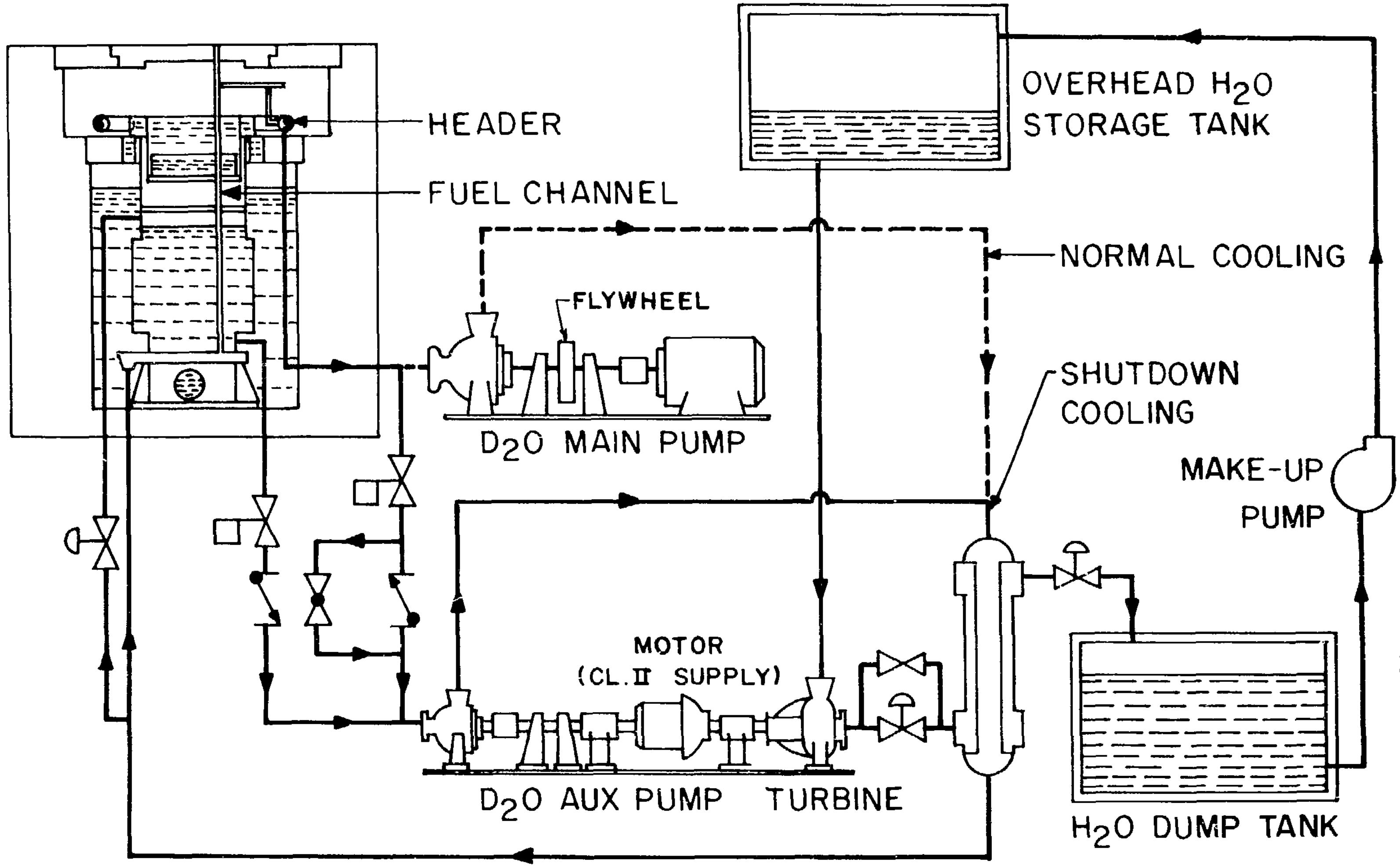

Fig. 5 SHUTDOWN COOLING SCHEMATIC